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Ergonomics in Industrial Design

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ABSTRACT

Today, the quality of work lives, occupational safety, and health are issues that both management and employees care about. Information and communication technology, specialized jobs that need repeated tasks, and other new advancements all contribute to the need for human factors engineering. Through the analysis, design, testing, and evaluation of the workplace and human interactions, human factors engineers are able to establish safe, effective, and fulfilling work environments. In order to create systems, organizations, jobs, machines, equipment, and consumer goods that are safe, effective, and comfortable for individuals to use, ergonomics incorporates knowledge of human capabilities and limitations. The basic philosophy of ergonomics is to design workstations that are comfortable, convenient, and productive to work at. According to its definition, ergonomics is the "science of fitting the job to the works". Hence, being an engineer is frequently advantageous when it comes to properly incorporating ergonomics into manufacturing design and planning. Ergonomics is highly related to safety due to its inherent linkage with human-environment interactions. The purpose of ergonomics is to employ design and training to improve comfort, safety, and productivity. Through the implementation of ergonomics an industrial engineer can improve productivity, high employ morale and the quality of products, which will smoothen the operation of an industry. The paper includes (i) the importance of ergonomics in industrial design (ii) ergonomics within industry and manufacturing (iii) ergonomics relation with industrial engineering and (iv) applicability of ergonomics in chair and table design have been cited in this paper.

Keywords: Ergonomics, Safety, Industry, Manufacturing, and Industrial Engineer.

1. Introduction

The word “ergonomics” comes from the Greek words: *ergon* (work) and *nomoi* (law) – roughly translating to “the science of work.” It was for the first time used by Wojciech Jastrzebowski in a Polish newspaper in 1858 [1]. Ergonomics is referred to as “human factors engineering” or “human factors” in the United States. Whilst ergonomics has its foundations in bio-mechanics, bio-physics, work physiology, and workstation design, "human factors" has its roots in experimental psychology, cognitive functioning, and focuses on system design and human performance [2]. Human factor designs take into account human traits, expectations, and behaviors while creating products that people use for work and daily living as well as the spaces where they live and work. In the simplest of terms, ergonomics has been referred to as designing products and spaces for human use [1].

The international labor organization (ILO) defines ergonomics as, "Ergonomics (or human factors) refers to the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system" [3].

Ergonomics started its journey with a few investigators, especially some psychologists, carrying out some exploratory studies dealing with human work during World War 1. It was during World War II that started to crystallize ergonomics as somewhat of a distinct discipline [4]. The investigation for such efforts was due to the fact that the newly-invented, complicated military equipment could not be operated safely or effectively, nor could it be maintained adequately by many well-trained military personnel.

For instance, during the Korean War, training claimed the lives of more pilots than combat operations [5]. This discovery concentrated its attention on aircraft control and display design. How might aircraft information be presented more effectively, and how might controls be rethought and incorporated into the work to make them more manageable - these questions led to improvements and programs, which resulted in the number of pilot training deaths dropping to a fraction (5%) of what it had been before those advancements. Thus, the importance of ergonomics in America started to gain traction, and its development with integration got started in the Department of Defense, the National Aeronautics and Space Administration (NASA), the National Highway safety, the National board for safety in the name of Human Factory. The initial use of it in product design for consumers was started by the Kodak company and International Business Machines Corporation (IBM).

In Europe, ergonomics went through a different journey from its American counterpart [6]. These days, the UK, France, Germany, the Netherlands, Italy, and Scandinavian countries are among the nations where the discipline is most well-established. While ergonomics emerged out of functional anatomy and medicine in Germany, the Netherlands, and Scandinavia, it grew out of industrial engineering concerns and professions in Eastern Europe. [7]. In the former USSR, the interest was primarily focused primarily on defense department. There initially had been few applications on the

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industrial side, but that interest quickly grew with the founding of USSR Research Institute of Industrial Design (VNTITE) in Moscow in 1960s [8].

Though people say ergonomics came as a subject in 1950s, even during the stone age pre-civilized humans were designing hand tools to fit the user and task [5]. About 2.8 million years ago, the genus *homo* and the first stone tools appeared. Over the next few million years, technology and humans have co-evolved in such a way that the increasingly advanced tools have allowed access to safer habitats, richer food sources, etc., which has fueled the development of the brain [9], [10]. But as technology has advanced at an exponential rate, human limits have become more apparent, particularly as robots have gained intelligence and humans have taken on the role of supervisory controller, responsible for monitoring, planning, and diagnosing. [11].

During the industrial revolution there were efforts to apply the concepts of "human centered design" where the main concern was to allocate tasks. Fedrick Taylor developed the "scientific study of work" at the dawn of the 20th century which was followed by Frank and Lillion Gilbreth developing the time and motion study, and the concept of dividing ordinary jobs into several small jobs. In UK, the "Ergonomics Research Society" was established in 1950.

With the design of workstation and work environment having a profound impact on the person's ability to safely and effectively perform the required tasks, ergonomics has evolved to be one of the guiding principle of industrial design over the world [12].

In a very general sense, there are two types of disciplines that have common ergonomics interest: (i) sciences generally provide knowledge and insight relative to human beings, and (ii) professional disciplines that are concerned with due processes. The scientific disciplines involved with ergonomics are psychology, physiology, mathematics, statistics, etc. and the professional disciplines are industrial engineering as well as other branches of engineering, industrial design, architecture, etc. [1].

It can also be defined as the field pertaining to the efficient use of machinery, labor, and raw materials in the production. It is especially crucial when considering production costs and economics, human operator safety, and the most effective use of automated equipment. With emerging fields of industrial collaborative robotics, ergonomics (especially the cognitive and organizational part) is becoming a crucial discipline [13].

With the emergence of the fourth Industrial Revolution, human-robot interactions in the fields from manufacturing assembly to workstation-design to even agriculture, ergonomics is likely to be the vanguard discipline for further research [14], [15], [16].

Industrial engineering is concerned with the analysis and design of systems for organizing the basic production resources such as personnel, information, material, and equipment [17]. Industrial engineers use knowledge from a vast array of fields: mathematics, physical and engineering sciences, behavioral sciences, and management sciences. A person who deals with ergonomics should know about machines, processes, and human capabilities of individual members of the workforce in order to optimize both the productivity of the organizational operation, as well as its workers' health, safety, and well-being. This can be done by improving the working environment, by reducing the operators' fatigue and strain, by increasing the efficiency of the manufacturing operation, by increasing efficiency of the manufacturing operation, by reducing physical workload, by improving working postures and facilitate psycho sensorial functions in instrument handling, by avoiding unnecessary information recalls, by assisting the job placement of workers, and so on.

Considering the multidisciplinary nature of ergonomics, it is apparent that an ergonomist must collaborate with a wide range of other professionals, including design engineers, production engineers, industrial designers, computer specialists, industrial physicians, health and safety practitioners, and human resources specialists. Ensuring that our understanding of human characteristics is applied to individual's practical problems at work and in leisure time is the ultimate objective of ergonomics. We recognize that humans frequently adapt to adverse situations, such adaptations often result in inefficiency, mistakes, intolerable stress, and costly bodily or mental consequences.

This paper discusses the components of ergonomics, and importance of ergonomics in industrial and manufacturing design with relevant examples. Also, the paper cited some application of ergonomics in designing architectural drawing table & tool, and chair with table for undergraduate level students in Shahjalal University of Science and Technology, Sylhet, Bangladesh.

2. Components of Ergonomics

The ergonomist uses anatomy, physiology, and psychology to maximize human productivity and maintain human health and well-being [18]. The job must 'fit the person' in all respects, and not compromise human capabilities [18].

The contribution of basic anatomy lies in improving physical 'fit' between people and the things they use ranging from hand tools to aircraft cockpit design. Considering the diversity of the human body sizes across the population, achieving good physical fit is no easy task. Data about the proportions of the human body in different positions are provided by the science of anthropometrics.

Human physiology knowledge underpins two primary technical domains. In addition to addressing the body's energy needs, work physiology establishes guidelines for appropriate physical exertion and work rate as well as dietary needs. By analyzing the effects of physical working environments, such as temperature, noise and vibration, and illumination, environmental physiology determines the ideal standards for these. Human information processing and decision-making abilities are the focus of psychology. Simply stated, this can be viewed as facilitating the cognitive "fit" that is prevalent between individuals and the objects they utilize. [19].

In today's "high-tech" world, the psychological elements of ergonomics are crucial and should not be undervalued [20]. The ergonomist advises on the design of interfaces between people and machines (Human Machine Interface or HMI), information displays for industrial processes, and the planning of training materials. The idea of "information overload" is well-known in many modern occupations. Ironically, when regular activities become more automated and human involvement is eliminated, the mental demands of monitoring, supervision, and maintenance often increase [21].

3. Advantages and Disadvantages of Ergonomics in Manufacturing Firm or Industry

3.1. Advantages of Ergonomics in Manufacturing Industry

By using ergonomics in a manufacturing industry it can improve its productivity, worker's efficiency, worker's psychology in manufacturing, system design, worker's health & safety, aesthetic appeal of the industry, worker's physical & mental satisfaction, loss of work days, reworks, and can overcome ergonomic challenges, e.g. (i) workstation design (ii) disturbing machine (iii) stressors (iv) fitting workers to the appropriate task (v) maintaining lead time (vi) delivery time, etc. (vii) design it right the first time (viii) fewer injuries (ix) noise reduction (x) design for tactile & auditory feedback (xi) improved communication (xii) improved housekeeping (xiii) reclamation and disassembly (xiv) continuous flow manufacturing (xv) material handling (xvi) recycling (xvii) design for ease manipulation (xviii) reuse of product (xix) reduced landfill (xx) design for visibility & visual feedback (xxi) design for spatial compatibility and (xxii) design for transfer of training, etc.

3.2. Disadvantages of Ergonomics in Manufacturing

Industry though ergonomics plays an essential role in manufacturing arena, but it increases the following costs - (i) wage of ergonomic personnel (ii) floor space (iii) equipment cost (iv) tooling cost and (v) training cost for workers.

4. Ergonomics Within Industry and Manufacturing

The science of designing and arranging tools in order to provide people with the means of efficient use is defined as the concept of ergonomics. Maximizing an individual's capabilities while focusing on his/her body constraints, is the process of applying ergonomic factors to either the system or the source. According to the International Encyclopedia of Ergonomics and Human Factors, “the operating philosophy of ergonomists is to adapt technology to the scientifically established characteristics of people” [22]. Daily, humans interact with machinery and devices that can present harmful effects of injuries or illnesses on their bodies. In order to reduce these negative effects, engineers use ergonomic principles to find the most efficient way to prevent the body from its common pressures of stress and strain.

4.1 Anthropometry

Anthropometry means "measurement of man" or "measurement of humans". Anthropometry deals with the measurement of the dimensions relevant to the physical characteristics of the body i.e. specific lengths of limbs, distances between parts, and static and dynamic measurements; such measurements are, of course relevant to the design of the things people use [23].

Through the use of technology when designing tools and equipment within the industrial and manufacturing realm, ergonomists can now consider the constraints of the human body and its wide range of sizes more efficiently. This approach to the challenges an individual face because of body form or composition is displayed in the field of human factors engineering. Whenever machinery is designed for the workplace, its model and function are analyzed with consideration for the human operator. The objective is to maximize the human's contribution to the overall effectiveness of the system to which he or she is related.

4.2 Functions of an Ergonomist

Manufacturing has traditionally been expected to construct whatever is given to them by the design office, making product design sort of a sacred field. Even though the goal of manufacturability liaison has often been formed, it has mostly concentrated on the capabilities of machines and equipment rather than taking into account the capacity and competence of the workforce.

Product designer training and a product review phase are two crucial ways that product design can be improved to lower exposure to worker injuries in the manufacturing environment. To introduce design engineers to the kinds of stressors that arise in manufacturing and the consequences that follow for both the organization and its personnel, an ergonomics training program can be offered.

Some representative examples of these opportunities include:
(i) types of material, (ii) tolerances, (iii) parts entanglement, (iv) parts movement, (v) manual handling including packaging of the final product, (vi) screw fasteners, (vii) accessibility, (viii) covers, (ix) control & displays, and (x) VDTs.

5. Workstation Guidelines

The fit between individuals and the process environment is emphasized by work systems. The workstation system that integrates comfort and efficiency, enables task-focused and operator-specific setup. In order to integrate tool assistance, Aero-Motive also offers a full range of suitable torque arms, retractors, and balancers.

Depending on the operator, different workstation heights will be advised.

- Male: plus-minus 8.1" for standing and 7.3" for sitting.
- Female: plus-minus 7.2" for standing and 6.6" for sitting.

The size of the object being worked on, and the worker's posture are important factors to take into account while figuring out the optimal level. Setting the height, a little lower than recommended would be prudent if the object being worked on is huge. This puts the object's center at a height that is easier for the operator to reach. “Reach zones” – are the spaces at which a worker has the optimality for working.

Fig.1 and Fig.2 shows workability of a worker both in sitting and standing position, which highlights how reach zones measured from anthropometry are necessary in design. Fig.3 shows the reach ability of worker’s hand during working period. Fig.4 shows the example of control panel of an aircraft in a cockpit that needs ergonomic set for proper functioning.

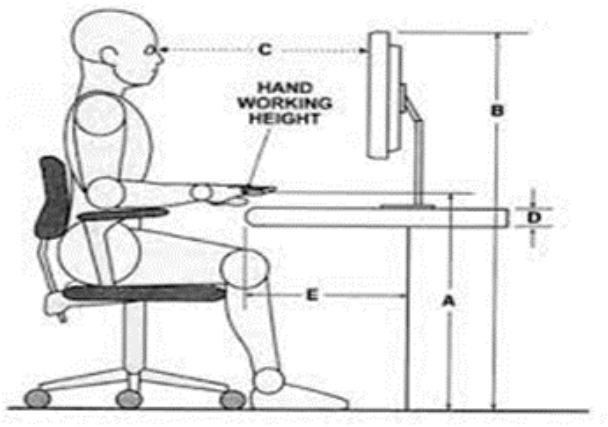

Fig.1 Sitting Reach Zone [1]

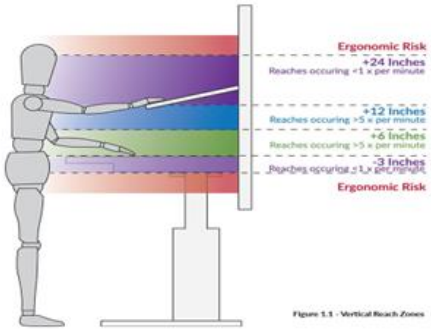

Fig.2 Vertical Reach Zone [24]

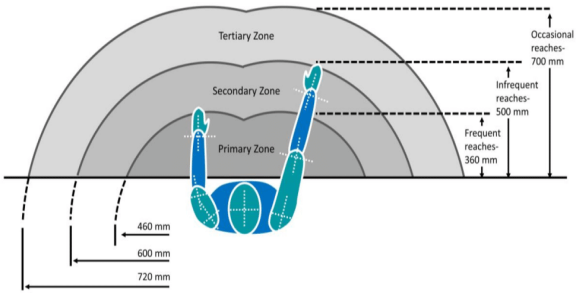

Fig.3 Horizontal Reach Zone [25]

Fig.4 Control Panel of a Plane [26]

Job design: While designing jobs using ergonomic principles, one must account for human differences such as size (length and width), strength, and ability to handle information for a wide range of users. These differences are then considered while designing the jobs, the workspace, and the equipment. This design can lower the risk of injury and improve overall performance by taking into account the needs, and limitations of workers. Increased productivity, quality, and job satisfaction are the benefits. Increased mistake rates and physical exhaustion, or worse, are the costs of failure.

Product design: If improperly designed, the simplest of items can turn into a nuisance to use. It was not a problem for our ancestors; they could just modify things to fit their requirements. These days, product designers often work separately from end users, so it is essential to use an ergonomic, user-centered approach to design. These includes asking people to test items, talking to them, and observing how they use the equipment. This is particularly crucial when it comes to "inclusive design," which involves designing commonplace items with elderly and disabled users in mind. Fig.5 shows different types of products incorporating ergonomic principles in design.

Fig.5 Different Types of Ergonomic Products [27]

6. Case Study: Analysis of Human-Machine Interface at a Computer Workstation

A human-machine system is any closed-loop system in which men and machines interact in performing a function to bring about, from given inputs, some sort of desired output, calling for continuous interaction between the man and machine. It is insightful to think about the man-machine interfaces as a complete information flow loop. Every component must work correctly if efficient job is to be accomplished.

Table 1 lists the various design issues that arise when computers get incorporated into workstations. An industrial engineer with experience in human factors must be able to identify, evaluate, and provide design solutions for a range of issues pertaining to the man-machine interaction in visual display terminal (VDT) workstations; specially as human-machine interface has evolved from buttons and diodes in control rooms, through web visualization to cognitive and intelligent space [28]. This brings us to the first maxim: design is the main goal of human factors.

Table 1: Design Problems Arising from the Introduction of Computers in The Workstation, and Knowledge Required to Solve the Issues.

Problem	Knowledge required to solve the problem
Work Posture	Anthropometry and biomechanics
Keying	Biomechanics
Size of screen characters	Perception, vision research
Layout of screen information	Cognitive aspects of human factors, cognitive science
Designing new system	Systems design and cybernetics
Environmental factors	Working environment design including illumination, noise, heat stress and cold stress

The application of these knowledges can be done in the various stages of Fig.6. wherein a human operator perceives information on a display. Upon interpreting the data, the most appropriate course of action is chosen. The action, which affects the information status on the display, is carried out manually as a control input. As a result, the computer screen acts as a prompt for the user to execute the next action.

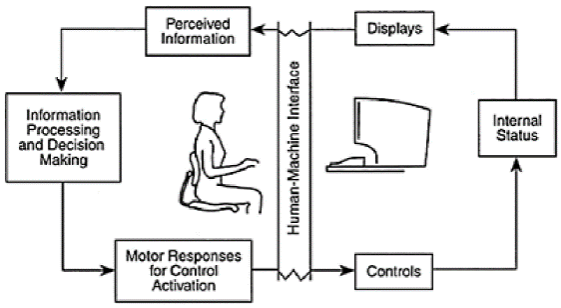

Fig.6 A Human Machine Interface [1]

It follows from the Fig.7 as shown below that interdisciplinary knowledge is required in the steps for design and redesign of a system for facilitating ergonomic principles in system. The existing situation must, therefore, first be analyzed, design solutions must be generated, and these design solutions must be analyzed for implementation. The framework may serve as the basis for integrating ergonomics in systems where they normally would not be, by formulating systems goal with ergonomic principles from the start. This ensured that the functional requirements are to have those "human values" i.e., ergonomic values, which can then be translated into a human-factored design.

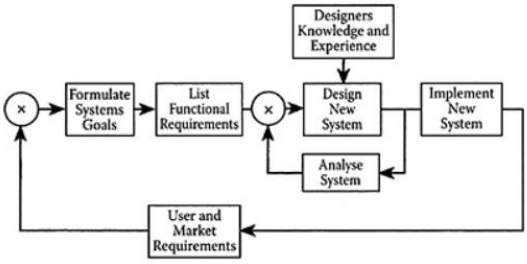

Fig.7 Procedure for Design and Redesign of a System [1]

7. Present Applications and Research of Ergonomics Across Universities in Bangladesh

In Bangladesh, research on ergonomics is progressing, albeit slowly, across industries to enhance worker productivity and well-being. In future research, the fundamental goals of furniture design for garment workers should be to improve productivity and lessen physical strain. To strike a balance between automation and worker well-being, researchers must also look into incorporating ergonomics into Industry 4.0. Educational and transportation industries are also to gain if ergonomic training and design of workstations for students, and truck-seats are sought after. Another scope of research could be the integration of ergonomics in agriculture, and animal husbandry with heavy emphasis on cost-optimization.

Fig.8 below shows an architecture drawing table which was designed and manufactured by the department of Industrial and Production Engineering (IPE), Shahjalal University of Science and Technology (SUST), Sylhet, Bangladesh. Thirty of such architecture drawing table with tool have been manufactured in the workshop of IPE. A newly designed classroom chair with table has been introduced in four departments of SUST, with ergonomics principles utilized.

Fig.8 An Architecture Drawing Table of SUST, Sylhet, Bangladesh

The department of IPE in (Bangladesh University of Engineering and Technology) BUET is also conducting research on workstation design, different product design, and manufacturing design using ergonomics.

8. Conclusion

With technology becoming more complex and necessitating human-machine/human-robot interactions, ergonomics ais becoming a crucial factor of importance in industrial engineering, industrial designing, production systems and designing, planning and control of systems, and industrial health and safety.

In industrial engineering and design, scientific principles are synthesized, formulated, and applied in order to study, design, install, and enhance integrated systems of men, materials, equipment, and management. In order to provide the graters system efficient, increased productivity, and efficient operating system, whilst improving the quality of life of the people and system in it, the importance of ergonomics in industrial design is profound.

An industrial engineer comprehending the field of human factors and capable of implementing concepts, techniques and principles of human factors engineering is undoubtedly the obvious person in workstation design and analysis, for the design of controls, for the design of displays of virtual display terminals in any human-machine system, and for the design of safe consumer products and working environments.

Recent decades have seen a rapid advancement in technology, necessitating the systematic and early consideration of human considerations throughout the design and development process. With the integration of more sophisticated technologies in industry, ergonomics in industrial design would need to be a focus for facilitating humans in those systems. This would require a certain amount of degree of change on how we approach industrial design from the get-go, since the changes later down the line becomes often very impractical due to the intricacy of many new and changed systems. Frequent retrofits are also extremely expensive, and would require high degree of system training of workers compound the cost associated with it. Therefore, it is imperative that the early designs of industrial systems, consumer or industrial goods, industrial and non-industrial equipment, and operating environments take human considerations into account as much as feasible, for the smoothening of operations in any industry or workspace.

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