SPECIAL SECTION PREFACE

Returning Human Factors to an Engineering Discipline: Expanding the Science Base through a New Generation of Quantitative Methods — Preface to the Special Section

ENGINEERING IN HUMAN FACTORS

Human factors is a disparate discipline. Academic programs in human factors are found in departments of industrial engineering, psychology, mechanical engineering, architecture, optometry, and elsewhere. Human factors professionals are employed in a variety of industries, at many levels in the organization chart, and hold an equally disparate array of job titles. However, many hold job titles along the lines of "human factors engineer," and many academic programs housed outside engineering departments still refer to an engineering component in their program – for instance, many human factors programs in psychology departments are termed *engineering psychology.* Thus, despite the fact that the field is far from uniform or unitary, there is clearly a strong engineering presence.

Is this merely a label or is this how human factors is actually practiced? The Accreditation Board for Engineering and Technology (ABET, which accredits for engineering higher education in the United States) defines *engineering* as "the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize economically the materials and forces of nature for the benefit of mankind" (ABET, 2003, back cover). For the purposes of this discussion, we will focus on the "mathematical and natural sciences" aspect of this definition. To what extent do mathematical and natural sciences guide work in human factors? It is our contention that the answer to this question has changed over time and, indeed, has been somewhat cyclical.

Consider two relatively influential publications from two different points in time: 1984's *Advances in Man-Machine Systems Research* (volume 1), edited by Rouse, who was originally trained as an engineer, and 2001's *Advances in Human Performance and Cognitive Engineering Research* (volume 1), edited by Salas, who was originally trained as an industrial/organizational psychologist. The Rouse volume is replete with equations and formalisms, whereas in the more recent Salas volume such presentations are largely (though not entirely) absent. This is in no way a criticism of the work that appears in the Salas volume, but we believe this reflects the realities of the problems approached by human factors researchers over that span of 17 years. In particular, many of the equations and formalisms presented in the Rouse volume deal with control theoretic models of manual control, whereas the Salas volume tackles a much more cognitively oriented set of issues. In those intervening 17 years, obviously psychological constructs such as "situation awareness" have risen to the forefront in the field of human factors. This orientation has allowed human factors practitioners to address complex problems in domains with much broader scope than manual control.

We see this shift as being driven, at least in part, by a raft of new technologies. These technologies have tended to shift the responsibilities of human operators from manual control to monitoring and directing complex, automation-driven systems. The cockpit of a commercial 777 jetliner produced in 2001 has as much on-board computer processing power as many universities and medium-sized corporations had, organization-wide, just 20 or 30 years ago. Pilots of such modern aircraft may deal with manual control problems if they choose not to

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use the automation available to them, but now they have a host of other systems to monitor and manage.

As the differences between the Rouse (1984) and Salas (2001) volumes reflect, this change in the character of many essential human factors problems has naturally given rise to a change in methodology and terminology. Even the best, most quantitatively accurate manual control model does not scale up to issues of crew coordination and training. However, this change has de-emphasized, at least to some extent, the use of methods and practices found in mathematics and natural sciences, a "de-engineering" of the field. Although this was probably necessary to scale up to modern human factors problems and issues, we believe the advancement of quantitative practices is critical to the continued development of human factors as an engineering discipline. Naturally, this raises the question as to whether such methods even exist for problems at the level of most modern human factors issues. Although the answer is not yet affirmative for every extant human factors domain, we believe there is a new movement toward the development of engineering-style approaches appropriate for problems in human factors.

This movement has been centered on quantitative models, which play a key role in modern engineering practice. In many engineering domains (including many human factors areas), the space of design possibilities is too large to allow empirical assessment of it all. Some winnowing of the space is accomplished through guidelines and intuition, but truly novel designs generally fall outside the scope of such techniques. Thus, in many engineering areas, design guidance and evaluation rely on quantitative modeling, and modeling practices have become codified enough that software tools to support such modeling are widely available. In fact, use of such tools is so standardized that thousands of undergraduate engineering students are trained on them each year. Human factors is certainly not as far down this road as other disciplines are, but at least a road map may be starting to emerge.

This special section is the third to emphasize the application of new model-based engineering techniques to the new human factors issues. These special sections and special issues have spanned the course of 6 years and three journals. The first appeared in the journal *Human-Computer Interaction* (Gray, Young, & Kirshenbaum, 1997) and was titled "Cognitive Architectures and Human-Computer Interaction." This issue gathered papers from representatives of four cognitive architectures – Soar (Howes & Young, 1997), LICAI (Kitajima & Polson, 1997), executive-process/interactive control (EPIC; Kieras & Meyer, 1997), and ACT-rational (ACT-R; Anderson, Matessa, & Lebiere, 1997) – and asked them to address practical human factors issues that arose in the context of human-computer interaction. Although these presentations were more theoretical than applied, they pointed toward new quantitative methods emerging from theoretical cognitive science that could be applied to engineering issues.

In 2001 the *International Journal of Human-Computer Studies* (Ritter & Young, 2001) presented a special issue titled "Using Cognitive Models to Improve Interface Design." The focus there was more applied as well as broader in scope than the first special issue was, moving away from simple human-computer interaction issues to include a cognitive simulation-based model of driving an automobile. The editors' introduction discussed the integration of the engineering modeling approach represented by the papers with more behaviorally oriented methods such as usability testing.

Human factors issues are broader than the domain of human-computer interaction. In light of that, this special section includes a wider set of quantitative methods and a wider set of problem domains than did either of the previous special issues. This difference reflects not only the breadth of human factors but also the breadth of quantitative methods and approaches found in other engineering disciplines. Despite the fact that both of us are often associated with particular quantitative approaches, we believe that the scope of the problems addressed in human factors is far too broad to be covered by any single quantitative approach or formalism; thus this special section represents the important diversity in the nature and goals of the approaches as well as in the domains covered. However, all of the papers have in common a strong quantitative focus that can help form the basis for a renewal of engineering approaches in human factors.

THE PAPERS AND THEMES OF THIS SPECIAL SECTION

Submitting a paper to *Human Factors* entails hard work on the part of the authors and reviewers with no guarantee of eventual success. We received 20 submissions for this special section. All were topical and interesting, and all served to push the state of the art in human performance modeling. However, in the judgment of our hardworking reviewers, only 9 submissions presented work that was sufficiently complete to allow us to ask the authors to revise and resubmit in time to meet the deadlines for the special section. Of the 9 resubmissions, 7 were eventually accepted for the current issue. None of the papers that we selected is the last word on its subject. Rather, each is a progress report on an important development in quantitative formal models of human performance. In the rest of this section, we provide an overview of each of these 7 papers.

Motor control is a classic area of interest for human factors practitioners. Over the last decade, researchers in this area have developed complex models that account for a wide range of movement in complex task environments. Jax, Rosenbaum, Vaughan, and Meulenbroek provide a tutorial covering the research that has come out of their lab in the last decade. Their paper provides an overview of their model and of the data that support it, as well as some discussion of the human-factors-related implications of their work. Those in the human factors community interested in the current state of the art in movement theory will find this paper to be an invaluable source.

The two papers we accepted in the area of visual cognition present an interesting contrast. The papers by Peebles and Cheng and by Witus and Ellis both report models developed for their work; however, the nature of the models and their application could hardly be more different. Peebles and Cheng take up a topic that has an extensive history of research and discussion in the pages of this journal (e.g., see the references and extensive bibliography provided by Gillan, Wickens, Hollands, & Carswell, 1998) – namely, why are graphs hard to read? They use the ACT-R architecture (Anderson & Lebiere, 1998), which was not developed for the purpose of modeling the comprehension of graphs, and develop an integrated model of cognition, perception, and action for their task. The model acts as a “simulated user” and interacts with the same software as do the human participants. The model both predicts and provides an explanation for the cognitive, perceptual, and motor operations (including eye movements) required by human participants in a graph-reading paradigm.

Witus and Ellis began with a different and more specific quest – namely, to develop a tool that would predict human detection of camouflaged, nonmoving, surface military vehicles. The model they developed, VDM2000, integrates basic research results from fields as diverse as early vision, object recognition, and psychophysics. We see VDM2000 as a classic engineering model in that, although it lacks the theoretical integration of its component parts that is the hallmark of systems such as ACT-R, it provides a pragmatic integration of otherwise isolated microtheories, and it is very successful in doing the job it is designed to do.

Taatgen and Lee are concerned with how the components of cognition, perception, and action that are present in novice performance combine to become the basis for smooth and integrated expert performance. Their task environment is the Kanfer-Ackerman air traffic controller task© (KA-ATC; Ackerman & Kanfer, 1994). Based on a detailed task analysis, Taatgen and Lee built a novice model of this complex laboratory task that matched the performance of human novices. They then ran the model through many trials of the KA-ATC task. With experience, the model developed expertise in this task that strongly mimicked the expertise of human participants when given the same experience. Hence Taatgen and Lee have demonstrated the beginnings of a new tool for human factors. Not only does the running model demonstrate the completeness of the task analysis, but also the model’s ability to acquire expert levels of performance suggests that instruction and practice based on the original task analysis would suffice to result in expert performance.

Schweickert, Fisher, and Proctor provide an outstanding tutorial on model-oriented task analysis as well as an interesting methodology for accurately estimating the duration of task components when the only source of data is expert judgment. We are very excited by this paper and see it as suitable for use in an advanced undergraduate course on human factors methods or in a graduate seminar on task analysis. The instructional use of the paper is facilitated by the authors' Web site, which provides an extensive set of Excel™ files that serve as working examples for the concepts and techniques discussed in the paper.

Weiss and Shanteau provide a tool with which to assess human expertise. This issue is an important problem in much of human factors research. In areas outside our personal expertise, how do we know that the people who have been identified to us as "experts" really are experts? This is an especially sticky problem in cases where an objective "gold standard" is ill defined or difficult to measure. Weiss and Shanteau present a novel and fairly general approach that diverges from the traditional "expert performance" perspective (e.g. Ericsson & Lehmann, 1996) and that will, we hope, spark both spirited discussion and useful applications.

The last paper in our special section is by Dorsey and Coovert. These authors introduce the human factors community to the use of fuzzy systems for modeling human decision making. The fuzzy system is an important mathematical technique that has been applied to many different areas in recent years. Dorsey and Coovert provide a comparison of fuzzy systems with more standard techniques (e.g., multiple regression analysis) of modeling decision making.

SUMMARY AND CONCLUSIONS

Newell and Card (1985) warned the human factors community that the way to deal with scientists, engineers, and designers was not through the use of platitudes or by advocating the empirical testing of an infinity of design alternatives but, rather, through the use of predictive and reliable quantitative techniques. As the scope and scale of the issues that the human factors community was asked to consider expanded, the tool chest of quantitative methods seemed to diminish. That situation appears to be changing. As the papers in this special section show, the science base and techniques available for applying that science through use of quantitative formalisms have progressed. The pendulum is swinging back, and human factors engineers are in the ascendance. Engineering quantitative formal models of human performance is the wave of the present and represents an important part of the future of our profession.

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