THEOR. ISSUES IN ERGON. SCI., 2000, VOL. 1, NO. 1, 22–33

The technology of ergonomics

HAL W. HENDRICK*

Hendrick and Associates, 7100 E. Crestline Avenue, Englewood, CO 80111, USA

Keywords: Human-system interface technology, Ergonomics technology, Ergonomics.

Attempts by the US Air Force, Human Factors and Ergonomics Society, and Board of Certification in Professional Ergonomics in the US, the Harmonization of European Training Programs for the Ergonomics Profession project group in Europe, and the International Ergonomics Association to determine the scope of ergonomics and its technology are reviewed. Based on these data, and the author's own observations of ergonomics internationally, the technology of ergonomics is defined as *human–system interface technology* (HSIT). HSIT is proposed to have five identifiable components. Each of these components is described, including a brief history of its development. Because it has developed a unique technology, the author concludes that ergonomics has evolved into a unique, stand-alone discipline that can be defined most directly by its technology. Further, that educating the general public about HSIT will increase public understanding of the nature and scope of ergonomics and its potential for enhancing organizational performance and the quality of human life.

1. Introduction

The most frequent method of defining the discipline of ergonomics is through the use of a descriptive statement. For example, recently the International Ergonomics Association (IEA) has defined ergonomics as follows: 'Ergonomics (or human factors) is the scientific discipline concerned with the fundamental understanding of interactions among humans and other elements of a system, and the application of appropriate methods, theory and data to improve human well-being and overall system performance'.

The old IEA definition states that 'Ergonomics integrates knowledge derived from the human sciences to match jobs, systems, products and environments to the physical and mental abilities and limitations of people' (IEA 1997: 1). The Board of Certification in Professional Ergonomics (BCPE) in North America describes ergonomics as 'a body of knowledge about human abilities, human limitations and other human characteristics that are relevant to design. *Ergonomic Design or Engineering* is the application of this body of knowledge to the design of tools, machines, systems, tasks, jobs, systems, products and environments for safe, comfortable and effective human functioning' (BCPE 1999: 1). The BCPE's definition was originally developed by Chapanis (1988). Similar descriptive statements are used by ergonomics societies throughout the world.

From analysing the content of a number of these descriptive definitions, the BCPE noted that the primary focus of ergonomics practice was the application of information about human abilities, limitations and other characteristics to *design*,

e-mail: hhendrick@aol.com

Theoretical Issues in Ergonomics Science ISSN 1463–922X print/ISSN 1464–536X online
http://www.tandf.co.uk/journals

with *analysis* and *test and evaluation,* being closely related ergonomics practice activities. More recently, based on the activities of its members and a review of some of the studies described later herein, the HFES added *standardization* and *control* of systems to the above as applications of ergonomics technology. Thus, ergonomics technology is applied 'to the design, analysis, test and evaluation, standardization, and control of systems' (HFES 1999: 389).

As used by the HFES in its Strategic Plan (HFES 1999), the term *technology* refers to the design principles, guidelines, specifications, methods and tools that are developed by a discipline's science and used by its practitioners to accomplish some end. This is the same operational definition of technology that is used herein.

Although useful for some purposes, descriptive definitions of a discipline often do not define clearly its *uniqueness* or delimit its boundaries. For example, the descriptive definitions of ergonomics, quoted earlier, do not clearly separate it from such disciplines as industrial and organizational psychology or industrial engineering. Indeed, it readily can be argued that, like ergonomics, both of these disciplines are concerned with human capabilities and limitations, and both are concerned with the design of systems. In fact, when the means of defining an area of research and application is purely descriptive, it is difficult to determine if the area is a discipline at all, or just a composite of sub-areas of several other disciplines. Indeed, for many, this has been the state of confusion about ergonomics. In an all member survey by the HFES in 1996, approximately 50% of the membership saw human factors/ergonomics as a distinct, stand-alone discipline. In contrast, the other 50% viewed it as an interdisciplinary or cross-disciplinary area of study and practice; most often, these persons viewed ergonomics as a combination of applied experimental or industrial psychology and industrial engineering. In some countries, such as Denmark and Australia, the rehabilitation disciplines are also viewed as integral parts of the inter- or cross-discipline of ergonomics.

When, instead of relying on descriptive definitions, a discipline is defined in terms of its *unique technology*, the nature and scope of a discipline becomes clear. In fact, it only is when one *does* attempt to define an area of research and practice in terms of its technology that one can clearly determine if it even is a separate discipline.

2. Determining the scope and practice of ergonomics

During the late 1970s, 1980s and early 1990s, there have been several studies in the US, a meeting of representatives from 10 ergonomics societies and an extensive survey by the IEA, and reviews by both the Western European ergonomics community and the Board of Certification in Professional Ergonomics in North America, to determine the scope and practice of ergonomics. With the exception of the first of the US studies, the primary purposes for these explorations was to determine the requirements for ergonomics professional education programmes and for developing a programme of professional certification in ergonomics.

2.1. *The US Air Force study*

In 1978, under the direction of Air Force Lt Colonel Joseph Birt, a PhD human factors professional, an extensive project was initiated to study all aspects of human factors engineering in the Department of Defense's (DoD) research, development, test and evaluation, and operations (RDTE&O) process in general, and in the Air Force in particular. Although many ergonomists/human factors professionals were involved in various stages of the project, the core group included Professor's Bob

Williges and Harry Snyder of Virginia Tech, Ed Jones, Chief of Human Factors Engineering at McDonnel Douglas in St Louis, and Hal W. Hendrick (author), an Associate Professor of Human Factors at the University of Southern California at the time. The lead human factors professional was L. McIlvane (Mac) Parsons. He, in turn, had a Co-PI who was a highly experienced system Programme office project manager. Lt Col Birt also actively participated in the entire project.

Although there was considerable overlap in the project responsibilities and efforts, Bob Williges had prime responsibility for documenting all of the various ergonomics methods and tools currently being used in the DoD and by its prime contractors, Harry Snyder for determining the educational and training requirements for being able to perform as a professional human factors engineer, and Ed Jones and Hal Hendrick for documenting how human factors engineering is employed at each stage of the RTDE&O process on major Air Force system development projects. As part of the effort, Ed Jones and Hal Hendrick also developed a series of behavioural objectives to cover what DoD human factors engineers and their counterparts in industry were required to do during the RTDE&O process. Because aspects of the project identified both strengths and weaknesses of the DoD system development process in general, and development and application of human factors technology in particular, much of the work was classified. Nevertheless, a number of useful products came out of the project which were beneficial to the human factors profession. For example, the work of Harry Snyder and others on educational requirements provided the groundwork for the HFES in developing its accreditation programme for professional human factors/ergonomics graduate education programmes. When Harry and his colleagues compared the educational needs to what was actually in the professional human factors educational programmes, it suggested how deficient most programmes were, and, thus, highlighted the need for the Human Factors Society, now the Human Factors and Ergonomics Society (HFES), to establish educational standards and institute an accreditation programme. The work of Ed Jones and Hal Hendrick on behavioural objectives for professional human factors engineers directly assisted the BCPE in developing its professional certification programme (Hendrick 1981, BCPE 1999: 7–8). The work of Bob Williges and other colleagues provided a listing of human factors/ergonomics tools and methods, and, thus, defined that aspect of the technology at the time. In addition, this part of the study pointed out some disparities between what tools and methods were being taught in the professional education programmes and what was actually being used in industry. Of particular importance, this project—the most extensive of its kind that had ever been undertaken in the human factors/ergonomics discipline—demonstrated that human factors/ergonomics had an identifiable technology. At the time, Lt Col Birt identified that technology *as human–machine interface technology*, with the term 'machine' being used loosely to refer not only to tools and machines, including computers, but also to the physical environment in which the 'machine' was being used.

2.2. *The Human Factors Society study*

In 1980, Harry Snyder, as President of HFS, formed a committee to explore the feasibility of developing a professional certification programme in human factors. That initial committee consisted of HFS members Jeff Koonce, Diane Damos and Hal Hendrick. The initial review of the field was assisted by the results of the Air Force study, cited above, and suggested that a core of human factors/ergonomics knowledge and skills could be identified to serve as the basis for a professional certification programme. It was determined that what was needed was a follow-on study to define just what the specific knowledge and skills are. Hal Hendrick then replaced Jeff Koonce as the committee's chair. Shortly thereafter, the committee became subsumed as a sub-committee of the newly formed HFS Professional Standards Committee. Two other sub-committees were then formed: one to develop a code of ethics, the other to develop an accreditation programme for graduate professional education programmes in human factors/ergonomics.

In 1984, the Professional Standards Committee was successful in obtaining the collaboration of the Air Force in conducting a contractual study to develop an occupational database for human factors. It was recognized by both the Air Force and the HFS that, among other applications, this database could be used for developing both an academic accreditation and a professional certification programme. The contract was awarded to Universal Energy Systems, with Lt Colonel Birt serving as the Air Force's programme manager. A method known as Functional Job Analysis (FJA) was used as an approach to identify and analyse job activities of human factors practitioners. The method had been developed by Dr Sydney A. Fine while he was director of research at the US Employment Service, and had been successful in revising the occupational classification system used in the third edition (1965) of the Dictionary of Occupational Titles. It also had been used by the US Coast Guard in developing training, qualification and licensing criteria for marine personnel, as well as in other applications. Using the FJA methodology, Dr Fine conducted two workshops with leading human factors experts in the respective application areas. The first workshop was to define the scope of human factors in the RTDE&O of military systems, and the second was to focus on the scope of human factors in the design of commercial/consumer products. The workshops identified both the skills and abilities required and the technology employed (Eckstrand *et al.* 1985). These data proved useful in the actual development of the HFES accreditation programme. With respect to certification, these data provided further assurance that development of a certification programme was feasible. Of particular relevance to this paper, these data defined the nature and scope of the existing technology of human factors for the two application areas covered in the study.

2.3. *Harmonizing European Training Programmes for the Ergonomics Profession (HETPEP) study*

At the beginning of the 1990s, an international working group of European ergonomists conducted an analysis of the field of ergonomics to determine the education and training requirements for professional ergonomists. It is known as the HETPEP study, which stands for Harmonizing European Training Programmes for the Ergonomics Profession. The HETPEP group published a report of their findings which outlined the core contents for a professional Euro-Ergonomist degree (Rookmaaker *et al.*, 1992). Known as the *ergonomist formation model* (EFM), it was then used as a basis for developing a Euro-Ergonomist professional registration (certification) programme by the *Centre for Registration of European Ergonomists* (CREE). The model covers the educational contact hours required in six content areas: ergonomics principles, human characteristics, work analysis and measurement, people and technology, applications projects (projects pursued by the individual during education/training), and professional issues. These six content areas or categories, in turn, are divided into various sub-areas. The EFM, thus, defines the scope of the ergonomics profession in Europe and identifies various aspects of ergonomics technology. The EFM was also adapted by the Board of Certification in Professional Ergonomics (BCPE) in the US in specifying the educational requirements for the Board's Professional Ergonomist and Human Factors Professional certifications (see BCPE 1999: 3–7, for the complete EFM).

2.4. *Board of Certification in Professional Ergonomics (BCPE) study*

In developing its international professional certification programme, the BCPE was first faced with the task of determining, internationally, what ergonomists do, and what skills, knowledge, and experience they require at the fully qualified professional practitioner level. The Board reviewed the results of the three studies cited above, the HFES accreditation programme criteria, the content of leading human factors/ergonomics textbooks and handbooks in the US and Europe, and information on the education, training, and skills of ergonomists found in Bernotat and Hunt (1977), Jahns (1991), Van Cott and Huey (1992), and Rentzsch (1994). In addition, various proceedings of the International Ergonomics Association (IEA) and several of its Federated Societies were also reviewed. At the time, the author was Vice President and President Elect of the Board and actively participated in these reviews. These reviews led to the development of a chart of the scope and practice of professional ergonomists (BCPE 1999: 9–12). With respect to the technology of ergonomics, the BCPE references the HFES Strategic Plan (BCPE 1999), which includes a brief description of ergonomics technology as is explained in greater detail later in this paper (see HFES 1999: 389).

2.5. *IEA meeting of representatives from 10 ergonomics societies,* 1988

At the 1988 Triennial Congress of the International Ergonomics Association (IEA) in Sydney, Australia, a meeting was held consisting of representatives from 10 national and regional ergonomics societies from around the world, representing more than 25 different countries. The purpose of the meeting was to review the characteristics, issues, and scope of ergonomics in the various countries represented by the 10 societies participating. The author was one of the US representatives at the meeting and, subsequently, published a summary of the comments of the various representatives (Hendrick 1989). For Hendrick, the results from that meeting confirmed the following. First, that the one common theme of ergonomics internationally is its focus on the design of the interfaces between the human component of systems and the other system components (i.e. hardware, software, jobs, internal and external environments, and work system structures and processes). Secondly, that the technology ergonomists develop through scientific investigation and apply as practitioners is for the purpose of designing human–system interfaces. As used here, a system can be as simple as a human using a hand implement or as complex as a multinational organization.

Over the following 6 years, while serving as Secretary General and then President of the IEA, the author had occasion to visit with the leadership of 20 ergonomics societies around the world and to participate in the annual meetings of many of them. These visits afforded an opportunity to learn first-hand about the science and practice of ergonomics in those countries. These experiences further reinforced the two conclusions formed at the IEA meeting, cited above, about the focus of ergonomics technology and its application.

2.6. *IEA special survey of federated societies*

In 1990, the IEA Policy and Planning committee began the development of a comprehensive survey of its member societies. The purpose of the survey was to help the IEA Executive Committee acquire a better understanding of both the state of ergonomics and professional ergonomics societies around the world. The completed survey then was administered in 1992. In 1996, a full report of the results was published by the IEA (Brown *et al.* 1996). Twenty-five national and regional human factors/ergonomics societies, representing over 35 countries, participated in the survey. Among other things, the survey identified both the current and emerging areas of research and practice throughout the world. Table 1 provides a listing of the areas into which ergonomics has expanded, and indicates the percentage of societies that responded to each area. Table 2 is a listing of important themes and emerging areas of interest that were listed by two or more societies. Again, the common thread among societies was on developing and applying ergonomics technology to the design of human–system interfaces.

Table 1. Application areas in ergonomics (from IEA 1992 survey of 25 member societies).

Topic	% Reporting	Topic	% Reporting
Safety	84	Test and evaluation	64
Industrial engineering	84	Organizational psychology	62
Biomechanics	76	Display/control	62
Workload	76	Consumer products	56
Human–computer	76	Medical equipment	60
Environmental/furniture design	76	Aviation	52
Education	72	Communication	44
Anthropometry	72	Time motion	36
Psychology	68	Transportation	32
Visual performance	64	Physiotherapy	08
Work physiology	64	Psychophysics	08

Table 2. Important themes and emerging areas of interest (from IEA 1992 survey of 25 member societies).

- Methodology to change work organization and design
- Work related musculoskeletal disorders
- Usability testing for consumer electronic goods
- Human computer interface: software
- Organizational design and psychosocial work organization
- Ergonomic design of physical work environment
- Control room design of nuclear power plants
- Training of ergonomists
- Interface design with high technology
- Human reliability research
- Mental workload
- Methodology for workforce cost calculation
- Product liability
- Road safety and automobile design
- Transfer of technology to developing countries

2.7. *HFES Strategic Plan Steering Committee review of ergonomics internationally*

In 1993, under the direction of President Elect, Deborah Boem-Davis, the HFES began the development of a strategic plan for the Society. Following development of an initial draft, a Strategic Planning Steering Committee was formed in 1994 with President Elect, Tom Eggemeier, as Chair. The Committee's primary purpose was to integrate comments from the membership into the draft. The author succeeded Tom as Chair and, while serving as HFES President Elect and President, continued with the draft's development during 1995 and 1996. Among other activities, most of the studies cited above were reviewed to gain a better understanding of ergonomics internationally, develop a clear understanding of the nature of the technology of ergonomics, and of the goals and purposes of ergonomics as practiced throughout the world. What follows is the authors interpretation of what was learned.

3. The technology of ergonomics and its applications

Although some of the underlying research can be traced directly back to the early part of the 20th century, human factors/ergonomics, as an identifiable area of study and practice, began in the 1940s during World War II. In the US, UK, and Germany, it was found that human factors/ergonomics research and application was conducted to enhance human performance in military weapons systems. For example, all three countries were concerned with how to improve the design of gun-sights in order to enable the human to use them more accurately. In the US, engineering psychologists were called upon to investigate military aircraft accidents to try to understand better why so many of them were being attributed to 'pilot error', and to gain a better understanding of what 'pilot error' really meant from a causation standpoint. The basic finding was that what was being called 'pilot error' really was *engineering design error*. Put simply, the controls, displays and workspace arrangements were being designed in ways that were not compatible with human capabilities, limitations, and other characteristics. Consequently, these designs were causing pilots to make errors. In the US, these findings led to research into better understanding of the *human factors* involved in designing human–machine interfaces and, hence, to the development of human factors as an identifiable area of research and application. Initially, the central focus was on human perception, reaction, and learning factors, and the use of laboratory studies as a means of developing what was then called *man–machine* technology. Following World War II, Europe and Japan were faced with the task of rebuilding their factories. As a result, a concern developed over how to systematically study the nature of human work, or *ergonomics*, and then apply that knowledge to the design of workplaces. The central focus was on human physiology, anthropometric characteristics, and biomechanics and the use of systematic field observation studies to develop ergonomics technology. Over time, the US and European approaches blended and broadened. Today, the areas of study and methods used to develop and apply human factors and ergonomics technology are similar, and 'ergonomics' and 'human factors' are formally recognized by the IEA as the same discipline.

3.1. *Human–system interface technology (HSIT)*

Based on the reviews cited above, the HFES Strategic Planning Steering Committee determined that human factors/ergonomics does, indeed, have a unique technology that has been developed through scientific research over the past 60 years. HFES has labelled that technology as *human–system interface technology* (HSIT). As a science, ergonomics is concerned with developing knowledge about human capabilities, limitations, and other characteristics as they relate to the design of the human interface aspects of other system components. This scientifically developed knowledge, in turn, is used to develop HSIT. As noted earlier, this technology takes the form of ergonomics design principles, guidelines, specifications, methods, and tools. As a practice, ergonomists apply human–system interface technology to the design or modification of systems to enhance safety, health, comfort, and performance, including productivity and quality. The overall societal goal of ergonomics is to develop and apply human–system interface technology to improve the quality of human life. This is achieved through applying human–system interface technology to the analysis, design, test and evaluation, standardization, and control of systems (HFES 1999: 389). It is this unique technology that clearly defines ergonomics as a unique, independent discipline. It is also this technology that clearly defines the scope of ergonomics and the role of the ergonomics profession.

Human–system interface technology, in turn, has at least five identifiable major components: human–machine interface technology or hardware ergonomics, human–environment interface technology or environmental ergonomics, human–software interface technology or cognitive ergonomics, human–job interface technology or job design ergonomics, and human–organizational interface technology or macroergonomics.

3.2. *Human–machine interface technology—hardware ergonomics*

As noted earlier, the study of human–machine interface technology began in the US to explain why so many military aviation accidents were being attributed to 'pilot error'. The finding that the causative problem was engineering design error led to human factors research to develop human–machine interface technology. Specifically, the concern was with the design of controls, displays, workspace arrangements, and seating to reduce human error, decrease human workload, and enhance human comfort and productivity. One early outcome of the resultant development and application of human–machine interface technology was to greatly improve aviation safety—an outcome society has benefited from ever since. In Europe and Japan, studies of the human operator led to a similar development of human–machine interface technology—particularly as applied to the biomechanical and anthropometric design aspects of controls and workspace arrangements in industrial systems. Today, human–machine interface technology enables the enhancement of safety and usability of a broad spectrum of human–machine systems via design, including all forms of transportation, industrial and office equipment and workstations, and consumer products.

3.3. *Human–environment interface technology*

This second aspect of HSIT is concerned with human capabilities and limitations with respect to the demands imposed by various environmental modalities, such as illumination, heat, cold, noise, and vibration. It is applied to the design of human environments to minimize environmental stress on human performance, including comfort, health, and safety, and to enhance performance, including productivity.

Perhaps the root of environmental ergonomics was the work of the British Industrial Fatigue Research Board, which began in the early 1900s and carried through to the 1930s. Over 30 excellent studies were conducted and reported on various aspects of environmental stress and human performance. In the 1960s, research was begun at such places as Aston, Loughborough, Wales and Birmingham universities in the UK, and various Department of Defense, NASA, and university (e.g. Cornell) units in the US. During this same period, parallel research to develop and apply human–environment interface technology was ongoing in other Western European countries, Japan, the USSR, Australia, and elsewhere.

During the last several decades, the importance of understanding the relation of humans to both their natural and constructed environments has gained increasing focus internationally, and a related, ecologically oriented human–environment interface technology is continuously developing. One aspect of this increased focus has been a growing trend towards more stringent ergonomics related health and safety legislation, such as that implemented in California and that which is under development by NIOSH in the US. This legislation covers both human–environment and human–machine aspects of systems with the goal of preventing human injury and disease—particularly work-related musculoskeletal disorders.

3.4. *Human–software interface technology—cognitive ergonomics*

This third HSIT is a relatively new development in the ergonomics discipline, having come into being with the invention of the silicon chip in the 1960s and the modern computer revolution that followed. Because this technology is primarily concerned with how people think and process information, it is often viewed as the major product of cognitive ergonomics. It consists of design principles, guidelines, specifications and methods for enhancing software usability—to enable software to dialogue with humans the way humans think and process data.

In the US, the development of cognitive ergonomics and the related human–software interface technology, and the demand for its application by industry, have resulted in an increase in the number of ergonomists by ~25%, based on the increase in the membership of HFES that occurred during the late 1970s and 1980s. That increase has held steady during the 1990s. In fact, as reflected in the job openings available through the HFES Placement Service, there is currently a shortage of ergonomists who have professional knowledge of human–software interface technology.

Because of the continuing growth in software technology and its application, and the growing realization of the importance of human–software interface technology to effective software design for usability, this aspect of ergonomics should continue to be a strong growth area within the discipline. The related growth in the technology of artificial intelligence (AI) and its high potential for expert systems development will further accelerate this part of the discipline's technology development and application.

3.5. *Human–job interface technology—work design ergonomics*

Human–job interface technology has its roots in the early work of such persons as Hugo Munsterberg and the development of industrial psychology (e.g. see Landy 1985), and in the work of Fredrick W. Taylor, Frank B. Gilbreth and others and the development of industrial engineering (Helander 1997). Industrial psychology was developed with a central focus on studying both human capabilities and limitations and job requirements in order to select persons for jobs whose personal characteristics matched the demands of the specific jobs in question. Many of the methods and tools for studying human capabilities, limitations and other characteristics and the characteristics of jobs, such as aptitude testing and task analysis, were developed by the discipline of industrial psychology. Similarly, much of the technology for studying work methods and procedures was developed as part of the discipline of industrial engineering (Helander 1997). Job design ergonomics has built on these technologies to develop its own unique human–job technology. Included are methods for developing work modules and combining modules into jobs to make them intrinsically motivating, better utilize human capabilities, and avoid stressing human limitations with respect to such things as physical and mental workload. The bottom-line payoff for employers is enhanced performance, including productivity, increased employee commitment, fewer grievances, and less absenteeism. For employees, jobs that enhance self-worth, personal health, and the quality of work life result.

3.6. *Human-organization interface technology—macroergonomics*

Macroergonomics, as an identifiable sub-discipline, is the newest aspect of the profession. The central focus of the first four technologies is the individual operator and, to some extent, operator teams or subsystems. Thus, the primary application of these four technologies has been at the micro-ergonomic level. In contrast, because it deals with optimizing the overall structure and related processes of the work system, human-organization interface technology tends to be *macro*- in its focus. Hence, it is referred to as *macroergonomics*. Conceptually, macroergonomics can be defined as a top-down, sociotechnical systems approach to work system design, and the carry-though of the work system's design characteristics to the design of human–job, human–machine and human–software interfaces. 'Sociotechnical systems approach' refers to systematically considering the key characteristics of the work system's (a) technological subsystem, (b) personnel subsystem, and (c) elements of the external environment upon which the organization is dependent for its survival and success (e.g. government policies and regulations, materials sources, customers, stock holders, etc.) in designing the work system's organizational structure and processes. Empirical models of the relationship of these key sociotechnical characteristics of a given organization to work system's structural and process characteristics have been developed which can aid in the analysis and design of the organization's work system (see Hendrick 1991, 1997a for a description of these models). The technology is referred to as human–organization interface technology because it deals most directly with the interface of the persons who comprise a given work system with the organization's structure, policies and procedures.

Although conceptually a top-down approach, in actual practice, macroergonomics usually involves employee participation at all organizational levels. It is, thus, top-down, middle-out and bottom-up in terms of analysis and implementation, and tends to be an iterative design process.

The goal of macroergonomics is to ensure that the structure and processes of the work system are designed to be compatible with the key characteristics of the organization's technological subsystem, personnel subsystem, and external environment. Secondly, by carrying the characteristics of a well-designed work system down to the design of the micro-ergonomic elements, the result can be a fully harmonized work system. A fully harmonized work system is one which, in comparison with a poorly designed system, can improve various measures of organizational performance (e.g. reductions in lost time accidents and injuries, grievances, or scrap rates) by 60–90% or more (see Hendrick 1997a, b for some case examples).

Although organizational factors have occasionally been considered in ergonomic design, since the beginning of ergonomics, as an identifiable profession, macroergonomics, as an identifiable sub-discipline, initially developed out of a study of future ergonomics needs by the Human Factors Society that was completed in 1980 (Hendrick 1991). This study noted such factors as (a) rapid changes in technology fundamentally changing the nature of work; (b) changing work force value systems; (c) demographic shifts—in particular, a graying of the work force; (d) increasing world competition; and (e) the inability of purely micro-ergonomic interventions either to improve over-all *system* administrative productivity as a cost of production or to reach potentially achievable increases in system safety, health, and related quality of work life goals. Among other things, the study concluded that, for human factors/ergonomics to meet the challenges of the 1980–2000 time period and beyond, ergonomists were going to have to integrate organizational design and management factors into their technology and practice. By 1986, sufficient human–organization interface technology had been developed to identify macroergonomics as a distinct sub-discipline of ergonomics.

4. Conclusion

A discipline is defined by the unique technology it develops though it science and applies though its practice to some end. For at least the past 60 years, ergonomics has been empirically developing and refining a unique technology: Human–system interface technology or HSIT. Over the last half of the 20th century, ergonomics practitioners have been using HSIT to improve human health, safety, comfort, and performance, including productivity and quality. Ergonomists have done this by applying HSIT to the analysis, design, test and evaluation, standardization and control of systems. The ultimate purpose of ergonomics internationally has been to improve the quality of human life.

In summary, ergonomics is no longer a cross-disciplinary or interdisciplinary area of research and application. Clearly, although still young, it has developed into a unique, independent discipline. Further, its unique technology clearly defines the scope of the discipline and the nature of human factors/ergonomics practice. By educating the general public about HSIT, understanding about the nature of ergonomics and its tremendous potential for enhancing the human condition can be increased and broadened. If successful in this effort, the first century of the new millennium truly can become the age of ergonomics.

References

BCPE 1999, *Candidate handbook: Policies, Practices & Procedures* (Bellingham, WA: Board of Certification in Professional Ergonomics).

Bernotat, R. and Hunt, D. P. 1977, *University Curricula in Ergonomics* (Wachtberg-Werthoven, Germany: Forschunginstitut fur Anthopotechnik).

Brown, O., Jr., Hendrick, H. W., Noy, Y. I. and Robertson, M. M. 1996, *Special survey of IEA Federated Societies, Final Report* (Zurich: International Ergonomics Association).

Chapanis, A. 1988, To communicate the human factors message you have to know what the message is and how to communicate it. Keynote address to the HFAC/ACE Conference, Edmonton, Alberta, Canada [reprinted in the *Human Factors Society Bulletin,* 1991, **34**, 1–4, part 1; 1992, **35**, 3–6, part 2].

Eckstrand, G. A., Christensen, J. M. and Williamson, G. P. 1985, *Development of an occupational data base for human factors: Methodology and preliminary efforts,* contract F33615-82-C-006 (Dayton, Ohio: Universal Energy Systems).

HELANDER, M. G. 1997, The human factors profession, in G. Salvendy (ed.), *Handbook of Human Factors and Ergonomics*, 2nd edn (New York: Wiley), 3–16.
HENDRICK, H. W. 1981, Engineering education's response to the need of human factors engineers, Unpublished paper, presented during the 89th ASEE Annual Conference, Los Angeles, CA, 24 June.
HENDRICK, H. W. 1989, Human Factors/Ergonomics Societies around the world: Characteristics and issues, *Human Factors and Ergonomics Society Bulletin*, **32** , 9–10.
HENDRICK, H. W. 1991, Human factors in organizational design and management, *Ergonomics*, **4**, 743–756.
HENDRICK, H. W. 1997a, Organizational design and macroergonomics, in G. Salvendy (ed.), *Handbook of Human Factors and Ergonomics*, 2nd edn (New York: Wiley), 594–636.
HENDRICK, H. W. 1997b, *Good Ergonomics is Good Economics* (Santa Monica, CA: Human Factors and Ergonomics Society).
HFES 1999, Human Factors and Ergonomics Society strategic plan, *Human Factors and Ergonomics Society Directory and Yearbook* 1999–2000 (Santa Monica, CA: Human Factors and Ergonomics Society), 389.
IEA 1997, *IEA Facts and Background* (Zurich: International Ergonomics Association).
JAHNS, D. W. 1991, The education and certification of ergonomists: A practitioner's perspective, *Human Factors Society Bulletin*, **34**, 4–6.
Landy, F. J. 1985, *Psychology of Work Behavior*, 3rd edn (Homewood, IL: Dorsey Press).
RENTZSCH, M. 1994, Registrierung und Zertifizierung eines Europa-Ergonomen, *Zeitschrift für Arbeitswissenschaft*, **48**, 189–190.
ROOKMAAKER, D. P., HURTS, C. M. M., CORLETT, E. N., QUEINNEC, Y. and SCHWEIR, W. 1992, Towards a European registration model for Ergonomists, Final report of the working group: Harmonizing European Training Programs for the Ergonomics Profession (HETPEP), Leiden, NL, June.
VAN COTT, H. P. and HUEY, B. M. (eds) 1992, *Human Factors Specialists' Education and Utilization, Results of a Survey*, Committee on Human Factors, National Research Council (Washington, D.C.: National Academy Press).

About the authors

Hal Hendrick is Emeritus Professor of Human Factors at the University of Southern California and Principal of Hendrick & Associates, an I/O psychology and ergonomics consulting firm. He holds an MS in Human Factors and a PhD in Industrial Psychology with a minor in Industrial Engineering from Purdue University. Hal has been a full time design practitioner, College Dean, Human Factors Department chair, and Executive Director of USC's Institute of Safety and Systems Management. He is a Past President of the International Ergonomics Association, Human Factors and Ergonomics Society, and Board of Certification in Professional Ergonomics. Among other accomplishments, he developed the psychology major and human factors M.S. programmes at the USAF Academy and co-developed the M.S. and PhD human factors and ergonomics programmes at USC. He is the author or editor of 10 books and over 150 other publications. He has received numerous awards including the HFES Alexander C. Williams, Jr. Award for system design, HFES Jack A. Kraft Award for extending the discipline of HF/E, and USC's highest teaching award. Hal is perhaps best known for formally conceptualizing and initiating the sub-discipline of macroergonomics.