THE ERGONOMICS OF ECONOMICS IS THE ECONOMICS OF ERGONOMICS

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INTRODUCTION

One of the clearest ways to delineate a discipline is by its unique technology. At its recent workshop, the HFES Strategic Planning Committee noted, as have others internationally, that the technology of human factors/ergonomics is *human-system interface technology*. Thus, the discipline of human factors can be defined as the *development and application of human-system interface technology*. Human-system interface technology deals with the interfaces between humans and the other system components, including hardware, software, environments, jobs, and organizational structures and processes. Like the technology of other design-related disciplines, it includes specifications, guidelines, methods, and tools. As noted by the Strategic Planning Committee, we use our discipline's technology for improving the *quality of life*, including health, safety, comfort, usability, and productivity. As a *science* we study human capabilities, limitations, and other characteristics for the purpose of developing human-system interface technology. As a *practice*, we apply human-system interface technology to the analysis, design, evaluation, standardization, and control of systems. It is this technology that clearly defines us as a unique, stand-alone discipline; that identifies who we are, what we do, and what we offer for the betterment of society.

Although they may come from a variety of professional backgrounds, such as psychology, engineering, safety, the rehabilitation professions, or medicine, it is their professional education and training in human-system interface technology that qualifies persons as human factors/ergonomics professionals. Indeed, the discipline needs both the breadth and richness of these professional backgrounds as well as the education and training in the unique technology of human factors/ergonomics. Human factors/ergonomics professionals have long recognized the tremendous potential of our discipline for improving the health, safety, and comfort of persons, and both human and system productivity. Indeed, through the application of our unique human-system interface technology, we have the *potential* to truly make a difference in the quality of life for virtually all persons on this globe. In fact, I know of no profession where so small a group of professionals has such a tremendous potential for truly *making a difference.*

In light of our potential, why is it, then, that more organizations, with their strong need to obtain employee commitment, reduce expenses, and increase productivity, are not banging down our doors for help, or creating human factors/ergonomics positions far beyond our capacity to fill them? Why is it that federal and state agencies are not pushing for legislation to ensure that human factors/ergonomics factors are systematically considered in the design of products for human use and work environments for employees? Why is it that both industry associations and members of Congress sometimes view us as simply adding an additional expense burden and, thus, *increasing* the costs of production, and thereby *decreasing* competitiveness? In response to these questions, from my experience, at least four contributing reasons immediately come to mind.

First, some of these individuals and organizations have been exposed to *bad ergonomics* – or what, in a recent article on this topic, Ian Chong (1996) labels as "voodoo ergonomics" – either in the form of products or work environments which are *professed* to be ergonomically designed, but are not, or in which the so-called ergonomics was done by incompetent persons. This, indeed, is a concern – particularly when persons lacking professional training pass themselves off as ergonomists or human factors professionals; or tout their services as a panacea for almost anything. It is one of the major reasons that both establishing educational standards for professional education in human factors/ergonomics *and* professional certification have become top priority issues for the International Ergonomics Association and, indeed, for many national human factors/ergonomics societies and governmental groups – such as the European Union.

Another reason, well known to us, is that "everyone is an operator" (Mallett, 1995). Everyone "operates" systems on a daily basis, such an automobile, computer, television, and telephone; and thus, it is very easy to naively assume from our operator experience that Human Factors is nothing more than "common sense". Most experienced ergonomists have their own personal list of "commonsense" engineering design decisions that have resulted in serious accidents, fatalities, or just plain poor usability. Buy me a beer and I will be glad to tell you some of my personal ergonomics "war stories." I also would refer you to Steve Casey's book, *Set Phasers on Stun*.

Third, I believe we sometimes expect organizational decision-makers to proactively support human factors/ergonomics simply because it is *the right thing to do*. Like God, mother, and apple pie, it is hard to argue against doing anything that may better the human condition, and so, that alone should be a compelling argument for actively supporting use of our discipline. In reality, managers have to be able to justify *any* investment in terms of its concrete benefits to the organization – to the organization's ability to be competitive and survive. That something "is the right thing to do" is, by itself, an excellent but decidedly *insufficient* reason for managers actually doing it.

Finally, and perhaps most importantly, as a group, we have done a poor job of documenting and advertising the cost-benefits of good ergonomics – of getting the word out that most often, *good ergonomics is good economics.* In fact, that the ergonomics of economics *is* the economics of ergonomics.

As one attempt to rectify this situation, I want to share with you a broad spectrum of ergonomics applications that my predecessor as HFES President, Tom Eggemeier, and I have collected from within the U.S. and elsewhere, where the costs and economic benefits were documented.

ERGONOMICS APPLICATIONS

Forestry Industry

My first set of examples deal with forestry. A coordinated series of joint projects were undertaken by the Forest Engineering Technology Department of the University of Stellenbosch and Ergotech – the only true ergonomics consulting firm in South Africa – to improve safety and productivity in the South African forestry industry.

Leg protectors. In one project, an anthropometric survey was conducted of the very heterogeneous workforce to provide the basic data for redesigning leg protectors for foresters. The South African forestry industry is populated with a wide variety of ethnic groups, having widely varying anthropometric measurements. The original protector, obtained from Brazil, was modified to ergonomically improve the types of fastening and anthropometric dimensions, as well as to incorporate improved materials. Included in the ergonomic design modification process was an extensive series of usability tests over a 6-month period. Then, in a well-designed field test, this ergonomically modified leg protector was introduced in a eucalyptus plantation for use by persons responsible for ax/hatchet de-branching. Among the 300 laborers, an average of ten injuries per day was occurring with an average sick leave of 5 days per injury. During the 1-year period of the test, not one single ax/hatchet leg injury occurred, resulting not only in the considerable savings in human pain and suffering, but also in a direct net cost savings to the company of $250,000. Use of the leg protectors throughout the South African hardwood forestry industry is conservatively calculated to save $4 million annually (Warkotsch, 1994).

Tractor trailer redesign. A second study involved ergonomically improving the seating and visibility of 23 tractor-trailer forwarding units of a logging company with an investment of $300 per unit. This resulted in a better operating position for loading, improved vision, and improved operator comfort. As a result, downtimes caused by accident damage to hydraulic hoses, fittings, etc. went down by $2,000 per year per unit; and daily hardwood extraction was increased by one load per day per vehicle. All told, for a total investment of $6,900, a hard cost savings of $65,000 per year was achieved – a 1 to 9.4 cost-benefit ratio (Warkotsch, 1994).

Other innovations. Other innovations by this same collaborative effort between Stellenbosch University, Ergotec, and various forestry companies have included (a) developing a unique lightweight, environmentally friendly pipe type of timber chute for more efficiently and safely transporting logs down slopes, (b) redesigning three-wheeled hydrostatic loaders to reduce both excessive whole-body vibration and noise, (c) classifying different terrain conditions – including ground slope, roughness, and other conditions – and determining the most effective tree harvesting system (method and equipment) for each, and (d) developing ergonomic checklists and work environment surveys tailored to the forest industry. All of these are expected to result in significant cost savings, as well as greater employee satisfaction and improved quality of work life (Warkotsch, 1994).

I believe this is a good example of what ergonomics potentially can contribute to *any* given industry when there is a true collaborative effort and commitment.

C-141 Transport Aircraft

Some 35 years ago, I joined the US Air Force's C-141 aircraft development system program office as the project engineer for both human factors and the alternate mission provisions. 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 Transport Command, and discussing their organizational 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 35 years. The changes also reduced installation time and labor, and storage requirements for the kits. In addition, it saved over $2 million 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 microergonomic design improvements to systems.

These, and numerous other cost-benefit human factors evaluations and improvements to the C-141's design, came at a total cost of less than $500,000 of professional human factors effort, and resulted in over $5 million in cost savings – better than a 1 to 10 cost-benefit ratio. I believe the aircraft's truly exceptional safety record, and related untold savings in lost aircraft avoided, can, at least in part, be attributed to having had a sound human factors engineering development effort.

MATERIALS HANDLING SYSTEMS

One group that does a somewhat better job of documenting the costs and benefits of its ergonomic interventions than many of us is the faculty of the Department of Human Work Sciences at Lulea University of Technology in Sweden. The following examples are from the Department's Division of Environment Technology's work with steel mills. The basic approach to ergonomic analysis and redesign in these projects was to involve employee representatives with the Lulea faculty. For each project, the economic "payoff" period was calculated jointly with the company's management.

Steel Pipes and Rods Handling and Stock-Keeping System

A semi-automatic materials-handling and stock-keeping system for steel pipes and rods was ergonomically redesigned. The redesign reduced the noise level in the area from 96 db to 78 db, increased production by 10%, dropped rejection from 2.5% to 1%, and paid back the redesign and development costs in approximately 18 months. After that, it was all profit.

Tube Manufacturing, Handling, and Storage System

In a tube manufacturing facility, a tube-handling and storage system had an unacceptably high noise level, high rejection rate from damage, required heavy lifting, had inefficient product organization, and had a poor safety record. Ergonomic redesign eliminated stock damage, improved stock organization, reduced lifting forces to an acceptable level, reduced the noise level by 20 db; and has, to date, resulted in zero accidents, and in a productivity increase with a payback period of only 15 months.

Forge Shop Manipulator

In a forge shop, the old manipulator was replaced with a new one, having an ergonomically designed cabin and overall better workplace design. In comparison with the old manipulator, whole-body vibration was reduced, noise was reduced by 18 db, operator sick leave dropped from 8% to 2%, productivity improved, and maintenance costs dropped by 80%.

PRODUCT DESIGN OR REDESIGN

The economic benefit of ergonomic design or redesign of a product can be assessed in several ways. For example, by its impact on (a) the value of the company's stock, (b) sales, (c) productivity, or (d) reductions in accidents. Four very different kinds of products are provided herein as illustrations of each of these beneficial economic impacts.

Replacement for Forklift Truck Lines

Alan Hedge and his colleagues at the Human Factors Laboratory at Cornell University participated with Pelican Design, a New York industrial design company, and the Raymond Corporation in the design and development of a new generation of forklift trucks to replace Raymond's two existing product lines. Human factors design principles were given prime consideration and an "inside-out" human-centered approach was taken, with the form of the truck being built around the operator's needs. The goal was to maximize operator comfort, minimize accident risks, and maximize productivity by optimizing task cycle times. At the time the development project was begun, Raymond's market share had eroded from its former position of dominance in the market of over 70% of sales to about 30%, and shrinking. Both the new narrow isle[?] and swing-reach truck lines were introduced in the U.S. in 1992, and the swing-reach in Europe in 1993. Order books at Raymond are full and once again the company is enjoying success. Raymond stock has risen from around $6 per share at the start of the project to around $21 today (Alan Hedge, personal communication).

TV and VCR Remote Controls

Thompson Consumer Electronics first developed their highly successful approach to user-centered design when they developed “System Link,” an ergonomically oriented remote control that can operate various types of products made by different manufacturers. The original Thompson remote control design differed little from the competition’s: A rectangular box with rows of small, identical buttons. It is the one in the middle of the picture[?]. Using their user-centered design approach, the initial design was replaced with the new ergonomic one, shown on the left in the picture, which, among other things, was easier to grasp, used color-coded, soft-touch rubber buttons in distinctive sizes and shapes, and [had] . . .the VCR and TV buttons . . . separated above and below the keypad. When introduced in 1988, this new, ergonomically designed “System Link” remote control gained the jump on the competition; and Thompson has since sold literally millions of them. As a result of this success, user-centered ergonomic design has become a key aspect of all new Thompson development projects (March, 1994).

DSS System

A more recent highly successful example is Thompson’s RCA DSS satellite digital television system. All aspects, including the on-screen display and remote control, utilized user-centered design and received extensive ergonomic attention (March, 1994). These units now are selling like “hot cakes.”

CRT Display

The CRT display used by the Directory Assistants at Ameritech (a U.S. regional telephone company) were ergonomically redesigned by Scott Lively, Richard Omanson, and Arnold Lund to meet the goal of reducing average call processing time. Included in the redesign were replacement of an all uppercase display with a mixed-case display and the addition of a highlighting feature for the listing selected by the Directory Assistant. Based on extensive before and after measurements, results showed a 600ms reduction in average call operating time after introduction of the ergonomically redesigned CRT display. Although seemingly small, this reduction represents an annual savings of approximately $2.94 million across the five-state region served by Ameritech (Scott Lively and Arnold Lund, personal communication).

Training System Redesign

In a related effort, done jointly with Northwestern’s Institute for Learning Sciences, the traditional lecture-and-practice training program for new Directory Assistants was replaced by an ergonomically designed computer-based training program which incorporates a simulated work environment and error feedback. As a result, operator training time has been reduced from 5 days to 1.5 days (Scott Lively, personal communication).

Center High-Mounted Automobile Rear Stop Lamp

The Center High-Mounted stop Lamp is perhaps the best known ergonomic improvement to a widely used consumer product. In the 1970s, the National Highway Traffic Safety Administration (NHTSA) sponsored two field research programs which demonstrated the potential of adding a center high-mounted stop lamp or CHML to reduce response times of following drivers and, thus, avoid accidents. In the mid 70s, this ergonomic innovation and three other configurations were installed in 2,100 Washington, D.C., area taxicabs. The CHML configuration resulted in a 50% reduction in both rear-end collisions, and collision severity. Following several additional field studies, Federal Motor Vehicle Safety Standard 108 was modified to require all new passenger cars built after 1985 to have CHMLs. Based on analyses of both actual production costs for the CHMLs and actual accident data for the 1986 and 1987 CHML-equipped cars, NHTSA calculated that, when all cars are CHML equipped (1997), 126,000 reported crashes will be avoided annually at a property damage savings of $910 million per year. Addition of the savings in medical costs would, of course, considerably increase this figure. The total cost of the entire research program was $2 million and for the regulatory program, $3 million (Transportation Research Board, National Research Council, 1989). A $5 million investment for a projected $910 million annual return: Not a bad ergonomics investment by the federal government!

PoultryDeboning Knife

A conventional type butcher's knife was being used for deboning chickens and turkeys at a poultry packaging plant. The knife did a poor job of deboning; and a high incident rate of carpal tunnel syndrome, tendinitis, and tenosynovitis, resulted in a $100,000 per annum increase in workers' compensation premiums. A new, ergonomically designed pistol-shaped knife was introduced by ergonomist Ian Chong, Principal of Ergonomics, Inc., of Seattle, Washington. Less pain and happier cutting crews were reported almost immediately. Over a 5-year period, upper extremity work-related musculoskeletal disorders were greatly reduced, line speeds increased by 2% to 6%, profits increased because of more efficient deboning, and $500,000 was saved in workers' compensation premiums (Ian Chong, personal communication). This is a good example of how a simple, inexpensive ergonomic solution sometimes can have a very high cost-benefit payoff.

WorkStation Redesign

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 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. Modification of these two stands was relatively costly because, as the development prototypes, they consumed considerable time and effort. 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 (Andrew Imada, personal communication).

This modification effort is but one part of a macroergonomics intervention project to improve productivity. Imada anticipates that ongoing 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.

Fine assembly workstations. Typical workstations at a major electronics assembly plant result in poor postures and resultant work-related musculoskeletal disorders. Valerie Venda of the University of Manitoba has designed a new type of fine assembly workstation which utilizes a TV camera and monitor. Not only does the TV camera provide a greatly enlarged image of the assembly work, but enables the worker to maintain a better posture and more dynamic motion.

Based on extensive comparative testing of the old and new workstations, a 15% higher productivity rate is obtained with the new one. Venda reports that the average value of products assembled per worker per shift at these types of workstations varies between $15,000 and $20,000. Thus, the additional value produced by one worker per day using the new workstation will be $2,250 to $3,000 per day. Although it is too early to say precisely, Venda predicts the new workstations eventually will decrease occupational injuries for these jobs by 20% (Valerie Venda, personal communication).

REDUCING WORK-RELATED MUSCULOSKELETAL DISORDERS

Given the importance of this issue, and the rather considerable attention and debate which have resulted from the introduction of proposed workplace ergonomics regulations at both the federal and state (e.g., California) levels, and two Canadian provinces, I have included five examples of documented, highly successful ergonomic intervention programs.

AT&T Global

AT&T Global Information Solutions in San Diego employs 800 people and manufactures large mainframe computers. Following analyses of their OSHA 200[ok?] logs, the company identified three types of frequent injuries: lifting, fastening, and keyboarding. The company next conducted extensive work site analyses to identify ergonomic deficiencies. As a result, the company made extensive ergonomic workstation improvements and provided proper lifting training for all employees. In the first year following the changes, workers' compensation losses dropped more than 75%, from $400,000 to $94,000. In a second round of changes, 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 workers' 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 (Center for Workplace Health Information, 1995a). Alltold, these ergonomic changes have reduced workers' 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.

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, CTD's, 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 WMSD's via ergonomics. The company purchased adjustable ergonomic chairs for all seated operators and antifatigue mats for all standing jobs; instituted Continuous Flow Manufacturing, which included operators working in groups, cross-training, and job rotation; ergonomically redesigned selected machines and workstations for flexibility and elimination of awkward postures, and greater ease of operation; and modified production processes to reduce cumulative trauma strain. As a result of these various ergonomic 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 perspective of this effort (Center for Workplace Health Information, 1995b).

Ergonomics Training and Follow-Up Implementation

In 1992, Bill Brough of Washington Ergonomics conducted a 1-day seminar for cross-disciplinary teams of engineers, human resource management personnel, and safety/ergonomics committee members from seven manufacturing companies insured by Tokyo Marine and Fire Insurance Company, Ltd. The seminar taught the basic principles of ergonomics and provided the materials to implement a participatory ergonomics process. The training focused on techniques for involving the workers in evaluating present workplace conditions and making cost-effective improvements. The class materials provided the tools for establishing a baseline, setting improvement goals, and measuring results. In six of the companies, the seminar data and materials were used by the teams to implement a participatory ergonomics program with the workers; and received both funding from management and support from labor. The seventh company did *not* participate in the implementation of the training. Follow-up support was provided by a senior loss control consultant for Tokyo Marine. For the six companies that *did* participate, reported strain-type injuries dropped progressively from 131 in the 6 months prior to the training to 42 for the 6-month period ending 18 months later. The cost of these injuries for the 6 months prior was $688,344, for the 6-month period ending 18 months later, the injury costs had dropped to $72,600, for a net savings over 18 months of $1,348,748, using the 6 months prior as the baseline. Worker involvement reportedly created enthusiasm and encouraged each individual to assume responsibility for the program's success. According to Bill Brough, the reduction of injuries resulted from a commitment to continuous improvement and was obtained by many small changes, not a major singular event. For the one company that did not participate in implementing the training, the number of reported strain injuries was 12 for the 6 months prior to training, and 10, 16, and 25, respectively, for the next three 6-month periods. In short, things got worse rather than better (Bill Brough, personal communication and supporting documentation).

Coupled with both management's and labor's active support, Tokyo Marine traces these reductions in strain-type injuries for the six participating companies directly back to Bill Brough's participatory ergonomics training program and related materials. A good example of what can happen when you couple collaborative management-labor commitment with professional ergonomics.

Deere and Company

One of the best known successful industrial safety ergonomics programs is that at Deere and Company, the largest manufacturer of agricultural equipment in North America. In 1979 Deere recognized that traditional interventions like employee lift training and conservative medical management were, by themselves, insufficient to reduce injuries. So the company began to use ergonomic principles to redesign and reduce physical stresses of the job. Eventually, ergonomics coordinators were appointed in all of Deere's U.S. and Canadian factories, foundries, and distribution centers. These coordinators, chosen from the industrial engineering and safety departments, were trained in ergonomics. Today, job evaluations and analyses are done in-house by both part-time ergonomics coordinators and wage-employee ergonomics teams and committees. The company has developed its own ergonomics checklists and surveys. The program involves extensive employee participation. Since 1979, Deere has recorded an 83% reduction in incidence of back injuries, and by 1984 had reduced workers' compensation costs by 32%. According to Gary Lovestead, each year, literally hundreds to thousands of ergonomics improvements are implemented; and today, ergonomics is built into Deere's operating culture (Center for Workplace Health Information, 1995c).

Union Pacific Railroad

In the early 1980s, the Palestine Car Shop near Dallas, Texas, had the worst safety statistics of the Union Pacific Railroad's shop operations. Of particular note was the high incidence of back injuries. For example, in 1985, 9 out of 13 lost-time injuries were back injuries; and 579 lost and 194 restricted or limited workdays accumulated. Only 1,564 cars were repaired that year, and absenteeism was 4% (Association of American Railroads, 1989). The University of Michigan Center for Ergonomics computer model for back compression was modified and expanded for easy application to the railroad environment, and packaged by the Association of American Railroads. The AAR-Back Model was introduced at the Palistine Car Shop to identify job tasks that exceeded acceptable back compression values, and equipment supporting various jobs requiring lifting was redesigned. For example a coupler knuckle storage table was designed for storing the 90-lb. knuckles. Previously, they were manually piled on the ground, and then lifted from there. In addition, a commercial back injury training program, "Pro-Back," was adopted and every employee was taught how to bend and lift safely. Finally, management attitude and priorities about safety were conveyed through weekly meetings with safety captains from each work area, and quarterly "town hall" meetings with all shop employees.

From 1985 to 1988, the total incidence of injuries went from 33 to 12; back incidents from 13 to 0; lost days from 579 to 0; restricted days from 194 to 40 (all from minor, non-back injuries), and absenteeism from 4% to 1%. Number of cars repaired per year went from 1,564 in 1985 to 2,900 in 1988, an increase in dollar value of $3.96 million. Union Pacific calculates the cost-benefit ratio as approximately 1 to 10 (American Association of Railroads, 1989).

HUMAN FACTORS TEST AND EVALUATION

One of the regional U.S. telephone companies, NYNEX, developed a new workstation for its toll and assistance operators, whose job is to assist customers in completing their calls and to record the correct billing. The primary motivation behind developing the new workstation was to enable the operators to reduce their average time per customer by providing a more efficient workstation design. The current workstation had been in use for several years and employed a 300-baud, character-oriented display and a keyboard on which functionally related keys were color coded and spatially grouped. This functional grouping often separated common sequences of keys by a large distance on the keyboard. In contrast, the *proposed* workstation was ergonomically designed with sequential as well as functional considerations; it incorporated a graphic, high-resolution 1200-baud display, used icons and, in general, is a good example of a graphical user interface whose designers paid careful attention to human-computer interaction issues.

Under the name *Project Ernestine*, Wayne Gray and Michael Atwood of the NINE Science and Technology Center, and Bonnie John of Carnegie Mellon University (1993) designed and conducted a comparative field test, replacing 12 of the current workstations with 12 of the proposed ones. In addition they conducted a goals, operators, methods and selection rules (GOMS) analysis (Card, Moran, & Newell, 1980) in which both observation-based and specification-based GOMS models of the two workstations were developed and used.

Contrary to expectations, the field test demonstrated that average operator time was 4% *slower* with the proposed workstation than with the currently used one. Further, the GOMS analyses accurately predicted this outcome, thus demonstrating the validity of the GOMS models for efficiently and economically evaluating telephone operator workstations. Had this test and evaluation *not* been conducted, and the proposed, presumably more efficient, workstation been adopted for all 100 operators, the performance decrement cost per year would have been $2.4

million. A good example of the value of doing careful human factors test and evaluation before you buy (Gray et al., 1993).

MACROERGONOMICS

Petroleum Distribution Company

Several years ago, Andy Imada of the University of Southern California 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, industrial injuries had been reduced by 54%, motor vehicle accidents by 51%, off-the-job injuries by 84%, and lost workdays by 94%. By 4 years later, further reductions occurred for all but off-the-job injuries, which climbed back 15% (Nagamachi & Imada, 1992). The company's area manager of operations reports that he continues to save one-half of 1% of the annual petroleum delivery costs every year as a direct result of the macroergonomics intervention program. This amounts to a net savings of approximately $60,000 per year for the past 3 years, or $180,000, and is expected to continue (Andrew Imada, personal communication). Imada reports that perhaps the greatest reason for these *sustained* improvements has been the successful installation of safety as part of the organization's culture. From my firsthand observation of this organization over the past several years, I would have to agree.

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, known internationally for the high quality of their clothing products. 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 2-year period in both the production and distribution divisions of the company. 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.

CONCLUSION

The above are but a sample of the variety of ergonomic interventions which we, as a profession, are capable of doing to not only improve the human condition, but the bottom line as well. From my 35 years of observation and experience, only rarely are truly good ergonomic interventions *not* beneficial in terms of the criteria that are used by managers in evaluating the allocation of their resources.

As many of the above ergonomic interventions also illustrate, ergonomics offers a wonderful common ground for labor and management collaboration; for invariably, both can benefit – managers, in terms of reduced costs and improved productivity; employees, in terms of improved safety, health, comfort, usability of tools and equipment, including software; and improved quality of work life. Of course, both groups benefit from the increased competitiveness and related increased likelihood of long-term organizational survival that ultimately is afforded.

Clearly, to enable our profession to approach its tremendous potential for humankind, we, the professional human factors/ergonomics community, *must* better *document* the costs and benefits of our efforts, and proactively *share* these data with our colleagues, business decision makers and government policy makers. It is an integral part of *managing* our profession. Thus, it *is* up to *us* to document and spread the word that *good ergonomics IS good economics*.

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