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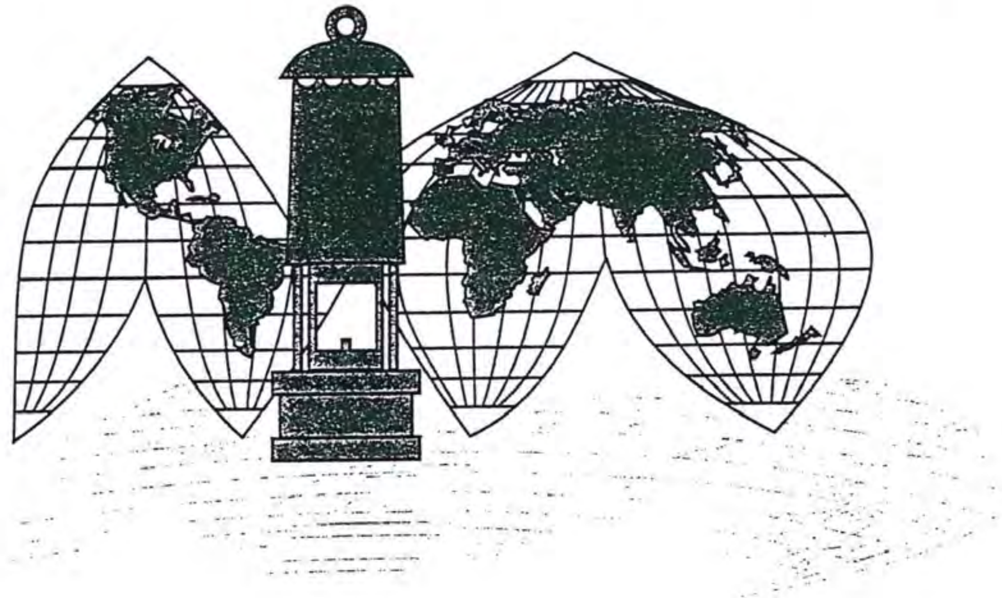

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A SOCIOTECHNICAL APPROACH TO THE UNINTENDED CONSEQUENCES OF TECHNICAL DESIGN IN MINING

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The drive for increased efficiencies in coal production has always accorded dominance to technological imperatives. Within such a paradigm the technology is changed, and only then are the social and organizational consequences of the change dealt with. This paper discusses four cases that reflect a framework within which system interactions and their social consequences may be examined concurrent with technological innovation.

There are numerous emerging technologies within the mining industry. Some of these new technologies are being developed in response to ever more stringent health, safety and environmental regulations. Most are intended to enhance a company's competitive position in a challenging and evolving regulatory environment. The performance of these technologies, if it is assessed at all, will probably be evaluated using some variation of benchmarking (Matters and Evans, 1998). For instance, in the simplest type of benchmarking (internal), a mine might compare production figures and costs for a section trying continuous haulage with those from a section using shuttle cars. Or, having embarked upon a program featuring new personal protective equipment, mine management might track lost time injuries or illnesses compared to industry leaders (functional).

Even well-done benchmarking does not guarantee the sort of improvements management might expect. Benchmarking offers comparison measures, and it can help guide organizational change only if the measures are relevant and

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appropriate. Organizational performance actually depends on a host of technical and social factors such as: (1) management commitment to safety; (2) worker capabilities; (3) the technology employed; and (4) organizational structure (Harrison, 1994:9). Additionally, benchmarking, in and of itself, does not offer a way to assess the unintended consequences of technological change. It only offers comparative insight. An example is the use of injury data. For instance, this data might suggest strongly that injuries and deaths occur when new technology is introduced into a system without an adequate evaluation of potential human-machine-environment interactions. Unfortunately, injury data is after the fact (i.e. a reactive measure). A different viewpoint is needed to deal proactively with such an issue. This viewpoint is provided by macroergonomics.

Macroergonomists are those concerned with the research, development, and application of organization/machine interface technology (Hendrick, 1991). In essence, these scientists employ the sociotechnical systems perspective (Trist and Bamforth, 1951). Sociotechnical systems theory (SST) was pioneered in British coal mines during the 1950s, and has since been applied to many industrial settings. Basically, SST assumes that work organizations have two interdependent systems: the technical system and the social system. The technical system includes the machinery, layout, workflow procedures, information, and so on, that are necessary to transform some material into a new state. The social system includes the human component of work. This refers to the attitudes, beliefs, abilities, and energies of individuals in a social network or system. It also includes how workflow procedures are actually carried out by the employees. The technical system has traditionally been the province of the engineer, while the social system has traditionally been designed by the social scientist. Sociotechnical designers argue that the engineer and social scientist have erred by considering only their own system and that trying to optimize one system (e.g., improving work methods) will not necessarily improve organizational effectiveness. Single-system optimization fails to recognize the interdependency between the two systems. Therefore, sociotechnical designers propose that optimizing both the technical and social systems, that is, trying to find the best match between them, will enhance organizational effectiveness.

SST maintains that changes in one aspect of a system often have both intended and unintended consequences in other parts of the system. When the British coal mining industry first tried to introduce an early form of longwall mining, workers reacted in a very negative fashion. Miners had been accustomed to working in close proximity to others in "rooms". The new technology significantly altered the social system. It required many miners to spend most of their day working in isolation from each other in a cold, dark, hazardous environment. This led to increases in job dissatisfaction, absenteeism, health problems (thought to be caused by psychological stress), and to decreases in morale and productivity. The situation became so bad that the technology was eventually modified to decrease the amount of time miners had to spend in isolation. Several additional examples of changes which resulted in a mismatch between the technical and social systems have been documented in the literature (Katz & Kahn, 1966).

Similar problems can result when mine safety researchers attempt to institute changes that may affect miners' physical, social, and organizational environment in ways that are hard to anticipate. It is, therefore, important to understand miners' views about any significant changes to their job. Are they willing and able to adjust to potential changes in equipment, operating procedures, working conditions, or policies and what would be the consequences if they didn't? In terms of consequences, macroergonomists would apply a systematic methodology to organization/machine interactions before technology is introduced. Their aim might be to provide critical information to workers about to be exposed to a new technology or operation, for instance. Their approach would concentrate not only on how things function under normal circumstances, but should also recognize and address surprises in the system. Proponents of this perspective argue that if firms selected for benchmarking comparisons were to examine the unintended consequences of new technologies, the results would be extremely useful.

"Almost every process has a predecessor, and studying the predecessor helps to define needs and shortcomings to be addressed in the new design. It also suggests what information is needed by the users in order for them to be able to operate safely and effectively. The end users of a system can provide important feedback to better evaluate current and proposed designs. When new technology is introduced into a system, incidents may occur before it is realized that human-system interactions were not considered adequately in the design process. A systematic methodology to evaluate the causes of these mishaps and to develop remedial recommendations can enhance safety (Steiner, Turin and Cornelius, 1997:603)." The following section contains a discussion of four research projects in which sociotechnical approaches have played a role in scientists' attempts to determine how a new system is likely to affect the tasks that workers are accustomed to performing.

Case Abstracts

The first case in which a sociotechnical perspective has been incorporated into project planning involves the development of a method for evaluating system interactions in mining (Steiner, Turin, and Cornelius, 1997). During the past decade, remote control technology has been introduced to provide a safer work environment. Now, machine operators are not required to be on the equipment, but can position themselves to one side and behind the machine. Because of that innovation, however, the technology has also provided a way for mines to take longer lengths of cuts, thus increasing production and leading to widespread adoption.

Once remote control technology began to be widely used, new issues became evident. Operator positioning was the primary human factors concern expressed by industry personnel, but there were many technical questions involving ventilation and ground control during increased cut depths. From a researcher's perspective, the ability to answer these questions is confounded by the fact that each mine is very different in terms of geological characteristics, management and mine planning, equipment, seam height, and geographical area. Solutions are difficult to generalize. Nevertheless, it is essential to develop mechanisms for mines to evaluate new systems in order to predict and reduce life threatening situations.

One of the main health and safety problems in underground and surface mining is that of personnel being killed or permanently disabled by machinery and powered haulage (Mine Safety and Health Administration, 1991-1995). In addition, out of a total of 34,555 nonfatal days-lost accidents in all mines, 4,658 were due to machinery and 4,302 to powered haulage (Mine Safety and Health Administration, 1992-1994). Therefore, a second project, related to the one above, involves an examination of emerging sensor technologies that could be implemented to protect people working around various types of mobile mining equipment. Particular emphasis is being placed on the development and field test of low-cost proximity detection and collision avoidance systems that will be suitable for the underground coal mining environment. Selected proximity warning systems (PWS) are being tested at the Pittsburgh Research Laboratory and on equipment at cooperating mines. A system designed for people working around a continuous mining machine is being actively pursued in cooperation with the Mine Safety and Health Administration, and will continue in 1999 with field evaluations of prototype technology. This will involve extensive trials with working miners to assess the efficacy of the technology and develop guidelines for its potential application. As with any new technology, it is important to assess what new risks may be introduced. One risk in the example given here is the potential for over-reliance on technology (audible or visual warning that one is too close) rather than judgment about distance and placement, which could lead to pushing the envelope of performance too far.

A third project looks at the emerging technology of programmable electronics in mining. Equipment control functions that were once hardwired are being implemented with software and very large scale integrated (VLSI) devices. Often this transition has resulted in increased flexibility, improved quality, and decreased costs. At the same time, it has created new concerns and challenges involving worker safety (Sammarco, et al., 1997). These issues, raised by labor, industry, and government, center upon the fact that the visible and well-defined ladder diagram for relay-logic has been replaced by programs in which the exact outcome for varied inputs can be more obscure. Such technology brings new hazards due to added complexities and the ambiguous nature of software. Longwall equipment, for example, is utilizing radio remote control, shearer-initiated supports, and shearer auto-steer. Thus, efforts to automate longwall mining systems have resulted in semiautonomous machines operating within the same space as workers.

The industry's experience with programmable electronic technology is slight and no formal guidelines or standards exist for its safe use in mining. Currently, safety is inferred from Mine Safety and Health Administration certification or approval that equipment is permissible. But permissibility does not encompass functional safety. The project takes a risk-based, systems approach to deal with the special safety challenges and needs attendant upon what is a relatively new technology. The process encompasses hardware, software, workers, and environment for the equipment's life cycle. Project personnel's efforts are establishing and documenting a framework for addressing the safety of programmable electronics technology. They will then provide formalized documents/processes for use by manufacturers and enforcement agencies. Consideration of social and technical systems is critical in this work. Literature dealing with the role of human factors in advanced technology suggests that, without such consideration, the technology has limited success in meeting organizational goals (Fowkes, 1994).

A fourth project that has been influenced by sociotechnical systems theory involves mine emergency response training. The industry has a very experienced work force, and many have learned the difference between safety theory and everyday practice. They know that dealing with emergencies entails much more than following "rules" of behavior and simple decision processes. But, advances in mine monitoring, detection and fire suppression technologies have led to a decline in mine disasters. As mines become safer and disasters fewer, the number of individuals that have hands-on experience with mine emergencies is decreasing. A gap in expertise is therefore being created, that could have serious consequences at future major emergency events. Workers present when such events occur (and those called upon to respond) are placed in danger. The goal of this project is to reduce the risks associated with these infrequent, but potentially catastrophic, incidents by: (1) improving response training for miners and incident responders; and (2) providing a tool for assessing whether or not emergency response plans work as their authors intended.

This project uses a multidisciplinary research team. Training programs are being developed and evaluated with the assistance of outside industry professionals, involving both formal and informal cooperators. The primary effort is development of a Mine Emergency Response Interactive Training Simulation (MERITS). MERITS will address the readiness of command center leaders to direct response efforts. MERITS is expected to be useful because simulators are an effective means of training when complex systems are involved or where hands-on training is too dangerous or too costly for practicality. Additionally, the simulation will address unintended consequences by providing a cost-effective way to test specific mine emergency response plans that may never have been assessed for strengths and weaknesses. With some modifications, this training product and methodology could have use for content areas outside of mining. Products related to this effort will be field-tested and revised in the near future.

Analysis

There are sociotechnical system themes in the foregoing discussion that shed light on the notion of unintended consequences. To begin with, the research is framed within an environmental context, taking into account the work system (production technologies) and personnel. Moreover, the studies generally show that each component carries a certain amount of variability. There are, for instance: (1) a wide variety of relatively high-risk work environments across many types of mining. These are inescapable, and the risk can often only be controlled rather than eliminated; (2) variability and continuous changes in the emerging technologies and tools used to mine the product. This involves not only new mining technology and equipment but also changes to work design; and, finally, (3) variability among people regarding the skills and experience they bring to the use of technology within a particular organizational context.

Unintended consequences, then, represent a departure from the expected variability surrounding both how a process is supposed to work and how it actually works in its environment. In mining, how the process is supposed to work has been the arena for design engineers and mine planners. How it "really works" within the mining system has not been assessed consistently. Thus, only one dimension of potential variability gets explored. This poses serious consequences to the work system. To illustrate: Before the introduction of remote control, a continuous miner operator had little variance in his work location - he was inside the operator's compartment, but task design placed him in close proximity to the hazards of roof or rib falls, dust, and noise. With remote operation, the system changed - the operator was positioned a greater distance from traditional underground mining hazards such as dust and unsupported roof. At the same time, his physical location became less predictable (more variable) - and he was now exposed to new hazards, including proximity to the remotely operated mining machine. Also, from injury records, it is clear fatalities and other serious injuries did occur from this change in technology and work practice. These incidents were not simply matters of an operator being in the wrong place at the wrong time. They might more accurately be termed a "system problem" that has components of work design, training, and technology.

A sociotechnical theme found in all these projects is recognition of a need to utilize the expertise of veteran workers to help identify potential system problems. This assumption establishes a conceptual connection between the social and technical systems. And importantly, the social and technical focus of the research allows for an integration of goals to help guide the design and implementation of technology so that it can be both efficient and effective. Such an approach follows well the tenets of sociotechnical systems theory and macroergonomics, since both are grounded in the notion of harmonized system performance.

Each project has its own focus, but the context is a mining system. This system is dynamic and challenging, because it involves the inherently hazardous work environment, a work system (tools and emerging production technologies), and a human component – the worker. Additionally, people function within an organizational culture that is undoubtedly unique to the individual mining firm. One thing a review of the projects makes clear: technology does not function in isolation, and even slight changes in the mining process based on that technology need to be tested. Bench testing of this technology should not take place through trial and error. If such were the case, the only measures of "success" within a system would be reports of injuries and some measures of productivity (or the cost to produce). Little would be learned by the general industry unless these data were gathered up periodically and assessed. And, the social cost could be quite high with this trial and error process.

Discussion and Conclusion

The themes mentioned above are grounded in a rather simple axiom: all technological progress is continual but variable, and this technology does not operate in isolation. Workers, also, will work variably, and designers are faced with two choices. They can continue to design and install systems (e.g. remote control continuous miners or processor controlled mining machines) and assume that the benefits of these machines outweigh their costs. Or, they can take a more thoughtful approach and treat these technological innovations as an ongoing experiment. This would entail an up-front assumption that these technologies will require significant and continuous changes in how organizations invest in the safety of the worker.

To accomplish these changes will require some formal or informal partnerships between the developers and users of technology. Objective and reliable data is essential to an understanding of the context and risks under which this technology will be used. Also, this data needs to be analyzed and interpreted within the context of a market economy and social goals. These goals may very well recognize that zero injury risk is not feasible. Even so, progress must be made, and might very well depend on our ability to solve complex problems that involve several integrated factors. These factors include the mining environment, the work system, the culture of an organization, and people. It can go well beyond traditional methods that treat these components as isolated, unitary variables. This paper suggests that there may be better ways to assess the impact of change and new technology - that process involves selective, controlled experimentation carried out not only at the bench, but in the workplace as well.

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