THE NATURE AND AIMS OF ERGONOMICS

Definition and Scope

Ergonomics means literally the study or measurement of work. In this context, the term work signifies purposeful human function; it extends beyond the more restricted concept of work as labour for monetary gain to incorporate all activities whereby a rational human operator systematically pursues an objective. Thus it includes sports and other leisure activities, domestic work such as child care and home maintenance, education and training, health and social service, and either controlling engineered systems or adapting to them, for example, as a passenger in a vehicle.

The human operator, the focus of study, may be a skilled professional operating a complex machine in an artificial environment, a customer who has casually purchased a new piece of equipment for personal use, a child sitting in a classroom or a disabled person in a wheelchair. The human being is highly adaptable but not infinitely so. There are ranges of optimum conditions for any activity. One of the tasks of ergonomics is to define what these ranges are and to explore the undesirable effects which occur if the limits are transgressed—for example if a person is expected to work in conditions of excessive heat, noise or vibration, or if the physical or mental workload is too high or too low.

Ergonomics examines not only the passive ambient situation but also the unique advantages of the human operator and the contributions that can be made if a work situation is designed to permit and encourage the person to make the best use of his or her abilities. Human abilities may be characterized not only with reference to the generic human operator but also with respect to those more particular abilities that are called upon in specific situations where high performance is essential. For example, an automobile manufacturer will consider the range of physical size and strength of the population of drivers who are expected to use a particular model to ensure that the seats are comfortable, that the controls are readily identifiable and within reach, that there is clear visibility to the front and the rear, and that the internal instruments are easy to read. Ease of entry and egress will also be taken into account. By contrast, the designer of a racing car will assume that the driver is athletic so that ease of getting in and out, for example, is not important and, in fact, design features as a whole as they relate to the driver may well be tailored to the dimensions and preferences of a particular driver to ensure that he or she can exercise his or her full potential and skill as a driver.

In all situations, activities and tasks the focus is the person or persons involved. It is assumed that the structure, the engineering and any other technology is there to serve the operator, not the other way round.

History and Status

About a century ago it was recognized that working hours and conditions in some mines and factories were not tolerable in terms of safety and health, and the need was evident to pass laws to set permissible limits in these respects. The determination and statement of those limits can be regarded as the beginning of ergonomics. They were, incidentally, the beginning of all the activities which now find expression through the work of the International Labour Organization (ILO).

Research, development and application proceeded slowly until the Second World War. This triggered greatly accelerated development of machines and instrumentation such as vehicles, aircraft, tanks, guns and vastly improved sensing and navigation devices. As technology advanced, greater flexibility was available to allow adaptation to the operator, an adaptation that became the more necessary because human performance was limiting the performance of the system. If a powered vehicle can travel at a speed of only a few kilometres per hour there is no need to worry about the performance of the driver, but when the vehicle's maximum speed is increased by a factor of ten or a hundred, then the driver has to react more quickly and there is no time to correct mistakes to avert disaster. Similarly, as technology is improved there is less need to worry about mechanical or electrical failure (for instance) and attention is freed to think about the needs of the driver.

Thus ergonomics, in the sense of adapting engineering technology to the needs of the operator, becomes simultaneously both more necessary and more feasible as engineering advances.

The term ergonomics came into use about 1950 when the priorities of developing industry were taking over from the priorities of the military. The development of research and application for the following thirty years is described in detail in Singleton (1982). The United Nations agencies, particularly the ILO and the World Health Organization (WHO), became active in this field in the 1960s.

In immediate postwar industry the overriding objective, shared by ergonomics, was greater productivity. This was a feasible objective for ergonomics because so much industrial productivity was determined directly by the physical effort of the workers involved—speed of assembly and rate of lifting and movement determined the extent of output. Gradually, mechanical power replaced human muscle power. More power, however, leads to more accidents on the simple principle that an accident is the consequence of power in the wrong place at the wrong time. When things are happening faster, the potential for accidents is further increased. Thus the concern of industry and the aim of ergonomics gradually shifted from productivity to safety. This occurred in the 1960s and early 1970s. About and after this time, much of manufacturing industry shifted from batch production to flow and process production. The role of the operator shifted correspondingly from direct participation to monitoring and inspection. This resulted in a lower frequency of accidents because the operator was more remote from the scene of action but sometimes in a greater severity of accidents because of the speed and power inherent in the process.

When output is determined by the speed at which machines function then productivity becomes a matter of keeping the system running: in other words, reliability is the objective. Thus the operator becomes a monitor, a trouble-shooter and a maintainer rather than a direct manipulator.

This historical sketch of the postwar changes in manufacturing industry might suggest that the ergonomist has regularly dropped one set of problems and taken up another set but this is not the case for several reasons. As explained earlier, the concerns of ergonomics are much wider than those of manufacturing industry. In addition to production ergonomics, there is product or design ergonomics, that is, adapting the machine or product to the user. In the car industry, for example, ergonomics is important not only to component manufacturing and the production lines but also to the eventual driver, passenger and maintainer. It is now routine in the marketing of cars and in their critical appraisal by others to review the quality of the ergonomics, considering ride, seat comfort, handling, noise and vibration levels, ease of use of controls, visibility inside and outside, and so on.

It was suggested above that human performance is usually optimized within a tolerance range of a relevant variable. Much of the early ergonomics attempted to reduce both muscle power output and the extent and variety of movement by way of ensuring that such tolerances were not exceeded. The greatest change in the work situation, the advent of computers, has created the opposite problem. Unless it is well designed ergonomically, a computer workspace can induce too fixed a posture, too little bodily movement and too much repetition of particular combinations of joint movements.

This brief historical review is intended to indicate that, although there has been continuous development of ergonomics, it has taken the form of adding more and more problems rather than changing the problems. However, the corpus of knowledge grows and becomes more reliable and valid, energy expenditure norms are not dependent on how or why the energy is expended, postural issues are the same in aircraft seats and in front of computer screens, much human activity now involves using videoscreens and there are well-established principles based on a mix of laboratory evidence and field studies.

Ergonomics and Related Disciplines

The development of a science-based application which is intermediate between the well-established technologies of engineering and medicine inevitably overlaps into many related disciplines. In terms of its scientific basis, much of ergonomic knowledge derives from the human sciences: anatomy, physiology and psychology. The physical sciences also make a contribution, for example, to solving problems of lighting, heating, noise and vibration.

Most of the European pioneers in ergonomics were workers among the human sciences and it is for this reason that ergonomics is well-balanced between physiology and psychology. A physiological orientation is required as a background to problems such as energy expenditure, posture and application of forces, including lifting. A psychological orientation is required to study problems such as information presentation and job satisfaction. There are of course many problems which require a mixed human sciences approach such as stress, fatigue and shift work.

Most of the American pioneers in this field were involved in either experimental psychology or engineering and it is for this reason that their typical occupational titles—human engineering and human factors—reflect a difference in emphasis (but not in core interests) from European ergonomics. This also explains why occupational hygiene, from its close relationship to medicine, particularly occupational medicine, is regarded in the United States as quite different from human factors or ergonomics. The difference in other parts of the world is less marked. Ergonomics concentrates on the human operator in action, occupational hygiene concentrates on the hazards to the human operator present in the ambient environment. Thus the central interest of the occupational hygienist is toxic hazards, which are outside the scope of the ergonomist. The occupational hygienist is concerned about effects on health, either long-term or short-term; the ergonomist is, of course, concerned about health but he or she is also concerned about other consequences, such as productivity, work design and workspace design. Safety and health are the generic issues which run through ergonomics, occupational hygiene, occupational health and occupational medicine. It is, therefore, not surprising to find that in a large institution of a research, design or production kind, these subjects are often grouped together. This makes possible an approach based on a team of experts in these separate subjects, each making a specialist contribution to the general problem of health, not only of the workers in the institution but also of those affected by its activities and products. By contrast, in institutions concerned with design or provision of services, the ergonomist might be closer to the engineers and other technologists.

It will be clear from this discussion that because ergonomics is interdisciplinary and still quite new there is an important problem of how it should best be fitted into an existing organization. It overlaps onto so many other fields because it is concerned with people and people are the basic and all-pervading resource of every organization. There are many ways in which it can be fitted in, depending on the history and objectives of the particular organization. The main criteria are that ergonomics objectives are understood and appreciated and that mechanisms for implementation of recommendations are built into the organization.

Aims of Ergonomics

It will be clear already that the benefits of ergonomics can appear in many different forms, in productivity and quality, in safety and health, in reliability, in job satisfaction and in personal development.

The reason for this breadth of scope is that its basic aim is efficiency in purposeful activity—efficiency in the widest sense of achieving the desired result without wasteful input, without error and without damage to the person involved or to others. It is not efficient to expend unnecessary energy or time because insufficient thought has been given to the design of the work, the workspace, the working environment and the working conditions. It is not efficient to achieve the desired result in spite of the situation design rather than with support from it.

The aim of ergonomics is to ensure that the working situation is in harmony with the activities of the worker. This aim is self-evidently valid but attaining it is far from easy for a variety of reasons. The human operator is flexible and adaptable and there is continuous learning, but there are quite large individual differences. Some differences, such as physical size and strength, are obvious, but others, such as cultural differences and differences in style and in level of skill, are less easy to identify.

In view of these complexities it might seem that the solution is to provide a flexible situation where the human operator can optimize a specifically appropriate way of doing things. Unfortunately such an approach is sometimes impracticable because the more efficient way is often not obvious, with the result that a worker can go on doing something the wrong way or in the wrong conditions for years.

Thus it is necessary to adopt a systematic approach: to start from a sound theory, to set measurable objectives and to check success against these objectives. The various possible objectives are considered below.

Safety and health

There can be no disagreement about the desirability of safety and health objectives. The difficulty stems from the fact that neither is directly measurable: their achievement is assessed by their absence rather than their presence. The data in question always pertain to departures from safety and health.

In the case of health, much of the evidence is long-term as it is based on populations rather than individuals. It is, therefore, necessary to maintain careful records over long periods and to adopt an epidemiological approach through which risk factors can be identified and measured. For example, what should be the maximum hours per day or per year required of a worker at a computer workstation? It depends on the design of the workstation, the kind of work and the kind of person (age, vision, abilities and so on). The effects on health can be diverse, from wrist problems to mental apathy, so it is necessary to carry out comprehensive studies covering quite large populations while simultaneously keeping track of differences within the populations.

Safety is more directly measurable in a negative sense in terms of kinds and frequencies of accidents and damage. There are problems in defining different kinds of accidents and identifying the often multiple causal factors and there is often a distant relationship between the kind of accident and the degree of harm, from none to fatality.

Nevertheless, an enormous body of evidence concerning safety and health has been accumulated over the past fifty years and consistencies have been discovered which can be related back to theory, to laws and standards and to principles operative in particular kinds of situations.

Productivity and efficiency

Productivity is usually defined in terms of output per unit of time, whereas efficiency incorporates other variables, particularly the ratio of output to input. Efficiency incorporates the cost of what is done in relation to achievement, and in human terms this requires the consideration of the penalties to the human operator.

In industrial situations, productivity is relatively easy to measure: the amount produced can be counted and the time taken to produce it is simple to record. Productivity data are often used in before/after comparisons of working methods, situations or conditions. It involves assumptions about equivalence of effort and other costs because it is based on the principle that the human operator will perform as well as is feasible in the circumstances. If the productivity is higher then the circumstances must be better. There is much to recommend this simple approach provided that it is used with due regard to the many possible complicating factors which can disguise what is really happening. The best safeguard is to try to make sure that nothing has changed between the before and after situations except the aspects being studied.

Efficiency is a more comprehensive but always a more difficult measure. It usually has to be specifically defined for a particular situation and in assessing the results of any studies the definition should be checked for its relevance and validity in terms of the conclusions being drawn. For example, is bicycling more efficient than walking? Bicycling is much more productive in terms of the distance that can be covered on a road in a given time, and it is more efficient in terms of energy expenditure per unit of distance or, for indoor exercise, because the apparatus required is cheaper and simpler. On the other hand, the purpose of the exercise might be energy expenditure for health reasons or to climb a mountain over difficult terrain; in these circumstances walking will be more efficient. Thus, an efficiency measure has meaning only in a well-defined context.

Reliability and quality

As explained above, reliability rather than productivity becomes the key measure in high technology systems (for instance, transport aircraft, oil refining and power generation). The controllers of such systems monitor performance and make their contribution to productivity and to safety by making tuning adjustments to ensure that the automatic machines stay on line and function within limits. All these systems are in their safest states either when they are quiescent or when they are functioning steadily within the designed performance envelope. They become more dangerous when moving or being moved between equilibrium states, for example, when an aircraft is taking off or a process system is being shut down. High reliability is the key characteristic not only for safety reasons but also because unplanned shut-down or stoppage is extremely expensive. Reliability is straightforward to measure after performance but is extremely difficult to predict except by reference to the past performance of similar systems. When or if something goes wrong human error is invariably a contributing cause, but it is not necessarily an error on the part of the controller: human errors can originate at the design stage and during setting up and maintenance. It is now accepted that such complex high-technology systems require a considerable and continuous ergonomics input from design to the assessment of any failures that occur.

Quality is related to reliability but is very difficult if not impossible to measure. Traditionally, in batch and flow production systems, quality has been checked by inspection after output, but the current established principle is to combine production and quality maintenance. Thus each operator has parallel responsibility as an inspector. This usually proves to be more effective, but it may mean abandoning work incentives based simply on rate of production. In ergonomic terms it makes sense to treat the operator as a responsible person rather than as a kind of robot programmed for repetitive performance.

Job satisfaction and personal development

From the principle that the worker or human operator should be recognized as a person and not a robot it follows that consideration should be given to responsibilities, attitudes, beliefs and values. This is not easy because there are many variables, mostly detectable but not quantifiable, and there are large individual and cultural differences. Nevertheless a great deal of effort now goes into the design and management of work with the aim of ensuring that the situation is as satisfactory as is reasonably practicable from the operator’s viewpoint. Some measurement is possible by using survey techniques and some principles are available based on such working features as autonomy and empowerment.

Even accepting that these efforts take time and cost money, there can still be considerable dividends from listening to the suggestions, opinions and attitudes of the people actually doing the work. Their approach may not be the same as that of the external work designer and not the same as the assumptions made by the work designer or manager. These differences of view are important and can provide a refreshing change in strategy on the part of everyone involved.

It is well established that the human being is a continuous learner or can be, given the appropriate conditions. The key condition is to provide feedback about past and present performance which can be used to improve future performance. Moreover, such feedback itself acts as an incentive to performance. Thus everyone gains, the performer and those responsible in a wider sense for the performance. It follows that there is much to be gained from performance improvement, including self-development. The principle that personal development should be an aspect of the application of ergonomics requires greater designer and manager skills but, if it can be applied successfully, can improve all the aspects of human performance discussed above.

Successful application of ergonomics often follows from doing no more than developing the appropriate attitude or point of view. The people involved are inevitably the central factor in any human effort and the systematic consideration of their advantages, limitations, needs and aspirations is inherently important.

Conclusion

Ergonomics is the systematic study of people at work with the objective of improving the work situation, the working conditions and the tasks performed. The emphasis is on acquiring relevant and reliable evidence on which to base recommendation for changes in specific situations and on developing more general theories, concepts, guidelines and procedures which will contribute to the continually developing expertise available from ergonomics.