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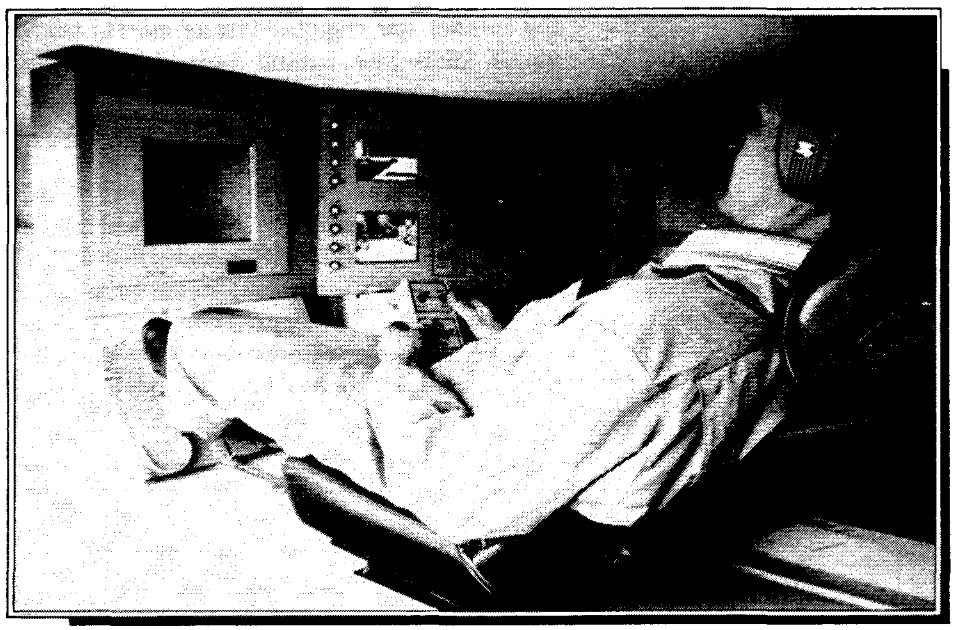
The Essential Role of Human Factors in Advanced Technology

By Richard S. Fowkes



United States Department of the Interior

Bureau of Mines

U.S. Department of the Interior
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Cover Photograph: Teleoperated equipment in a low-coal seam. With the advent of advanced mining technology, mine operators will be faced with a host of new human factors challenges. (Photo by William D. Monaghan, Pittsburgh Research Center)

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Advanced technology, including automation and computerized information systems, is being adopted in mining at an ever increasing rate to improve safety and productivity and to decrease overall costs. This report focuses on the human factors issues related to advanced technology. Among the significant facts discovered were: experts studying the design, adoption, and implementation of new technology have stated repeatedly that human factors specialists should be involved from the early planning stages, through design and fabrication, and up to and during production since human factors has been consistently identified as the biggest obstacle to the efficient utilization of new technology. Also, middle management is generally the greatest obstacle to the adoption of advanced technology; this technology can give rise to worker alienation, boredom, stress, job insecurity, and a sense of isolation; training most of the present work force is most cost-effective than hiring new workers; workers are willing to accept new technology if they are given a voice in its implementation; the social and the technical systems should be jointly optimized; and with the introduction of advanced technology, the cognitive or mental, rather than the physical, aspects of human-machine interaction must be emphasized.

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THE ESSENTIAL ROLE OF HUMAN FACTORS IN ADVANCED TECHNOLOGY

By Richard S. Fowkes[1]

ABSTRACT

Advanced technology, including automation and computerized information systems, is being adopted in mining at an ever-increasing rate to improve safety and productivity and to decrease overall costs. This U.S. Bureau of Mines report focuses on the human factors issues related to advanced technology. Among the significant facts discovered were the following: Experts studying the design, adoption, and implementation of new technology have stated repeatedly that human factors specialists should be involved from the early planning stages, through design and fabrication, and up to and during production, since human factors has been consistently identified as the biggest obstacle to the efficient utilization of new technology. Also, middle management is generally the greatest obstacle to the adoption of advanced technology; this technology can give rise to worker alienation, boredom, stress, job insecurity, and a sense of isolation; training most of the present work force is more cost effective than hiring new workers; workers are willing to accept new technology if they are given a voice in its implementation; the social and the technical systems should be jointly optimized; and with the introduction of advanced technology, the cognitive or mental, rather than the physical, aspects of human-machine interaction must be emphasized.

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INTRODUCTION

The U.S. Bureau of Mines (USBM) has been involved with in-house and contract research and development on automation for many years. The USBM's emphasis has been on underground coal mining, although the USBM is presently developing an automation research program for underground metal and nonmetal mining.

The most comprehensive USBM mine mechanization program, known as Advancing Mining Technology, began in 1974 after the Organization of Petroleum Exporting Countries (OPEC) oil embargo. The program was divided into 13 subprograms, including both the underground and surface mining of coal, and was almost totally an equipment development program with the goal of increasing coal mining productivity without impacting negatively on the health or safety of miners. This program did not rely heavily on USBM in-house research, but rather was implemented through contracts with mining equipment manufacturers, operating mines, consultant companies with expertise in various areas of mining, and universities, as well as through cooperative agreements with U.S. national laboratories and foreign organizations. Three of the underground mining programs focused on automation: Automated Longwall, Automated Remote-Controlled Continuous Miner, and Automated Continuous Roof Support. Some of the other subprograms devoted part of their effort to the consideration of automation, such as an automated extraction system, continuous face haulage, and hydraulic transportation. In addition, there have been USBM projects that addressed the automation of equipment or functions such as a shuttle car, a continuous miner, coupling-decoupling of mine cars, a bolter with temporary roof support, rail haulage, and a scoop.

The present USBM automation program also encompasses robotics and concentrates on underground mining. Its goal is to eliminate the presence of workers in hazardous areas of underground mines. The program is attempting to accomplish this goal through both near- and long-term research. The short-term research emphasizes the automation or robotization of state-of-the-art mining equipment and methods (such as a continuous mining machine, a roof bolter, and haulage in room-and-pillar sections) and the development of knowledge-based computer systems that will aid management and improve safety. The long-term research focuses on the design of new mining systems that can take advantage of the specific attributes of robotic and artificial intelligence technology and will enhance both safety and productivity, i.e., the development of intelligent autonomous mining systems. Sensors and sensor systems are being studied because they are the only means by which autonomous, computer-controlled mining machines can obtain the data required for control and for making decisions. Substantial USBM research is being performed involving sensing technologies to determine coal-rock interfaces so that coal, not rock, will be cut, and to determine rib-pillar thickness for highwall miner lateral guidance, roof integrity, and the geology in advance of mining.

The target machine chosen by the USBM for the development of autonomous mining machines is the continuous miner, which is used in underground coal mining for room-and-pillar mining in advance and retreat, longwall entry development, and shortwall mining. Successful results from this research will provide information, experience, and technology that can be applied to other equipment and systems used in underground mining.

The USBM's research on automation and robotics has now reached the technical stage, at which an in-depth consideration of human factors is important. The significance of human factors for advanced technology in mining was stressed by Forshey[2] in his paper on USBM research in advanced technologies: "As mining systems become more sophisticated technically, for example, computer-assisted, etc., the significance of human decision making and behavior will increase. Future design of mining systems will require more, not less, emphasis on the human element."

This report includes four major sections. The first is a summary of a literature review of human factors and its importance in adopting, implementing, and utilizing advanced technology. The second section contains the results of interviews of mining personnel dealing with such human factors topics as the effects of advanced technology on the following: management practices and organizational structure, the importance of human factors research, mining employment, training and retraining, labor-management problems and how they should be addressed, employee resistance to the new technology and overcoming this, and productivity. The third section is a summary of a literature search that concentrated on the following topics with respect to the impacts of advanced technology: barriers to adoption, job design and redesign, organizational structure and management practices, psychological factors (e.g., alienation, boredom, stress, job insecurity, isolation), quality of working life, social (people) and technical systems compatibility, training and retraining, worker acceptance, worker communication, worker displacement, worker involvement and participation, and the human-machine interface (from the human factors perspective). Finally, the fourth section is an appendix, which is an annotated bibliography and gives details on the results of the literature search.

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[2]Forshey, D. R. U.S. Bureau of Mines Research in Advanced Mining Technologies. Paper in International Conference on Reliability, Production and Control in Coal Mines (Wollongong, NSW, Australia, Sept. 1991). Australasian Inst. Min. and Metall., 1991, pp. 306-313.

IMPORTANCE OF HUMAN FACTORS IN ADVANCED TECHNOLOGY

Human factors is the study and application of known information about human abilities, limitations, motives, and behaviors to the analysis and design of organizations, machines, tools, environments, and systems. It stresses the design of equipment and systems in terms of safe, productive, and psychologically satisfying human use. Human factors plays an essential role in the adoption, implementation, and utilization of advanced technology. However, human factors is all too often ignored or introduced as an afterthought after the advanced technology is in operation. Even with automation and the most advanced technology, people are involved in monitoring, controlling, and maintaining the technology and in making critical decisions. Since the importance of human factors for advanced technology has received less formal attention in mining than it has in manufacturing, the bulk of publications emphasize manufacturing (the two studies that are mining oriented were done in the United Kingdom). In fact, the importance attributed by manufacturing to human factors is shown by the number of conferences that have been and still are devoted totally or in part to human factors and the human aspects of advanced manufacturing systems and by the continuing appearance of articles in journals on these subjects by persons associated with manufacturing. The experience gained and the results of studies by the manufacturing personnel on the adoption of advanced technology should provide some useful information to their counterparts in the mining industry. Figure 1 illustrates the importance of human factors when advanced technology is adopted.

Specific conclusions based on the literature review are as follows:

- In general, the consideration of human attitudes and needs and the role of people in new technology systems implementation is insufficient and too late.

- Human factors are the biggest problems in implementing advanced technology
- The human role in utilizing advanced technology includes
  - Supervising
  - Monitoring
  - Controlling
  - Maintaining
  - Decisionmaking
- Mistakes made by companies adopting advanced technology
  - Ignoring human factors
  - Applying human factors too late
  - Not using human factors principles enough
- Results of not considering human factors
  - Disgruntled employees
  - Not realizing the full productivity potential
  - Maintenance problems
  - Accidents
- Measures to correct the mistakes
  - involvement of human factors specialists during
    - Planning
    - Design
    - Fabrication
    - Operation
    - Maintenance
  - Training
  - Worker participation
  - Communication with workers and feedback

Figure 1.—Importance of human factors in advanced technology.

- The human factors specialist should be involved at all stages, from very early planning through design and fabrication to operational use of the system.
- Human factors is consistently identified as the biggest problem in implementing automation and must be taken into account if the full benefits of automation are to be realized.
- Human factors should not be considered as an afterthought, since once new technology is installed it is difficult and costly to adapt it.
- Human factors is of equal importance to the technical aspects since it directly impacts on the safety and economic efficiencies of the new technology and its eventual success or failure.
- Often the people who design advanced technology do not sufficiently consider the requirements of those who manage it and those who implement or maintain it.
- Even in the most automated systems, the human roles of monitoring, supervising, and maintaining remain critical to the accomplishment of operational goals.
- Not only is the nature and level of the human contribution to advanced technology important, but of equal importance is the interaction between the human and machine components of the system.
- The human-centered approach, whereby the human role in the system is regarded as crucial to its effective operation rather than a drawback and potential source of error, should be emphasized in the design and implementation of new technology.
- Planning for human systems is generally done after the fact, i.e., only after technical choices have been solidified are the impacts on humans and the organization considered.

INTERVIEWS WITH MINING PERSONNEL

Interviews were conducted by telephone with 50 persons who were known by the author of this report to be knowledgeable in various mining areas. Interviewed were 11 supervisors or managers at mining companies, 5 mining equipment designers, 12 university mining department professors, 7 mining consultants, 5 Government mining researchers, and 10 representatives of USBM contractors who had had USBM mining contracts. All had familiarity with one or more aspects of advanced technology in mining. A total of 41 had been or were involved with underground coal mining, although their direct expertise in most cases spanned underground and surface mining of both coal and noncoal mined materials. A series of questions pertaining to human factors and advanced technology for mining was asked of each individual with some variations depending on the person's background and area of responsibility. There was universal agreement among the interviewees that more and more automation will be used in mining, although there were differences of opinion on the types and degree of automation that will be desirable. Figure 2 recapitulates the opinions of those interviewed in response to several important questions. The questions and summaries of responses follow.

1. *Question:* What managerial and organizational changes have been made to accommodate advanced technology?

Summary of responses: The introduction of more advanced technology has led mining companies to hire a number of young engineers with recent training who are familiar with computers and the latest relevant software. Owing to the increasing complexity of mining equipment, there is a trend toward hiring specialized engineers in the electrical, hydraulic, and mechanical fields. Some companies want their engineers not only to be able to maintain their equipment but also to modify equipment already being used at mines and to write specifications for equipment manufacturers for new equipment. Companies in general have had to reduce the size of their work force as they have sought ways to cut costs to remain competitive. In some cases, this has meant cutting the managerial staff, mostly by eliminating jobs that were not considered necessary or by using computers rather than managers to obtain, manipulate, and/or disseminate information. The overall opinion of the interviewees was that mining companies have done well on cutting costs at all levels, instilling in management a sense of cost consciousness, and having a management that is more technically trained than in the past. Human factors is considered when new technology is adopted but not as a formal discipline. The new technologies have been partly responsible for some of the organizational changes, notably in elevating the status of the maintenance department and its management. This is because the new technology is so complex and the cost of downtime has increased. However, the most important stimulus to management and organizational changes has been and will continue to be trying to survive and make a profit in a very competitive energy market. None of the mining people with whom discussions were held believes that increased automation, utilization of computers, etc. will result in any major shift in management or organizational practices beyond those that have occurred in recent years. There were some mining personnel, however, who believe that the criteria by which managers and supervisors are chosen by mining companies emphasize technical expertise excessively. Those who make the decisions on

- Managerial and organizational changes
  - Hiring of specialized engineers
  - Hiring of recent university graduates
  - Eliminating unnecessary jobs
  - An increased sense of cost consciousness by management
  - An elevated status for the maintenance department
  - Selecting managers who can motivate employees
  - An increasing utilization of computers for both managerial and technical functions
  - Improved communications with feedback from employees
  - An increase in worker participation in decisionmaking
  - A flatter hierarchy with fewer middle managers
- Effects on employment
  - An increase in the number of maintenance personnel at operating mines
  - An increase in the number of engineers and computer specialists at operating mines
  - An increase in the number of employees in longwall mining
  - An overall decrease in the number of mining employees
- Effects on training
  - Higher levels of education required
  - Engineers and computer scientists must keep up to date
  - Ongoing training must be given to managers and maintenance personnel
  - Operators must be trained in the new technology
- Suggested applications of ergonomics-human factors
  - Ergonomic design of equipment and systems
  - Human factors taken into consideration during the adoption and implementation of new technology
  - Motivation of workers to ensure the new technology is used safely and productively
  - Communication with workers, including feedback
- Overcoming management and worker resistance to adoption
  - Emphasize that more (maybe all) jobs will be lost without the new technology
  - Stress that sincere attempts will be made to limit the job loss by attrition
  - Make as many of the required organizational changes as feasible before the new technology arrives
  - Terminate any unneeded middle managers as quickly as possible

Figure 2.—Results of interviews with mining personnel on impacts on mining of adoption of advanced technology.

hiring and promoting should realize that it is just as important, perhaps more so, that supervisors be competent people managers who can motivate their employees as it is that they have technical expertise.

2. *Question:* What managerial and organizational changes should be emphasized by mining companies as more advanced technology is adopted?

Summary of responses: The starting point is people. Management must be more technical because of the new technology including computers, but it also must be people oriented, and the work force must be better trained and educated. Maintenance is so critical that a manager of maintenance must be appointed who is on a level equal to that of other top managers. The use of computers for information systems means that managers must know how to use computers and know what they should be used for. The mining work force is better educated than in the past, and there is increased competition with other industries for quality people. This means that motivating employees and giving them more responsibility for making decisions should receive more emphasis. The organization must be constantly scrutinized to eliminate unnecessary or nonproductive jobs. Communication among all layers of management and between management and the workers becomes vital, which means that the organization must be set up to ensure that the desired communication occurs including feedback to the workers. The organization should change from a hierarchy to a horizontal form of management with as few layers of management between the workers and top management as is feasible.

3. *Question:* What training has been developed relative to the new technology?

Summary of responses: Companies that supply the equipment provide manuals and also send persons to the mining company to train operators and maintenance personnel. Larger companies have their own training divisions. Training operators has not constituted a large problem, but companies have spent considerable time and effort in training maintenance personnel because the new machinery is so complicated. Diagnostics using sensors where the machine "tells" what is acting up or what has gone wrong with it aids maintenance people immeasurably. Modular replacements are favored in many instances since another unit can be inserted and the machine can continue operating, thus minimizing downtime.

4. *Question:* Is adoption of new technology being delayed because of any anticipated problems?

Summary of responses: Companies are not postponing the adoption of new technology because of fears of problems. However, they do tend to wait until any new technology has been proven to work reliably, safely, and productively and to be cost effective. That is, companies similar to those that have demonstrated the benefits to be gained by using the technology will follow suit. Mining companies that adopt the new technology first have one or more managers who believe that the way to surpass the competition or to stay in business is to improve productivity through advanced technology. Sometimes an equipment manufacturer attempting to retain or increase its share of the market persuades a mining company that has production problems or that is behind the competition that its new equipment will alleviate these problems.

5. *Question:* Do you believe increasing utilization of advanced technology has had or will have any effect on mining employment (i.e., increase, decrease, remain the same)?

Summary of responses: Underground and surface coal mining productivity (tons per employee-hour) has significantly increased for more than a decade. Production has increased to a more limited extent. Since productivity gains have far outpaced the increases in production, the number of miners had to decrease. However, the number of support personnel has not decreased to any extent in those mines that have stayed open; and several of the interviewees believe that as mines become more automated the number of maintenance personnel will increase significantly. Since many jobs in mining cannot be feasibly automated, there will not be many mining jobs lost to automation. However, if productivity continues to grow and the demand for coal does not keep pace with productivity, some mines will go out of business, thus eliminating jobs. Also, if Western U.S. surface mines with their high productivity increase their share of the coal market, many coal mining jobs at other mines will be lost. In addition, if the tons of coal mined using the longwall method increases, there will be miners laid off elsewhere, since longwall mining is generally more productive than continuous mining. The interviewees essentially agreed, nonetheless, that at a particular mine adopting advanced technology there will not be fewer people employed than before this technology was acquired.

6. *Question:* What effects will the adoption of advanced technology have on the types of workers and training that will be needed?

Summary of responses: Better educated persons will be needed at mining companies as advanced technology is increasingly adopted, especially in maintenance and management. Operators who are competent in operating one machine can be taught to operate another machine. Engineers and computer scientists will have to keep abreast of the latest technical developments and relate them to mining systems and equipment. Ongoing training is essential for both managers and technical personnel.

7. *Question:* How important are human factors and ergonomics as they relate to advanced technology?

Summary of responses: The interviewees believed that ergonomic design of equipment and systems is important and should be considered as the equipment or systems are designed, not after the fact. The human factor is central and of major importance when new technology is adopted and implemented. No matter how potentially productive any new technology is, without competent and motivated people it will not achieve its potential. Human factors must be considered as it relates to both the technical and nontechnical aspects of a company. Communicating with workers and allowing for feedback, involving the workers in decisions that impact their jobs, and motivating them to be productive and safe are requisites with the more highly trained and educated mining work force that is required for using advanced technology safely and productively.

8. *Question:* Are older workers capable of learning the new systems?

Summary of responses: Opinions were divided on the answer to this question no matter where the interviewee was employed. Some believed that older miners with experience have no real trouble learning to use new machinery, while others believed that the older miner was lacking in education and could not learn enough about the new systems to perform safely and productively. However, it was generally agreed by the interviewees that many of the older maintenance people will have difficulty learning, even after taking training courses, how to repair the complicated new equipment or prevent it from breaking down.

9. *Question:* What labor-management problems arise when new technology is introduced?

Summary of responses: The first concern of workers is the loss of jobs, followed by the usual fear of having to learn something new when one is comfortable and satisfied with the manner in which one is currently performing. Miners realize that the number of miners and operating mines have declined significantly in recent years as productivity has risen faster than demand, and they believe that more advanced technology means even fewer mining jobs. Workers tend to doubt management's assurances that the new technology will benefit them. Also, many mining companies that remain in business have become parts of conglomerates that introduce reorganizations and often eliminate jobs. Managers are often pressured to improve the profit picture quickly, which generally means cost cutting and a consequent reduction in the work force size.

10. *Question:* What are the best ways to overcome management and worker resistance to the introduction of new technology?

Summary of responses: Miners only agree that the adoption of new technology will benefit them when they are convinced that without the new technology their company cannot remain competitive. The argument presented to them is that without the new technology the company will go out of business, leaving them unemployed. However, since advanced technology is generally introduced over several years, management can tell the workers that none of them will lose their jobs and that the decrease in employees will be accomplished by attrition. Middle management remains almost impossible to convince that it won't be negatively affected when advanced technology is adopted. These managers believe that either the nature of their jobs will drastically change or, worse yet, they will be laid off. Top management must decide as early as possible in the process of obtaining new technology how the organizational structure will change and take the steps necessary to implement the organizational changes before the new technology is acquired. Top management must decide which middle managers will be retained, ensure that these managers know they will remain employed, involve them at all stages of adoption and implementation of the new technology, and terminate the unneeded managers as quickly and painlessly as possible.

11. *Question:* What will be the effects of even more advanced technology on accidents in underground coal mining that can lead to injuries or fatalities?

Summary of responses: The technology introduced to date has affected the frequency and severity of accidents in several ways. For example, the number of roof fall accidents in longwall mining has decreased since the miners are protected by shields. However, in the cramped quarters of the longwall face, there have been more severe, although less frequent, accidents. Semiremote- and remote-controlled continuous miners have reduced the sorts of accidents that used to occur to continuous miner operators while mining at the face. However, continuous miner operators who use remote control have no canopy protection and can be injured by roof falls. Conveyor belt systems have replaced most rail haulage, decreasing rail haulage accidents significantly. Continuous haulage eliminates shuttle car accidents. Miner-bolters and automated roof bolting also eliminate many roof fall accidents. Automated longwalls will abolish jobs such as shearer operator, meaning the elimination of accidents for those persons. However, the types of accidents may be different than those encountered in the past with automated equipment. For example, the equipment could run into persons doing maintenance. There are at present many accidents involving support personnel such as those in maintenance, performing cleanup, or handling supplies and materials. The advanced technology to be introduced into mining in the next 10 years or so may not decrease the number of accidents to these people and could even lead to additional accidents.

Highlights from the mining interviews are as follows:

- The introduction of more advanced technology has caused mining companies to hire many young engineers with recent training and a familiarity with computers and some engineers specialized in electrical, electronic, hydraulic, or mechanical systems and components.
- Mining companies want engineers who can not only modify on-hand equipment but also write specifications for equipment manufacturers for new equipment that is wanted.
- Mining companies have done well at cutting costs at all levels, instilling in management a sense of cost consciousness, and forming a staff that is more technically competent than in the past.
- The new technology has elevated the status of the maintenance department, and a manager of maintenance should be appointed who is on a level equal to that of other top managers.
- Neither increased automation nor utilization of computers will result in any different sorts of management or organizational changes in the mining industry than those that have occurred in recent years.
- Management has to be people oriented as well as technical, and the work force has to be better trained and educated.
- The use of computers for information systems means that managers must know how to use computers and what they should be used for.
- Competition with other industries for quality people and the complexity of the new technology means an

increased emphasis by management on motivating employees.

- Communication between all layers of management and between management and the workers is critically important, and the organization must be structured such that the desired communication, with feedback, takes place.
- The organization should change from a hierarchy to a horizontal form of management with as few layers of management between the workers and top management as is feasible and with more decisionmaking responsibility and autonomy given to the workers.
- Companies that supply the new technology provide manuals and also send persons to the mining company to train operators and maintenance personnel, and larger companies have their own training divisions.
- There has not been any real problem in training operators, but companies have spent considerable time and effort in training maintenance personnel on how to maintain and repair the advanced equipment, including using diagnostics and modular replacements.
- Mining companies have not postponed adopting new technology because of fears of problems, but there is a tendency to wait until any new technology has been shown to be cost effective and to work reliably, safely, and productively at one or more other companies before adopting it.
- The number of miners employed has decreased in recent years, primarily because the gains in productivity have outstripped the demands for mined products, but the number of support personnel at mines that have stayed open has remained the same and might even increase with the adoption of more advanced technology.
- Better educated persons will be needed at mining companies as new technology is increasingly adopted, especially in maintenance, engineering, computer science, and management.
- Ergonomic design of equipment and systems is important and should be considered as these are designed and not after the fact.
- The human factor is central and of the utmost importance when new technology is adopted and implemented, because without competent and motivated people this technology will not live up to its potential.
- Miners can be apprehensive when new technology is introduced because of a fear of losing their jobs or a belief that their jobs will change in negative ways.
- The only time miners agree that the adoption of new technology might benefit them is when they are convinced that without the new technology their company cannot be competitive.
- Middle management is almost impossible to convince that it won't be negatively affected when advanced technology is adopted. These managers believe that either their jobs will change drastically or, worse yet, that they will be laid off.
- The introduction of new technology has decreased the number of certain types of mining accidents, but attention must be paid to the fact that this technology might be responsible for other accidents as it is adopted.

LITERATURE REVIEW OF HUMAN FACTORS AND ADVANCED TECHNOLOGY

This section presents a summary of the information obtained from the author's literature search on human factors and advanced technology. It is divided into several categories to help the readers to quickly grasp what is known or believed in the most important human factors areas of advanced technology. The categories that were chosen are

- Barriers to adoption
- Job design and redesign
- Organizational structure and management practices
- Psychological factors
- Quality of working life
- Sociotechnical systems analysis and applications
- Training and retraining
- Worker acceptance
- Worker communication
- Worker displacement
- Worker participation.

Appendix section contains an annotated bibliography with details on the publications from which this information was gathered.

BARRIERS TO ADOPTION

There is widespread agreement among managers everywhere that automation and/or robotics will be needed for companies to stay in business because of both domestic and foreign competition. Virtually every job and every system are analyzed by managers to determine the feasibility and the economics of replacing people with machines and replacing present technology with more advanced technology. Despite this awareness of the necessity to modernize, new technology is often not adopted at the appropriate time or not adopted at all. Why is this so? In some cases, the most advanced technology does not seem to be appropriate for the products or services that the company provides. Obviously, persons at all levels who think that they might lose their jobs or that the nature of their jobs will change in ways they do not like oppose the introduction of new technology. However, even before any of these other factors can be considered, initial barriers to the adoption and implementation of new technology are a lack of sufficient capital to enable a company to purchase the equipment and insufficient funds to operate and maintain the technology. But, even if an organization has or can obtain the required finances for the purchase, operation, and maintenance of advanced technology, human factors can, and often does, override technical and economic judgments. Figure 3 indicates major barriers to the adoption of advanced technology. Publications indicate the following barriers to the adoption of new technology:

- Availability of capital;
- Lack of know-how or trained personnel within the company;
- Organizational resistance to change;
- Availability of appropriate education and training programs;
- Traditional lines of management and traditional organizational structures;
- Management and workers who fear changes in their jobs or loss of their jobs; and
- Lack of an infrastructure of supporting systems, polices, and procedures.

JOB DESIGN AND REDESIGN

As advanced technology is introduced into a company, some jobs are inevitably eliminated, the remaining jobs from the top to the bottom of the hierarchy are altered to some degree, and some new jobs (generally requiring a high level of skills, training, or education) are created. This means that present jobs have to be redesigned, often drastically, and new jobs must be designed. Simply rewording job descriptions or positions is not sufficient—the tasks to be performed must be given in detail, and ergonomic or human factors principles should be used in which human abilities, limitations, and psychological factors are emphasized. Figure 4 lists several important considerations for job design or redesign when advanced technology is introduced. Publications claim that the key aspects of job design and redesign can be delineated as follows:

- Those persons who have been most heavily involved with job design and redesign claim that the important elements to be included in job design in order to provide worker satisfaction and well being and to reduce worker stress and improve productivity are as follows: The operator should be able to check his or her results and to supervise the monitoring system, variety should be enhanced by allowing for the possibility of task expansion and job rotation, interrelations or socialization with others should be possible so that mutual support and communication can occur, opportunities should be present for learning by experimenting in new ways, and the operator should have sufficient autonomy or decision latitude in order to be able to assess malfunction and to eliminate it.
- Many of today's top job designers believe in human-oriented job design and that worker participation, enhanced task content through job enlargement and job enrichment, and group decision making help to reduce job stress as well as improve worker performance and job satisfaction.

- Insufficient capital available for purchasing
- Organizational and middle management resistance to change
- Insufficient involvement by top management
- Lack of know-how or expertise within the company
- Nonavailability of appropriate training programs
- Lack of personnel who can program and operate computer systems
- Fear of de-skilling, learning new tasks, and/or job loss
- Lack of an infrastructure of supporting systems, policies, and procedures within the company
- Lack of a champion or project sponsor
- Conservative management that waits until the new technology has been proven to be cost effective elsewhere
- High cost of maintenance, repairs, and downtime
- Necessity to keep the new technology active owing to its high capital cost

Figure 3.—Barriers to adoption of advanced technology.

- Employee control over the work situation and working methods or how tasks are performed
- Understanding by the employee of the whole work process
- Opportunity by employees for technical and social skill use and development
- The possibility for employees to interact socially
- A work schedule that allows employees to engage in off-the-job activities
- Increased worker autonomy and decisionmaking
- Enhanced task content through job enlargement and job enrichment

Figure 4.—Important considerations for job design or redesign when advanced technology is introduced.

ORGANIZATIONAL STRUCTURE AND MANAGEMENT PRACTICES

Organizations have found that when new technology is introduced the company must change its structure and its management practices. One notable example is a decrease in the number of management levels. One reason a hierarchy with fewer middle-level managers can be installed is the availability of computers to store and disseminate information to top management, a role previously played by lower management. Another reason is that there has been a trend toward shifting decisionmaking to the operators and maintainers of the new technology. Thus, there has been a flattening of the hierarchy and a shifting downward of decisionmaking as to the actual work performed. In addition, advanced technology demands a more highly skilled and trained work force than was required when manual labor dominated the industrial scene. Mental and cognitive knowledge and ability are now required. Employees at companies using advanced technology are more highly educated than workers of previous generations. They demand more latitude in how their work is implemented since they are capable of assuming more responsibility and want more challenge and variety to their jobs. Management should rely on a motivational, rather than a dictatorial, approach. Figure 5 lists important organizational and management changes that have been suggested when advanced technology is introduced. Publications that deal with the subject of the effects of new technology on organizational structure and management practices stress the following:

- The authoritarian style of management is totally inappropriate, even disastrous, in modern underground coal mines with their high degree of mechanization and their skilled work forces, while decentralization and flat hierarchical management structures are the means of achieving important advances in productivity and costs.
- How mines should be managed as technology becomes even more advanced requires continuous appraisal.
- As new technology is adopted, organizations should have fewer hierarchical levels, allow more decisions to be made by employees at all levels, and develop a feedback mechanism between management and workers.
- The desired changes in organizational structure are seldom considered at the design and planning stage when new technology is to be introduced but definitely should be.
- Top management of those companies that have been most successful in applying advanced technology are as much concerned about its effects on their people as they are about their technology.
- Successful managerial strategies for implementing organizational change when new technology is introduced include (1) recognizing the importance of guaranteeing job security, (2) incorporating known and predictable ways of working the new technology into the new organizational structure, (3) using work groups as the basis for presentation of what is planned to be done, (4) ensuring that the pace of implementation is not hurried, (5) keeping a balance between programmed and nonprogrammed activities, (6) respecting the natural orderings of group and structures, (7) allowing feedback and acting on the feedback, (8) having managers act as trainers and facilitators rather than as controllers, and (9) presenting a positive picture to the employees as to the future of the company.
- An organization becomes more dependent on the nonmanagerial worker as new technology is used, and this dependency creates tensions with managers and supervisors and requires a more flexible application of work rules.
- A prodigious amount of planning, troubleshooting, and anticipatory problem solving by teams of people is required when automation is to be introduced.
- Advanced technology to fulfill its potential requires that the table of organization be much broader at the bottom, there be fewer levels of management, each manager or supervisor be given more authority in his or her realm, the organization function more like a grouping of colleagues and less like a hierarchical bureaucracy, and groups of workers be made smaller.

- A decrease in the number of management levels
- A hierarchy with fewer middle-level managers
- An increase in the autonomy and decisionmaking of operators and maintenance personnel
- An emphasis on a more highly trained and educated work force
- Development of methods by which employees can have continuous training or be retrained
- Consideration of workers as assets rather than as extensions of machines
- Development of a communication and feedback system between management and workers
- Looking at what changes will be needed in the organizational structure at the planning and design stage
- Using work groups composed of employees from all levels to determine and present which organizational changes and job changes will result from introducing the new technology
- An emphasis on predictive maintenance rather than on preventive maintenance
- An increased emphasis on the planning and service support activities that management performs
- Preparation of workers to accept more responsibility and to make more decisions
- A change in management style from a control type to one that gives workers more responsibility and freedom
- Involvement by top management in the implementation of the advanced technology
- A continuation of informal organizational networks

Figure 5.—Advocated organizational and management changes when advanced technology is introduced.

- Aspects of organizations that need to be addressed when new technology is adopted in mining include multiskill training and retraining of both management and the work force, predictive maintenance rather than preventive maintenance, and a more accurate assessment of economic life cycle costs for new technology.
- One of the main problems facing corporate and individual managers at mining companies is the design of appropriate and effective organizational structures for the management of present and future advanced technology.
- As much time and thought is required to design an organization compatible with the new technology as is required to plan and implement that technology.
- The effective management of advanced technology dictates changes in managerial style and approach from a control to a commitment style in the workplace wherein individuals are given responsibility and freedom and management puts considerable time into maintaining human relations.
- Estimates have been made that 60% of the benefits resulting from the installation of flexible manufacturing systems (FMS's) are actually derived from reorganization of the company and the work and only 40% from the technology itself.
- Middle management is primarily responsible for motivating employees and must change its attitude toward employees when new technology is adopted by encouraging employee involvement, having a rapid and positive follow-up of employee suggestions, and having a system of ongoing rewards for exceptional contributions to the improvement of the operation.
- Top management should ensure that newly installed technology lives up to its expectations or that new software works properly in their organizations, since most implementations of manufacturing systems fail because top management is not involved in the process.
- Experience has proven again and again that when top management is involved in the adoption and implementation of advanced technology, then lower levels in the organization try to make the new technology work since they believe they are being evaluated on their contributions.
- A too-formal restructuring of an organization when new technology is introduced is counterproductive, because actual management systems are characterized by both formal organizational structures and informal information networks.

PSYCHOLOGICAL FACTORS

The importance of psychological factors when new technology is adopted and implemented has been well documented. Stress, which has been found to be commonplace when new technology is introduced, can lead to excessive absenteeism, alcohol and/or drug addiction, depression, neurosis, disharmony in the workplace, lessened productivity, departure of key employees, and a lack of loyalty to the company. With advanced technology, a sense of alienation and isolation can occur as social contacts are diminished. Boredom and psychological fatigue become endemic if management does not take steps to minimize them. Task variety, worker autonomy, opportunities to interact with coworkers, and management support and praise are instrumental in overcoming the negative psychological impacts that affect workers when advanced technology is introduced. Increased wages and incentive plans are not by themselves sufficient for job satisfaction. Figure 6 presents a listing of the potential negative psychological effects on workers when advanced technology is introduced and suggested solutions to these effects. Publications dealing with psychological factors and advanced technology emphasize the following:

- Stress due to the introduction of new technology can lead to worker resistance, organizational instability, lower productivity, increased absenteeism, higher turnover, job dissatisfaction, and disruption.
- Psychological problems that have arisen among workers when advanced technology is adopted include depression, anxiety, alienation, boredom, a sense of isolation, tension, anger, and frustration.
- New technology has increased alienation, which arises when workers have a feeling of powerlessness, meaninglessness, a lack of social norms, and self-estrangement.

- Potential negative effects
  - Increased stress
  - Worker resistance
  - Excessive absenteeism
  - Alcohol and/or drug addiction
  - Depression
  - Sense of powerlessness
  - Feelings of instability, impermanence, and unpredictability
  - Neurosis
  - Disharmony in the work force
  - Lessened productivity
  - Destruction of worker self-respect
  - Lack of loyalty to company
  - Low morale
  - Organizational instability
  - Sense of alienation and isolation
  - Boredom and monotony
  - Psychological fatigue
  - Anger, anxiety, and frustration
- Suggested solutions
  - Task variety
  - Worker autonomy and decisionmaking
  - Opportunities to interact with coworkers
  - Management support and praise
  - Incentive plans
  - Availability of counseling
  - Quality circles or planning groups
  - Communication from management
  - Feedback on workers' suggestions and complaints
  - Development of coping mechanisms
  - Opportunities for training
  - Treating workers as assets rather than as things
  - Using a commitment rather than a control style of management

Figure 6.—Potential negative effects on workers when advanced technology is adopted and suggested solutions.

QUALITY OF WORKING LIFE

The quality of working life has been investigated extensively because it is argued if employees perceive their work and their working conditions as attractive, then they are more likely to be productive, perform their tasks safely, and be absent from work less often. There has also been a tendency in recent years in industrialized societies to consider the psychological consequences of the work environment on employees as the negative role of excessive stress on the mind and on the body has become apparent. In addition, as the work force has become more highly educated and trained, it has demanded more humane working conditions. All of these factors have led to what has been called the quality of working life movement. Publications that discuss the quality of working life emphasize that

- Advanced technology has the potential to decrease the quality of working life by restricting the amount of autonomy, control, and challenge available to the worker and by closer monitoring of workers' performance;
- On the other hand, advanced technology can increase the quality of working life by expanding the decisionmaking opportunities of workers.

SOCIAL (PEOPLE) AND TECHNICAL SYSTEMS COMPATIBILITY

Whenever and wherever advanced technology is introduced, it forms an integral part of the technical system of the company. However, of equal importance is the social system within and external to the company. These two—the technical and the social systems—must be made, at the very least, compatible (jointly optimized if feasible). One approach to solving this compatibility problem that has been used extensively is called sociotechnical systems theory (SST). It stresses that every organization is comprised of people (the social system) who use tools, techniques, and knowledge (the technical system) to produce goods or services for customers (who are part of the organization's external environment). Sociotechnical systems thinking arose as an antidote to the ills of military-bureaucratic organizational designs. Traditional organizational designs emphasize bureaucratic procedures, narrowly defined jobs, and tight supervision and elucidate exactly what individuals can or cannot do. Such management methods send clear messages to employees that their judgment and creativity are not held in high esteem by the company. Flexible structures with little formalization send the opposite message. Lower-than-expected productivity, poor product or service quality, high levels of alienation, and the inability to introduce innovations were clear signs that traditional organizational designs were not working as well as intended. Management finally recognized that even the most advanced technical systems required human direction, maintenance, and improvement. This made the goal of designing human variation out of organizations unattractive, and so the search for alternative organizational assumptions began. Since insufficient attention to the social or technical aspects of an organization and their interactions decreases productivity and affects employee morale, SST has as its goal the joint optimization of the social and technical systems. This goal is accomplished through sociotechnical system interventions. These are organizational development (OD) techniques typically involving the restructuring of work methods, rearrangements of technology, or the redesign of organizational social structures. It is claimed that SST enhances the commitment and energy of employees to the organization by—

1. Enriching the content of work,
2. Establishing challenging goals,
3. Emphasizing shared values,
4. Flattening the organizational structure,
5. Minimizing status differentials,
6. Creating performance-based reward systems,
7. Stressing continuous training,
8. Involving employees in important decisions,
9. Sharing business information, and
10. Enhancing job security.

Sociotechnical systems advocates claim that there is a need to design jobs that give employees control over the key (critical) variances (deviations from standard procedures, plans, or normal routines of an organization's production or service process). This has typically been accomplished by forming self-directing autonomous work groups that have major responsibility for task performance. However, sociotechnical systems analysis (SSA) can be applied at the individual level or group level, to any parts of the organization including managerial levels, or to the organization and its outside environment as a whole. At the same time, SST advocates claim that internal measures of success are insufficient predictors of organizational survival. The external environment is the ultimate judge of organizational design effectiveness. However, organizations persist in ignoring or downplaying the very real threats to their continued existence posed by their environments. Hence, advocates of SST claim that organizational effectiveness must be tested against external criteria. Figure 7 illustrates some of the essential points about the field of SSA. Advocates make the following claims:

- SSA has been very successful when applied to the joint optimization of the social system (people) and the technical system (tools, techniques, and knowledge) of organizations usually by forming autonomous work groups and by OD, which uses a change agent or intervention.
- Several experiments at mining companies in which team-building and OD, intervention were used resulted in improvements in productivity and safety and were maintained when follow-up studies were made.

- Sociotechnical systems analysis (SSA) began with a study of underground coal mining
- Assumes advanced technical systems require
    - Human direction
    - Human maintenance
    - Humans to make improvements
- Goals of SSA
    - Joint optimization of the social and technical systems
    - Development of organizational ability to respond to external environmental changes (competition, markets)
- SSA goal is achieved by interventions
    - Uses organizational development techniques
    - Restructures the work force
    - Rearranges the technology
    - Redesigns the organizational social structures
- Motivates employees by
    - Enriching the content of work
    - Setting challenging goals
    - Emphasizing shared values
    - Flattening the organizational structure
    - Minimizing status differentials
    - Creating performance-based reward systems
    - Stressing continuous training
    - Communicating with employees, including feedback
    - Involving employees in important decisions
    - Sharing business information
    - Enhancing job security
- Sociotechnical systems (STS) questionnaire
    - Used to determine the extent to which organizational design is consistent with STS principles
    - Contains six sections
        - Innovativeness
        - Human resource development
        - Environmental agility
        - Cooperation
        - Commitment-energy
        - Joint optimization
- Most common STS methods
    - Autonomous work groups
    - Technical skill development
    - Action groups
    - Reward system changes
    - Self-inspection of quality
    - Technological change
    - Nonrating teams
- Effectiveness of STS methods at companies
    - 87% improvement in productivity
    - 89% decrease in costs
    - 81% decrease in absenteeism
    - 65% decrease in turnover
    - 94% improvement in attitudes
    - 88% improvement in safety
    - 89% decrease in grievances
    - 97% improvement in product quality

Figure 7.—Sociotechnical systems analysis (SSA) and achievement of social (people) and technical systems compatibility.

TRAINING AND RETRAINING

Everyone in a company, at all levels, is aware that training and skills are required for the vast majority of jobs in industrialized societies. Everyone is also cognizant of the fact that retraining is required for most of today's workers as more and more new technology is adopted, which leads to changes in present jobs, the elimination of existing jobs, and the creation of new jobs. Figure 8 lists key points regarding training and retraining for advanced technology. Publications indicate the following:

- Maintenance personnel working with the new technologies must have skills of a high order to be able to diagnose and repair systems that consist of hydraulic, pneumatic, electrical, electronic, and mechanical subsystems.
- Formal schooling was found to be more crucial than vocational courses for fitting workers into technologically new work settings, since formal education provides verbal, scientific, and technological training that makes workers more adaptable to changes in the job and more able to meet increased job demands.
- The adoption of advanced technology in coal mining means that retraining must become a normal feature of working life, and both management and workers should be multiskilled.

WORKER ACCEPTANCE

The acceptance by the work force of new technology is a key to its safe and efficient utilization. But how can upper management ensure that the introduction of this technology does not result in disgruntled, perhaps rebellious, workers at one or more levels within the company? Figure 9 lists ways in which workers can be induced to accept in a positive way advanced technology. Publications claim the following:

- Acceptance of new technology by workers can be enhanced by obtaining their commitment to planning goals at the feasibility stage. Management can involve workers in the planning process and communicate with them at each stage of the project.
- Those companies that allowed human resource specialists to have a significant role in the introduction of new technology were generally successful in having the workers accept change, especially if these specialists were involved at the planning stage.

- Training should be continuous for managers and technical personnel at all levels
- Retraining is feasible and less expensive than terminating employees and hiring new ones if the work force is properly trained and motivated to begin with
- Workers should have competence in
    - Mathematics
    - Science
    - Reading
    - Communicating
    - Problem solving
- Flexibility is required for workers in
    - What they can do
    - What they can be readily trained to do
    - Being able to develop multiple skills
- Emphasis in management training should be on
    - How to successfully manage innovation
    - How to use and determine the consequences to the company of new technology
    - How to best utilize human resources
    - How to motivate a highly skilled work force
    - How to develop company loyalty among employees

Figure 8.—Training and retraining for an advanced technology work force.

WORKER COMMUNICATION

There is no doubt that workers want to know what is going on within their company especially as it affects their jobs. Most managers today try to communicate with their employees, but often the messages become garbled in their transmission through other layers of management, or they are misinterpreted by the workers. Hence, it is extremely important to utilize feedback from the employees to determine if they got the messages correct and to allow them to provide their opinions and viewpoints on the feasibility and/or utility of what they are being told to do. With the increasing sense of isolation and alienation that workers feel as advanced technology is introduced, top management must stress their commitment to the workers and their interest in the workers' job satisfaction. Otherwise absenteeism and turnover (among the most competent workers) will increase and productivity will suffer. One way that top management can enhance morale is through communication accompanied by worker feedback that is acted upon. Publications claim the following:

- Organizations should communicate with workers and give as full a picture as possible of the employment implications when new technology is introduced, since communication with the workers is an early indication by the organization that it is concerned over jobs and is a critical factor in developing a constructive working relationship between management and the work force.
- Management should incorporate some feedback mechanism to monitor communication effectiveness when new technology is introduced, since there is usually a discrepancy between what management is trying to communicate to workers, what the workers receive, and how they interpret what they do receive.

WORKER DISPLACEMENT

The loss of jobs due to the introduction of advanced technology is a serious problem for the employees affected, the local economy, tax collection agencies, and society as a whole. Historically with the advent of the Industrial Revolution, many jobs were eliminated but even more jobs were created through the years. However, automation and robotics have significantly decreased the percentage of jobs that require manual labor, the large majority of new jobs are in the service-information-knowledge industries, and the skill and educational requirements are becoming ever higher even in manufacturing and mining. Also, the global economy is growing, with more and more countries producing various goods and services. The trend is for manufacturing to be done in countries with lower labor costs and less strict environmental laws than those found in the industrialized countries. In addition, there is massive emigration of unskilled, untrained workers from the Third World into the First World, a process that will only be accelerated because of population growth patterns. What all of this portends for the future job market and for worker displacement is not agreed upon by those who have analyzed employment trends. Publications indicate the views of these analysts at this time:

- Worker displacement due to advanced technology will generally be among the unskilled and semiskilled, while there will be an increasing demand for engineers, computer scientists, technicians, mechanics, repairers, upper-level management, and technical sales and service personnel.
- The use of advanced technology should lead to greater wealth and higher levels of employment in the long

- Worker acceptance can be aided by
  - Obtaining employee commitment to planning goals at the feasibility stage
  - Communicating with employees at each stage of the project and taking feedback seriously
  - Having human resource specialists significantly involved at all stages of the project
  - Having top management take an active role
  - Convincing the work force that the new technology will benefit them
  - Retraining as many employees as possible rather than replacing them
  - Stressing that the new technology is required for the company to remain competitive

Figure 9.—Worker acceptance of advanced technology.

run, since the increased wealth can be used to create more jobs in the service industries.

• A comparison of four stages of progressive and improved mechanization, automation, and remote control of underground continuous mining compared with the present system found that with each stage of increasing automation, productivity increased significantly even though the total number of employees also increased (additional employees being required in management and maintenance).

WORKER INVOLVEMENT AND PARTICIPATION

With the introduction of advanced technology and its attendant highly skilled and educated work force, many companies believe that employees at all levels should become more involved in the decisionmaking pertaining to their work, i.e., employees are encouraged to participate in deciding how the work is to be done and what changes can be implemented to make the system more productive and safe. Workers are no longer being viewed at these companies as appendages to machines or as dull automatons to be told in minute detail exactly what to do and how to do it. The involvement of workers in all facets of their work not only unleashes the creativity of these people but generally results in improved morale and a lessening of negative psychological consequences such as stress, boredom, and alienation. Figure 10 presents some key points pertaining to worker involvement and participation when advanced technology is introduced. Publications expound upon the importance and beneficial consequences of worker involvement and participation in the following manner:

• Implementation of new technology through worker involvement may be as important as the new technology itself.

• Studies on improved or increased participation by workers in management decisionmaking has generally focused on how to restructure the organization to allow employee participation, but more attention should be paid to the role of worker participation in improving communications within organizations and in improving the quality of information available for management decisions.

• Managers should allow employees to participate in decisions, since a strong motivating factor is feeling one is part of a team.

• Direct involvement of workers in the organization of their work needs ensures their acceptance of and commitment to new technologies and changes in work assignments.

HUMAN FACTORS AND THE HUMAN-MACHINE INTERFACE

The basic idea of a human-machine interface is quite simple. The interface is the boundary or place of interaction between a person and a machine or device. Examples from everyday life abound: turning a light switch on or off, driving an automobile, using a television channel changer, adjusting a thermostat for heating or cooling, etc. However, the mental or cognitive aspects of the operators who are involved with machines are generally overlooked, i.e., operators construct mental models that should be taken into consideration in the design of human-machine systems. The field that focuses on these mental models and processes is called cognitive systems engineering (CSE). Subfields of CSE are cognitive ergonomics and cognitive task analysis. The former has been chiefly applied to the design of equipment and systems in terms of human use (safely and productively), while the latter has been used primarily to develop training materials. The fundamental claims, principles, and applications of CSE are very important yet generally overlooked. Figure 11

- Worker involvement is as important as the new technology itself
- Less rigid forms of work organization are more productive than rigidly organized ones
- Autonomous work groups have been shown to be highly productive at many companies
- Workers should be involved in decisions at all stages, including planning
- Worker participation in decisionmaking improves
    - Productivity
    - Safety
    - Communications
    - Morale
- Worker participation is the best assurance that new technology will be adopted quickly and used efficiently

Figure 10.—Worker involvement or participation when advanced technology is adopted.

- Insufficient attention is paid to the human component of human-machine systems at many companies
- Advanced technology emphasizes cognitive (mental) rather than physical tasks
- The human-machine interface should be compatible with human cognitive characteristics or thought processes
- All too often the human is forced to adapt to the machine rather than having the machine designed in terms of human abilities and limitations
- Cognitive systems engineering
    - Its goal is the achievement of an integrated relationship between humans and machines
    - This goal can be accomplished by engineering the cognitive aspects of task performance into the human-machine system
    - Can be used to improve the efficiency of advanced technology
    - Is based on the findings of cognitive psychology
    - Analyzes thinking processes and develops mental models
    - Uses an information processing approach
    - Claims that a human-machine system needs to be conceived, designed, analyzed, and evaluated in terms of a cognitive system
- New approaches are needed for work design and measurement
    - The traditional time study techniques are inadequate
    - The models used should be based on descriptions of human mental functions

Figure 11.—Human factors and human-machine interface.

gives some highlights on the human-machine interface and cognitive or mental models. Details on CSE are given in the appendix. Publications mention the following:

• Improvements in productivity can be realized if CSE, which applies the techniques and knowledge of cognitive psychology to the design of human-machine systems, is used to develop mental models of how operators deal with input information instead of relying strictly on physical models of how the operator and machine function and interact.

• Human-machine systems should be conceived, designed, analyzed, and evaluated in terms of human mental processes (an operator mental model that describes the operations and functions of the system), since the nature of tasks has shifted from (and will do so even more in the future) those that require perceptual-motor skills to cognitive activities of problem solving and decisionmaking in monitoring and supervisory tasks.

CONCLUSIONS

There are four major conclusions based on the results of the interviews with mining personnel and the literature searches upon which this report is based:

1. Human factors is of extreme importance when advanced technology is adopted and implemented by a company;
2. Managers in general are aware of the importance of the human aspects when automation and robotics are introduced but all too often fail to develop and put into effect a well-thought-out plan to deal with the human consequences of and responses to this technology;
3. Manufacturing (a much larger and more diverse industry than mining) has spent and continues to spend much time and effort on understanding and ameliorating the human reactions to and ramifications of new technology than does the mining industry; and
4. As more and more automation is introduced, the mining industry can learn from and apply the experience obtained by manufacturers in adopting and using advanced technology.

APPENDIX—ANNOTATED BIBLIOGRAPHY

Summaries of relevant information from the various publications listed in the references are given in detail in this appendix under the same categories used in the main text. Quantitative data and its analysis are seldom found in the literature on advanced technology and human factors, the studies being in general of a qualitative nature.

IMPORTANCE OF HUMAN FACTORS FOR ADVANCED TECHNOLOGY

1. Brennan, L. The Influence of New Technology on the Allocation of Functions Decision. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 79-86.

Brennan considered the influence of new technology on the allocation of functions between the operator and the machine and the effects of the increasingly rapid changes in technology on conventional approaches to this problem. The area he investigated was computer-integrated manufacturing (CIM) systems. He said that there is a growing imbalance between the technical and social aspects of production systems. According to Brennan, the consideration of human attitudes and needs and the role of people in new technology adoption and implementation is insufficient and too late to ensure efficient utilization of this technology. Critical decisions are made by systems specialists seeking a technical "best" in conjunction with departmental managers with restricted views of staffing requirements. Those involved in the development of advanced technological systems see the process as exclusively one of substitution or replacement of human inputs. They should consider the process as one that seeks to increase human satisfaction by allowing enhancement of the human contribution. Instead, engineers and designers attempt to suppress the abilities of workers rather than making the technology a tool of the worker. Overlooked is the importance of the human factors specialist being involved at all stages from very early planning through design and fabrication to operational use of the system. Human factors experts should also aid in the application of job enrichment, job rotation, job enlargement, and autonomous work groups (in which workers are given responsibility for many decisions affecting their work) as a means of better using human abilities in the workplace.

2. Goodridge, J. M. Employee Relations and New Technology Systems. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 227-240.

Goodridge performed a survey of companies introducing new technologies and found that the human factor aspects were being ignored by most of them. For example, 89% had made or were making provisions for technical training, but only 28% had or were going to have training on how the technology would impact the organization and its employees. Human factors and employee relations must be fully integrated into the process of adopting and implementing new technology. Consultation and information disclosure to and communication with workers are required.

3. McArthur, D. W. What Good Is Technology If You Are Faced With Disenchanted Employees? The Office, v. 10, No. 1, Jan. 1985, p. 128.

McArthur claimed that new technology is of little benefit to a company if it is faced with disgruntled employees. The human factor must be taken into account by companies when introducing new technology. Motivated, well-trained people can make a success of even the most minimal automation, while angry, disgruntled people can and will undermine the best that technology has to offer. One way of stressing the human element is to allow workers to participate in decisions.

4. Meredith, J. R. Managing Factory Automation Projects. J. Manuf. Syst., v. 6, No. 2, 1987, pp. 75-91.

Meredith discussed the major project management concepts and techniques used in a number of industrial automation projects to achieve the benefits of automated systems within reasonable time and cost limitations. He found that human factors is consistently identified as the biggest problem in implementing automation. People do not like to change and can resist automation to the point that its benefits are not realized.

5. Ebel, K.-H. Social and Labour Implications of Flexible Manufacturing Systems. Int. Labour Rev. (Switzerland), v. 124, No. 2, Mar./Apr. 1985, pp. 133-145.

Ebel discussed the social and employee implications of flexible manufacturing systems (FMS's). He claimed that it is very important to design systems that consider worker preferences and characteristics by using ergonomic principles. Human factors should not be considered as an afterthought, since once a new technology is installed it is difficult and costly to adapt it. In fact, human factors are every bit as important as the technical aspects, if not more so, because they may well determine the economic efficiency and success of the new systems. Worker acceptance of the new technology is critical.

6. Greatrex, M. D. Human Implications of Technological Change. Ch. in Ergonomics of Hybrid Automation Systems I, ed. by W. Karwowski, H. R. Parsaei, and M. R. Wilhelm. Elsevier, 1988, pp. 61-70.

Greatrex investigated the human implications of technological change. He contended that the effects on humans arising from the introduction of new technology are frequently overlooked, often leading to unsatisfactory utilization of both systems and personnel. The human factor is always present as is the potential for human error and inadequate performance, but their adverse consequences can be reduced through an improved awareness and development of human abilities.

7. Salvendy, G. Human Factors in Planning Robotic Systems. Ch. in Handbook of Industrial Robotics, ed. by S. Nof. Wiley, 1985, pp. 639-664.

Salvendy discussed the nature and characteristics of the human factors that impact effective planning, design, control, and operation of industrial automated and/or robotic systems. These systems must be economically viable, and humanly acceptable, and they must result in increased productivity and quality of working life. Social, safety, human performance, and motivational issues must receive due consideration at all stages of development of these systems. For example, a number of human performance capabilities impact the effective design and operation of advanced technology: design of controls, human variability in work performance, information processing capabilities, task pacing, and job satisfaction.

8. Haynes, M. J. New Mining Technology and Its Expected Influence on Health and Safety in Mining in the 1990s. Min. Eng. (London), v. 150, No. 348, Sept. 1990, pp. 91-98.

Haynes examined the safety record of the U.K. underground coal mining industry in the 20th century and identified some of the major trends that have led to a decrease in the number of fatal accidents. The author claimed that if a fatality-free year 2000 is to be realized in underground coal mining, then new technology must be adopted and human error must be controlled. This is because human factors will remain critical in all mining situations, and it is technically feasible to eventually eliminate most dangers stemming from humans performing underground tasks.

9. Beckert, B. A., B. Knill, P. Pascarella, and G. Weimer. Integrated Manufacturing: The Shape of Work to Come. Comput. Aided Eng., v. 8, No. 4, Apr. 1989, pp. IM-2, 4, 7, 8, 10, 12, 16, 18, 20.

Beckert, Knill, Pascarella, and Weimer investigated the changes in work to be expected in manufacturing as technology continues to advance and quoted a number of executives. They believe that it may be more important to study the human factor, especially as it relates to management, than the technology itself. The reason for this is that there is a breakdown between the people who design, the people who manage, and the people who implement the new technology.

10. Hirsch-Kreinsen, H., and R. Schultz-Wild. Implementation Processes of New Technologies—Management Objectives and Interests. Automatica, v. 26, No. 2, Mar. 1990, pp. 429-433.

Hirsch-Kreinsen and Schultz-Wild reviewed several studies, some conducted worldwide, and documented the lack of initial consideration of human needs and consequences when advanced manufacturing technology is installed. Planning concepts are required that enable an interaction and integration of the technological and the human factors, e.g., job design and work reorganization.

11. Rahimi, M., P. A. Hancock, and A. Majchrzak. On Managing the Human Factors Engineering of Hybrid Production Systems. IEEE Trans. Eng. Manage., v. 35, No. 4, Nov. 1988, pp. 238-249.

Rahimi, Hancock, and Majchrzak discussed human factors engineering and hybrid production systems. They contended that human activities in hybrid automated manufacturing systems are critical in achieving productivity gains. However, optimal human factors engineering is possible only when engineers and managers are aware of the challenges created by hybrid systems and of the range of options available for meeting these challenges. Even in the most automated systems, the human role remains critical to the accomplishment of operational goals. Equally important, however, is the interaction between the human and machine components of the system.

12. Ammons, J. C., T. Govindaraj, and C. M. Mitchell. Decision Models for Aiding FMS Scheduling and Control. IEEE Trans. Syst., Man, and Cybern., v. 18, No. 5, Sept.-Oct. 1988, pp. 744-756.

Ammons, Govindaraj, and Mitchell gave an overview of decision models for aiding flexible manufacturing systems (FMS's) and control. Current research has focused on computers to perform automated control and routing activities. Human factors is not considered sufficiently even though humans are required to supervise the automation, monitor system flow and outputs, and intervene to diagnose and either correct or compensate for unanticipated events. An "optimal" real-time scheduling system effectively combines computer scheduling algorithms and artificial intelligence techniques with the versatile capabilities of the human supervisor.

13. Kumar, U. Human Reliability and Its Impact on Mechanized and Automated Mining Operations. Paper

in Proceedings of the International Symposium on Mine Mechanization and Automation: Volume II, ed. by L. Ozdemir, R. King, and K. Hanna (Denver, CO, June 10-13, 1991). CO Sch. Mines, 1991, pp. 16-1 to 16-8.

Kumar attempted to define and discuss the human as a critical element in mechanized and automated mining operations. The current trend toward mine mechanization and automation is altering the nature of human involvement at various levels of operation in mines. However, even with high levels of automation, humans are needed to monitor, supervise, and execute mining operations. In fact, the human factor is more important than ever as mining technology advances, since the consequences of a human error (e.g., incorrect reading of a display, a minor lapse of memory, failure to notice a warning signal, misunderstanding of instructions) are much more severe in an automated operation than in a conventional operation. For example, the contribution of human error to accidents and breakdowns of equipment can be as high as 65% to 70%.

14. Sage, L., and B. Fox. Human Integrated Manufacturing. CIM Rev., v. 6, No. 3, Spring 1990, pp. 41-44.

Sage and Fox state that Japanese manufacturers stress two critical success factors for automated systems: optimal systems performance and the integration of human factors into the manufacturing process. Japanese manufacturers automate for function and attack the nonphysical entities of integration, while U.S. manufacturers automate for cost and attack the physical entities of integration. To compete in global markets, U.S. manufacturers must follow the lead of Japanese competitors and include human factors when they introduce advanced technology. Without workers' pride, commitment, and positive attitude, even state-of-the-art manufacturing technology cannot make products competitive.

15. Symon, G. Human-Centered Computer Integrated Manufacturing. Comput. Integrated Manuf. Syst., v. 3, No. 4, Nov. 1990, pp. 223-229.

Symon advocated the human-centered approach for computer-integrated manufacturing (CIM). This approach to the design and implementation of new technology differs from the technology-centered approach in a fundamental way: The human role in the system is regarded as crucial to its effective operation rather than a drawback and potential source of error. One of CIM's principles is that people should not be subordinated to machines, i.e., human skill, ingenuity, flexibility, creativity, and knowledge should be appreciated and enhanced (rather than suppressed) in the technological system. CIM's advantages are that the system will be usable more quickly, users will want to use it, and it will remain productive longer.

16. Majchrzak, A. The Human Infrastructure Impact Statement (HIIS): A Tool for Managing the Effective Implementation of Advanced Manufacturing Technology. Comput. Integrated Manuf. Syst., v. 1, No. 2, May 1988, pp. 95-102.

Majchrzak indicated that studies and research on how advanced manufacturing technologies have been managed in factories have found that planning for human systems as an essential component of new technology is generally done after the fact. It is only after technical choices have been solidified that the impacts on humans and the organization have been considered. Even then, consideration of human factors is often handled only when problems arise such as high accident rates. However, problems occur when planning for the human factor is delayed until after equipment arrives or even longer. Unfortunately, there have been few tools to help those designing advanced technology in systematically and completely integrating the human factor into the technical planning. Majchrzak advocates the human infrastructure impact statement (HIIS) as a tool to rectify this deficiency. The HIIS is discussed in detail in a subsequent section of this appendix.

BARRIERS TO ADOPTION

1. Office of Technology Assessment (Washington, DC). Computerized Manufacturing Automation: Employment, Education, and the Workplace. U.S. GPO 84-601053, 1984, 471 pp.

The Office of Technology Assessment stated that human factors problems such as the ease of use slow the rate of adoption of programmable automation (PA) technologies. Other factors that affect the adoption of advanced technology include the availability of capital, a lack of know-how or expertise within the company, organizational resistance to change, and the availability of appropriate education and training programs.

2. Flynn, P. M. The Impact of Technological Change on Jobs and Workers. Bentley Coll., Waltham, MA, Final Rep., Mar. 1985, 104 pp.; NTIS PB 85-218022.

According to Flynn, who analyzed 197 case studies of U.S. and European firms, small firms have the barriers to adoption listed in the previous reference and more. For instance, small firms cannot compete with large firms in terms of wages and fringe benefits in the hiring and retaining of skilled workers, who are in short supply in the new technologies. Also, the relatively low levels of production in small firms often result in underutilization of advanced technology.

3. Ouellette, R. P., L. W. Thomas, E. C. Mangold, and P. N. Cheremisinoff. Automation Impacts on Industry. Ann Arbor Sci., 1983, 186 pp.

Ouellette, Thomas, Mangold, and Cheremisinoff claimed that the availability of trained personnel who can program and operate computer systems is the greatest factor determining the use of automation. This problem should lessen as more persons are trained to perform these functions and as manufacturers of automation equipment develop systems that are easier to operate with factory-level skills by using more interactive languages and improved displays and controls. However, continuing barriers to the adoption of new technology are traditional lines of management and traditional company organizations that have difficulty in accepting the disruption of established patterns that accompany the introduction of advanced technology.

4. Goodridge, J. M. Employee Relations and New Technology Systems. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 227-240.

Goodridge contended that the main source of resistance to the introduction of new technology is "ignorant and backward management" that opposes change and does not understand the need for new technology to compete. In addition, there are many individuals within the company who are affected by fear—fear of redundancy; fear of deskilling (the redesigned job will require less skill); and fear of losing position, status, influence, and career progression.

5. Beatty, C. A., and J. R. M. Gordon. Barriers to the Implementation of CAD/CAM Systems. Sloan Manage. Rev., Summer 1988, pp. 25-33.

Beatty and Gordon said that there are human barriers or psychological factors that arise in most periods of change when outcomes are uncertain and possibly detrimental to employees. It is in the self-interest of some groups within a company to resist the introduction of new technology, or if they do not succeed in that, to ensure its failure.

6. Meredith, J. R. Implementing the Automated Factory. J. Manuf. Syst., v. 6, No. 1, 1987, pp. 1-13.

Meredith found that the adoption rates of new technologies lag far behind what even the most prudent levels of cautious investment dictate. The reasons for this occurrence were insufficient internal skills; the difficulty of implementing computerized systems; the multiplicity of apparent implementation paths; the importance of adopting one technology or system at an early stage, which either limits or enhances options and benefits at a later stage; the need for incremental skill building; and the necessity to have an infrastructure of supporting systems, policies, and procedures. For adoption, a champion or project sponsor must be found at the early planning stage. Meredith concludes that "it is now well recognized that the adoption and implementation of advanced manufacturing technologies is not a technical problem but a managerial problem."

7. Chamot, D. Human Aspects of Automation: A Union Perspective. SME Tech. Pap. MM84-638, 1984, 8 pp.

Chamot affirms the last statement of Meredith above by saying that the real center of opposition to technological change is not workers or unions but generally middle management.

8. Kassler, M. Robots and Mining: The Implications for Australian Industry in the 1980's. Paper in Proceedings of the National Conference on Robotics (Melbourne, Australia, Aug. 1984). Inst. Eng., Australia, 1984, pp. 13-19.

9. _____. Mining, Robots in. Entry in International Encyclopedia of Robotics: Applications and Automation, ed. by R. C. Dorf and S. Nof. Wiley, 1985, pp. 897-902.

Kassler investigated advanced technology in mining over the next 10 to 20 years. He believes that it generally takes a long time for advanced technology to penetrate the mining industry. The major barrier to the adoption of new technology in mining is that mining company management in general is conservative and waits until the new technology has been proven to be cost effective and productive at other mining companies or in other industries before adopting it at their company. Other reasons are as follows: The environmental conditions of underground mines are harsh, complex equipment requires many highly paid maintenance people who are unoccupied much of the time, persons with the requisite maintenance skills are in short supply and are not usually attracted to mining or are not amenable to living in a mining community, and advanced equipment is very expensive and can be quite costly to repair.

JOB DESIGN AND REDESIGN

1. Edwards, J. R. Stress, Coping and Worker Well-Being in Computer-Aided Manufacturing: A Field Investigation of a CNC Machine Shop. Paper in Ergonomics of Hybrid Automated Systems I, ed. by W. Karwowski, H. R. Parsaei, and M. R. Wilhelm. Elsevier, 1988, pp. 101-108.

Edwards showed that designing jobs to reduce worker stress also can improve productivity. Management should design work to facilitate the coping efforts of workers. Examples given for maintenance tasks were providing time and resources for both preventive maintenance and repairs, allowing breaks during prolonged repair jobs, encouraging group work when repairs require multiple skills, and providing adequate training for workers.

2. Smith, M. J., and P. C. Sainfort. A Balance Theory of Job Design for Stress Reduction. Int. J. Ind. Ergonom., Apr. 1989, pp. 67-79.

Smith and Sainfort indicated that in 1911 Taylor proposed that jobs be redesigned using methods that decompose tasks into small elements that are easy to measure. Gantt invented the Gantt chart in 1919, retaining Taylor's assumption that workers are motivated basically by money. Even today, job designers generally attempt to minimize immediate costs by minimizing skills and deemphasizing job satisfaction in job design. The Human Relations Movement led to the development of concepts of job design that claim that once the basic safety and physical comfort needs of workers are met, higher order ego needs of workers must be considered in order for them to be motivated and satisfied with their jobs. The important job considerations that should be part of the job design and that provide worker satisfaction and well-being are (1) control over the work situation, working methods, and pace, (2) understanding of the work process as a whole, (3) technical and social skill use and develop-ment, (4) possibility for social interaction, and (5) a work schedule that allows for extraorganizational activities. Many of today's top job designers believe that worker participation, enhanced task content through job enlargement and job enrichment, and group decisionmaking are cures for job stress, even though these factors were invoked to improve worker performance and job satisfaction.

3. Chamot, D. Human Aspects of Automation: A Union Perspective. SME Tech. Pap. MM84-638, 1984, 8 pp.

Chamot said that people are not machines and thus should not be treated as machines. Proper job design should result in a job that offers some challenge and variety, is not accompanied by job pacing and stress, and allows the worker reasonable autonomy. For example, in Sweden factory jobs are designed to allow as much decisionmaking as possible to be done by the worker on the floor of the shop. Management and unions there have developed production criteria that permit small independent production units, the untying of workers from machine pacing, jobs with more personal involvement, and reliable and fast production systems.

4. Salvendy, G. Human Factors in Planning Robotic Systems. Ch. in Handbook of Industrial Robotics, ed. by S. Nof. Wiley, 1985, pp. 639-664.

Salvendy said evidence pertaining to job design indicates that 45% of the labor force prefers simplified jobs, 45% prefers enriched jobs, and 10% does not like work of any type. It is typically the older worker who prefers simplified jobs, whereas younger workers prefer enriched jobs. These findings make the design or redesign of jobs in a mixed work force difficult when new technology is introduced.

5. Hirsch-Kreinsen, H., and R. Schultz-Wild. Implementation Processes of New Technologies—Management Objectives and Interests. Automatica, v. 26, No. 2, Mar. 1990, pp. 429-433.

Hirsch-Kreinsen and Schultz-Wild stated that in order for advanced technology to be used productively the following basic job design criteria must be considered: (1) Hierarchical and functional division of labor should be reduced to a minimum, (2) the differentiation between relatively complex tasks on the one hand and relatively monotonous and difficult tasks on the other hand should not be permitted, and (3) technology adopted should allow skilled operators easy access to planning, programming, and control functions and use of their skills, experience, and tacit knowledge.

6. Schilling, A., H. Schuepbach, and E. Ulich. Sociotechnical Design of Advanced Manufacturing Systems. Ch. in Ergonomics of Hybrid Automated Systems I, ed. by W. Karwowski, H. R. Parsaei, and M. R. Wilhelm. Elsevier, 1988, pp. 71-77.

Schilling, Schuepbach, and Ulich claimed that to maintain and promote motivation and skills when advanced technology is adopted, the following features of job design and redesign must be considered: (1) Completeness—the operator should be able to check his or her results and to supervise the monitoring system, (2) variety—manual and automated work activities should be decoupled to allow for the possibility of task expansion and job rotation, (3) interaction—interrelations with others should be possible so that mutual support and communication can occur, (4) chances for learning—opportunity to experiment in new ways should be present, and (5) autonomy—the operator should have decision latitude in assessing malfunction and its elimination.

7. Volpert, W., W. Kotter, H. E. Gohde, and W. G. Weber. Psychological Evaluation and Design of Work Tasks: Two Examples. Ergonomics, v. 32, No. 7, July 1989, pp. 881-890.

Volpert, Kotter, Gohde, and Weber said jobs should be designed based on the fact that work activities are supportive to learning and personal development when there are sufficient demands as well as chances for personal decisionmaking and action. The structuring of work tasks and the conceptualization of human-machine interactions should allow for personality-promoting schemes of action. However, when work is redesigned with the adoption of advanced technology, there is a risk that severe, inhumane working conditions will result. To avoid this problem, a method of job or work redesign should be employed that is aimed at tasks and conditions that are conducive to human development, i.e., focused on human-oriented job design.

ORGANIZATIONAL STRUCTURE AND MANAGEMENT PRACTICES

1. Office of Technology Assessment (Washington, DC). Computerized Manufacturing Automation: Employment, Education, and the Workplace. U.S. GPO 84-601053, 1984, 471 pp.

The Office of Technology Assessment stated that the advantages of programmable automation (PA) for management are its ability to facilitate information flow, coordinate factory operations, and increase efficiency and flexibility. In addition, the new technologies can increase management's control over operations, which can decrease problems stemming from human error. However, an excess of management control can decrease opportunities for constructive worker input and degrade the work environment.

2. Ayres, R. U., and S. M. Miller. Exploratory Assessment of Second Generation Robotics and Sensor-Based Systems (NSF contract PRA8302137). Carnegie-Mellon Univ., Pittsburgh, PA). Final Rep., Sept. 1984, 287 pp.; NTIS PB 85-132793.

Ayres and Miller quote a response to their papers on second-generation robotics and advanced sensor-based systems: "I think the question is whether we construct organizations that distribute responsibility and the exercise of creativity fairly evenly, or whether we construct tightly controlled organizations. U.S. management believes in substituting external control for motivation. In Japan plant managers report directly to the CEO without elaborate intervening staff and control structures. Subordinates are told what is expected and then will be left to carry it out."

3. Business Higher Education Forum (Washington, DC). The New Manufacturing: America's Race To Automate. Final Rep., June 1984, 42 pp.

The Business Higher Education Forum mentioned several factors that managers must consider as automation in manufacturing increases. Management will have to rethink the roles of humans and machines in the organization and the relationships between them. The decrease in the number of people in the manufacturing workplace (office and factory floor) will mean each employee will be extremely critical. Organizationally, there will be fewer people between the production process and vice presidents of manufacturing, i.e., fewer hierarchical levels than without automation. Managers in every function, from marketing to accounting, must become more knowledgeable about the basic production process and its technology.

4. Beaty, R. T. Evolution Towards Automation. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 29-39.

Beaty contended that those employees working for companies where automation is involved are more highly educated than previous workers and expect management to provide satisfying and challenging jobs. Also, management should realize that an evolutionary rather than a revolutionary approach to automation will provide dividends in the long run. Finally, management must consider the system as an integrated whole, since a delay anywhere will make automation ineffective.

5. Brennan, L. The Influence of New Technology on the Allocation of Function Decision. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 79-86.

Brennan claimed that management should be aware that more than one option exists in the development of technology and associated systems. It is inefficient to consider a technology as given and to observe the effects that follow from it. Alternative patterns of development are possible, and these are reflective of organizational policies and procedures. Such policies and procedures are in turn a product of the attitudes and motivations of managers, engineers, and system designers.

6. Tynan, O. People Are Assets. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 119-126.

Tynan said there are two ways in which managers can regard people: as objects and as agents. In the former, the worker is viewed as an extension of his or her machine and thus as a dispensable spare part. Workers work, and managers do the thinking. In the latter, the machine is regarded as complementing the worker by extending the effects of his or her skills while the worker is viewed as a unique resource to be developed. The management methodology to be utilized, especially when new technology is introduced, is the latter if the potential gains of this technology are to be realized. In addition, since people have a wide range of talents that they will use if work structures are right, managers should listen to the ideas of everyone to improve the work itself, the work environment, and the company.

7. Amram, F. M. Designing a Social Environment for Human-Robot Cooperation. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 127-135.

Amram stated that in introducing new technology the organization should develop some feedback mechanism between management and workers. Often there is a vast discrepancy between what managers try to communicate to workers and what the workers actually receive. Managers should have a clear understanding of human responses to technological changes, i.e., a clear vision in contrast to traditional industrial relations cliches.

8. Goodridge, J. M. Employee Relations and New Technology Systems. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 227-240.

Goodridge argued that rarely is the organizational structure considered at the design and planning stage when new technology is to be introduced. An organization should examine its capacity to effect and manage change, including having the proper managerial, sales, technical, and worker personnel. Owing to the importance of effective interaction between people, new technology dictates that managers must possess a wide range of interpersonal skills at a high level as well as an understanding of this technology. In fact, many managers find the management of the human aspects of change more demanding than the technical aspects.

9. Oliver, M. V. L. The Management and Training Implications of Innovation and Change Due to Advanced Manufacturing Technologies. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 249-258.

Oliver attempted to enlighten top management on how to manage technological innovation and change in manufacturing. The technology of people is a very different concept from the technology of manufacturing, but few managers take people-technology seriously. Top management of those companies that have been most successful in applying advanced technology place as much emphasis on their people and team development as they do on their technology. Too often managers ask, What can the equipment do? rather than the basic question, What does our business really need? Perhaps all it needs is to improve scheduling, inventory control, and/or information processing. Perhaps advanced technology is not the answer. Much of the change in manufacturing today is being technologically driven, but successful change must be management driven, by managers who understand the process of change.

10. Weir, D. T. H. Organizational Stress and the Introduction of New Technology. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 361-373.

Weir emphasized managerial strategies available for introduction of a major organizational change when advanced technology is adopted. Successful programs are those in which management (1) recognizes the importance of job security, (2) incorporates known and predictable ways of working the new technology into the new organizational structure, (3) uses work groups as the basis for presentation of what is planned to be done, (4) ensures that the pace of implementation is not hurried, (5) maintains a balance between programmed and unprogrammed activities, (6) respects the natural orderings of groups and structures, (7) allows feedback and responds to the feedback, and (8) presents a positive picture to the employees as to the future of the firm.

11. Preece, D. A. The Management of the Adoption and Introduction of New Technology. Paper in Proceedings of the 2nd International Conference on Human Factors in Manufacturing (Stuttgart, West Germany, June 11-13, 1985). IFS Publications Ltd., 1985, pp. 353-361.

Preece stated that the managerial strategies that should be used when introducing new technology into the workplace are as follows: using a low-key approach and working through employee representatives, linking the new technology skills with the skills-acquisition procedures of the company, and accommodating wages within the grading structure. The managerial style should emphasize managers being trainers and facilitators rather than controllers.

12. Chiaromonte, F. Management and New Technologies. Paper in Proceedings of the 2nd International Conference on Human Factors in Manufacturing (Stuttgart, West Germany, June 11-13, 1985). IFS Publications Ltd., 1985, pp. 363-370.

Chiaromonte believed it is a serious shortcoming of industrialized societies that the interaction between management and new technologies has not been studied to any degree. To be successful, the management of innovation requires an innovative environment in which management, particularly top management, ensures that financially, organizationally, and culturally there are sufficient resources to stimulate and support innovation. It is also becoming increasingly evident that technological innovation depends on a network of interacting managerial roles, each one contributing its specific knowledge and skills.

13. Majchrzak, A., and M. Rahimi. Differential Organizational Impacts of the Transition From Stand-Alone to Integrated Flexible Production. Ch. in Ergonomics of Hybrid Automated Systems I, ed. by W. Karwowski, H. R. Parsaei, and M. R. Wilhelm. Elsevier, 1988, pp. 153-159.

Majchrzak and Rahimi reviewed studies of the human and organizational impacts of advanced manufacturing technology (AMT). There is a need to teach problem-solving skills to operators and to maintenance personnel and to provide the latter with the proper tools for repair. The organization becomes more dependent on the nonmanagerial worker as new technology is used. This creates tensions between workers and managers or supervisors and requires a more flexible application of work rules. Management should consider a gradual introduction of automation, which if successful helps foster a confident attitude among the work force about future automation efforts. This gradual approach also provides management with useful knowledge about how to handle resistance to change.

14. Hagedorn, H. J. The Factory of the Future: What About the People? J. Bus. Strategy, v. 5, No. 1, 1984, pp. 38-45.

Hagedorn said that organizations will have to do a prodigious amount of planning, troubleshooting, and anticipatory problem solving by teams of people when automation is to be introduced. The table of organization will be much narrower at the bottom, and there will be fewer levels of management. Each manager or supervisor will have much more authority in his or her realm. The organization will function more like an informal grouping of colleagues and less like a bureaucratic, hierarchical army. Small groups, which are almost always easier to motivate than larger groups with similar characteristics, will be the norm.

15. Coates, V. T. The Potential Impacts of Robotics. ASME, Tech. Pap. 83-WA/TS-9, 1983, 3 pp.

Coates discussed a User-Institution Model. It is based on the fact that any institution or company undergoes a cycle of change as innovative technology becomes available. First the institution adopts the new technology to accomplish existing functions more efficiently. Then the institution changes internally to take better advantage of the technology's efficiencies. Following this, it develops new functions and activities made possible by the additional capabilities of the new technology. Finally, the institution may become obsolete or be replaced if it does not adopt the new technology or be radically transformed if it does adopt the new technology.

16. McCarthy, P. J. Overview of New Technology and Its Introduction to the Australian Coal Industry. Paper in Proceedings of a Seminar on Factors Influencing Underground Productivity (Sydney, Australia, Aug. 21, 1987), pp. 292-307.

McCarthy discussed human relations, motivational aspects, and organizational and management issues that influence the success of new technology in coal mining. The introduction of new technology is changing the demands and roles of most personnel in the mining industry. Aspects of organizations that must be addressed are multiskill training and retraining of both management and the work force, predictive maintenance rather than preventive maintenance, and a more accurate assessment of economic life cycle costs for new technology. Management techniques may differ significantly from present management techniques as mines automate. One of the main problems facing corporate and individual mine managers is the design of appropriate and effective organizational structures for the management of present and future advanced technology.

17. Whaley, G. L. The Impact of Robotics Technology Upon Human Resource Management. Personnel Admin., v. 27, No. 9, Sept. 1982, pp. 61-71.

Whaley contended that the most immediately recognizable effects of advanced technology are on the behavior of work groups and individuals through changes in organizational structure. One of the most far-reaching changes will be more control at the bottom and less at the top or executive level. This will mean that fewer middle managers will be needed.

18. Susman, G. I., and R. B. Chase. A Sociotechnical Analysis of the Integrated Factory. J. Appl. Behav. Sci., v. 22, No. 3, 1986, pp. 257-270.

Susman and Chase think that as much time and thought will be required to design an organization compatible with the new technology as will be required to plan and implement that technology. Values that support information sharing, joint action, and problem solving with others must be widely supported, practiced, and rewarded from the top management down.

19. Frantz, R. L., and R. H. King. Study of the Human Factors Aspects of an Automated Continuous Mining Section (grant SO144115). PA State Univ., Dep. Min. Eng., Final Rep., 1977, 305 pp.; NTIS PB 299 945.

Frantz and King believe that automation and remote control in mining will produce changes in managerial practices. Much greater emphasis must be placed on the planning and service support activities that management performs. The transition stages between various levels of automation will magnify the need for clear communication between workers and management. Both sides must spend time discussing the implications of the new technology and attempt to resolve problems before they occur. Managers will have to prepare workers to accept more responsibility and make more decisions, since supervision under automation will be more subtle. For example, forepersons will provide workers with the material and training necessary to accomplish a task but then will not interfere unless the worker requests assistance or does the job incorrectly.

20. Goodridge, M. Managing Operations Into the 1990s. Manage. Decision (UK), v. 26, No. 1, 1988, pp. 5-10.

Goodridge contended that the effective management of advanced technology dictates changes in managerial style from a control to a commitment orientation in the workplace. A management whose wish is to establish order, exercise control, and achieve efficiency through close supervision will lead to an increasing disillusionment on the part of managers and employees with the benefits of new technology. A commitment style of management is needed that gives individuals responsibility and freedom and uses a flat organizational structure. Japanese companies put considerable time into the maintenance of human relations with beneficial consequences to both the company and its employees, and their managers receive extensive training in this area.

21. Carr, T. L. Technical Trends From the User's Viewpoint. Min. Eng. (London), Aug. 1987, pp. 57-62.

Carr stated that the authoritarian style of management used in the 1940's, 1950's, and even later is totally inappropriate, even disastrous, in modern underground coal mines with their high degree of mechanization and their skilled work forces. Decentralization and flat hierarchical management structures are the means of achieving important advances in productivity and decreases in costs. Studies have shown that successful companies consider employees' ideas and needs, regard employees as the basis for quality and productivity, and push decisionmaking downward. Japanese managers are taught that workers know the business best and that innovation and improvement come from where the action is. The author claimed that if ever there was a subject that required debate, it is how mines with advanced technology should be managed, but such debate has been lacking.

22. Meredith, J. R. Implementing the Automated Factory. J. Manuf. Syst., v. 6, No. 1, 1987, pp. 1-13.

Meredith said that there are three primary matters that need to be considered when a firm is contemplating new technology: its economic feasibility, its technical feasibility, and its organizational feasibility. In general, companies pay extreme attention to the economic feasibility and have sufficient competence to pay attention, though perhaps not enough, to technical matters. However, most firms only minimally consider the necessity for organizational compatibility and feasibility. Studies have shown, however, that the main problems companies encounter in the implementation of automation are not technical but rather organizational. This deficiency in investigating organizational feasibility has produced a lack of fit between the demands made by the new technology and the skills, attitudes, needs, and values embodied in the social and technical structures of companies.

23. Ebel, K.-H. Social and Labour Implications of Flexible Manufacturing Systems. Int. Labour Rev. (Switzerland), v. 124, No. 2, Mar./Apr. 1985, pp. 133-145.

Ebel said it has been estimated that 60% of the benefits resulting from the installation of flexible manufacturing systems (FMS's) are actually derived from reorganization of the company and the work and only 40% from the hardware itself. Decentralization of management should be implemented since work preparation, programming, and inspection functions can be performed on the shop floor. Autonomous groups of workers are feasible with an FMS, which is more in keeping with the desires of the workers. The formation of such groups and the assignment of more responsibility to their members also permits more cooperative forms of work organization by reducing the number of management levels.

24. Roitman, D. B., J. K. Liker, and E. Roskies. Birthing a Factory of the Future: When Is "All At Once" Too Much? Ch. in Corporate Transformation: Revitalizing Organizations for a Competitive World. Jossey-Bass, San Francisco, 1987, pp. 205-246.

Roitman, Liker, and Roskies described a manufacturing firm that made major changes in all of its organizational aspects while implementing a computer-integrated manufacturing (CIM) system. Management tried to change the organization by introducing programs on training, job displacement, autonomy and job enrichment, compensation, worker involvement, communication to and from workers, restructuring departments, and modifying supplier and customer relations. The results were poor because of this "all at once" approach, i.e., management attempted to do too much, too fast and caused morale problems and destroyed the trust of employees.

25. Black, M. C. Evolution or Revolution in Automation in Mining? Paper in Proceedings of the 3rd Canadian Symposium on Mining Automation (Montreal, PQ, Canada, Sept. 14-16, 1988). J.-M. Robert, Sainte-Foy, PQ, 1988, pp. 115-119.

Black discussed both the evolutionary and revolutionary approaches to automation in mining. He advocated the evolutionary or piece-wise approach by management since problems are certain to arise when new technology is introduced and implemented. Each step in the automation process should be cost effective on its own merit, and when the next step makes no sense in an operation, management is not obligated to go the whole route. Even if the end result of automation does not appear to be applicable, management should investigate the process of automation since some of the steps toward full automation might be worth taking.

26. Beckert, B. A., B. Knill, P. Pascarella, and G. Weimer. Integrated Manufacturing: The Shape of Work to Come. Comput. Aided Eng., v. 8, No. 4, Apr. 1989, pp. IM-2, 4, 7, 8, 10, 12, 16, 18, 20.

Beckert, Knill, Pascarella, and Weimer said that middle management is primarily responsible for motivating employees and must change its attitude toward employees when new technology is adopted. Active encouragement of employee involvement, rapid and positive follow-up of all employee suggestions, and ongoing rewards for exceptional contributions to the improvement of the operation are essential. Each employee should be regarded as an innovator, a person who can be motivated to propose improvement in operations in which he or she is involved. Managers will be faced with increasingly complex situations, incomplete data, high information costs, increasing time pressures, and reduced formal authority. This scenario calls for an integrated approach to problem solving. The analytical approach may no longer be sufficient as the only decisionmaking tool.

27. Bromley, W. P., and D. E. Kukla. Six Common Manufacturing System Mistakes and How To Avoid Them. P and IM Rev. APICS News, v. 8, No. 4, 1988, pp. 36-39.

Bromley and Kukla emphasize the role of top management to ensure that newly installed technology lives up to expectations or that new software works properly in their organizations. Most of the common manufacturing system mistakes are managerial in nature. For example, top management lacks education in and commitment to the new technology. It is a fact that most implementations of manufacturing systems fail because top management is not involved in the process. A lack of top management commitment also leads to a failure to define short-term objectives and to meet deadlines during implementation. Often no one in the organization understands the entire system, and no one is in charge, which leads to lack of user training and understanding of the system and its objectives. Experience has proven repeatedly that when top management is involved, lower levels in the organization try to make the new technology work since they believe they are being evaluated on their contributions.

28. Kidd, P. T. Organization, People, and Technology: Advanced Manufacturing in the 1990s. Comput. Aided Eng. J., v. 7, No. 5, Oct. 1990, pp. 149-153.

Kidd discussed organizational change in advanced manufacturing. Many managers and engineers approach manufacturing as a set of technical problems and seek technical solutions. Often the problems associated with advanced technology are not technical but organizational or are derived from improper work practices. Too many managers believe that technology provides the answers to all problems. It does not, and it is wrong to attempt to solve nontechnical problems as though they were technical ones. Technology does not resolve the problems that arise from inappropriate business and production strategies, does not remedy the effects of poor-quality managers, is not a substitute for training, is not an alternative to organizational innovation and modern work practices, and is not a panacea. Instead of installing new technologies and adapting the organization and the people to the new technology, companies should consider adapting the new technology to the organization and the people. Management should design appropriate organizations and work practices, define an appropriate role for people, and use technology in a way that reflects the needs of the new organizations and work practices. Only after they have considered organization and people issues should managers address the technological factors. As for the organizational changes that a company should implement when new technology is introduced, productivity is improved by reducing hierarchies, reducing the number of departments, simplifying procedures, processing information more quickly, and increasing worker autonomy. In a flatter, less hierarchical type of organization, workers will need more decisionmaking authority, which means their competence will have to be improved.

29. Er, M. C. A Critical Review of the Literature on the Organizational Impact of Information Technology. IEEE Technol. and Soc. Mag., v. 8, No. 2, June 1989, pp. 17-23.

Er contended that a too-formal restructuring of an organization when new technology is introduced is counterproductive. This is because management systems in most organizations are characterized by formal organizational structures and informal information networks. A formal organizational structure provides the chain of command and the formal authority. An informal information network provides management with crucial information to sense opportunities in the market and to detect crises before they occur. It also allows managers at different levels to achieve harmony. Er also states that an overly rigid and formalized system causes emotional problems in employees.

PSYCHOLOGICAL FACTORS

1. Office of Technology Assessment (Washington, DC). Computerized Manufacturing Automation: Employment, Education, and the Workplace, Volume 2: Working Papers, Part A and Part B. June 1984, 489 pp.; NTIS PB 85-138824.

The Office of Technology Assessment found that when managers establish greater control over the manufacturing process with the adoption of new technology, less worker autonomy results, leading to less job satisfaction. Boredom was a common complaint among numerically controlled (NC) machine and flexible manufacturing system (FMS) operators. Some of the boredom stemmed from machinery design, which eliminated or minimized operator intervention and control, while some of the boredom resulted from management decisions about the organization of work on automated machines and systems. Work-related stress was a significant feature in computer-automated workplaces, mainly owing to the lack of worker autonomy and to workers' having responsibility for very complicated and very capital-intensive systems.

2. Office of Technology Assessment (Washington, DC). Computerized Manufacturing Automation: Employment, Education, and the Workplace. U.S. GPO 84-601053, 1984, 471 pp.

The Office of Technology Assessment also claimed that the impact of programmable automation (PA) on the work environment with respect to job satisfaction, stress, skills, and productivity is a significant yet largely neglected issue.

3. Investigative Research Committee (Ministry of Labor, Tokyo, Japan). Effects of Microelectronics on Employment. Interim Rep., Oct. 1983, 136 pp.; NTIS PB 84-111996.

The Ministry of Labor in Japan contended that the introduction of microelectronics-based devices into the workplace means an increased change from manual to mental labor, which makes mental fatigue a problem. Smaller work groups with closer supervision increase the work burden on the individual and cause feelings of isolation. The close attention required and the small room for error permitted make emotional stress commonplace. It has been noticed that older workers are becoming more fatigued because of mental and emotional strain.

4. Mueller, E. Technological Advance in an Expanding Economy: Its Impact on a Cross-Section of the Labor Force (U.S. Dep. Labor contract 81-24-67-02). Univ. MI, Final Rep., 1969, 254 pp.

Mueller studied the impact of advanced technology on a cross section of the labor force. He found that the major determinants, besides income change, of both increased and decreased job satisfaction among people affected by automation were those job characteristics related to job challenge: More demanding jobs meant increased job satisfaction. Furthermore, the tendency of increased job challenge to generate increased job satisfaction was not confined to young, well-educated, or white-collar workers.

5. Amram, F. M. Designing a Social Environment for Human-Robot Cooperation. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 127-135.

Amram discussed the socioemotional needs of workers impacted by new technology rather than, as is usually the case, their skill and information needs. Work is, at least in part, a social activity, and workers' psychological and emotional needs impact on productivity. Teaching technical skills is the easiest part of helping workers adapt to new technology, while the socioemotional impact remains the neglected aspect. For most people, work deters isolation and alienation by satisfying powerful socialization needs. However, increased automation decreases the opportunities for workers to interact with coworkers. The speed and complexity of new machinery can require greater alertness and concentration, thus forbidding distractions and leading to even greater worker isolation. Stress due to new technology is like other stress in its effects. By ignoring worker stress, one risks worker resistance, organizational instability, and disruption. Workers in transition need much emotional support, recognition that they are in transition, and praise for adapting well. Isolation can lead to stress, as can boredom from watching machinery doing the work or monitoring the work on computer screens. With advanced technology, human self-esteem can suffer, and workers become alienated because of a feeling of powerlessness. Quality circles or planning groups can make employees feel respected and needed—even smart. In an increasingly alienating work setting, purposeful efforts must be made to help workers feel like fully functioning and useful human beings.

6. Cure, K. G. AMS: Friend or Foe. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 185-192.

Cure found that new stresses have appeared as a result of faster paces and increased boredom imposed by automated systems. The Germans, as part of their humanizing working-life program, are paying particular attention to stress-related factors and new technology. A fundamental problem that may be encountered as advanced technology replaces many workers is the loss of a work ethic. Self-respect is being destroyed, and a sense of aimlessness and alienation never before experienced on such a large scale has been fostered.

7. Cooley, M. J. E. Problems of Automation. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 199-207.

Cooley claimed that computer-aided design (CAD) de-skills the designer, subordinates the designer to the machine, and gives rise to alienation. Most computerized design environments display those elements constituting industrial alienation, in particular powerlessness, meaninglessness, loss of self, and normlessness.

8. Bullinger, H.-J. Planning Method for Competitive Work Systems. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 323-333.

Bullinger studied 200 European companies that had adopted new technology. A total of 70% of the workers said there were no positive aspects to their jobs, 75% said there were negative aspects to their jobs that had not been present previously, 38% felt bored on the job frequently and 25% felt bored sometimes, 47% seldom enjoyed their work and 29% enjoyed it sometimes, and 33% experienced mental fatigue on the job frequently and 19% experienced it sometimes.

9. King, J. R. Is There Any Future for Man in Man-Machine Manufacturing Systems? Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 353-358.

King said that monitoring and control of automated systems will be most effectively conducted from a control center where the status of all parts of the system will be continuously displayed. The control center will be staffed by a small nucleus of highly skilled and versatile personnel. A problem will be that for long periods there will be little or nothing to do, which will lead to boredom and a decrease in alertness.

10. Weir, D. T. H. Organizational Stress and the Introduction of New Technology. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 249-258.

Weir said that modern organizational life with its crowding, rapid pace, mobility, and urgent requirement to change gives rise to feelings of instability, impermanence, and unpredictability among employees. Such a situation leads to anxiety, which induces stress. Fear as a psychological factor is manifested in four ways prior to the introduction of new technology: (1) fear of changes in the organizational structure or work groups, (2) fear of unknown power shifts, (3) uncertainties about one's ability to perform within the new system, and (4) uncertainties about how to use the new system.

11. Edwards, J. R. Stress, Coping and Worker Well-Being in Computer-Aided Manufacturing: A Field Investigation of a CNC Machine Shop. Paper in Ergonomics of Hybrid Automated Systems I, ed. by W. Karwowski, H. R. Parsaei, and M. R. Wilhelm. Elsevier, 1988, pp. 101-108.

Edwards studied stress, coping, and worker well-being in a computer numerical control (CNC) machine shop. Stress damages psychological and physiological well-being and stimulates coping, which is defined as efforts to reduce the negative impacts of stress. Coping influences stress by altering the perceptions, desires, and importance that constitute stress. Overall, 86% of the workers interviewed reported experiencing stress during normal machine operation and 79% during machinery malfunction. Workers coped mostly by taking a break, engaging in kidding and conversation, and not dwelling on work-related problems after working hours. Other methods included performing preventive maintenance, talking to supervisors about changing stressful working conditions, and adjusting their performance standard to meet the situation.

12. Tanaka, H. Human Implications of Robotization in the Worksite: The Japanese Experience. Robotics, v. 1, No. 3, Oct. 1985, pp. 143-153.

Tanaka said that even in Japan, with its highly publicized work ethic, many workers are developing stress symptoms owing to the pace and pressures associated with new technology. For instance, surveys by both the Electrical Machine Workers' Union and by the Metal Workers' Union found that stress and mental fatigue increased significantly when new technology was introduced. Also, loneliness and isolation on the job have been identified as an emerging problem. Depression is a growing problem among both managers and workers. Neurosis has become a definite problem in the highly stressful computer and high-technology fields. At one time, Tanaka says, the Japanese blue-collar worker was believed to be immune to the alienating effects of mechanization that are prevalent in Western companies, but this is no longer the case.

13. Hacker, S. L. Automated and Automators: Human and Social Costs of Technological Change. Paper in System Approach for Development (Proc. 3d

IFAC/IFIP/IFORS Conf., Rabat, Morocco, Nov. 24-27, 1980), pp. 471-480.**

Hacker studied the human and social costs of technological change. He found that psychological problems have arisen for those workers who were displaced or feared that they might be displaced because of new technology. Symptoms of these problems are anger, frustration, alcoholism, depression, anxiety, and tension.

14. Rudinger, R. Social Aspects of Automation and Robotics. Pres. at ASME Winter Annu. Meet., Anaheim, CA, Dec. 7-12, 1986, 8 pp.; available from ASME.

Rudinger indicated that consideration of human beings when technological change occurs is of relatively recent origin. From the inception of the Industrial Revolution in Europe until well into the 20th century, workers were, by and large, viewed as machines that could be made to perform functions efficiently by authoritarian management. Nevertheless, many jobs under the new technology are just as tedious as those on the assembly line and just as unskilled. Many workers consider their jobs prior to automation to have been more interesting and feel that they had more opportunity to interact with other workers. The changes in their jobs have led to stress, boredom, and job dissatisfaction in many cases. People do not want to be paced by machines and treated inhumanely.

15. Susman, G. I. Automation, Alienation, and Work Group Autonomy. Hum. Relat., v. 25, No. 2, Apr. 1972, pp. 171-180.

Susman claimed that the worker does make a significant contribution to the automated production process. The quality of this contribution is influenced by the degree of alienation the worker experiences. Factors that predispose a worker to alienation are powerlessness, meaninglessness, lack of social norms, and self-estrangement.

16. Ebel, K.-H. Social and Labour Implications of Flexible Manufacturing Systems. Int. Labour Rev. (Switzerland), v. 124, No. 2, Mar./Apr. 1985, pp. 133-145.

Ebel also expressed concern about alienation of workers owing to the new technological systems. He believed that these systems will further isolate the worker, increase boredom and monotony, and magnify job-related stress by accelerating the pace of work.

17. Salvendy, G. Human Factors in Planning Robotic Systems. Ch. in Handbook of Industrial Robotics, ed. by S. Nof. Wiley, 1985, pp. 639-664.

Salvendy claimed that the psychological disadvantages of machine-paced (MP) work include a lack of psychological growth for the workers and resultant boredom and job dissatisfaction. These shortcomings are overcome and the human body's efficiency is higher for self-paced (SP) work.

18. Oliver, M. V. L. The Management and Training Implications of Innovation and Change Due to Advanced Manufacturing Technologies. Paper in Proceedings of the 1st International Conference on Human Factors in Engineering (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 249-258.

Oliver indicated that the importance of psychological factors in developing and retaining efficient and productive employees is often downplayed. Many successful companies (admittedly over a long period of time in most cases) have attended to their employees' psychological needs as well as to their work needs.

19. Slem, C. M., D. J. Levi, and A. Young. The Psychological Impact of New Technologies: Anticipation of Stress. Paper in Proceedings of the Human Factors Society 33rd Annual Meeting: Perspectives—Volume 2 (Denver, CO, Oct. 16-20, 1989). Hum. Factors Soc., 1989, pp. 811-815.

Slem, Levi, and Young studied the psychological impact of new technologies especially as related to stress. Stress has been identified as one of the major negative consequences of technological change. When experienced as stressful, technological change is likely to produce a number of negative outcomes for the organization, such as increased overt and covert resistance to the new technology, lower product quality, lower productivity, greater absenteeism, increased illness and drug abuse, and higher turnover. The authors developed a model of the psychological impact of technological change on the work force. They administered a questionnaire called "Impact of Technological Change Survey" to workers in five large electronics manufacturing firms. Anticipated role conflict, role ambiguity, and quantitative work overload produced the strongest and most consistent relationships with the overall measure of stress. Qualitative role overload and beliefs about reductions in the work force were more closely allied to job insecurity stress. When people were unclear about how the technology would affect their responsibilities or when they anticipated conflicting expectations from different managers on what they should do, they were more likely to experience stress. When they believed they would be overloaded with too many new tasks or too difficult tasks, they were also more likely to experience stress. When people feel that they are participating in the design and implementation of new technology, that the company will provide adequate training, that job decisions are fair, and that existing employees will fill the positions created by the new technology, then stress is reduced.

20. Majchrzak, A., and J. Cotton. A Longitudinal Study of Adjustment to Technological Change: From Mass to Computer-Automated Batch Production. J. Occup. Psychol., v. 61, pt. 1, Mar. 1988, pp. 43-66.

Majchrzak and Cotton identified from the literature four independent sets of factors as potentially influencing worker adjustment to technological change: (1) actual job changes experienced on the job, (2) perceived changes to jobs, (3) personal factors, and (4) management support. This paper describes a longitudinal study of responses by 31 unskilled workers to a change using low-automated, mass assembly technology to jobs using computer-automated batch (CAB) technology. The high-school-educated workers had originally been assembling telephone equipment by hand on a mass production line. Their new jobs entailed a small batch operation producing hybrid integrated circuits for the telephones. The authors measured four indices of adjustment: (1) stress and psychological problems, (2) job satisfaction, (3) organizational commitment, and (4) perceived quality of life. The psychological problems index combined three scales: stress, somatic complaints, and depression. Results of this study showed that workers' adjustment to technological change was enhanced by job modifications that increased task variety, operator control, and social discussions. Stress was reduced when workers perceived that feedback was taken seriously, role clarity was increased, and automation would benefit them. Adjustment to technological change may be studied by comparing the individuals' important values and abilities to the values and abilities demanded by the new technology. If both of these change in similar directions to similar degrees, then job satisfaction, stress, and commitment will not change from previous desirable levels.

21. Edwards, J. R. Computer-Aided Manufacturing and Worker Well-Being: A Review of Research. Behav. and Inf. Technol., v. 8, No. 3, May-June 1989, pp. 157-174.

Edwards claimed that although managers typically consider technical and economic factors in the implementation of computer-aided manufacturing (CAM), they rarely consider the psychological implications. This paper reviewed and evaluated empirical research concerning the impacts of work in CAM on worker psychological and/or physical well-being. Because of the importance of the worker's own perceptions in the determination of stress, only studies that involved data collected from workers (interviews or questionnaires) were included, thereby omitting studies based solely on the observations of the investigator. Seventeen studies were found in the literature that met these criteria. The studies reviewed indicated that although the introduction of CAM often eliminated heavy and dangerous work, jobs involved with the operation of CAM machinery were often unsatisfactory and stressful for the workers. The level of dissatisfaction and stress depended on the content and composition of the tasks assigned to the worker. When tasks were limited to monitoring and performing miscellaneous support activities, high levels of boredom and monotony were reported. Monotony and stress were also reported when computerized controls were used to pace worker activities. When the worker was also responsible for programming or when the CAM machinery facilitated the performance of other tasks, an element of challenge was added. When workers were involved with maintenance activities, a combination of increased challenge and stress was often reported. In most cases, CAM allowed little social interaction between workers, which led to an increased sense of isolation. The author concluded that overall the studies reviewed indicate that advanced technology does not improve worker psychological well-being but creates jobs that are often stressful, unsatisfying, monotonous, and boring.

QUALITY OF WORKING LIFE

1. Pemble, R. J. Traditional Technology and Quality of Working Life—A Managerial Perspective. Paper in Proceedings of the 2nd International Conference on Human Factors in Manufacturing (Stuttgart, West Germany, June 11-13, 1985). IFS Publications Ltd., 1985, pp. 371-378.

Pemble discussed the theory of and research on the quality of working life and how managers can improve it. Management looking downward perceives the organization in one way, while the workers looking up perceive it in another way. Modern organizations, designed to operate on a top-down basis, attempt to achieve measurable financial and production targets. The workplace is viewed as a machine in which the worker is an interchangeable part. The ideology of the quality of working life arose as a reaction to Taylorism (essentially treating workers as machines) and has attempted to prove that acceptable levels of task performance can be best achieved by involving and motivating the work force. The idea of work as a task and consequently the worker as a task performer just like a machine was replaced by the idea of work as a social behavior and consequently the worker as a motivated human being. However, there is no research or workplace empirical evidence to prove that productivity or task performance improves under humanitarian work practices and management. The current status of quality of working life is the existence of a strong, clear ideology but a lack of experimental studies that would convincingly prove its contentions. Management believes that it knows what should be done in order for the work force to be productive. Managers must be convinced that improving the basic quality of working life variables (i.e., worker control over the task and the immediate work environment, the quality of the task, the nature and extent of management control, and the degree of identification with the organization) improves morale and, through this improvement, increases productivity and product quality.

2. Lane, J. D., G. Lundstrom, and W. Warnat. Education Efforts and Implications Facing the World's Robotics Industry. Paper in Proceedings of the 14th International Symposium on Industrial Robots and 7th International Conference on Industrial Robot Technology (Goteborg, Sweden, Oct. 2-4, 1984). IFS Publications Ltd., 1984, pp. 25-36.

Lane, Lundstrom, and Warnat mentioned a study that had been performed on the improvement of the quality of working life in several industrialized countries (France, Italy, Norway, Sweden, the United Kingdom, the United States, and West Germany). In those countries that organized their programs mainly along the lines of job redesign (the United Kingdom and the United States), the humanization-quality of working life effort is not as significant as in those countries that incorporated job redesign into a broader approach (West Germany, France) or that deemphasized the area altogether in favor of health and safety matters and employee participation (Sweden). The Trades Union Congress contended that with the introduction of new technology the quality of working life can be maintained by increasing the responsibility and autonomy of work groups and by enlarging job content (job enrichment).

3. Warnat, W. I. Employment Projections/Education Implications for the Robotics Industry in the USA. SME Tech. Pap. MM84-642, 1984, 11 pp.

4. Shaiken, H. The Human Impact of Automation: Keynote Speech to the 1985 Conference on Decision and Control. IEEE Control Syst. Mag., v. 6, No. 6, Dec. 1986, pp. 3-6.

Warnat and Shaiken claimed that advanced technology can decrease the quality of working life by restricting the amount of autonomy, control, and challenge available to the worker and by closer monitoring of worker performance. Conversely, advanced technology can increase the quality of working life by expanding the variety of job tasks and the decisionmaking opportunities of workers. However, the reality is that with the introduction of new technology managers have become more, not less, authoritative.

5. Majchrzak, A., and J. Cotton. A Longitudinal Study of Adjustment to Technological Change: From Mass to Computer-Automated Batch Production. J. Occup. Psychol., v. 61, pt. 1, Mar. 1988, pp. 43-66.

Majchrzak and Cotton assessed changes in the quality of working life for workers whose hand assembling jobs were replaced by jobs using computer-automated batch (CAB) technology. A 10-item scale was used to assess the quality of working life. Sufficient variation was found between workers so that no conclusions could be drawn as to the effects on quality of working life stemming from the transition from one type of job to another. That is, some of the workers felt that their quality of working life had been improved, some that it had decreased, and some that there had been no significant change.

6. Roe, R. A. New Technologies and Work. Pres. at the 24th Int. Congr. Psychol., Sydney, Australia, Aug. 28-Sept. 2, 1988, 21 pp.; NTIS PB 90-245150/XAB.

Roe discussed research on new technologies and work conducted in Europe. The quality of working life as affected by the adoption of automation was addressed in most of the studies that were reviewed. Humanization of work was mentioned as a possible motive for automation in industry but, in reality, was seldom taken seriously. The studies presented no clear-cut picture of the effects of automation on working life. A decrease, an increase, and no change were all reported on the quality of working life when automation was introduced. Nonetheless, the opportunities that automated systems have for improving the work situation have seldom been found to be realized in practice.

SOCIAL (PEOPLE) AND TECHNICAL SYSTEMS COMPATIBILITY

1. Pasmore, W. A. Designing Effective Organizations: The Sociotechnical Systems Perspective. Wiley, 1988, 200 pp.

The most comprehensive treatment of sociotechnical systems (STS) theory and its applications is by Pasmore, who details how to design or redesign effective organizations using the STS perspective. He admits that with the continuous changes in the external environment (customers, competition) joint optimization may be replaced by organizational flexibility (which allows rapid responses to changes) as an STS design objective. Pasmore has detailed chapters on the social system, the technical system, the environment, the objectives of STS design, the use of STS to redesign an organization, and the leadership required to implement STS properly. In addition, he includes as an appendix a STS survey that can be used to determine the extent to which an organization's design is consistent with STS principles. The survey can be administered to an entire organization or to subunits. It may be used prior to an STS intervention to guide organizational improvement, or during or after an intervention to assess progress in designing the organization for improved performance.

The six sections of his STS survey are Innovativeness, Human Resource Development, Environmental Agility, Cooperation, Commitment-Energy, and Joint Optimization. Each section contains questions that use a rating scale of 1 to 5. For example, under Innovativeness, question 5 at the lower part of the scale is "Most people here are afraid to take risks;" in the middle of the scale is "Some people here take some risks, but not big ones;" and at the higher part of the scale is "Most people here are not afraid to take risks, especially when they are important."

Pasmore in this book also presents the various STS methods that have been used and their success based on a review of the literature by several researchers. He shows a figure in which the percentage of organization using a particular STS feature is given, with 20 features shown in all. The ones that have been most widely applied (with the percentage of organizations in parentheses) are autonomous work groups (53%), technical skill development (40%), action groups (22%), change reward system (21%), self-inspection of quality (16%), technological change (16%), and nonrating teams (16%). When autonomous work groups were utilized and results were reported, they were associated with improvements in productivity, costs, attitudes, and quality over 80% of the time. Training was associated with improvements in performance in more than 90% of the cases that reported its use. When more than one of the features was applied, productivity improved in 87% of the cases reported, costs decreased for 89%, absenteeism decreased for 81%, turnover decreased for 65%, attitudes improved for 94%, safety improved for 88%, grievances decreased for 89%, and quality improved for 97%.

2. Pasmore, W. A., and J. J. Sherwood (eds.). Sociotechnical Systems: A Sourcebook. University Associates Inc., 1978, 365 pp.

Pasmore and Sherwood edited a sourcebook on sociotechnical systems that preceded the textbook discussed in the previous reference by several years. There are seven sections in the book, a total of 24 papers by a variety of authors, a foreword, and an introduction to each section except for the first one. Some of the highlights of this sourcebook are as follows:

1. The four things that must be known to perform a sociotechnical systems intervention,
2. The seven basic contentions or propositions of sociotechnical systems theory,
3. The nine principles of sociotechnical systems design,
4. The order (four steps) in which data should be collected by the change agent or interventionist,
5. The five steps of open systems (considers the environment outside of the organization) planning,
6. The five functions any social system in an organization must fulfill if it is to survive,
7. The nine components of a widely used sociotechnical systems analytical model for physical technologies,
8. The five social processes existing in an organization,
9. Eight examples of what may need to be changed in the social system of an organization,
10. Four examples of conditions in organizations that require system interventions,
11. Six examples of types of feedback systems that are used frequently to determine the effects of interventions,
12. Three requirements for autonomous work groups,
13. Four social system properties that must be considered simultaneously when adopting new technology, and
14. Methods for reducing the three results of worker alienation by altering the social system.

There are many other publications that have to do with sociotechnical systems theory and application. Brief summaries of representative publications are as follows:

3. Trist, E. L., and K. W. Bamforth. Some Social and Psychological Consequences of the Longwall Method of Coal-Getting: An Examination of the Psychological Situation and Defences of a Work Group in Relation to the Social Structure and Technological Content of the Work System. Hum. Relat., v. 4, No. 1, 1951, pp. 3-38.

Sociotechnical systems analysis began with the seminal work of Trist and Bamforth in 1951. They traced in detail the connection between the health and productivity of coal miners using the longwall method and the social structure of the work system that controlled their relationships, i.e., an account of the social and psychological consequences of longwall coal mining and how these arose from changes in mining methods. Four types of defense from the stress of longwall mining were used by miners: informal organization, reactive individualism, mutual scapegoating, and self-compensatory absenteeism. Trist and Bamforth believed that the persistence of socially ineffective structures at the coal face can be a major factor in preventing an improvement in morale, discouraging recruitment of competent and productive employees, and increasing employee turnover. They suggested that responsible autonomy should be given to primary groups throughout the mining system, and each group should receive a satisfying portion of the work to be done as its task assignment with some flexibility in work pace. Face workers probably should be multiskilled, i.e., capable of performing a variety of tasks, in order for their autonomous work group to succeed.

4. Trist, E. L., G. W. Higgin, H. Murray, and A. B. Pollock. Organizational Choice: Capabilities of Groups at the Coal Face Under Changing Technologies. Tavistock Publ., London, UK, 1963, 330 pp.

A later study of the interaction of technological and social factors in underground coal mines in England was done by Trist, Higgin, Murray, and Pollock in 1963. Since any production system requires both a technological organization (equipment and process layout) and a work organization relating those who carry out the necessary tasks to each other, each production unit was considered as a sociotechnical system. The technological demands place limitations on the type of work organization possible, but a work organization has social and psychological properties of its own that are independent of technology.

It is of fundamental importance to realize that the optimization of the whole sociotechnical system does not require an optimum state for either the social or technical subsystems. The authors focused their attention on the sociopsychological system. This system may be studied at different levels in coal mining as in other industries: the individual worker, the work group, the section, the mine, or the company. The unit of study for this research was the primary work group, and not only were face crews studied but also other individuals and groups with whom they had relations. The qualities found to be especially appropriate for the organization of the mining crews were acceptance of responsibility for the entire cycle of operations, recognition of the interdependence of one man or group on another for effective progress of the mining cycle, and responsible autonomy or self-regulation by the whole team and its constituent groups. Primary work groups of up to 50 members were found to be capable of sustained self-regulation and maintenance. This leaves management free to concentrate on providing effective communications to workers within the mine, anticipating the support required for operations at the face, and giving attention to longer term planning and development.

5. Brown, G. R., G. Susman, and E. Trist. Sociotechnical Design and Its Effect on Individual and Group Performance. Paper in 1st Symposium on Coal Management Techniques, Volume I (NCA/BCR Coal Conf. and Expo II, Louisville, KY, Oct. 21-23, 1975). NCA, 1975, pp. 61-70.

Brown, Susman, and Trist discussed a sociotechnical research project carried out at a room-and-pillar underground coal mine belonging to Rushton Mining Co. in Pennsylvania. The concept of work used was that of autonomous or self-governing work groups. The Rushton experiment used one section of the mine and the crews in that section during all three shifts. Crew members became increasingly multiskilled as time went on and interchanged their tasks more frequently. The final results were not in when this paper was written; but the first year's results showed that the number of violations for the experimental section had dropped about 60% while they almost doubled for the other two sections. The number of accidents stayed about the same during this first year for the autonomous work group but almost tripled for the other two sections. The costs of production and maintenance declined for the experimental section while they rose dramatically for one of the other sections and declined only slightly for the third one. At the end of the first year, there were indications that productivity was increasing for the experimental section.

6. Peters, R. H. Review of Recent Research on Organizational and Behavioral Factors Associated With Mine Safety. BuMines IC 9232, 1989, 38 pp.

Peters discussed several experiments with mines in team-building and organizational development (OD) intervention (both are sociotechnical systems techniques). Team-building and OD intervention were used in order to determine their effects on productivity and safety at an underground hard rock mine. Results indicated that the methodology used was highly effective at improving both safety and productivity, and this improvement was still in existence 5 years later. The impact of Quality Circles (QC's) was studied at a large surface coal mine. The QC's seemed to provide a framework for employee input that improved both safety and productivity as workers not only identified problems but also became actively involved in their solutions. The effectiveness of a structured management training intervention on productivity and safety at an underground trona mine was assessed. The intervention was highly effective in improving safety and productivity, and the improvements were maintained for the ensuing 5 years. The impact of an intervention on safety, productivity, quality of working life, and several other factors was studied at an underground coal mine. Safety shifted slightly in the positive direction while productivity increased slightly. Applied behavioral analysis and management techniques were used as a training intervention at four salt mines to determine their effectiveness in decreasing the frequency of eye, hand, and back injuries. The principal behavior reinforcer used was positive verbal feedback. The number of injuries per month did decrease to some extent after the intervention.

7. Sanders, M. S., and J. M. Peay. Human Factors in Mining. BuMines IC 9182, 1988, 153 pp.

Sanders and Peay discussed organizational development (OD) and its methodology. OD is a long-term effort that examines and alters management policies, practices, and organizational dynamics in a systematic way for the purpose of assisting a company in solving its major problems and goals. OD uses a change agent or intervention to initiate and guide the activity. The change agent is a third party, external to the particular part of the organization that is initiating the OD activity. The change agent intervenes in the ongoing processes of the organization and assists the organization in understanding its problems and how to solve them. Four examples of OD were given, which were also discussed by Peters.

8. Robinson, G. H. Accidents and Sociotechnical Systems: Principles for Design. Accid. Anal. and Prev., v. 14, No. 2, 1982, pp. 121-130.

Robinson discussed principles for the design of sociotechnical systems in order to reduce the number of accidents. These principles are as follows:

1. Workers should have an appropriate role in controlling variances or unprogrammed, random events.

Accidents can be reduced if unpredicted events are catalogued and made an explicit part of both training and design;

2. Boundaries of technology, territory, and time should be drawn so as to contain a group necessary to carry out some segment of the work, such as maintenance, as close to the operations as possible;

3. Autonomous work groups should be formed whose strength is adaptability to change;

4. Support from management and organizational rules should reinforce desired organizational behaviors instead of the usual emphasis, which is placed on short-term production goals, competition between workers, and individual achievement;

5. The ability of an organization to continually redesign is frequently one of the most important attributes for future survival;

6. Safety should be aided by having the people who will have to live with a design participate in its creation; and

7. Quality of working life will be enhanced and the accident problem will be addressed directly by admitting that people are largely required in the system for their discretionary, decisionmaking abilities and will assume necessary responsibility if given the correct organization and support.

9. Shani, A. B., and O. Elliott. Applying Sociotechnical System Design at the Strategic Apex. Organ. Dev. J., v. 6, No. 2, Summer 1988, pp. 53-66.

Shani and Elliott examined the relationships between sociotechnical systems design and strategic management. Strategic management stresses the management of the organization's relationship with its environment (external factors) as a means for attaining goals. It responds to the increasingly volatile and often hostile environment by focusing on basic action strategies and competitive marketing strategies while taking into account the internal functioning of the organization. Shani and Elliott applied their methodology to a company that produced semiconductors. Changes were made in the organization in updating the technical subsystem, developing the skills of teamwork, improving communications, and attempting to reposition the company in terms of what technologies to emphasize.

10. Miller, E. J. The Human Element. Paper in New Technology in Water Services, Proceedings of a Symposium (London, UK, Feb. 20-21, 1985), pp. 199-208.

Miller addressed the problem of managing change. What is required is the design of new sociotechnical systems that call into question the established assumptions about the role of the manager and the state of the relationship of the individual to the organization. The autonomous or self-regulating work group has time after time been shown to have a high probability of being more productive, more responsible, more effective, and more satisfying for its members than previous forms of work organization. The question arises as to why it has not been widely adopted and become the norm rather than the exception. There is no unrecognized flaw in the concept, resistance of workers is not a major constraint, and unions accept this type of work group as long as it adds to the quality of working life. The fact of the matter is that management resistance has been the main factor responsible for the autonomous work group's not being widely adopted. Management loses some of its power and bureaucratic control over workers. Also, fewer supervisors, fewer junior managers, and fewer middle managers are needed.

11. Blumberg, M. Job Switching in Autonomous Work Groups: A Descriptive and Exploratory Study in an Underground Coal Mine. Ph.D. Thesis, PA State Univ., 1977, 309 pp.

Blumberg described research he conducted over a 13-month period inside an underground room-and-pillar coal mine at Rushton, PA. His aim was to identify and assess variables related to job-switching behavior in two autonomous work groups each composed of 27 miners. The study reviewed the literature on sociotechnical systems theory, worker participation, employee resistance to change, job enrichment, and individual response to task characteristics. Based on this review, 24 hypotheses were developed that predicted relationships between job-switching behavior and variables at the individual and group level. These hypotheses were tested by means of a 76-item questionnaire administered underground over a period of 3 weeks. The most general finding was that job-switching behavior was more closely related to the demands of the technical system and absenteeism than to the social and psychological needs of the miners. Conclusions were as follows: Job switching is important for the proper functioning of autonomous work groups, autonomous work groups are important for the sociotechnical design of the workplace, and sociotechnical design can improve the quality of working life. Over 10 pages of references are given, and there are 15 appendixes that contain the detailed questionnaires, indexes, scales, etc. used for this study.

12. Manz, C. C., and H. P. Sims, Jr. Leading Self-Managed Groups: A Conceptual Analysis of a Paradox. Econ. and Ind. Democracy, v. 7, No. 2, May 1986, pp. 141-165.

Manz and Sims claimed that one particularly puzzling aspect of self-managed groups is the identification of an appropriate role for external work group leaders. What is the role of such groups? Why should a leader be necessary if groups are indeed to be self-managing? Is the existence of such a leader a logical inconsistency? The authors used perspectives from sociotechnical systems (STS) and social learning theory (SLT) to develop a conceptual framework that suggests a role for this unique type of leader. This person is called a Superleader and can be either external to or a member of the group. This leader's role to a great extent is that of creating a positive atmosphere for exercising self-management and primarily is to help the group to manage itself. He or she can help provide social and technical knowledge that the group does not have, act as a link between the group and other groups or management, encourage within-group communications and training, and guide group planning.

13. Bean, A., and C. Ordowich. Managing the Impact of Technological Change on Organizations. SME, Tech. Pap. MM85-727, 1985, 15 pp.

Bean and Ordowich described the key ideas in sociotechnical systems analysis that pertain to the design and redesign of manufacturing organizations in the process of introducing technological change. Participative management is the way that plants are making high technology work to their greatest advantage. Successful companies emphasize (1) teams rather than jobs as the basic unit of organization, (2) multiple, decentralized decisionmaking centers, (3) high-quality work as a result of autonomy of workers rather than close control by supervisors, and (4) trust and cooperation rather than isolation and competition. As advanced technology is adopted, the employees required to make this technology productive will be more independent and educated and will expect autonomy, challenge, learning, mobility, recognition, and meaningfulness. Also, the environment external to the company is becoming more turbulent and unpredictable, which places a premium on managers and employees who are flexible and innovative. The challenge for managers is to delegate the operation of the technical system to their subordinates and to focus on shaping, renewing, and maintaining the social system. The challenge for engineers is to design technical systems that are compatible with human factors. Three case studies were presented to illustrate the application of sociotechnical systems design and redesign: an oil refinery that was in operation, a new computer-integrated manufacturing (CIM) plant that produced high tolerance parts, and a very old and physically deteriorated chemical plant. Significantly successful results were obtained in all three cases. It was found that in organizational redesign the major transformation should be in the social system, although the transformation must be compatible with changing technologies in a changing environment. Redesign consists of building participation through information sharing, creating cooperative teams, flattening the hierarchy, and establishing closer relationships between functional departments.

14. Pasmore, W. A. Overcoming the Roadblocks in Work-Restructuring Efforts. Organ. Dyn., v. 10, No. 4, Spring 1982, pp. 54-67.

Pasmore said that work restructuring involves enriching the motivational aspects of jobs through changes in the structures of organizations, the technology used to produce goods or services, and/or the activities workers are expected to perform. The two major methods of work restructuring that are commonly used are job redesign and the sociotechnical systems approach. The former is primarily aimed at the level of the individual and seeks ways to improve productivity and the quality of working life through increased variety, autonomy, task completeness, task importance, and feedback on performance. The latter considers the relationships between both people and technology and between the organization and its environment and suggests changes in work arrangements designed to improve the fit among the needs of individuals, groups, and technological processes in the pursuit of organizational goals. Both job redesign and sociotechnical systems interventions are based on the following two basic underlying assumptions: (1) organizational performance can be improved by allowing employees at lower levels to assume more responsibility for the management of their own efforts, and (2) employees will become more responsibly self-directing as their work offers them greater opportunities to fulfill such important psychological needs as learning, growth, self-esteem, and significance in their working lives. A recent review by the author found that nearly 90% of the reports on work-restructuring interventions cited improvements in productivity, costs, absenteeism, attitudes, and quality. One of the beneficial fallouts from work restructuring is usually a more highly skilled and flexible work force, one that is better able to respond to changes that might be hurled at the organization by its environment. However, middle- or low-level managers often present a formidable resistance to change, and if they manage using traditional beliefs, work restructuring will probably not be of benefit to the organization.

15. Kelly, J. E. A Reappraisal of Sociotechnical Systems Theory. Hum. Relat., v. 31, No. 12, Dec. 1978, pp. 1069-1099.

Kelly performed a detailed reexamination of case studies from which the major principles of sociotechnical systems analysis had been partly derived. He found that the objective of all of the cases studied in which sociotechnical systems methodology had been applied was to create a work organization that would extract the maximum use and value from the existing machinery and from the labor force. None of the ensuing improvements in productivity, quality, etc. for these cases were due to the fact that individual needs were afforded more satisfaction in the work organization. The significance of pay incentives as a method for increasing productivity was greatly underestimated by those who performed the sociotechnical systems studies.

16. Margulies, N., and L. Colflesh. A Sociotechnical Approach to Planning and Implementing New Technology. Train. and Dev. J., v. 36, No. 12, Dec. 1982, pp. 16-29.

Margulies and Colflesh used the sociotechnical systems concept as developed by Trist and Bamforth and by Rice and a generic planning model to investigate the implementation of computer-aided design and manufacturing (CAD-CAM) technologies. The strength of this approach was considered to be its ability to integrate changes in people and technology during periods of rapid technological change. The authors described an approach by which efforts are designed to implement new technology while evaluating appropriate human subsystem modifications, and then changes are made in the managerial-organizational subsystem. The process is an iterative one in which "fine tuning" of the subsystems to maximize productivity is ongoing. Factors that contribute to the successful implementation of new technology are communications and education, user participation, dealing with uncertainty and resistance, and awareness of organizational dynamics. The sociotechnical framework and the system development planning model require several specialists with specific areas of expertise (management, technical systems analysis and design, organizational change, human factors). Although the outside consultant is often useful in the preliminary stages of analysis, successful change programs must rely on informed and motivated persons within the organization. Effective implementation of change occurs when those directly affected by the change are involved at the beginning. The importance of ongoing communication, involvement of all employees to varying degrees, and careful planning at every stage cannot be overemphasized.

17. Sinha, M., and D. Roitman. Sociotechnical Systems Design and Computer Integrated Manufacturing. Paper in Management of Evolving Systems (1987 IEEE Conf. on Manage. and Technol., Proc., Atlanta, GA, Oct. 27-30, 1987). IEEE, 1987, pp. 57-66.

Sinha and Roitman found that companies that have led the way in computer-aided manufacturing (CIM) implementation have had considerable difficulty in reaping the expected benefits from this new technology. The problems are not primarily technological but instead stem from organizational obstacles involved in implementing complex new technology. Fundamental shifts in organizational thinking and culture are required for the new technology to be successful. Sinha and Roitman contend that sociotechnical systems (STS) design represents the most viable approach to CIM implementation, since STS is the most comprehensive and highly structured approach to changing social and technical systems.

18. Majchrzak, A. The Human Infrastructure Impact Statement (HIIS): A Tool for Managing the Effective Implementation of Advanced Manufacturing Technology. Comput. Integrated Manuf. Syst., v. 1, No. 2, May 1988, pp. 95-102.

Majchrzak discussed the human infrastructure impact statement (HIIS) as a tool for helping managers and researchers assess the socio-organizational impacts of advanced technology before the final equipment decisions are made. HIIS will help in the selection of equipment to ensure that the new technology will be compatible with existing and evolving organizational, personnel, job design, and training practices. HIIS, which is based on concepts and practices developed by social and organizational theorists, is closely related to the sociotechnical systems approach.

TRAINING AND RETRAINING

1. Office of Technology Assessment (Washington, DC). Computerized Manufacturing Automation: Employment, Education, and the Workplace. U.S. GPO 84-601053, 1984, 471 pp.

2. ____. Computerized Manufacturing Automation: Employment, Education, and the Workplace, Volume 2: Working Papers, Part A and Part B. June 1984, 489 pp.; NTIS PB 85-138824.

3. ____. Computerized Manufacturing Automation: Employment, Education, and the Workplace. Final Rep., Apr. 1984, 234 pp.; NTIS PB 84-196500.

4. ____. Automation and the Workplace: Selected Labor, Education, and Training Issues. Interim Rep., Mar. 1983, 105 pp.; NTIS PB 83-191320.

The Office of Technology Assessment said that as automation and robotics increase the depth and breadth of skills for many jobs will change, and more persons should be trained as technicians or engineers. A solid background in mathematics, science, reading, communicating, and problem solving are essential for those entering the U.S. work force for decades to come. Workers will have to be capable of being retrained, perhaps several times during their working lifetime, and should have a process of continuing education. Some displaced manufacturing workers have not been able to be retrained because of a lack of basic skills in reading, mathematics, and science. One problem that has arisen is a shortage of technical instructors and state-of-the-art equipment. Another problem is that persons most likely to be affected by technological and economic change, namely those with lower incomes and lower levels of education, seem to be the least inclined to enroll in courses that would develop new, more marketable skills for them.

5. Husband, T. M. (ed.). Education and Training in Robotics. IFS Publ. and Springer-Verlag, 1985, 315 pp.

Husband claimed that maintenance personnel working with the new technologies will have to have skills of a high order to be able to diagnose and repair systems that consist of hydraulic, pneumatic, electrical, electronic, and mechanical subsystems. The skill is likely to lie in using computer-based equipment where on-line sensors are built into the equipment. Colleges and universities must decide what the curriculum should be for engineers and technicians for the new technologies and train qualified instructors to teach the courses. Present curriculums are inadequate for creating a work force with the requisite technical and managerial skills. Proper training both before and after the introduction of new technology is an important factor in the economic use of this technology.

6. Carnegie-Mellon University (Pittsburgh, PA). The Impacts of Robotics on the Workforce and Workplace. Sch. of Urban and Public Affairs, Dep. of Eng. and Public Policy, and Dep. of Humanities and Soc. Sci., June 1981, 218 pp.

Students from three departments at Carnegie-Mellon University, Pittsburgh, PA, conducted a study on the impacts of robotics on the work force and workplace. Two industries were studied: newspaper printing and underground coal mining. The students found that the major types of retraining at that time were on the job, classroom, and institutional. Continuing education was becoming more popular as new technology was being introduced. Firms were doing a great deal of retraining, but unskilled workers were seldom trainable for new jobs. There is a difference in the skills required for operation and for maintenance. Almost anybody can be taught to operate a machine with minimal training. As for maintenance, although the courses needed to learn to repair automated and/or robotic equipment are extremely technical, they do not involve skills very different from those involved in maintaining other pieces of complex machinery. Almost anybody who has experience in machine maintenance can easily be retrained in this field.

7. Flynn, P. M. The Impact of Technological Change on Jobs and Workers. Bentley Coll., Waltham, MA, Final Rep., Mar. 1988, 104 pp.; NTIS PB 85-218022.

Flynn does not believe that a shortage of skilled workers lasts very long. For instance, when production processes were first automated, there was a shortage of workers with the required electronic skills. Initially, firms retrained their own maintenance and technical staff. Noting the demand for those with electronics skills, colleges and vocational schools expanded the courses they offered in this field, and courses were paid for by individuals or government. As a result of a more plentiful labor supply in electronics skills, companies became more choosy in whom they would hire and increased the educational requirements for new hires.

8. Ayres, R. U., and S. M. Miller. The Impacts of Industrial Robots. Robotics Inst., Carnegie-Mellon Univ., Pittsburgh, PA, CMU-RI-TR-81-7, Nov. 1981, 54 pp.

Ayres and Miller contended that there has been little serious discussion of how to cope with the hard reality of developing needed new work skills on the one hand and how to deal with people who have obsolescent skills on the other. Effective training and educational facilities should be provided to upgrade workers from skill categories that are or will be in surplus supply to skill categories that are or will be scarce. Unfortunately, publicly sponsored training programs have seldom been successful at training the "hard core" unemployed for productive jobs.

9. Mueller, E. Technological Advance in an Expanding Economy: Its Impact on a Cross-Section of the Labor Force (U.S. Dep. Labor contract 81-24-67-02). Univ. MI, Final Rep., 1969, 254 pp.

Mueller studied the impact of advanced technology on a cross section of the U.S. labor force. He presented several conclusions on the training aspects associated with the introduction of new technology. Many workers believed that they needed more training, and few believed that they were overeducated or overtrained for their new job assignments. The chance that a worker will adjust well to new technology is, if anything, enhanced by education. Formal schooling was more crucial than vocational courses for fitting workers into technologically new work settings. Formal education provides verbal, scientific, and technological training that makes workers more adaptable to changes in the job and more able to meet increased job demands. Also, on-the-job training seemed to be more effective than vocational courses.

10. Hunt, T. L. Robotics, Technology, and Employment. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 9-15.

Hunt stated that the existing labor force should be prepared for and receptive to the need for training and retraining. Since the demographic structure of the U.S. population guarantees (unless immigration increases significantly) that there will be fewer young people entering the work force for years to come, there has to be training and retraining of existing workers. More general training rather than narrow vocational training should be emphasized. People need to be taught how to think and reason logically so they can adapt more easily to the new technologies.

11. Rasmussen, L. B., P. L. Jensen, and N. Moller. New Technology and the Quality of Working Life. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 149-155.

Rasmussen, Jensen, and Moller investigated changes in qualifications and the need for additional education when new technology was introduced into metal factories in Denmark. They found that the main goal of management was to increase productivity while decreasing the size of the work force. What management should have paid more attention to was educating the work force. There is a vital difference between education and training. Education gives a deeper insight and understanding of the rationality of the system compared to training, which gives only the most necessary knowledge and abilities to operate the system from given instructions.

12. Cure, K. G. AMS: Friend or Foe. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 185-192.

Cure pointed out that a major factor in the Japanese success is an adequate supply of engineering skills and the necessary training of the work force in order to exploit the full potential of conventional and new technologies. Also, Japan employs more persons in research and development than France, Germany, and the United Kingdom and graduates 10 times as many engineers per year as does the United Kingdom. Each industrialized country must develop a system of education and training that will ensure an adequate labor pool for the technical jobs that need to be filled with the adoption of new technology. Flexibility in what workers can do, or can be readily trained to do, is required since there are sure to be unknown technological developments.

13. Senker, P. J. Coping with the New Technology: The Need for Training. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 241-248.

Senker said that the requirement for new skills as fewer employees are needed in manufacturing demands extensive retraining programs. Of special importance is the training or retraining of maintenance personnel, since downtime is very costly with the expensive new technology being used.

14. Oliver, M. V. L. The Management and Training Implications of Innovation and Change Due to Advanced Manufacturing Technologies. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 249-258.

Oliver claimed that, despite all of the research that has been done, the impact of advanced technology on the training needed for managerial, technical, and manual skills has not been evaluated in precise terms. The problem is that new technology never stays still and is advancing at a faster rate than ever before. As a consequence, skills that were transferrable from one job or one firm to another in prior years are no longer applicable. Thus the aim of training should be to develop flexible people who can be readily retrained.

15. Chiaromonte, F. Management and New Technologies. Paper in Proceedings of the 2nd International Conference on Human Factors in Manufacturing (Stuttgart, West Germany, June 11-13, 1985). IFS Publications Ltd., 1985, pp. 363-370.

According to Chiaromonte, there is absolutely no doubt that the widespread application of new technologies and their impacts on management mean that new requirements exist in the field of management training. Previously, the process of management education was always a process of adjustment to a more or less defined model. Now, there is no accepted model. Management education should parallel the changes brought about by new technologies and should help managers to understand what is happening and what will happen. Management education or training topics should emphasize attitudes and knowledge suitable to the successful management of innovation, concentrate on the use and consequences of new technology for the organization, and focus on the utilization of human resources.

16. Hagedorn, H. J. The Factory of the Future: What About the People? J. Bus. Strategy, v. 5, No. 1, 1984, pp. 38-45.

Hagedorn said that the workers who will be replaced by new technology will primarily be unskilled or semiskilled and will be less than ideal for retraining. They will tend to be older, less educated, less mobile, and more oblivious or resistant to the new technology than the average worker. For all workers who will be involved with the new technology in the future, training will have to be different than that given in schools now. However, there is little reason to believe that we know how to teach the needed new skills, procedures, principles, and concepts to large numbers of average people, much less do it efficiently. Nor is there much reason to believe that we know who these people will be, how to go about selecting them, and how to motivate them. Where these people will come from and how they will obtain the necessary skills and knowledge constitute potential major problems.

17. Garg, D. P. The Impact of Automation and Computer-Integrated Manufacturing on Industrial Employment. Pres. at ASME Winter Annu. Meet., Anaheim, CA, Dec. 7-12, 1986, 5 pp.; available from ASME.

Garg, in contrast to Hagedorn, believes that 95% of the U.S. work force consists of retrainable workers. However, the methods for retraining many displaced workers will have to be improved upon, but this is feasible.

18. McCarthy, P. J. Overview of New Technology and Its Introduction to the Australian Coal Industry. Paper in Proceedings of a Seminar on Factors Influencing Underground Productivity (Sydney, Australia, Aug. 21, 1987). Australasian Inst. Min. and Metall., 1987, pp. 292-307.

McCarthy said that the rate of change of technology in coal mining is such that retraining must become a normal feature of working life, and financial support should be given to workers during retraining. It is important that both management and workers be multiskilled. For example, electricians should be trained on both conventional and solid-state circuitry, and engineers must be knowledgeable in computer science and management.

19. Frantz, R. L., and R. H. King. Study of the Human Factors Aspects of an Automated Continuous Mining Section (grant SO144115). PA State Univ., Final Rep., 1977, 305 pp.; NTIS PB 299 945.

Frantz and King said that with the adoption of automation in underground coal mines continuing training will be required from both workers and management, although this training will differ from what is given now. For instance, training programs in electrical, mechanical, and hydraulic systems for automatic mining equipment are definitely necessary, with particular attention to be paid to diagnosis because component change-out rather than repair will be the most practical maintenance technique.

20. Guterl, F. An Unanswered Question: Automation's Effect on Society. IEEE Spectrum, v. 20, No. 5, May 1983, pp. 89-92.

Guterl quoted the president of an automation consulting firm as saying, "Our biggest problem is that many people who become unemployed are not retrainable. Unless somebody has a real flair for the computers used in flexible automation, you'll have a great machinist but a lousy programmer." On the other hand, a vice-president at the John Deere Co. said that successful retraining is simply not a question of intelligence on the part of the employee. The teacher is an important part of the equation. He contended that the persons who run training programs "don't know how to motivate people. Anybody with a reasonable IQ is retrainable. It has been demonstrated that if you indicate to an average child he won't learn, then he won't learn. This principle holds for laid-off workers as well. The problem is also cultural, since it isn't macho to be a computer programmer."

21. Groover, M. P., J. E. Hughes, Jr., and N. G. Odrey. Productivity Benefits of Automation Should Offset Work Force Dislocation Problems. Ind. Eng., v. 16, No. 4, Apr. 1984, pp. 50-59.

Groover, Hughes, and Odrey questioned whether the worker displaced by automation is capable of being retrained in areas requiring scientific and mathematical aptitudes. Many of the displaced workers were chosen for relatively routine jobs in the first place because of their low skill and educational levels. The workers that originally applied who did have technical aptitudes and some basic courses in mathematics and science were seldom hired by employers for the more routine jobs because such people were considered to be overqualified.

22. Warnat, W. I. Employment Projections/Education Implications for the Robotics Industry in the USA. SME Tech. Pap. MM84-642, 1984, 11 pp.

Warnat addressed the problem of hiring and of retraining workers at companies that introduce robotics. For new hires, the majority of occupations within the robotics industry are technical in nature and thus require postsecondary education. Those occupations requiring college degrees also require postgraduate study and continuing education to maintain competency in the field. Of growing urgency is the need for continuous education and training of the robot-using manufacturing work force to enable ongoing adaption to technological change. However, there is likely to be a critical shortage of qualified teachers to satisfy the training needs of those who are or will be employed in robotics.

23. Rudinger, R. Social Aspects of Automation and Robotics. Pres. at ASME Winter Annu. Meet., Anaheim, CA, Dec. 7-12, 1986, 8 pp.; available from ASME.

Rudinger stressed the importance of improved education in America, especially in mathematics, science, and the ability to communicate effectively both orally and in writing. Continuing lifetime education is becoming necessary for almost all workers. However, retraining of older workers is a formidable task since many of them are specialized and lack a knowledge of fundamentals and principles needed to learn new skills. The best approach for older workers is on-the-job training by peers who have undergone the required training. Management must stress learning and give learning a high priority status.

24. Hunt, V. D. Industrial Robotics Handbook. Industrial Press Inc., 1983, 435 pp.

Hunt contended that education and training assume ever greater importance as the new technologies are adopted, since there is a need for a more technologically literate work force with a basic understanding of technology and mathematics. In addition, a worker with this basic understanding is easier to retrain for some other job elsewhere in the plant. If the introduction of new technology into a plant is not to result in unemployment, a program of retraining for those workers who are actually displaced is necessary so that they can take on other jobs.

25. Salvendy, G. Human Factors in Planning Robotic Systems. Ch. in Handbook of Industrial Robotics, ed. by S. Nof. Wiley, 1985, pp. 639-664.

Salvendy said that not enough attention has been paid to the feasibility of retraining workers. This deficiency should be remedied by assessing who can be retrained by analyzing the skills and knowledge requirements for various jobs in the new technology, developing either work samples or tests that simulate the various jobs, and then administering these work samples or tests to displaced workers to determine the likelihood of their success in mastering the new skills.

26. Mowrey, D. C., and B. E. Henderson (eds.). The Challenge of New Technology to Labor-Management Relations. U.S. Dep. Labor, Bur. of Labor-Manage. Relat. and Coop. Programs, BLMR 135, 1989, 66 pp.

In a publication edited by Mowrey and Henderson, it is stated that the decision to adopt new technology carries with it the demand for new skills and knowledge but does not determine which individuals should acquire which skills and knowledge. Slowly but surely, training, or more accurately organized learning, is becoming an integral and continuing part of every job. Learning implies that the learner is an active partner in the process, not merely an empty vessel into which information is poured. Employees, in addition to mastering the skills specific to their own jobs, are expected to learn the skills of others in their work unit. Most employers take for granted that it is easier to fire employees with obsolescent skills and replace them with already trained outsiders than to retain existing employees and retrain them to handle new technology. Typically, employers underestimate the ability of employees to learn new skills, as well as the true financial costs of hiring and firing and the negative psychological effects on the remaining work force, and overestimate the costs of retraining. There is a strong link between job security and retraining in that if employers do not have the option of laying off workers, they have stronger incentives to invest in training for these workers.

WORKER ACCEPTANCE

1. Office of Technology Assessment (Washington, DC). Exploratory Workshop on the Social Impacts of Robotics: Summary and Issues. A Background Paper. Feb. 1982, 137 pp.; NTIS PB 82-184862.

The office of Technology Assessment found that robotics was welcomed by workers in Japan because of guaranteed employment (job security), larger bonuses (economic incentives), and more interesting jobs (challenging jobs with a variety of tasks).

2. Rushton, D. F. H. Success in Changing Attitudes to Help Introduction of New Manufacturing Technology. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 107-118.

Rushton claimed that support from employees for the adoption and implementation of new technology can be aided by obtaining their commitment to planning goals at the feasibility stage and by communicating with them at each stage of the project.

3. Goodridge, J. M. Employee Relations and New Technology Systems. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 227-240.

Goodridge studied employee relations and worker acceptance of new technology. He claimed that employees should be brought into the planning process, because employee commitment before projects are given final sanction by management yields enormous advantages in worker acceptance and in implementation of the new technology. As an example of a country where workers are committed and where new technology is accepted by the workers he gave West Germany. As an example of a country where the workers are not committed and where new technology is grudgingly accepted by workers he gave the United Kingdom. The difference in attitudes on the workers' part in these two countries is due to deficiencies on the part of top management in the United Kingdom in developing employee trust of management and employee commitment.

4. Preece, D. A. The Management of the Adoption and Introduction of New Technology. Paper in Proceedings of the 2nd International Conference on Human Factors in Manufacturing (Stuttgart, West Germany, June 11-13, 1985). IFS Publications Ltd., 1985, pp. 353-361.

Preece found that those companies that allowed human resource specialists to have a significant role in the introduction of new technology were generally successful in having the workers accept change, especially if these specialists were involved at the planning stage. Human resource specialists are those staff members whose main responsibilities have to do with employee hiring, promoting, developing, and training.

5. Spencer, R. W. Robots: Does the Worker Win or Lose? Paper in InteRobot 83 (Proc. 1st Annu. Int. Robot Conf., Long Beach, CA, June 14-16, 1983), pp. 143-147.

Spencer said that worker acceptance is mandatory when advanced technology is introduced into the workplace; otherwise the best engineered and constructed installation will fail to realize its potential. Parts will disappear, equipment will have premature failure, and high downtime will result. No matter how well the new technology is designed and no matter how well it is made to function in testing, sooner or later it must be turned over to the work force. Top management is generally the force behind the introduction of new technology, so they naturally accept it. There is small likelihood that the suggestion came from the employees' suggestion box. Middle management accepts new technology because of top management pressures, even though managers at this level may not want it. The foreperson probably sees new technology as a repair headache but as a part of management has to accept it. Workers view new technology as a threat to their jobs. Thus the first step in getting employees to accept new technology is for management to determine whether the new technology will or will not result in layoffs and how employees' work assignments will be changed. Once the effects on employment and on work duties are established, management should tell employees the truth about the effects on their jobs of the new technology and attempt to minimize any negative effects. If the company has to adopt new technology in order to remain competitive and stay in business even though some layoffs may occur, the workers should be made aware of this situation and told that it is better to preserve most jobs than to lose all jobs.

6. Robson, I. Managing the Introduction of Robots for Factory Efficiency. Paper in Proceedings of the 16th International Symposium on Industrial Robots; 8th International Conference on Industrial Robot Technology (Brussels, Belgium, Sept. 30-Oct. 2, 1986), pp. 1161-1169.

Robson said that the work force needs to be convinced of the benefits to themselves of new technology in order to willingly accept it. Negotiations with the workers should start as soon as possible since any new technology needs motivated and committed people for it to be used efficiently. Training should start even before the new technology arrives in order to minimize installation time.

WORKER COMMUNICATION

1. Husband, T. M. (ed.). Education and Training in Robotics. IFS Publ. and Springer-Verlag, 1985, 315 pp.

In a book edited by Husband on education and training in robotics, the importance of communication with workers was stressed. There is a need for awareness of what is going on at all levels of the company hierarchy, and employee consultation is necessary at each stage of implementation.

2. Goodridge, J. M. Employee Relations and New Technology Systems. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 227-240.

Goodridge believes that it is incumbent upon organizations to communicate with workers and to give as full a picture as possible of the employment implications when a project on introducing new technology is announced. Communication with the workers is an early indication by the organization that it is concerned over jobs and is a critical factor in developing a constructive working relationship between management and the work force.

3. Argote, L., P. S. Goodman, and D. Schkade. The Human Side of Robotics: How Workers React to a Robot. Sloan Manage. Rev., v. 24, No. 3, Spring 1983, pp. 31-41.

Argote, Goodman, and Schkade claimed that management should incorporate some feedback mechanism to monitor communication effectiveness when new technology is introduced since there is usually a discrepancy between what management is trying to communicate to workers, what the workers receive, and how they interpret what they do receive.

4. Brennan, L. The Influence of New Technology on the Allocation of Functions Decision. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 79-86.

Brennan found that worker communication in firms he had discussions with was undertaken before the installation of new technology. One or more of the following measures were taken: talks with worker representatives, interoffice memoranda, instructions on maintenance, departmental meetings, in-depth discussions with the work force, and/or full factory meetings.

5. Owen, D. Information Systems for More Effective Maintenance. Paper in Proceedings of the 3rd Canadian Symposium on Mining Automation (Montreal, PQ, Canada, Sept. 14-16, 1988). J.-M. Robert, Sainte-Foy, PQ, 1988, pp. 211-222.

Owen discussed the importance of information flow, both formal and informal, in the effective management of maintenance in underground coal mines. He found that in many mines there are poor communications within a department, and in nearly all mines there are poor communications between one department and another. The skills that were highly developed by those working in such an environment were finding excuses, passing the buck, and avoiding the issues. There was a lack of orderly information available to persons that might have enabled them to make more rational decisions. Not only was there a lack of factual information, but there was also a failure to realize the need for it.

6. Bauman, M. B., and H. P. Van Cott. Effects of an Automated Maintenance Management System on Organizational Development. Paper in IEEE Fourth Conference on Human Factors and Power Plants. IEEE Serv. Cent., Piscataway, NJ, Cat. n88ch2576-7, 1988, pp. 394-402.

Bauman and Van Cott said that communication at nuclear power plants was found to be a problem warranting special attention. For instance, communication problems were a contributing factor to maintenance personnel's spending less that 50% of their time in repair activities and to maintenance work delays and extended outages. A project was undertaken that compared two different techniques for improving the maintenance work control process: an automated (computerized) maintenance management system (AMMS), and interdepartmental coordination meetings. The results were mixed, but they did show the importance of matching the functions selected to be included in any AMMS with the communications problems existing at the plant.

WORKER DISPLACEMENT

1. Ayres, R. U., and S. M. Miller. Robotics and Flexible Manufacturing Technologies: Assessment, Impacts, and Forecast. Noyes Publ., 1985, 443 pp.

Ayres and Miller claimed that the impact of automation and robotics on employment in mining, construction, transportation, communications, and agriculture will not be drastic. These fields will continue to use human workers and in most of the same functions such workers currently perform. Any jobs that require high-quality sensory capability or rapid responses to a changing environment require human beings. Machines and humans are complementary, not competitive, since, for instance, specialized robots will be wanted for particular tasks or families of tasks, not general-purpose robots that are flexible and adaptive and with a high level of general intelligence. An example is a possible mining robot, which would be an armored track vehicle specialized to a specific task such as drilling holes and inserting roof bolts.

2. Office of Technology Assessment (Washington, DC). Computerized Manufacturing Automation: Employment, Education, and the Workplace. U.S. GPO 84-601053, 1984, 471 pp.

The Office of Technical Assessment stated that programmable automation (PA) will cause the following long-term trends in occupations:

1. A rise in the demand for engineers, computer scientists, technicians, mechanics, repairers, and installers;
2. A fall in the demand for operators and laborers, especially the least skilled doing the most routine work;
3. A fall in the demand for clerical personnel;
4. A rise in the demand for upper level managers and technical sales and service personnel; and
5. A possible fall in the demand for lower and middle level management personnel.

3. Carnegie-Mellon University (Pittsburgh, PA). The Impacts of Robotics on the Workforce and Workplace. Sch. of Urban and Public Affairs, Dep. of Eng. and Public Policy, and Dep. of Humanities and Soc. Sci., June 1981, 218 pp.

A Carnegie-Mellon University report pointed out that support personnel have grown from about 10% of the total underground coal mining work force in 1890 to almost 50% in the late 1970's, and the ratio of supervisors to workers in underground coal mines increased from 1:100 in 1890 to 12:100 in 1969. Even more support personnel will probably be needed with the more advanced mining technology that is being or will be developed.

4. Leontief, W. W., and F. Duchin. The Future Impact of Automation on Workers. Oxford Univ. Press, 1986, 170 pp.

5. ____. Impacts of Automation on Employment, 1963-2000. Abstract and Executive Summary. Apr. 1984, 29 pp.; NTIS PB 84-191790.

6. ____. Impacts of Automation on Employment, 1963-2000. Final Rep., Apr. 1984, 373 pp.; NTIS PB 84-191782.

Leontief and Duchin developed a dynamic computer model to predict the direct and indirect effects of new technology on employment throughout all sectors of the U.S. economy between 1963 and 2000. Almost 100 industries producing goods and services and several consuming sectors, including households and government, were represented in the model. Employment in the mining industry was broken down into iron and ferroalloy ores; nonferrous metal ores; coal; stone, clay, and quarrying; and chemical and fertilizer minerals. For coal mining, the number of worker-years was projected to increase from 290,000 in 1980 to about 550,000 by the year 2000 under all four scenarios (a different degree of new technology being adopted under each scenario). The graph of worker-years as a function of time showed a steady increase with almost a straight line relationship. For other types of mining, the graphs of worker-years versus time oscillated (meaning demand for the product varied and hence employment) with high peaks of employment at times, but by 2000 the number of worker-years was about the same as in 1980.

7. Flynn, P. M. The Impact of Technological Change on Jobs and Workers. Bentley Coll., Waltham, MA, Final Rep., Mar. 1985, 104 pp.; NTIS PB 85-218022.

Flynn analyzed 197 case studies on the effects on employment at mostly large firms in over a dozen countries (108 case studies from the United States) that underwent technological change. Only relatively small numbers of employees were demoted or given more monotonous work and even fewer were displaced. However, those workers who were laid off or demoted were those with the least potential for obtaining an equivalent job elsewhere. Employees laid off in declining industries found their skills and experience of little value in finding other jobs. Older workers were considered to be too old to retrain. Automation of production processes requiring highly skilled workers resulted in their replacement by semiskilled and lesser skilled workers in many cases. Some relatively high-level jobs were created, but these required significantly different types of skills than the jobs that were eliminated or downgraded and were much fewer in number.

8. Miller, S. M. Impacts of Robotic and Flexible Manufacturing Technologies on Manufacturing Costs and Employment. Robotics Inst., Carnegie-Mellon Univ., Pittsburgh, PA, CMU-RI-TR-84-23, 1984, 40 pp.

Miller analyzed the extent to which unit costs and production labor requirements might be reduced if there were widespread adoption of flexible manufacturing systems (FMS's), including industrial robots, by metalworking industries. Almost half of the tool handlers, over half of the metalforming machine operators, about one-fourth of assemblers and laborers, and one-eighth of craft workers would be displaced. However, no maintenance or transport workers would be displaced. If the highest projected level of new technology were introduced, 28.6% of the workers in the metalworking industry would be displaced (about 1.5 million workers) and about the same percentage in all of manufacturing would be displaced (about 4.0 million workers).

9. Business Higher Education Forum (Washington, DC). The New Manufacturing: America's Race To Automate. Final Rep., June 1984, 42 pp.

The Business Higher Education Forum contended that there will be several implications for workers as automated manufacturing increases. In the long term, the use of automation in manufacturing should lead to greater wealth and higher levels of employment (primarily in the service industries). In the short term, uneducated, unskilled, or semiskilled factory workers will be displaced in considerable numbers by more efficient machines. However, the widespread introduction of advanced manufacturing technologies is likely to be gradual, perhaps taking decades or more. This transition should provide adequate opportunities to address the issues of worker displacement.

10. Ouellette, R. P., L. W. Thomas, E. C. Mangold, and P. N. Cheremisinoff. Automation Impacts on Industry. Ann Arbor Sci., 1983, 186 pp.

Ouellette, Thomas, Mangold, and Cheremisinoff reviewed the impacts of computer automation on employment in 10 industries. They found that automation had frequently been used to replace humans in tasks that are monotonous, physically tiring, dangerous, or harmful to health. Low-skilled workers were often replaced by machines, while higher skilled workers were taught how to program and operate the equipment.

11. Cure, K. G. AMS: Friend or Foe. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 185-192.

Cure stated that advanced manufacturing systems (AMS's) that use automation and robots in every area of work cause a number of unskilled, semiskilled, and skilled jobs to be eliminated. There will be many new jobs at places with AMS's, but these jobs will require increased skills. For instance, because factories are becoming more capital intensive, downtime is more expensive than ever, which means skilled maintenance personnel are needed if the increased productivity potential is to be realized.

12. Lane, J. D., G. Lundstrom, and W. Warnat. Education Efforts and Implications Facing the World's Robotics Industry. Paper in Proceedings of the 14th International Symposium on Industrial Robots and 7th International Conference on Industrial Robot Technology (Goteborg, Sweden, Oct. 2-4, 1984), pp. 25-36.

Lane, Lundstrom, and Warnat claimed that the new technology has created a system of employment requiring a work force with higher skill qualifications (e.g., researchers, engineers, technicians, and professional staff). At the same time, there has been an increasing reduction of unskilled and skilled jobs at the production level, even those of foremen and first-line supervisors.

13. Groover, M. P., J. E. Hughes, Jr., and N. G. Odrey. Productivity Benefits of Automation Should Offset Work Force Dislocation Problems. Ind. Eng., v. 16, No. 4, Apr. 1984, pp. 50-59.

Groover, Hughes, and Odrey said that new technology means fewer workers. These workers will have to be technically smarter and more versatile than their counterparts of generations past. They will include computer programmers and operators, maintenance personnel, and technical support specialists.

14. King, J. R. Is There Any Future for Man in Man-Machine Manufacturing Systems? Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 353-358.

King said that people will continue to be needed in the manufacturing systems of the future but in far fewer numbers. Generally, they will be on the shop floor to perform some installation, maintenance, service, or material supply or collecting task. They will do this as quickly as possible and then withdraw.

15. Arayama, A., and P. Mourdoukoutas. Automation and Employment Adjustment: A Japanese Case Study. Int. J. Manpower, v. 8, No. 5, 1987, pp. 8-11.

Arayama and Mourdoukoutas contended that the impact of new technology on employment can be decomposed into three effects: job replacement, job creation, and job savings. The jobs of some workers are replaced by the new technology while other jobs are obviously created in and by this technology. The job savings effect refers to the fact that declining or noncompetitive companies that would have had to go out of business and lay everyone off manage to survive through their adoption of new technology. Some workers are displaced, but others keep their jobs and new hires are made.

16. Warnat, W. I. Human Factors Beyond the Workplace: A Social Context for Robotics. SME Tech. Pap. MS83-927, 1983, 8 pp.

Warnat claimed that some of the workers are displaced in most job categories when new technology is adopted by a company. Even middle level managers, who previously were left relatively untouched when companies had layoffs, will be displaced in large numbers as automation permeates the workplace. However, because of the aging of the U.S. population, there will be fewer young and middle-aged workers and hence the disappearance of unemployment as a persistent problem.

17. Hunt, V. D. Industrial Robotics Handbook. Industrial Press Inc., 1983, 435 pp.

Hunt pointed out that even if more jobs are created by new technology than are eliminated, most of these jobs may be in different industries and/or require different skills, which can mean significant worker displacement.

18. Tanaka, H. Human Implications of Robotization in the Worksite: The Japanese Experience. Robotics, v. 1, No. 3, Oct. 1985, pp. 143-153.

Tanaka said that automation and robotics have two major employment impacts: On the one hand, new technology induces productivity increases, triggers new industries, and expands employment, but on the other hand, new technology eliminates labor and results in reduced employment in the affected industries and in those firms directly or indirectly dependent on those industries.

19. Albus, J. S. Socio-Economic Implications of Robotics. Pres. at 1983 World Congr. Conf. on the Human Aspects of Autom., Ann Arbor, MI, Aug. 8-11, 1983, 10 pp.

Albus said that the threat to employment due to advanced technology is vastly overrated. There is no historical evidence to suggest that any form of mechanization or automation has ever caused, or will ever cause, a net increase in unemployment in any country. Unemployment in America is not due to automation and will not be due to robotics but is the result of industries that are becoming obsolete through a lack of modernization. The new technologies used in computer-integrated manufacturing will create entirely new industries employing millions of people in jobs that do not exist today. There will also be many jobs in the companies that which manufacture, sell, install, and maintain new technology.

20. Rudinger, R. Social Aspects of Automation and Robotics. Pres. at ASME Winter Annu. Meet., Anaheim, CA, Dec. 7-12, 1986, 8 pp.; available from ASME.

Rudinger pointed out that opinions on the long-range effects of new technology on employment range from optimistic—technology has always produced more jobs than it has eliminated—to pessimistic—the new technology is different and will cause widespread unemployment. A dilemma is that although advanced technology can eliminate a significant fraction of the work force (including such highly skilled persons as quality controllers, supervisors, and trainers), not to automate may mean that a company is no longer able to compete and will go out of business, which means all of its jobs are lost. Also, if the foreign competition automates, it solves its unemployment problem by creating one in the United States.

21. Frantz, R. L., and R. H. King. Study of the Human Factors Aspects of an Automated Continuous Mining Section (grant SO144115). PA State Univ., Final Rep., 1977, 305 pp.; NTIS PB 299 945.

Frantz and King compared four stages of progressive and improved mechanization, automation, and remote control of underground room-and-pillar mining with the system being used at present. They found that with each stage of increasing automation, productivity increased significantly even though the total number of employees also increased. The additional employees were predominantly in management and maintenance.

22. Brix, A. J. Productivity, Technology, and Organized Labor. Enterprise, Spring 1982, pp. 21-24.

Brix contended that although automation is the most dreaded job killer in labor's doomsday book, it can be a powerful ally in moving toward the ultimate in job security as productivity rises. For example, increased productivity allows the work week to be decreased from its present 40 hours, thus providing additional jobs.

23. Guterl, F. An Unanswered Question: Automation's Effect on Society. IEEE Spectrum, v. 20, No. 5, May 1983, pp. 89-92.

Guterl mentions that a long-term solution to worker displacement due to automation that has been proposed is to shorten the work week. The number of hours worked per week has steadily declined since the beginning of the Industrial Revolution in 1840 when it was 72 hours long. By decreasing the work week from the 35 to 40 hours a week it is now, the United States could provide well-paying jobs for many more of its people, virtually eliminate the creation of meaningless make-work jobs for the unemployed, and reduce concern about overproduction. In addition, and quite importantly, productivity could then be stressed and encouraged without reservation.

24. Picozzi, V. J. Automation for the USA. Paper in Proceedings: International Congress on Technology and Technology Exchange: Technology and the World Around Us (Pittsburgh, PA, Oct. 8-19, 1984), pp. 27-28.

Picozzi claimed that although programmable automation (PA) will reduce the need for certain workers, the demand for engineers, computer programmers, operators, repair and maintenance mechanics, and managers and supervisors who understand what is required to operate and optimize PA systems will increase.

25. Segal-Horn, S. The Human Implications of New Technology. Manage. Serv., v. 29, No. 11, Nov. 1985, pp. 9-12.

Segel-Horn contends that it is impossible for as many jobs to be created by the new technology as will be lost because of the increased productivity arising from its introduction. In addition, new technology facilitates the transfer of jobs from the fully industrialized countries to the newly industrializing countries where labor is cheaper. New technology reduces the skill content of many manufacturing jobs, which frees companies from having to be located near sources of highly trained, skilled labor. Telecommunications and information technology have made it technically feasible to coordinate plants in different parts of the world. However, for a country, industry, or company not to adopt the new technology is to invite economic ruin. People in the industrialized countries must accept unemployment, early retirement, and part-time work as permanent fixtures and not as temporary aberrations.

26. Ebel, K.-H. The Impact of Industrial Robots on the World of Work. Int. Labour Rev. (Switzerland), v. 125, No. 1, Jan.-Feb. 1986, pp. 39-51.

Ebel contended that where a flexible manufacturing system (FMS) is introduced the unskilled and semiskilled functions (machine operators, loaders, transport workers, stock controllers, etc.) are done away with. The jobs of those machinists remaining have reduced skill content. Overall, productive activities decline and production supporting activities increase. The requirements for manual skills decrease and some skills become obsolete, while cognitive skills gain in significance.

27. Cramer, R. Robots—Doom or Boom? Mod. Mach. Shop, v. 57, No. 6, Nov. 1984, pp. 74-77.

Cramer believes that the predicted loss of many jobs, a declining economy, labor strife, and all of the evils resulting from widespread unemployment due to the introduction of new technology, including robotics, is wrong. History shows that productivity improvements increase employment in a country, while outdated methodologies cause unemployment. Even labor leaders realize that the road to progress and the blueprint for the betterment of the lot of workers lie in, as always, improved productivity.

28. Warnat, W. I. Employment Projections/Education Implications for the Robotics Industry in the USA. SME Tech. Pap. MM84-642, 1984, 11 pp.

Warnat presented tables based on Bureau of Labor statistics showing the projected changes in the number of people employed in 21 manufacturing occupations and in 9 manufacturing job classifications over the next few years as new technology is adopted. These tables indicated that the manufacturing work force is becoming increasingly salaried and white collar and that endangered occupations make up a substantial percentage of the work force.

29. Chamot, D. Human Aspects of Automation: A Union Perspective. SME Tech. Pap. MM84-638, 1984, 8 pp.

Chamot claimed that the increasing pace of technological change in manufacturing and the widespread application of computers and telecommunications technologies give rise to serious concern about future employment. In the past, new technologies were introduced into a single industry, or a part of an industry. Any slack that occurred in employment could be absorbed in other parts of the business or other sectors of the economy. Today, however, work is being transformed throughout manufacturing facilities, as well as in warehousing operations, engineering departments, general office environments, agriculture, traditionally labor-intensive service industries, and both public and private organizations.

30. Ayres, R. U., and S. M. Miller. Socioeconomic Impacts of Industrial Robots: An Overview. Ch. in Handbook of Industrial Robotics, ed. by S. Nof. Wiley, 1985, pp. 467-496.

Ayres and Miller claim that the transition to an automation-robotic-computer industrial base will not be catastrophic on a national scale with massive unemployment in the United States if new entrants into the job market are properly trained and directed. The oncoming transition in manufacturing will probably be less dramatic than the impact of office automation at least through the year 2010. The industries that are candidates for extensive robotization are mostly characterized by the presence of strong unions and well-established collective bargaining procedures. Unions will try to counteract the loss of jobs and members by insisting on the transfer and retraining of displaced workers and by restricting work rules, decreasing the hours worked each week, lengthening paid vacations, adding paid personal holidays, guaranteeing employment, and providing lucrative early retirements, all of which discourage the introduction of new technology by increasing the cost of doing so.

WORKER INVOLVEMENT AND PARTICIPATION

1. Goodridge, J. M. Employee Relations and New Technology Systems. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 79-86.

Goodridge claimed that implementation of new technology through worker involvement may be as important as the new technology itself. The workers should participate in any redesign of their jobs and any physical or organizational restructuring of the workplace.

2. Mowrey, D. C., and B. E. Henderson (eds.). The Challenge of New Technology to Labor-Management Relations. U.S. Dep. of Labor, Bur. of Labor-Manage. Relat. and Coop. Programs, BLMR 135, 1989, 66 pp.

In a book edited by Mowrey and Henderson, it was stated that the Japanese organize their production systems in a way that permits extensive worker interaction with technology, and this seems to have had large payoffs. Workers are allowed to modify or add relevant functions to machines and production systems. Evidence is accumulating from many sources that less rigid forms of work organization are more productive than rigidly organized ones. For example, in the United States and other countries, allowing workers to participate in decisionmaking and to take over many of the functions associated with supervisors, such as production planning, inventory control, and quality control, has resulted in increased productivity.

3. Lawlor, M. Participation—Involvement: The Guiness (Dublin) Experience. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 17-24.

Lawlor said that his company managed to stay in business by adopting a participative style of management. People need to be motivated and happy to use advanced technology effectively, and thus should be allowed to share in decisions at the local level.

4. Weir, D. T. H. Organizational Stress and the Introduction of New Technology. Paper in Proceedings of the 1st International Conference on Human Factors in Manufacturing (London, UK, Apr. 3-5, 1984). IFS Publications Ltd., 1984, pp. 361-373.

Weir claimed that studies on improved or increased participation by workers in management decisionmaking have generally focused on how to restructure the organization to allow worker participation. Insufficient attention has been paid to the role of worker participation in improving communications within organizations and in improving the quality of information available for management decisions. One of the chief effects of the Quality Circle movement as it is practiced in Japan has been to provide management with useful information, which allows better decisionmaking.

5. Whaley, G. L. The Impact of Robotics Technology Upon Human Resource Management. Personnel Admin., v. 27, No. 9, Sept. 1982, pp. 61-71.

Whaley claimed that worker participation in planning the introduction of new technology into a company is important if the anticipated economic and productivity benefits are to be realized. New technologies are generally viewed by workers as reducing job opportunities, being imposed on them by management without consultation, and involving little or no worker participation in decisionmaking regarding their jobs. Workers nowadays expect entitlement of choice, multiple choices, participation, and immediate gratification.

6. Webb, T. Social and Employment Aspects of Automation. Pres. at Eng. Design '86 Conf. Inst. Mech. Eng. (UK), London, UK, 1986, 7 pp.; available from Inst. Mech. Eng.

Webb stressed that employees who will be affected by the changes brought about by the introduction of new technology should be involved in the planning stage. If these employees are not allowed to participate in decisionmaking right from the start, the end result will be inefficient use of the systems.

7. McArthur, D. W. What Good Is Technology If You Are Faced With Disgruntled Employees? The Office, v. 10, No. 1, Jan. 1985, p. 128.

McArthur stated that managers should allow employees to participate in decisions. There is no substitute for feeling part of a team. It is one of the strongest motivating factors in the workplace. Workers do not feel as though they are part of a team if they are left out of the planning stage for new technology. Managers should discuss plans and solicit ideas from workers.

8. Smith, M. J., and P. C. Sainfort. A Balance Theory of Job Design for Stress Reduction. Int. J. Ind. Ergonom., Apr. 1989, pp. 67-79.

Smith and Sainfort said that worker participation has been widely used in goal-setting approaches. Advocates of worker involvement have argued that participative goal setting as opposed to assigned goal setting should yield increased performance. The assumption is that participation helps workers to attain higher order ego needs, thus leading to increased satisfaction, which in turn strengthens motivation and eventually improves productivity.

9. Argote, L., P. S. Goodman, and D. Schkade. The Human Side of Robotics: How Humans React to a Robot. Sloan Manage. Rev., v. 24, No. 3, Spring 1983, pp. 31-41.

Argote, Goodman, and Schkade emphasized that management should involve the workers in ways to minimize the changes in social interaction patterns that occur when new technology is introduced. Social interaction is very important to workers, and altering or eliminating this interaction has negative consequences in terms of the psychological well-being of workers and their productivity. In addition, the cooperation of support personnel should be obtained by involving them in the planning and implementation of new technology.

10. Meredith, J. R. Managing Factory Automation Projects. J. Manuf. Syst., v. 6, No. 2, 1987, pp. 75-91.

Meredith observed that the standard advice for introducing new technology is to bring everyone in the company in at the beginning during the planning stage. The argument is that this will allow employees to understand what is happening and why, and how each of them will be affected. However, in practice the design of the new system keeps changing, which leads to frustration and decreased interest on the part of workers. What should be done is to have workers participate in the planning when their input will make a difference.

11. Ebel, K.-H. The Impact of Industrial Robots on the World of Work. Int. Labour Rev. (Switzerland), v. 125, No. 1, Jan.-Feb., 1986, pp. 39-51.

Ebel said that the direct involvement of workers in the organization of their work needs should be made a reality. Such a procedure can assure their acceptance of and commitment to new technologies and changes in work assignments. It is absolutely essential for workers and their representatives to be kept fully in the picture about impending automation and/or robotization. Genuine consultation and implementation should take place at the plant level. To be effective, consultation with workers must take place before changes are made and not, as is far too often the case, only after the major decisions affecting the workplace have been made by management. The direct involvement of the work force from the start is also the best assurance that the new technology will be used efficiently.

12. Brown, G. R., G. Susman, and E. Trist. Sociotechnical Design and Its Effect on Individual and Group Performance. Paper in 1st Symposium on Coal Management Techniques, Volume I (NCA/BCR Coal Conf. and Expo II, Louisville, KY, Oct. 21-23, 1975). NCA, 1975, pp. 61-70.

Brown, Susman, and Trist stressed the importance of worker participation and autonomy in underground coal mining when they looked at sociotechnical design and its effect on individual and group performance. They claimed that workers must be involved in the creation and innovation of new mining technology and methods so they will accept change.

HUMAN FACTORS AND THE HUMAN-MACHINE INTERFACE

Because the number of publications on human-machine systems and the human-machine interface is vast and few of them are really relevant to this report, only a few representative publications that discuss human factors and cognitive processes will be presented.

1. Kvalseth, T. O. Design of Man-Machine Systems. Ch. in Handbook of Industrial Engineering, ed. by G. Salvendy. Wiley, 1982, pp. 6.8.1 to 6.8.9.

Kvalseth discussed the design of human-machine systems from the human factors-ergonomics viewpoint. By machine is meant anything ranging from simple tools and equipment to complex physical processes. The design of systems involving persons and machines all too often focuses on the hardware or machine component while failing to give proper consideration to the human component. The design relies instead on human versatility and unique abilities to take care of any design problems and to make the system work. The proper integration of person and machine, which benefits the human operator and enhances the overall system performance, is a primary aim of human factors or ergonomics. Human operators receive information from various displays (dials, counters, lights, charts, buzzers, cathode-ray tubes, etc.). They respond by moving or exerting pressure on various controls (knobs, wheels, pedals, levers, keyboards, etc.) or by using their voice. The outputs of the control devices in turn provide the input to the machine or controlled system. This system of displays and controls interacts with its environment; it receives information about the goals or desired outputs of the system as well as possible disturbances or noise that may affect the various system elements. The layout or the location of individual controls and displays in relation to each other and to the operator is an important factor in human-machine design, affecting system performance, safety, and the operator's job satisfaction. Anthropometric data (physical dimensions and motions of the operators) of the persons who will operate the machine are used for the design of human-machine interfaces and work stations.

2. Weaver, C. L., III. Ergonomics Handbook: Practical Applications of Man-Machine Engineering. L. A. Weaver Co., Raleigh, NC, 1984, 125 pp.

Weaver wrote about the practical applications of human-machine engineering from the ergonomics perspective. Topics covered included applied anthropometry, biomechanics, illumination, hand tools, work height, seating, physical space arrangements, controls and displays, minimization of manual materials handling, robotics, and visual display terminals (VDT's).

3. Sanders, M. S., and J. M. Peay. Human Factors in Mining. BuMines IC 9182, 1988, 153 pp.

Sanders and Peay presented a broad overview of major human factors considerations and issues in the design of controls, equipment, and tools with an emphasis on mining applications. Special attention was given to the problems of seating for low-seam underground mining equipment, restricted field of vision in underground and surface mining equipment, egress and ingress in surface equipment, and designing for ease of maintenance in all types of mining equipment. They also discuss the choice and design of information displays. Topics covered included visual displays, signal and warning lights, signs and labels, auditory displays, and olfactory displays.

4. Siegel, A. I., J. J. Wolf, and M. R. Lautman. A Family of Models for Measuring Human Reliability. Paper in Proceedings of the American Society for Quality Control Annual Reliability and Maintainability Symposium, 1975, pp. 110-115.

Siegel, Wolf, and Lautman discussed eight computer models for simulating the human component in human-machine systems. The models emphasized human behavioral variables along with equipment, environmental, and crew composition considerations. All of the models sequentially simulate the behaviors of human operators and maintainers in a human-machine system as they perform the necessary tasks or activities required for completing a given goal. The human variables considered (only proficiency and stress were considered in all of the models) included proficiency, reaction to stress, fatigue, physical capability, group identification, and aspiration.

5. Meister, D. A Critical Review of Human Performance Reliability Predictive Methods. IEEE Trans. Reliab., v. 22, No. 3, 1973, pp. 116-123.

Meister summarized the status of human performance reliability predictive methods for the human-machine system. The overall goals of these methods are to measure and predict the effect of the operator on equipment-system performance and the effect of equipment-system elements on operator behavior. Most methods output probability estimates of successful task-system performance and completion time but are relatively insensitive to equipment design parameters, manpower selection, and training needs.

6. Anderson, J. R. Cognitive Psychology and Its Implications. W. H. Freeman and Co., 2d ed., 1985, 472 pp.

Cognitive systems engineering is based on the findings of cognitive psychology. Anderson stated that cognitive psychology attempts to understand the nature of human intelligence and how people think. It analyzes intellectual processes and develops models of mental structures. It is dominated by the information-processing approach, which analyzes cognitive processes into a sequence of ordered stages. Each stage reflects an important step in the processing of cognitive information. The information-processing approach grew out of human factors research and information theory. "Human factors," as used here, refers to the study of human skills and performance. Information theory is a branch of communication sciences that provides an abstract way of analyzing the process of knowledge. Ideas from human factors and information theory were integrated in the development of the information-processing approach. The important characteristic of an information-processing analysis is that it involves a tracing of a sequence or serial ordering of mental operations and their products (information) in the performance of a particular cognitive task. By information is meant the various mental objects operated on. For example, consider the question, What are the two most common methods used for extracting coal in underground mines in the United States? First, each word must be identified and its meaning retrieved. Second, the meaning of this configuration of words must be determined, i.e., the question being asked must be understood. Third, a person must search his or her memory or, if the answer is not in his or her memory, go to an external source for the answer. Fourth, once the answer is retrieved from memory or an external source, a plan must be formulated for generating the answer in words. Fifth, the plan must be transformed into the actual answer. In this case, the answer is continuous mining and longwall.

7. Hollnagel, E., and D. D. Woods. Cognitive Systems Engineering: New Wine in New Bottles. Int. J. Man-Mach. Studies, v. 18, 1983, pp. 583-600.

Hollnagel and Woods advocated the application of cognitive systems engineering (CSE) to the description and analysis of complex human-machine systems. Cognitive systems engineering can be defined as the application of the techniques and knowledge base of cognitive (how people think and construct mental models) psychology to the design of human-machine systems. The central tenet or claim of cognitive systems engineering is that a human-machine system needs to be conceived, designed, analyzed, and evaluated in terms of a cognitive system. This tenet is based on the fact that advances in technology, notably the growth of computer applications, has changed the nature of the human-machine interface from emphasizing the worker's physical tasks to emphasizing his or her cognitive tasks such as problem solving and decision-making, thus making a purely technological approach to human-machine systems obsolete. In addition, a human-machine system is not merely the sum of its parts, human and machine; the configuration or organization of human and machine components is a critical factor in how well the system performs. Intelligent action is produced by means of an internal mental model or representation of the environment. This model is used for planning or decisionmaking, formulating messages to be sent, and interpreting messages received. Humans have such internal models as do advanced computer systems. Hence, both the operator and the machine should be considered as cognitive systems. Human engineering and ergonomics typically focus on the limits of human performance in the physical domain, not on cognitive functions. For example, such topics are dealt with as anthropometric limits (e.g., can an operator reach a control?) and sensory limits (e.g., can an operator see a display or read a label?). Thus, human engineering techniques and guidelines are designed to identify and correct violations of the operator's physical limits. For instance, activity and link analyses are designed to determine how much physical movement is demanded of the operator or if related controls and displays are physically associated. The human engineering approach, though a necessary step in human-machine interface design, does not and cannot address the problem of making person and machine work as an effective cognitive system. It does not possess the tools, concepts, and models necessary to analyze and understand human-machine systems from a cognitive standpoint. This deficiency is due to the influence of behaviorism or behavioral psychology, which reduces the human to a black box and focuses on what can be observed as stimuli and responses to the stimuli. Although human engineering has accepted that the perceptual capacity of the operator is limited and in many cases deficient, it has given very little consideration to how the operator deals with the input information he or she has obtained. The need for cognitive systems engineering when designing human-machine systems can be expressed in another way. A machine or system designer works from a model that describes a portion of the physical world. However, the same designer will attempt to build a human-machine interface without a proper model that describes the relevant portion of the psychological world. One goal of cognitive systems engineering is to provide the designer with a realistic model of how a human functions cognitively. The models for the physical and the psychological worlds are not the same. People function according to a psychologic rather than a logic, but standard decision theory assumes that the decisionmaker is strictly rational. What this means is that the way in which humans go about making decisions, solving problems, thinking logically, making diagnoses, etc. can be described by rules and principles developed by psychology rather than the rules of logic. The machine designer should build a human-machine interface compatible with human cognitive characteristics rather than one that forces the human to adapt to the machine in order for the machine to be used efficiently and the human not to develop stress symptoms. But the designer has to be provided with a clear description of these characteristics and with methods and principles that allow him or her to adapt machine properties to humans. Hence, cognitive systems engineering must develop methods for cognitive task analysis that will identify the operator's mental model of a system, provide the designer with data on characteristics of human cognition, and develop the techniques for building machines with explicit and appropriate images of the user.

8. Karwowski, W., and M. Rahimi. Work Design and Work Measurement: Implications for Advanced Production Systems. Int. J. Ind. Ergonom., v. 4, No. 3, Nov. 1989, pp. 185-193.

Karwowski and Rahimi discussed the importance of cognitive psychology for the development of a new generation of work measurement systems that allow the measurement of work in terms of human mental functioning in complex production environments. They propose a framework based on developments in cognitive systems engineering that take into account human cognitive behavior. Cognitive engineering proposes that human-machine (hybrid) systems need to be conceived, designed, analyzed, and evaluated in terms of human mental processes (operator mental model that describes the operations and functions of the system). Advanced technology requires new approaches to work design and measurement that cannot be met by traditional time study techniques that utilize models of human operator and human-task interaction based on physical and physiological levels of description, not the cognitive ones. The nature of tasks in modern production systems has shifted from (and will do so even more in the future) those that require perceptual-motor skills to cognitive activities of problem solving and decisionmaking in monitoring and supervisory control of tasks. Work measurement systems compatible with the requirements of advanced (computerized) production systems must be based on the description of human mental functions needed for a specific task rather than on the description of the task in terms or production time requirements. What is needed is a realistic model of how the worker functions cognitively.

9. Goodstein, L. P., H. B. Andersen, and S. E. Olsen (eds.). Tasks, Errors, and Mental Models. Taylor and Francis, 1988, 342 pp.

Goodstein, Andersen, and Olsen edited a publication on tasks, errors, and mental models that focused on cognitive systems engineering. The critical issue considered was achieving an integrated relationship between humans and machines by engineering the cognitive aspects of task performance into the human-machine system. This human-machine matching is considered to be crucial in order for error-tolerant, more productive, and more reliable systems to be developed. Subjects dealt with include (1) prologue on sources of a new paradigm for engineering psychology, (2) skills, rules, and knowledge (five chapters), (3) complexity and cognitive tasks (six chapters), (4) errors and faults (five chapters), (5) theoretical and methodological issues (four chapters), (6) epilogue on the contributions of Jens Rasmussen, and (7) a discussion of cognitive engineering as a new profession.

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