# Macroergonomics: A Better Approach to Work System Design

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The concept of macroergonomics is reviewed, including its historical development and relation to other ergonomics technologies. Basic concepts of organizational design and sociotechnical systems are presented. Sociotechnical system considerations and models for macroergonomically designing or modifying work systems are discussed. The relating of macro- to micro-ergonomic design to achieve synergistic harmony is suggested as a means of *exponentially* improving organizational performance and related cost benefits, including reducing work related musculoskeletal disorders (WMSD's). Seven case studies are presented as validation of this hypothesis.

## INTRODUCTION

Historically, ergonomics has tended to focus on the design of specific jobs, work groups and related human-machine interfaces. Although applied within systems, most of the above-described activities actually are at the individual, team, or, subsystem level. In short, these constitute what herein shall be referred to as ergonomics activities at the *micro-ergonomic* level. Conceptually, it is entirely possible to do an outstanding job of micro-ergonomically designing a system's work-stations and environments, yet fail to reach relevant system effectiveness goals because of inattention to the *macro*-ergonomic design of the system (Hendrick, 1984).

The classic example of this inattention problem was the introduction of the *longwall* method of coal mining in a British deep-seam coal mine. The traditional mining system was largely manual and utilized teams of small, fairly autonomous groups of miners. Control over work was exercised by the group itself. Each minor performed a variety of tasks, and most jobs were interchangeable among workers. The workers derived considerable satisfaction out of being able to complete the entire "task". In addition, there was opportunity to satisfy social needs on the job. Sociotechnically, the psychosocial characteristics, the characteristics of the external culture, the task requirements , and the work system's design were congruent. The more automated, technologically advanced longwall method replaced this costly manual method of mining. This new, more *technologically* efficient system resulted in a work system design that was not congruent with the psychosocial and cultural characteristics of the work force. Instead of small groups, large shifts of men were required. Workers were restricted to narrowly defined tasks and job rotation was not possible. There now was a high degree of interrelationship among the tasks of the three shifts, and problems from one shift carried over to the next. This complex and highly rigid design was very sensitive to both productivity and social disruptions. Low production, absenteeism, and inter-group rivalry became common (DeGreene, 1973). Later, in studies of other coal mines by the Tavistock Institute of Human Relations in London (Trist, Higgin, Murray, and Pollock, 1963), this conventional longwall method was compared with a *composite* longwall method in which the work system's design incorporated many of the features of the old, shortwall work system. Production was significantly higher than for either the conventional longwall or the old manual system. Absenteeism and other measures of poor morale dropped dramatically. Based on the Tavistock Institute studies, Emory and Trist (1960) concluded that different work system designs can utilize the same technology. The key is to select the design that is most effective in terms of both the people who will constitute the work system and the relevant external environments, and then employ the available technology in a manner that achieves congruence

**Historical Development of Macroergonomics**

Macroergonomics, as a formally recognized sub-discipline, is less than two decades old. It first was given formal recognition as an important area for human factors development in the report of the "Human Factors Society Select Committee on the Future of Human Factors, 1980-2000", presented at the 1981 Human Factors Society (HFS) Annual Meeting. This committee was formed by the HFS in 1988 to research trends in all aspects of society to determine their implications for the growth, development, and effectiveness of the human factors discipline.

My responsibility on this committee was to study organizational trends to see if there were any new or unique implications for our profession. Based on my research, I noted in my portion of the Committee's report several major trends of significance to ergonomics. These included (a) breakthroughs in technology that would fundamentally change the nature of work; (b) the "graying" of the work force and related increase in education and experience, as well as greater maturity; (c) fundamental differences in the values about work of the post world war II baby boomers as compared with their older colleagues -- in particular, the baby boomers expected to participate in decision making about their work, have meaningful jobs, and to have satisfying social relationships at work; (d) the inability of purely micro-ergonomic interventions to achieve expected reductions in lost time accidents and injuries and productivity increases; and (e) increasing workplace and product liability litigation, based on ergonomic safety design deficiencies. In addition, it was clear that increasing world competition was going to require more efficient work system structures and processes in order for companies to be competitive. It is interesting to note that all of these predictions from 1980 have come to pass, and are continuing

Based on these findings, I concluded that if ergonomics was to realize its potential and be responsive to the needs of industry, the discipline was going to have to integrate organizational design and management factors into its research and practice. Since that report in 1980, the sub-discipline of macroergonomics has come into being and has enjoyed rapid growth.

## THE CONCEPT OF MACROERGONOMICS

**An Historical Perspective**

One way to define, or to otherwise understand the nature of any field of science and practice is by noting the nature of its *technology*. I have proposed that the unique technology of ergonomics is *human-system interface* technology (Hendrick, 1991). As a *science*, ergonomics is concerned with developing knowledge about human performance capabilities, limitations and other characteristics as they relate to the design of the interfaces between, and among, people and other system components. As a *practice,* ergonomics involves the application of human-system interface technology to the design or modification of systems to enhance system safety, comfort, effectiveness and quality of life. At present, this unique technology has at least five identifiable major components. Ranging from the earliest to the most recently developed, they are as follows.

<u>Human-machine interface technology</u> or hardware ergonomics. It primarily concerns the study of human physical and perceptual characteristics and the application of these data to the design of controls, displays, seating, workstations and related workspace arrangements

<u>Human-environment interface technology</u> or environmental ergonomics. It concerns the effects of various physical environmental factors, such as illumination, heat, cold, noise and vibration, on human performance, and the application of these data to the design of physical environments for people.

<u>Human-job interface technology</u> or work design ergonomics. It concerns the design of jobs to ensure proper workload and characteristics such as *task variety* or having different meaningful things to do in one's work, *identity* or sense of job wholeness, *significance* or perceived job meaningfulness, *autonomy* or control over one's work, and *feedback* or knowledge of results.

<u>Human-software interface technology</u> which is the central focus of cognitive ergonomics. It concerns the way people think, conceptualize, and process information, and the application of these data to software design

<u>Human-organization interface technology</u>, or macroergonomics. It concerns the interfacing of employees with the over-all organizational design of the work system so as to most effectively utilize both the personnel and technology employed in the system in responding to the organization's external environment.

The central focus of the first four ergonomics technologies has been the individual operator and operator teams or subsystems. Thus, the primary application of these technologies has been at the *micro*-ergonomic level. In contrast, because it deals with the over-all structure and processes of the total work system, the human-organization interface aspect is *macro* in focus; hence, it is referred to as "macroergonomics".

**Macroergonomics Definition**

Conceptually, macroergonomics is a top-down sociotechnical systems approach to work system design, and the design of related human-job, human-machine, human-software, and human environment interfaces. Although top-down conceptually, in practice, macroergonomics involves analysis of the work system at all organizational levels. It usually involves extensive participation of persons from all units and levels of the work system.

**Dimensions of Organizational Design**

In order to gain an understanding of macroergonomics, one must first have a grasp of the key dimensions of organizational design and of the empirically derived sociotechnical systems model.

An organization may be defined as "the planned coordination of two or more people who, functioning on a relatively continuous basis and through division of labor and a hierarchy of authority, seek to achieve a common goal or set of goals" (Robbins, 1983, p.5). This concept of organization, with its division of labor and hierarchy of authority, implies structure. The structure of an organization can be conceptualized as having three major components: *Complexity*, *formalization*, and *centralization* (Robbins, 1983).

<u>Complexity</u> refers to the degree of *differentiation* and *integration* that exist within an organization. Three major kinds of differentiation are found in an organization's structure: (a) vertical differentiation, (b) horizontal differentiation, and (c) spatial dispersion.

(a) <u>Vertical differentiation</u> is operationally defined as the number of hierarchical levels separating the chief executive's position from the jobs directly involved with the systems output.

(b) <u>Horizontal</u> <u>differentiation</u> refers to the degree of departmentalization and job specialization that is designed into the organization. Although it has the inherent disadvantage of increasing organizational complexity, the division of labor afforded by job specialization also has inherent efficiencies. Adam Smith (1970) demonstrated this over 100 years ago by noting that ten men, each doing a particular function (job specialization) could produce about 48,000 pins per day. Conversely, if each man worked separately, performing all of the production tasks, they would be lucky to make 200. Division of labor creates groups of specialists. The optimal degree of specialization to ergonomically design into the system depends upon various sociotechnical system factors, which are discussed later.

(c) <u>Spatial</u> <u>dispersion</u> may be defined operationally as the degree to which an organization's facilities and personnel are dispersed geographically from the main headquarters. The three major measures of dispersion are (1) the number of geographical locations within the organization, (2) the average distance to the separated units from the organization's headquarters, and (3) the number of employees in the separated locations in relation to the number at the headquarters location (Hall and Haas, 1967).

Increasing any one of the three differentiation dimensions, described above, increases an organization's complexity.

<u>Integration</u> refers to the extent to which structural mechanisms for facilitating communication, coordination and control across the differentiated elements of the system have been designed into its structure. Some of the more common integrating mechanisms that can be designed into a work system are formal rules and procedures, liaison positions, committees, system integration offices,

and information and decision support systems. Vertical differentiation, in itself, also serves as a key integrating mechanism. In general, as the complexity of a work system increases, the need for integrating mechanisms also increases. Incorporating the appropriate kinds and numbers of integrating mechanisms into the work system is a critical macroergonomic design task.

Formalization. From an ergonomics standpoint, formalization may be defined as the degree to which jobs within organizations are standardized. In highly formalized work systems, jobs are designed so as to allow for little employee discression over what is being done, when or in what sequence tasks will be accomplished, and how they shall be performed. The work system includes explicit job descriptions, extensive rules, and clearly defined procedures covering work processes (Robbins, 1983). Often, the design of the system's hardware, software and related human-machine and user interfaces, in themselves, restrict employee discression. Organizations having low formalization allow employees more freedom to exercise discression; jobs, and related human-machine and human-software interfaces are ergonomically designed to permit considerable autonomy and self-management. Employee behavior thus is relatively unprogrammed and workers are able to make greater use of their mental capacities. The simpler and/or more repetitive the jobs to be designed into the system, the greater is the utility of formalization; the higher the level of professionalism designed into jobs, the lower should be the level of formalization.

Centralization refers to the degree that formal decision-making is concentrated in an individual, unit or level (usually high in the organization) thus permitting employees (usually low in the organization) only minimal input into decisions affecting their jobs (Robbins, 1983). In general, centralization is desirable (a) when a comprehensive perspective is required, such as in *strategic* decision-making, (b) when operating in a highly stable and predictive environment, (c) for financial, legal and other decisions where they clearly can be done more efficiently when centralized, and (d) when significant economies clearly can be realized. Decentralization should be utilized (a) when operating in a highly unstable or unpredictable environment, (b) when the design of a given manager's job will result in exceeding human information processing and decision-making capacity, (c) when more detailed "grass roots" inputs to decisions are wanted, (d) for providing greater intrinsic job motivation to employees, (e) for gaining greater employee commitment to the organization and support of organizational decisions by involving employees in the process, and (f) for providing greater training opportunities for lower-level managers. (Hendrick, 1997)

**The Sociotechnical Systems Model**

To more adequately convey the nature of complex human-machine-environment systems, Emory and Trist (1960) coined the term "sociotechnical system". The sociotechnical system concept views organizations as open systems engaged in transforming inputs into desired outputs. Organizations are viewed as open because they have permeable boundaries exposed to the environments in which they exist and upon which they depend for their survival. Organizations bring two major components to bear on the transformation process: Technology in the form of a *technical subsystem*, and people in the form of a *personnel subsystem.* These two subsystems interact with one another at every human-machine and human-software interface. They thus are interdependent and operate under *joint causation*, meaning that both subsystems are affected by causal events in the environment. Joint causation gives rise to an important related sociotechnical system concept of *joint optimization.* Joint optimization means that since both the technical and personnel subsystems respond jointly to causal events, optimizing one subsystem and then fitting the other to it will result in sub-optimization of the joint work *system*. Joint optimization thus requires *joint design* of the two subsystems

**SOCIOTECHNICAL SYSTEM CONSIDERATIONS IN WORK SYSTEM DESIGN**

As inferred from the above, the design of a work system's structure (which includes how it is to be managed) involves consideration of the key elements of three major sociotechnical system components: (a) the technological subsystem, (b) the personnel subsystem, and (c) the relevant external environments. Each of these three major sociotechnical system components has been studied in relation to its effect on the fourth component, organizational structure, and empirical models have emerged that can be used to optimize a system's organizational design. The models of each of these components that I have found most useful are as follows.

**Technology: Perrow's Knowledge-Based Model**

Perhaps the most thoroughly validated and generalizable model of the technology-organization design relationship is that of Perrow (1967) which utilizes a *knowledge-based* definition of technology. In his classification scheme, Perrow begins by defining technology by the action a person performs upon an object in order to change that object. Perrow notes that this action always requires some form of technological knowledge. Accordingly, technology can be categorized by the required knowledge base. Using this approach, he has identified two underlying dimensions of knowledge-based technology. The first of these is *task variability* or the number of exceptions encountered in one's work. For a given technology, these can range from routine tasks with few exceptions to highly variable tasks with many exceptions.

The second dimension has to do with the type of search procedures one has available for responding to task exceptions, or *task analyzability*. For a given technology, the search procedures can range from tasks being well defined and solvable by using logical and analytical reasoning to being ill-defined with no readily available formal search procedures for dealing with task exceptions. In this latter case, problem-solving must rely on experience, judgement and intuition. The combination of these two dimensions, when dichotomized, yields a 2 X 2 matrix as shown in Table 1. Each of the four cells represents a different knowledge-based technology.

Table 1. Perrow's knowledge-based technology classes.

| | Task Variability | |
|---|---|---|
| | Routine with few exceptions | High variety with many exceptions |
| Well defined and | Routine | Engineering |

| | | | |
|---|---|---|---|
| Problem Analyz-ability | analyzable | | |
| | Ill defined and unanalyzable | Craft | Nonroutine |

(a) Routine technologies have few exceptions and well-defined problems. Mass production units most frequently fall into this category. Routine technologies are best accomplished through standardized procedures, and are associated with high formalization and centralization.

(b) Non-Routine technologies have many exceptions and difficult to analyze problems. Aerospace operations often fall into this category. Most critical to these technologies is flexibility. They thus lend themselves to decentralization and low formalization.

(c) Engineering technologies have many exceptions, but they can be handled using well-defined rational-logical processes. They therefore lend themselves to centralization, but require the flexibility that is achievable through low formalization.

(d) Craft technologies typically involve relatively routine tasks, but problems rely heavily on experience, judgement and intuition for decision. Problem-solving thus needs to be done by those with the particular expertise. Consequently, decentralization and low formalization are required for effective functioning.

**Personnel Subsystem**

At least two major aspects of the personnel subsystem are important to organizational design. These are the degree of professionalism and the psycho-social characteristics of the work force. Degree of professionalism refers to the education and training requirements of a given job and, presumably, possessed by the incumbent. Robbins (1983) notes that formalization can take place either on the job or off. When done on the job, formalization is *external* to the employee; rules, procedures, and the human-machine and human-software interfaces are designed to limit employee discression. Accordingly, this tends to characterize unskilled and semi-skilled positions. When done off the job, it is done through the professionalization of the employee. Professionalism creates formalization that is *internal* to the worker through a socialization process that is an integral part of formal professional education and training. Thus, values, norms and expected behavior patterns are learned *before* the employee enters the organization.

From a macroergonomics design perspective, there is a trade-off between formalizing the organizational structure and professionalizing the jobs and related human-machine and human-software interfaces. As positions in the organization are designed to require persons with considerable education and training, they also should be designed to allow for considerable employee discression. If low education and training requirements characterize the design of the positions, than the work system should be more highly formalized.

Psychosocial characteristics. In addition to careful consideration of cultural differences (e.g., norms, values, mores, role expectations, etc.), I have found the most useful integrating model of psychosocial influences on organizational design to be that of *cognitive complexity*. Harvey, Hunt, and Shroder (1961) have identified the higher-order structural personality dimension of concreteness-abstractness of thinking, or cognitive complexity, as underlying different conceptual systems for perceiving reality. We all start out in life relatively concrete in our conceptual functioning. As we gain experience we become more abstract or complex in our conceptualizing, and this changes our perceptions and interpretations of our world. In general, the degree to which a given culture or subculture (a) provides through education, communications and transportation systems an opportunity for *exposure* to diversity, and (b) encourages through its child-rearing and educational practices and *active* exposure to this diversity (i.e., an active openness to learning from exposure to new experiences), the more cognitively complex the persons of that particular group will become. An active exposure to diversity increases the number of conceptual categories that one develops for storing experiential information, and number of "shades of gray" or partitions within conceptual categories. In short, one develops greater *differentiation* in ones conceptualizing. With an active exposure to diversity one also develops new rules and combinations of rules for *integrating* conceptual data and deriving more insightful conceptions of complex problems and solutions. Note from our earlier review, that these same two dimensions of "differentiation" and "integration" also characterize *organizational* complexity.

Relatively concrete adult functioning consistently has been found to be characterized by a relatively high need for structure and order and for stability and consistency in ones environment, closedness of beliefs, absolutism, paternalism, and ethnocentrism. Concrete functioning persons tend to see their views, values, norms and institutional structures as relatively unambiguous, static and unchanging. In contrast, cognitively complex persons tend to have a relatively low need for structure and order or stability and consistency, and are open in their beliefs, relativistic in their thinking, and have a high capacity for empathy. They tend to be more people-oriented, flexible, and less authoritarian then their more concrete colleagues, and to have a dynamic conception of their World: They *expect* their views, values, norms and institutional structures to change. (Harvey et al., 1961; Harvey, 1963)

In light of the above, it is not surprising that I have found evidence to suggest that relatively concrete managers and workers function best under moderately high centralization, vertical differentiation and formalization. In contrast, cognitively complex workgroups and managers seem to function best under relatively low centralization, vertical differentiation and formalization.

Although only weakly related to general intelligence, cognitive complexity is related to education. Thus, within a given culture, educational level can sometimes serve as a relative estimate of cognitive complexity.

Of particular importance is the fact that since the post World War II "baby boomers" have entered the work force, the general complexity level of educated or highly trained employees has become moderately *high.* This can be traced to the greater exposure of diversity, and less authoritarian and absolutist child rearing practices these adults experienced while growing up, as compared with those who experienced childhood prior to World War II (Harvey, et. al, 1961;

Harvey, 1963). As a result, successful firms are likely to be those having work system designs that respond to the guidelines given herein for more cognitively complex work forces.

**Environment**

Critical to the success, and indeed, the very survival of an organization is its ability to adapt to its external environment. In open systems terms, organizations require monitoring and feedback mechanisms to follow and sense changes in their specific task environment, and the capacity to make responsive adjustments. "Specific task environment" refers to that part of the organizations external environment that is made up of the firm's critical constituencies (i.e., those that can positively or negatively influence the organization's effectiveness). Neghandi (1977), based on field studies of 92 industrial organizations in five different countries, has identified five external environments that significantly impact on organizational functioning. These are *socioeconomic* including the nature of competition and the availability of raw materials; *educational* including both the availability of educational programs and facilities and the aspirations of workers; *political* including governmental attitudes towards business, labor, and control over prices; *legal*; and *cultural* including the social class or caste system, values, and attitudes.

Of particular importance to us is the fact that specific task environments vary along two dimensions that strongly influence the effectiveness of a work system's design: These are the degrees of *environmental change* and *complexity*. The degree of change refers to the extent to which a specific task environment is dynamic or remains stable over time; the degree of complexity refers to whether the number of relevant specific task environments is few or many in number. As illustrated in Table 2, these two environmental dimensions, in combination, determine the *environmental uncertainty* of an organization.

Table 2. Environmental uncertainty of organizations.

| | | Degree of Change | |
|---|---|---|---|
| | | Stable | Dynamic |
| Degree of Complexity | Simple | Low Uncertainty | Mod. High Uncert. |
| | Complex | Mod. Low Uncert. | High Uncertainty |

Of all the sociotechnical system factors that impact on the effectiveness of a work system's design, environmental uncertainty repeatedly has been shown to be the most important (Burns and Stalker, 1961; Duncan, 1972; Emory and Trist, 1965; Lawrence and Lorsch, 1969; Neghandi, 1977). With a high degree of uncertainty, a premium is placed on an organization's ability to be flexible and rapidly responsive to change. Thus, the greater the environmental uncertainty, the more important it is for the work system's structure to have relatively low vertical differentiation, decentralized tactical decision-making, low formalization, and a high level of professionalism among its work groups. By contrast, highly certain environments are ideal for high vertical differentiation, formalization, and centralized decision-making, such as found in classical bureaucratic structures. Of particular note is the fact that, today, most high technology corporations are operating in highly dynamic and complex environments. From my observations, although many of these corporations have increased the level of professionalism of their employees, they have not yet fully adapted their work system's design to their environments.

## RELATION OF MACRO- TO MICRO-ERGONOMIC DESIGN

Through a macroergonomic approach to determining the optimal design of a work system's structure and related processes, many of the characteristics of the jobs to be designed into the system, and of the related human-machine and human-software interfaces, already have been prescribed. Some examples are as follows (Hendrick, 1991).

(a) Horizontal differentiation decisions prescribe how narrowly or broadly jobs must be designed and, often, how they should be departmentalized.

(b) Decisions concerning the level of formalization and centralization will dictate (1) the degree of routinization and employee discression to be ergonomically designed into the jobs and attendant human-machine and human-software interfaces, (2) the level of professionalism to be designed into each job, and (3) many of the design requirements for the information, communications and decision support systems, including what kinds of information are required by whom, and networking requirements.

(c) Vertical differentiation decisions, coupled with those concerning horizontal differentiation, spatial dispersion, centralization and formalization will prescribe many of the design characteristics of the managerial positions, including span of control, decision authority and nature of decisions to be made, information and decision support requirements, and qualitative and quantitative educational and experience requirements.

In summary, effective macroergonomic design drives much of the micro-ergonomic design of the system, and thus insures *optimal ergonomic compatibility* of the components with the work system's overall structure. In sociotechnical system terms, this approach enables joint optimization of the technical and personnel subsystems from top to bottom throughout the organization. The result is greater assurance of optimal *system* functioning and effectiveness, including productivity, safety, comfort, intrinsic employee motivation and quality of work life.

## SYNERGYSM AND ORGANIZATIONAL PERFORMANCEE

From the above, it should be apparent that macroergonomics has the potential to improve the ergonomic design of organizations by ensuring that their respective work system's designs harmonize with the organizations' critical sociotechnical characteristics. Equally important, macroergonomics offers the means to ensure that the design of the entire work system, down to each individual job and workstation, harmonizes with the design of the over-all work system. A widely accepted view among system theorists and researchers is that organizations are synergistic -- that the whole is more, or less, than the simple sum of its parts. Because of this synergism, it is my experience that the following tend to occur in our complex organizations.

### When Systems Have Incompatible Organizational Designs

When a work system's structures and related processes are grossly incompatible with their sociotechnical system characteristics, and/or jobs and human-system interfaces are incompatible with the work system's structure, the whole is *less than* the sum of its parts. Under these conditions, we can expect the following to be poor: (a) productivity, especially *quality* of production, (b) lost time accidents and injuries, and (c) motivation and related aspects of quality of work life (e.g., stress).

### When Systems Have Effective Macroergonomic Designs

When a work system has been effectively designed from a macroergonomics perspective, and that effort is carried through to the micro-ergonomic design of jobs and human-machine, human-environment, and human-software interfaces, then production, safety and health, and quality of work life will be much *greater* than the simple sum of the parts would indicate.

### Implications for the Potential of AMT Organizations

Assuming the above two propositions are indeed true, then macroergonomic approaches to productivity, safety and health, and QWL have the potential to improve system functioning exponentially rather than linearly. For example, quality measures, lost time accidents and injuries, scrap rates, and employee job satisfaction indices should not show the typical 10% to 20% improvement often seen as the result of typical *successful* micro-ergonomic efforts. Instead, improvements of 60% to 90% more typically should occur (and, in some cases, much greater) and be sustainable. The following section briefly summarizes seven macroergonomic interventions across a variety of work systems that provide validation for this assertion.

## CASE STUDIES INVOLVING MACROERGONOMIC INTERVENTIONS

Except for the university design case, the following are adopted from Hendrick (1997). As can be noted, several of these studies began as micro-ergonomics interventions. When those interventions proved successful, the companies involved expanded their efforts to the macroergonomic level, resulting in significant changes to the total work system. Four of the cited cases actually began as macroergonomic analysis and design efforts. These cases all demonstrate that the kinds of improvements in organizational performance and cost benefits theoretically predicted can, and do, happen.

### C-141 Aircraft

My earliest experience with taking a macroergonomic approach to design occurred well before the concept was articulated or the term "macroergonomics" was coined. Some 40 years ago, I joined the US Air Force's C-141 aircraft development System Program Office as the project engineer for human factors and alternate mission configurations. The C-141 was to be designed so that its cargo compartment, through the installation of alternate mission kits, could be reconfigured for cargo aerial delivery, carrying paratroopers and paratroop jumping, carrying passengers, or for medical evacuation. As initially configured, anything that did not absolutely have to be included in the aircraft for straight cargo carrying was placed in one of the alternate mission kits, making them heavy, complex, and requiring considerable time and effort to install. By meeting with the intended using organization, the Air Force Material Air Command, and discussing their work system design and management plan for actual utilization of the aircraft, I was able to identify numerous kit components that rarely ever would be removed from the airplane. Using these data, I worked with the Lockheed design engineers to reconfigure the kits to remove these components and, instead, install them permanently in the aircraft.

As documented by the engineering change proposals, this effort greatly simplified the system and reduced actual operational aircraft weight - and thus, related operating and maintenance costs for over 200 aircraft over the past 30 years. The changes also reduced installation time and labor, and storage requirements for the kits. In addition, it saved over $2.5 million dollars in the initial cost of the aircraft fleet. I believe this is a good illustration of how macroergonomic considerations can result in highly cost effective micro-ergonomic design improvements to systems.

### Dodger Stadium Food Service Stands

Using a participatory ergonomics approach with food service personnel, my USC colleague, Andy Imada and George Stawowy, a visiting ergonomics doctoral student from the University of Aachen in Germany, redesigned two food service stands and the related work system at Dodger Stadium in Los Angeles (Imada and Stawowy, 1996). The total cost was $40,000. Extensive before and after measures demonstrated a reduction in average customer transaction time of approximately 8 seconds. In terms of dollars, the increase in productivity for the two stands was approximately $1,200 per baseball game, resulting in a payback period of 33 games, or 40% of a single baseball season. Modifying the other 50 stands in Dodger Stadium can now be done at a price of $12,000 per stand, resulting in a payback period of only 20 games. Potentially, the resulting productivity increases can be used to reduce customer waiting time, thereby also increasing customer satisfaction.

This modification effort is but one part of a macroergonomics intervention project to improve productivity. Imada anticipates that on-going work to improve the total system process, including packaging, storage and delivery of food products and supplies, and managerial processes, eventually will result in a much greater increase in productivity and cost benefit. (Imada, personal communication)

**Designing a University College.**

In the middle 1980's, as the Dean of a new college at the University of Denver (DU), I had the opportunity to head a macroergonomics project to develop this new school. This project involved transferring a graduate program in Systems Management from the University of Southern California to DU to serve as the core program for the new college. The program was being taught in university study centers (mini-campuses) at over 30 locations in the U.S. and Germany. We used a macroergonomic analysis of the entire system, together with assistance from a special educational technology analysis group from IBM to determine the structure and process of the entire work system. This analysis enabled us to streamline our organizational structure, improve processes, and make more efficient use of available technology, including computers and software programs. The result was better-designed jobs, a 23% reduction in staffing requirements, and a 25% savings in operating expenses. It also reduced the administrative time of our study center managers by 20%, thus giving them more time to devote to students and potential students. Over the next several years we experienced a progressive rise in our student registrations and significantly increased our number of study centers.

**Reducing WMSDs at AT&T Global**

AT&T Global Information Solutions in San Diego employees 800 people and manufactures large mainframe computers. Following an analysis of their OSHA 200 logs, the company conducted extensive work site analyses to identify ergonomic deficiencies. As a result, the company made extensive micro-ergonomic workstation improvements and provided proper lifting training for all employees. In the first year following the changes, worker's compensation losses dropped more than 75%, from $400,000 to $94,000

A second round of changes took a more macroergonomics approach, resulting in significant changes to the work system. Conveyor systems were replaced with small, individual scissors-lift platforms, and heavy pneumatic drivers with lighter electric ones; this was followed by moving from an assembly line process to one where each worker builds an entire cabinet, with the ability to readily shift from standing to sitting. A further reduction in worker's compensation losses to $12,000 resulted. In terms of lost workdays due to injury, in 1990 there were 298; in both 1993 and 1994 there were none. In total, these ergonomic changes have reduced worker's compensation costs at AT&T Global over the 1990-1994 period by $1.48 million. The added costs for these ergonomic improvements represent only a small fraction of these savings. (Center for Workplace health Information, 1995a).

**Red Wing Shoes**

Beginning in 1985 with (a) the initiation of a safety awareness program which includes basic machine setup and operation, safety principles and body mechanics, and monthly safety meetings, (b) a stretching, exercise and conditioning program, (c) the hiring of an ergonomics advisor, and (d) specialized training on ergonomics and workstation setup for machine maintenance workers and industrial engineers, the Red Wing Shoe Company of Red Wing, Minnesota made a commitment to reducing work-related musculoskeletal disorders via ergonomics. The company purchased adjustable ergonomic chairs for all seated positions and anti fatigue mats for all standing jobs. In addition, selected machines and workstations were ergonomically redesigned for flexibility and elimination of awkward postures and greater ease of operation. Next, macroergonomic measures were taken, including instituting Continuous Flow Manufacturing - which included operators working in groups, cross training, and job rotation - and work processes were ergonomically redesigned.

As a result of these various micro- and macroergonomic interventions, workers compensation insurance premiums dropped by 70% from 1989 to 1995, for a savings of $3.1 million. During this same period, the number of OSHA reportable lost time injury days dropped from a ratio of 75 for 100 employees working a year, to 19. The success of this program is attributed to upper management's support, employee education and training, and having everyone responsible for coordinating ergonomics. I also would note the total systems or macroergonomics perspective of this effort. (Center for Workplace Health Information, 1995b).

**Petroleum Distribution Company**

A few years ago, My USC Colleague, Andy Imada, began a macroergonomic analysis and intervention program to improve safety and health in a company that manufactures and distributes petroleum products. The key components of this intervention included an organizational assessment that generated a strategic plan for improving safety, equipment changes to improve working conditions and enhance safety, and three macroergonomic classes of action items. These items included improving employee involvement, communication, and integrating safety into the broader organizational culture. The program utilized a participatory ergonomics approach involving all levels of the division's management and supervision, terminal and filling station personnel, and the truck drivers. Over the course of several years, many aspects of the system's organizational design and management structure and processes were examined from a macroergonomics perspective and, in some cases, modified. Employee initiated ergonomic modifications were made to some of the equipment, new employee-designed safety training methods and structures were implemented, and employees were given a greater role in selecting new tools and equipment related to their jobs.

Two years after initial installation of the program, motor vehicle accidents had been reduced by 51%, industrial injuries by 54%, off-the-job injuries by 84%, and lost work days by 94%. By four years later, further reductions occurred for all but off-the-job injuries, which climbed back by 15%. (Nagamachi & Imada, 1992). The company's Area Manager of Operations reports that, as a direct result of the macroergonomics program, he continues to save $60,000 per year in petroleum delivery costs (Imada, personal communication).

**A Macroergonomic Approach for Implementing TQM at L. L. Bean**

Rooney, Morency, and Herrick (1993) have reported on the use of macroergonomics as an approach and methodology for introducing total quality management (TQM) at the L. L. Bean corporation. Using methods similar to those described above for Imada's intervention, but with TQM as the primary objective, over a 70% reduction in lost time accidents and injuries was achieved within a two year period in both the production and distribution divisions of the company. Approximately 80% of the injury reductions were in soft tissue injuries (Rooney, personal communication, 1995). Other benefits, such as greater employee satisfaction and improvements in additional quality measures also were achieved. Given the present emphasis in many organizations on implementing ISO 9000, these results take on an even greater significance

**REFERENCES**


Burns, T. and Stalker, G. M. (1961). The Management of Innovation. London: Tavistock.

DeGreene, K. (1973). Sociotechnical Systems. Englewood Cliffs, NJ: Prentice-Hall.

Duncan, R. B. (1972). Characteristics of organizational enviroments and perceived environmental uncertianty. Administrative Science Quarterly, 17, 313-327.

Emery, F. E. and Trist, E. L. (1960). Sociotechnical systems. In C. W. Churchman and M. Verhulst (Eds.), Management Science: Models and Techniques, Vol 2. Oxford: Pergamon.

Harvey, O. J., Hunt, D. E. and Schroder, H. M. (1961). Conceptu al Systems and Personality Organization. New York: Wiley.

Harvey, O. J. (1963). System structure, flexibility and creativity. In O. J. Harvey (Ed.), Experience, Structure, and Adaptability. New York: Springer.

Hendrick, H. W. (1980). Human factors in management, invited paper, presented during the symposium on Professional Planning,1980-2000 at the 24th Annual Meeting of the Human Factors Soci ety, Los Angeles, CA, October.

Hendrick, H. W. (1984). Wagging the tail with the dog: Organizational design considerations in ergonomics, Proceedings of the Human Factors Society 28th Annual Meeting. Santa Monica, CA: Human Factors Society, 899-903.

Hendrick, H. W. (1991). Human factors in organizational design and management. Ergonomics, 34, 743-756.

Hendrick, H. W. (1997a). Good Ergonomics is Good Economics. Santa Monica, CA: Human Factors and Ergonomics Society, 16 pages.

Hendrick, H. W. (1997b). Organizational design and macroergonomics. In G. Salvendy (Ed), Handbook of Human Factors and Ergonomics, 2nd Edition. New York: Wiley, 594-636.

Nagamachi, M., and Imada, A. S. (1992). A Macroergonomic approach for improving safety and work design. In Proceedings of the Human Factors Society 36th Annual Meeting. Santa Monica, CA: Human Factors Society, 859-861.

Negandhi, A. R. (1977). A model for analysing organization in cross cultural settings: A conceptual scheme and some research findings. In A. R. Negandhi, G. W. England, and B. Wilbert (Eds.), Modern Organization Theory. Kent State, OH: Kent State University Press.

Rooney, E. F., Morency, R. R., and Herrick, D. R. (1993). Macroergonomics and total quality management at L. L. Bean: A case study. In R. Neilsen and K Jorgensen (Eds.), Advances in Industrial Ergonomics and Safety V. London: Taylor & Francis, 493-498.

Parrow, C. (1967). A framework for the comparative analysis of organizations, American

Sociological Review, 32, 194-208.
Robbins, S. R. (1983). Organization Theory: The Structure and Design of Organizations. Englewood Cliffs, NJ: Prentice-Hall.
Smith, A. (1970). The Wealth of Nations. London: Penguin (Originally published in 1876).
Trist, E. L., and Bamforth, K. W. (1951). Some social and psychological consequences of the longwall method of coal-getting. Human Relations, 4, 3-38.
Trist, E. L., Higgin, G. W., Murray, H., and Pollock, A. B. (1963). Organizational Choice. London: Tavistock.
Yenkelovich, D. (1979). Work, Values and the New Breed. New York: Van Norstrand Reinhold.