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Issues and Challenges in Human Performance Modeling in Aviation: Goals, Advances, and Gaps

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As in many areas in Human Factors, human performance modeling has a long history in the aviation community. The real-time dynamism and safety criticality of the domain calls for the most advanced tools possible, and also provides a strong testbed for any modeling formalism Recent work has demonstrated significant advances in this field in the last decade, both in terms of applications to aviation and in terms of the domain pushing back and advancing the state of the art in modeling. Despite these advances, however, there is still a gap between even the most advanced models and engineering practice. In this panel, we intend to discuss all of these aspects of human performance modeling in aviation.

OVERVIEW

Models of human performance to support human factors work in aviation are nothing new. For example, control-theory based models for manual control have been around for decades. However, modern technology has changed flight considerably over those decades. In the modern jetliner cockpit, for instance, a substantial portion of what used to be manual control is now handled by the flight management system. Pilots in these contexts now also act as supervisors of complex automation. Similarly, the demands of air traffic control have changed with the increased load on the air travel system. To what extent can current modeling methods assist with these kinds of problems? Do they scale up?

In their 1990 volume, Elkind, Card, Hochberg, and Huey essentially concluded that the answer was no, the models of that time were not really up to the task. However, there have been substantial advances in human performance modeling since then. It now seems time, particularly given the recent volume by Foyle and Hooey (2008), to re-examine such questions. Are contemporary modeling methods able to help solve applied problems in aviation?

Of course, there may be value in modelers working in aviation for other reasons. The real-time dynamism and safety criticality of the domain stresses the capabilities of many of these modeling formalisms, and attempting to address these issues may lead to useful theoretical progress which may ultimately lead to methods which can more adequately address such problems.

What we intend to discuss in this panel is the full range of issues and challenges in applying performance modeling methods to aviation human factors. The panel represents a diverse and experienced set of researchers who have all approached this problem from different angles, and thus will offer a variety of perspectives on how aviation and performance modeling relate to one another.

NEXTGEN REQUIREMENTS FOR HUMAN PERFORMANCE MODELING AND SIMULATION

Terry Allard, Federal Aviation Administration

Computational human-system performance modeling and other formal analytic methods have matured from psychologically plausible theoretical models of human information processing to engineering models that could be applied to complex socio-technical systems. The question for the FAA is whether those technical developments have matured enough to help transform civil aviation, reducing air traffic delays, increasing air traffic capacity and improving safety.

The FAA and collaborating agencies have embarked on an ambitious plan to meet an expected doubling or tripling of demand for air traffic services over the next twenty years. The Next Generation Air Transportation System, or NextGen, will transform the roles, responsibilities and capabilities of air and ground stakeholders throughout the system. Highly automated

NextGen systems will introduce new forms of human error and safety risks into the operations of the National Airspace System. Supervisory control of large numbers of aircraft by air navigation service providers will reduce situation awareness regarding individual aircraft. Extensive collaboration and negotiation among stakeholders will create new opportunities for communication errors. Network-enabled operations have the potential for creating information overload on all stakeholders in the system. High levels of automation could produce low workload conditions leading to human error in abnormal conditions requiring immediate human intervention. Competing goals and benefits among air and ground stakeholders must be optimized and authority must be clearly defined and communicated for safe system performance when demand exceeds airspace capacity due to system perturbations such as adverse weather conditions. Mixed equipage airspace could cause confusion about aircraft capabilities compromising the safety of tactical self-spacing by flight crews and the effectiveness of strategic traffic management by air navigation service providers and airline dispatchers. New display concepts and decision support tools are needed to guide probabilistic decision-making. All of these factors must be considered in evaluating NextGen system performance and safety risk from concept development, through test and evaluation to acquisition and operations.

Computational and analytic methods must be developed and validated with current operations and systems and applied to new concepts, technologies, policies and systems. Challenges range from individual human-computer interaction, to individual and team design and decision support, situation awareness with increased span of control, multi-agent interaction including human-automation, and human-system performance metrics. The most difficult challenge will be applying modeling and simulation of current systems to the myriad NextGen possibilities. We must define personnel selection and training standards for flight crews and ground personnel matched to evolving NextGen operational requirements, define design standards for air and ground technologies and procedures that minimize human error, develop and apply fast-time human error modeling technologies that predict human error vulnerabilities and system risk in NextGen systems, and understand cost-benefit trades in dynamic, integrated and distributed systems. Can we do it? How do we get there?

THE NASA HUMAN PERFORMANCE MODELING PROJECT: IMPLICATIONS FOR FUTURE MODELING EFFORTS

David C. Foyle, NASA Ames Research Center
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The National Aeronautics and Space Administration (NASA) as part of the Aviation Safety and Security Program (AvSSP), recently completed a 6-year Human Performance Modeling (HPM) project (documented in a recent book edited by Foyle & Hooey, 2008). The NASA HPM project followed the approach of applying multiple cognitive modeling tools to a common set of aviation problems. Five modeling teams attempted to predict human error and behavior given changes in system design, procedures, and operational requirements. The five human performance modeling tools applied in the NASA HPM project were: Adaptive Control of Thought-Rational (ACT-R); Improved Performance Research Integration Tool/ACT-R hybrid (IMPRINT/ACT-R); Air Man-machine Integration Design and Analysis System (Air MIDAS); Distributed Operator Model Architecture (D-OMAR); and, Attention-Situation Awareness (A-SA) model.

The NASA HPM project focused on modeling the performance of highly skilled and trained operators (commercial airline pilots) in complex aviation tasks. Leveraging existing NASA data and simulation facilities, NASA was able to offer rich data sets of highly skilled operators performing complex operational aviation tasks to the five modeling teams for use in model development and validation. Two task-problem domains were chosen for study and application of the modeling efforts representing different types of aviation safety problems, and spanning NASA's charter. The two aviation domain problems addressed by the modeling teams of the HPM project, were:

1) Airport surface (taxi) operations (Problem time frame: Current-day operations; Problem class: Errors (taxi navigation errors); and,

2) Synthetic vision system (SVS) operations (Problem time frame: Future operations; Problem class: Conceptual design, concept of operations development). Note: SVS is a new display technology for a visual virtual representation of the airport environment from a digital database via computer-generated imagery.

Because of the relatively unique opportunity to apply multiple HPMs to two different aviation-domain problems at different phases of the design lifecycle, the project revealed several important considerations regarding the utilization of the models for aviation system design and evaluation. Specifically, important considerations related to model selection, development, interpretation, and validation were observed. First, with regards to selecting a model, the philosophies, approaches, and underlying assumptions of the models differ widely and these factors must be considered in the selection of a model. Second, with regards to model development, it was observed that models of complex environments require intensive knowledge engineering and would be aided greatly by the availability of task analysis techniques and approaches aimed at populating models with relevant input including not only task sequences, but also operator strategies. Third, there was a clear need for visualization and documentation tools to enable easier interpretation of the underlying model assumptions and model results to ensure the model output is understood and useful for the end-user. Fourth, it was evident that the validation of complex aviation HPMs, especially for novel systems in the concept development phase, presents a number of challenges. Several validation techniques focused on different end-goals, and employed in different phases of the model development efforts, are presented. Each of these four considerations will be discussed in turn.

Foyle, D.C. and Hooey, B.L. (2008). *Human performance modeling in aviation*. Boca Raton, FL: CRC Press/Taylor & Francis.

IMPROVING HUMAN PERFORMANCE AND LEARNING MODELS FOR WARFIGHTER READINESS

Kevin A. Gluck, Air Force Research Laboratory

The role of the Air Force Research Laboratory (AFRL), like the other service laboratories, is to conduct the basic and applied research and advanced technology development necessary to create future technology options for the Department of Defense. At the Warfighter Readiness Research Division of AFRL's Human Effectiveness Directorate we have a research program focused on mathematical and computational cognitive process modeling for replicating, understanding, and predicting human performance and learning. This research will lead to new technology options in the form of human-level synthetic teammates, cognitive readiness analysis tools, and predictive and prescriptive knowledge-tracing algorithms. Creating a future in which these objectives become realities requires tightly coupled, multidisciplinary, collaborative interaction among scientists and engineers dedicated to overcoming the myriad challenges standing between current reality and our future vision.

Our Performance and Learning Models (PALM) research program is organized around a set of methodological strategies with associated benefits. First, we are using and improving on the ACT-R (Adaptive Control of Thought—Rational) cognitive architecture (Anderson et al., 2004; Anderson, 2007) because it provides well validated a priori theoretical constraints on the models we develop; facilitates model reuse among members of the ACT-R research community; and serves the integrating, unifying role described earlier. Second, we use the architecture, or equations and algorithms inspired by it, to make quantitative predictions in order to facilitate eventual transition to applications that make accurate, precise predictions about human performance and learning. Third, we develop models in both abstract, simplified laboratory tasks and in more realistic, complex synthetic task environments in order to begin constructing those bridges between the laboratory and the real world. Fourth, we compare the predictions of our models to human-subject data, in order to evaluate the necessity and sufficiency of the computational mechanisms and parameters that are driving those predictions and in order to evaluate the validity of the models. We are pursuing this research strategy in several lines of research, which are briefly described next.

We have one research line that is entirely mathematical modeling and does not involve a computational simulation component. Progress to date involves an extension and (we think) improvement to the general performance equation proposed by Anderson and Schunn (2000) that allows us to make performance predictions or prescribe the timing and frequency of training, both of which will enable tailored training experiences at individual and team levels of analysis, both in aviation-related and other domains (Jastrzembski, Gluck, & Gunzelmann, 2006). On the computational modeling side we have research underway in all of the following areas: (1) natural language communication in knowledge-rich, time-pressured team performance environments similar to those encountered in real-world situations, such as unmanned air vehicle reconnaissance missions (Ball, Heiberg, & Silber, 2007); (2) a neurofunctional and architectural view of how spatial competence is realized in the brain and the mind (Gunzelmann & Lyon, 2008); (3) implementing new architectural mechanisms and processes that allow us to replicate the effects of sleepiness on the cognitive system, in order to predict what the precise effects of sleep deprivation or long-term sleep restriction will be in a given performance context (Gunzelmann, Gluck, Kershner, Van Dongen, & Dinges, 2007); (4) contextual grounding of human performance and learning through situated perception and action (Douglass, 2007); (5) the interactive dynamics of cognitive coordination for development of a synthetic teammate (Myers et al., in prep); and finally (6) creation of a distributed and high performance computing software infrastructure for faster, broader, and deeper progress in computational cognitive modeling (Gluck, Scheutz, Gunzelmann, Harris, & Kershner, 2007).

A-SA AND SEEV

Christopher D. Wickens, Alion Science and Technology

In many advanced airspace systems, the human adopts a supervisory-monitoring role, which focuses the modeler's attention on the processes of maintaining situation awareness, in a way that can complement more procedures-oriented modeling such as ACT-R. The Attention-Situation Awareness (A-SA) model is one such approach that contains two meta-components.

- An **attention** module models how attention (usually, but not exclusively visual) is driven by events that are are **ex**pected, of **v**alue to the task and are **s**alient but is inhibited to the extent that **e**ffort is required to transition between visual fixations. The first two components here capture the degree of optimality in information sampling. This model is called SEEV, after the first letters in the four components above; it is implemented as a Monte-Carlo model that drives the eyeball in real time, and it has been well validated to describe visual scanning in both ground (Horrey et al, 2005) and air (Wickens et al, 2003; Wickens McCarley et al, 2008) vehicle control.
- Once attended, information about dynamic environments, contributes to the momentary state assessment, prediction or degree of belief about the state of environmental variables; that is, **situation awareness**. The SA portion of the model then accounts for how this awareness is updated by the fixation, but decays, with time-constants associated with working memory, as fixations are directed elsewhere within the same task, or as attention is shifted to other tasks.

In this panel, I described two applications of the A-SA model. First, I briefly review a validated application to flying with an synthetic vision system, in which individual pilot differences in multi-task flight management (requiring task awareness) are accounted for by the degree of adherence to the optimizing (expected value) characteristics of the model. Second, in more detail, we describe an application of the A-SA model to predicting the efficacy of three different formats for cockpit wake vortex displays, a critical concept in the NexGen airspace, which will enable more flexible and safe spacing of arriving and departing aircraft. These involve a co-planar display, a plan view display that can be readily integrated into the moving map, and a 3D immersive display, compatible with emerging SVS concepts. The A-SA model is employed to predict differences in overall levels of SA, as well as differences in noticing (attentional capture) of the onset of wake vortex alerts. The value of redundancy in such a design is illustrated by the outputs of the model.

TOWARD A TOOLBOX OF MODELS

Alex Kirlik, University of Illinois at Ubana-Champaign

I will attempt to make the argument that the huge variety of challenges and opportunities posed by efforts to modernize future aviation operations indicates a need for a research agenda dedicated to developing a toolbox of modeling techniques keyed to particular problem types, rather than one devoted to achieving some sort of ideal, monolithic human performance model or computational cognitive architecture. The problems to be addressed, and the situations to which modeling formalisms must represent are simply too numerous and diverse. Our own research efforts over the past 15 years or so have illustrated, to some degree at least, the gains that can be made by selecting, formulating, and using a wide variety of modeling approaches. These include techniques such as Markov decision process modeling, statistical modeling, systems theoretic modeling, information theoretic modeling, control theoretic modeling and computational cognitive modeling.

I will illustrate the potential benefits of this toolbox-oriented approach by briefly presenting an example application of each of these modeling techniques. The applications address human-autopilot interaction, human-automation interaction in system monitoring, shared and adjustable autonomy between humans and automation, statistical modeling of human judgment, decision making, and situation awareness, situated action and cognition, and aviation ground operations and pilot interaction with synthetic vision displays.

In each case, I will briefly mention how modeling informed, or was able to inform, either the solution to a design or training problem or else the identification of potential problems or error-inducing situations prior to system operation. More specifically, our modeling has been able to help identify display design flaws, training interventions to improve judgment and decision making under stress, barriers to effective situation awareness, to ensure safe yet joint system control shared by both human operators and automation, and the design of decision support systems that yield levels of judgment and decision making superior to either computer models or unaided experts acting alone. Although I cannot hope to truly communicate the nature of each of these modeling techniques, application domains, and interventions in their full complexity, I do at least hope to convince some of the need for, and value of, a multiplicity of human performance and cognitive modeling techniques instead of a monolithic human performance model.