

# ENGINEERING PSYCHOLOGY/HUMAN FACTORS/ERGONOMICS

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## Introduction

Ergonomics and human factors seek to enhance the fit between individuals and their work environments by applying knowledge of human abilities and limitations to the design of operational processes, system interfaces, training, and performance aids. Developed along similar lines as industrial and organizational psychology, the career field owes much of its early successes to applications in support of military efforts in World War II. Of these early success stories, one of the most notable involved redesigning pilot controls on military aircraft in response to a large number of pilots flying their airplanes into the ground. Despite extensive training, the pilots were not able to control their aircraft under stressful emergencies; primarily because system design was in contrast to pilot expectations of how things should work. A lack of standardization between different aircraft models was improved by modifying the handles of the landing gear control into the shape of a wheel and the handles of the aileron control to resemble a wing; eliminating “belly landings” almost overnight.

What may seem trivial sixty years after the fact is actually an exemplar for the profession. Real-world operational problems (i.e., belly landings) lead to an investigation of work processes (i.e., analysis of pilot tasks during landing) that serves to identify a set of constraints that impact performance (i.e., pilots must rapidly discriminate between two identical controls) and lead to design modifications (i.e., alternative handles). This principled approach to the assessment and design of complex socio-technical systems (i.e., aircraft cockpit) is the cornerstone of the field.

In the ensuing 60 years, the field has expanded and human factors is often presented as a catch all label for a discipline that encompasses tasks familiar to engineering psychology, industrial engineering, ergonomics, systems engineering, human computer interface design, and software usability. Most recently, human factors, along with much of psychology, has been greatly influenced by advancement of cognitive science. A variety of theories and approaches, including naturalistic decision making, shared mental models theory and metacognition, to name a few, have markedly influenced current approaches. The result is a greater focus on the information processing and decision making aspects of job performance. Furthermore, the many recent advances within cognitive engineering and cognitive psychology provide human factors professionals with additional tools for knowledge elicitation and measurement of knowledge structures.

This broader context, leveraging interdisciplinary methods to enhance the relationship or fit between humans and work environments, can be thought of as a method of human-centered engineering (HCE). The objectives of HCE, therefore, are to understand human skills and knowledge, study and analyze work environments, design better interactions between human and technology, and engineer better teams and organizations. The underlying intention is to prepare and enable humans to excel at their work. The use of models within HCE, both descriptive and executable, provides a framework to analyze work processes and identify opportunities and means for performance enhancement. Within this context there remains a focus on design that harks back to landing gear

controls and views the work environment as changeable and a source of constraints on human performance. There are several defining characteristics of the HCE approach.

### **Systems approach**

Within HCE, the human operator is the central figure within a complex sociotechnical system composed of the operator, the technology (i.e., tools, computers, etc) necessary to complete the required tasks, and the work environment (i.e., organization, physical setting, task requirements). These systems are characterized by common purpose, shared information networks, interactions between components, and imposed constraints that influence behaviors. Due to system complexity a structured, systematic approach to design and evaluation is required, simultaneously considering all components across the sociotechnical system.

A variety of models have been proposed to describe the system approach and the systems development process. Common to all are a set of stages that begin with a representation of the system requirements (i.e., operational needs) that facilitate a design process and evaluation methods. Additionally, they identify a wide range of HCE methods (i.e., task analysis, cognitive work analysis, decision support systems, etc.) that can be used to enhance the fit between the components of a sociotechnical system. Looking across these models, one is aware of a continuum of influence on the work environment. Within this context, HCE methods to enhance fit can be applied at the person (e.g., training), technology (e.g., interface design) or organizational level (e.g., team design).

### **Model-based approaches**

The complexity of the systems approach provides a comprehensive method to understand, assess, and design for performance. This also creates a requirement to represent a variety of detailed parameters to describe a system. As such, the use of models within HCE has emerged as a key enabler to apply the system approach to ever larger and more complex systems. Models provide a useful mechanism to structure the design space and highlight the constraints that will impact overall system performance. Many modeling approaches exist and a review is beyond the scope of the current entry.

One important benefit of a model-based approach is that it provides both reactive and proactive approaches. In the reactive mode, models can be developed to describe current systems, diagnose performance, and highlight areas for improvement. In a proactive mode, models can be used to predict and develop reasonable designs, providing both cost and risk reduction. Models are limited by the fact that there are representations of real-world systems and require some means of validation. Therefore, the results of modeling efforts ultimately require evaluation with prototype or test systems. The outcomes of these evaluations serve a dual use as they can be used to iterate and refine both the models and the design.

### **Knowledge Elicitation**

Traditional systems approach and model based approaches require an understanding of overall system processes. This understanding develops from a variety of knowledge elicitation methods employed by HCE, including:

- *Cognitive Task Analysis*: This approach is a group of techniques that identify the cognitive processing requirements that are required when working with complex computer-based systems. To identify these requirements, the analyst interviews workers in the context of the work environment (contextual inquiry), about critical incidents, or critical decisions.
- *Cognitive Work Analysis*: This constraint based method is performed in five stages. Each stage further constrains the next. The first identifies the physical work environment or system functions that must be considered. The second stage determines the tasks that must be accomplished. The third stage delineates the strategies that can be used in accomplishing those tasks. The fourth stage focuses on the socio-organizational aspects of completing the tasks using that strategy. The final phase defines the required worker competencies.
- *Needs Analysis*: This method identifies the goals of the system, the environmental factors which will impact the worker and the needs of the system and the workers to reach these goals in this environment. There are several methods for obtaining this information including interviews, observation, literature review, and critical incident analysis. Some of the information that will be gathered in this analysis includes, for example, the protective equipment to be used and if it interferes with operation or maintenance, tasks to be performed to meet the goals, and information requirements to complete the tasks.

There are many variations on these and other techniques based on the position within the continuum of influence and the nature of the work. A central component of each, however, is a focus on the human cognitive and information processing requirements.

### **Process Design**

Central to the systems approach are the interactions among the components of the sociotechnical system. As such, core to a HCE approach is assessment and design of the processes for using a system. Processes may be developed in parallel with new technologies or can be designed around existing technology. In either case, the objective is to improve the fit between worker and environment. A well designed process is one where individuals can easily learn and efficiently perform their tasks and understand the other functions in the system. There are two components of process design: Task Analysis and Work Flow Analysis.

*Task Analysis* is the documentation of the tasks that are performed and the steps that comprise these tasks. The method to complete this depends on the nature of the work. Analysis of cognitive tasks should be obtained through interviews often centered on atypical incidents; physical tasks should be observed. The information and equipment used, the time required, and the variety of methods employed should be included (especially between experienced workers and novices or documentation).

In the *work flow analysis*, the analyst combs through the data documented in the task analysis looking for constraints, redundancies, and clusters of actions that require the same equipment or information. These are often demonstrated in those differences

between experts and novices. The analyst then develops a new process that eliminates redundancies and increases efficiency by having actions with the same equipment or information performed consecutively. These workflows must also consider infrequent but predictable situations (e.g., errors, increased volume, etc). The more complex the system is, the harder it is to identify and evaluate all possible workflows for all possible situations. Therefore, models based on the constraints and the task analysis can be used to determine the best workflow for both typical and infrequent situations.

## **System Design**

One of the most effective ways to enhance the fit between the human and the work environment is to design a system in which each of the following factors are considered:

- (1) Technological Constraints
- (2) Environmental Factors (Temperature, Ambient Noise Levels, etc...)
- (3) Goals of the System
- (4) User Capabilities and Limitations.

While these factors provide design goals, a more principled approach is needed to achieve desired outcomes. While some may view system design as a structured and formalized process, it is less rigid in reality. A variety of design methods have evolved over time, providing the design practitioner with different approaches for different applications. Sample approaches are listed below; however, it is important to identify the commonalities across them to understand the core elements of systems design.

A review of the system design literature highlights key features necessary to ensure an effective design. The design process must create an integrated sociotechnical system that considers the organization (formal and informal), the interactions between the human organizations and the technological systems, and the constraints imposed by the environment. The process must also consider multiple operational situations or scenarios and allow for comparisons among these scenarios using prototypes or models. The design process must include the user throughout life-cycle development. Finally, the process must include iterations to facilitate redesign and modification, especially to make affordances for technological changes.

### **Example system design approaches**

- *Traditional system design*: linear or waterfall approach that spans from conceptual design to physical design to implementation and evaluation. This is generally believed to have become obsolete as the capabilities of system technology have outpaced designers' abilities to understand all the design ramifications of these technological advancements.
- *Sociotechnical systems approach*: design driven by the analysis of the environment, the social system, and the technology system with the objective of maximizing the fit between the three components.

- *User centered design*: system design in which the primary objective is to design systems that explicitly satisfy human operator task and information processing requirements. Emphasizes user involvement throughout the design process.
- *Participatory ergonomics*: related to user centered design with user involvement throughout the design process, but goes further, allowing users, with expert supports, to complete the design.

### **User interaction and usability**

The user interface (UI) is the primary means by which a user interacts with a system. To the user, however, the UI *is* the system; very rarely does the user have a strong comprehension of how the system is actually working. Thus the UI must serve two functions: (1) provide users with an understanding of how the system functions and (2) permit users to operate the system in a manner that is most natural for them. Therefore, the flow of information is a critical component to designing a user friendly UI. There are several guiding cognitive-perceptual principles to consider including:

1. Logical display groupings (e.g., follow gestalt principles, etc)
2. Consistency of look and function (e.g., like items look and function similarly and vice versa)
3. Labels are legible, visible, meaningful and discriminable
4. Controls are reachable and movable by the population in work environment

These are not all of the concepts that must be considered, but it is clear that UI design in particular and system design in general can enhance or impede the effectiveness of the system.

### **Summary**

HCE serves as a global terms to describe a variety of methods, tools, and approaches associated with human factors, ergonomics, engineering psychology, industrial engineering, ergonomics, systems engineering, human computer interface design, and software usability. As a discipline, HCE represents a powerful method to enhance the fit between humans and their work environment.

### **Further readings**

Norman, D. (2000). *The Design of Everyday Things*. London/New York: MIT Press.

Reason, J (1990). *Human Error*. Cambridge University Press

Salvendy, G. (Ed.). (1997). *Handbook of Human Factors & Ergonomics, Second Edition*. New York: John Wiley and Sons.

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