Human Factors and Ergonomics in Manufacturing, Vol. 10 (4) 363–367 (2000)

Preface: Cognitive Engineering in Automated Systems Design

This special issue was motivated by an apparent paucity of research on applications of cognitive engineering principles in the design of complex systems including maintenance, manufacturing, and transportation systems. *Cognitive engineering*, in simple terms, is the discipline of considering human thinking (or cognition) in designing human-machine systems. It has been formally defined as the intersection of human factors engineering and experimental psychology (Wickens, 1992). It involves developing a knowledge base on human information processing capabilities and formulating human-centered system design alternatives. Cognitive engineering applies a human behavior and performance perspective to system design. Aspects of human cognition found to be critical in designing human interfaces for complex systems include perception, attention, memory, situation awareness, and decision making or response selection. Ancillary factors include cognitive workload, stress, and personality factors.

Substantial empirical research has been conducted to describe human cognitive performance capabilities in laboratory experiments involving low-fidelity simulations of, for example, flexible manufacturing system (FMS) control, aircraft flight tasks, air traffic control, and so forth. Unfortunately, little fieldwork has been done to describe the impact of real-world system design on human performance. Applied cognitive engineering research is important because prior to the 1990s the majority of errors and failures of complex human-machine systems, such as catastrophic airliner crashes, were attributed primarily to operator error (Heinrich, Petersen, & Ross, 1980). A new paradigm has developed within the recent past, however, identifying poor system design as the root cause of human errors and malfunctions, which are merely a symptom of greater design flaws. With this in mind, there is a need to describe methods for improving real, complex system design based on human information processing capacity and to document successes and failures in the application of cognitive engineering principles to automated systems.

The purpose of this special issue is to provide a sample of current methods and empirical studies related to the application of cognitive engineering to the design and operation of complex systems. Our goal for the special issue is that it will provide researchers and practitioners working in the field of manufacturing with insight into the need for, and potential effectiveness of, considering human cognition in designing advanced manufacturing technologies. We also hope that the special issue will promote cross-fertilization of the two broad research areas of manufacturing engineering and cognitive engineering. Recent research (Kaber & Usher, 1998) has demonstrated that many methods developed through manufacturing science with the objective of reflecting human information processing in, for example, supervisory control workstation design for a FMS have previously been formulated through cognitive engineering research for dynamic control systems such as aircraft. The special issue may also serve to promote awareness among cognitive engineering researchers of similar work on going across different task domains. It is our belief that it is essential for these aspirations to be achieved for appropriate design and prescription of use of rapidly advancing manufacturing technologies.

The special issue begins with an article by C. Harvey and R. Koubek on "Cognitive, social, and environmental attributes of distributed engineering collaboration," which discusses the influence of engineering design task characteristics, new collaborative design technologies, and group development and dynamics on engineering collaboration. Harvey and Koubek translate these effects into a model and method for understanding and facilitating group engineering collaborations. The article provides a starting point for validating a model of collaborative, distributed engineering design.

The next two research articles in the special issue are primarily empirical in nature and describe experiments with the objective of relaying the impact of advanced automation technologies on human cognition and performance in complex systems control. The second article in the issue, by N. Ward, focuses on, "Automation of task processes," and presents investigations of human performance in interacting with intelligent transportation systems including automobiles with automated cruise control, automated steering control keeping the vehicle in the center of a lane, and automated route guidance devices. This article is motivated by the need for human safety, efficiency, and comfort in working with increasingly sophisticated advanced automation technologies. The potential deleterious effects of these devices on human driving performance are detailed, including reduced situation or system awareness and responsiveness to critical events (impending collisions), due to the operator being removed from the vehicle control loop. Ward primarily describes automation-induced decrements in situation awareness, or human awareness of environmental information relevant to successful task performance (driving), the meaning of that information in the specific task context, and the ability to predict the future state of the environment and system (the driving environment and automobile; Endsley, 1988). The article establishes the importance of considering these effects as part of a formal engineering design protocol in order to maximize the benefits of automation. The article features a framework and methodology for this process. Ward relates his work to the manufacturing domain.

In the next article in the special issue, "Design of automation for telerobots and the effect on performance, operator situation awareness and subjective workload," D. Kaber, E. Onal, and M. Endsley discuss the need to empirically validate the hypothesized effectiveness of different degrees of human-automation interaction in complex systems control for optimizing performance during normal operating conditions and failure modes. They review literature on taxonomies of levels of automation developed by considering human and technological capabilities for performance in various contexts, including automobile navigation with an expert system, teleoperator and telerobot (remote robot) control, and dynamic system control, in general (e.g., aircraft, air traffic management systems). The negative effects of traditional automation, that is automating as many system functions as possible and subsequently defining the human operator's role in the system, are presented including loss of operator situation awareness due to removal from system control loops. The authors present an experiment using a high-fidelity simulation of a telerobot material handling system to assess the usefulness of intermediary levels of automation between human manual control and full automation for enhancing telerobot performance and operator situation/system awareness. Kaber et al. investigated system performance under normal modes of robot control and simulated system failures. The article also presents the effect of automation of the material-handling task on human perceptions of workload. The benefits of unique telerobot system function allocations to human and automated controllers are described.

The remainder of the special issue is devoted to presentation of ergonomics research results applicable to advanced and traditional manufacturing systems design, including an article by J. Usher and D. Kaber entitled, "Establishing information requirements for supervisory controllers in a flexible manufacturing system using goal-directed task analysis." The article identifies supervisory controller information requirements for process control intervention in FMS operation. The information requirements are used as a basis for formulating general system interface content guidelines. Usher and Kaber used a form of hierarchical-task analysis to analyze FMS operator goals toward achieving planned system output including scheduling jobs to meet due dates, avoiding system bottlenecks, expediting orders, and maintaining critical system functions. This method yielded detailed information on what tasks are required of operators to meet these goals and what they need to know to perform the tasks. This study was motivated by recent dramatic technological changes in complex manufacturing systems and changes in the role of human operators in controlling the systems. Specifically, the work was targeted at the challenge of ensuring that new advanced manufacturing technology interfaces are supportive of human performance in machine system control.

Following this article, the special issue presents a basic human factors study by A. Chan, A. Courtney, and K. So on hand-control and dial-display design relevant to manufacturing system interfaces. The article is an excellent counterpoint to Usher and Kaber's writing, which offers general supervisory control interface information content design guidelines. Both articles are intended to provide interface design guidance to optimize the flow of information between humans and machine systems and to improve overall systems performance. Chan et al. address the challenge of considering population stereotypes in using circular indicator displays in conjunction with translatory system controls, specifically thumbwheels. They examined the preferences of Hong Kong Chinese in using horizontally and vertically oriented thumbwheels to respond to target markers presented on a dial gauge in which the initial position of a system status pointer was varied. A real-world example use of this type of technology can be found in process control interfaces in which multiple circular displays are arranged in a line and operators globally process the displays detecting deviations in the status of multiple systems from the nominal simultaneously by looking for misalignments between display pointers. This type of display could be used as a trigger to process supervisor control intervention to recover machine systems from error states. Chan et al. found robust control stereotypes for thumbwheels positioned in different planes to be dependent upon initial positions of pointers in dial displays. They provided specific design recommendations for thumbwheel controls.

In the final article in the special issue, J. Sauer, B. Zimolong, and S. Ingendoh address the need to reconsider the role of computer-numerical controlled (CNC) machine operators in organizations today. Their consideration of this role is similar to Usher and Kaber's discussion of historical changes in the role of FMS operators. Sauer et al. offer that as advanced manufacturing technology progresses one would expect the operator's job to require less skill. However, given the trend of companies today to utilize a more holistic approach to quality management, the contrary has been found to be true. That is, the operator plays a more important role in improving the efficiency of the manufacturing process and its contribution to quality management. This article presents the results of a study whereby qualitative methods are employed to gather information from six advanced mechanical engineering organizations located in Germany. The authors explore the role of the operator and its interaction with other functional areas within the organization, all within the context of quality management. Based on these results, the article makes recommendations concerning redesign of the operator's job.

We thank the editor of *Engineering Design and Automation*, Hamid R. Parsaei, and the editors of the *International Journal of Human Factors in Manufacturing*, Waldemar Karwowski and Gavriel Salvendy, for providing us with the opportunity to make a contribution to the publication of cognitive engineering research and their support during the development of this special issue. I (Kaber) also thank my coeditor, John Usher, for assuming responsibility for handling the review of the article I authored to ensure the integrity of the journal review process and to maintain the anonymity of the reviewers. As well, we thank Waldemar Karwowski for handling the review of the paper John Usher and I coauthored.

A total of 12 manuscripts was submitted for this special issue, with topics including cognitive engineering in system maintenance training protocol design, cognitive engineering in air traffic control system design, human-automation communication in aircraft cockpits, human factors in automated traffic incident detection system design, user issues in web browser interface design, and design of passive controllers for robot motion control based on human motion patterns. Through a great deal of editorial review, several of these articles were not selected to appear in this publication based on relevance to the topic of the special issue. The majority of articles were accepted for publication; however, many manuscript resubmissions were not made after initial reviews were completed.

We are indebted to the outstanding assistance provided by all reviewers of the published and unpublished manuscripts. The reviewers were Clint A. Bowers, Hugh David, John V. Draper, Mica R. Endsley, Eileen B. Entin, Peter A. Hancock, Craig M. Harvey, Debra G. Jones, Richard J. Koubek, Emrah Onal, Victor A. Riley, S. Armida Rossiles, Nicholas J. Ward, and Jeffrey C. Woldstad. Their careful reviews and editorial suggestions improved the scientific rigor and clarity of communication in the special issue.

Finally, we thank the authors for submitting their research articles. We greatly appreciated their patience and the professional responses to revisions we asked them to make. Cognitive engineering is becoming increasingly critical in the design of human-machine systems as substantial advancements are made in the development of automation technologies. It is crucial that we consider the human in the automated systems design process to prevent potential system errors and failures. We hope that this special issue will encourage increased research and application of cognitive engineering methods and principles in manufacturing research.

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