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

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Byrne, M.D., Kirlik, A., Allard, T., Foyle, D.C., Hooey, B.L., Gluck, K.A., and Wickens, C.D. (2008). Issues and challenges in human performance modeling in aviation: Goals, advances, and gaps. Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting. Santa Monica: HFES

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.

The NASA Human Performance Modeling Project: Implications for Future Modeling Efforts

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NASA Human Performance Modeling (HPM) Project

Six-year NASA research effort

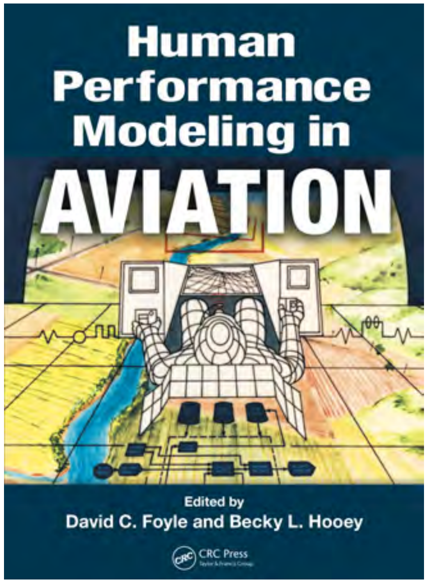
- Under NASA Aviation Safety and Security Program (AvSSP)
- Five human performance modeling teams participated
- NASA provided human-in-the-loop data for model development and validation

Addressed two aviation safety problems

- Surface (taxi) operations error analysis
- Synthetic Vision System (SVS) design, evaluation & integration

Outcomes

- Model cross-comparisons
- Modeler round-table
- Lessons-learned and challenges developed



Foyle & Hooey (Eds), (2008).
Taylor & Francis / CRC Press

The NASA HPM Project: Human Performance Models

Human Performance Model Tools	Each model represents a unique approach to representing the human and the environment
ACT-R Rice University University of Illinois	ACT-R, a validated, bottom-up cognitive model represents the human combined with a desktop flight simulator that represents the environment. Focus: Dynamic Decision Making in a Closed-loop Context
Air MIDAS San Jose State University	An integrated approach to modeling the functional and physical aspects of the operator, the system, and the environment. Integrated with a dynamic aircraft model (desktop flight simulator). Focus: Aviation/ATM human-system interaction, Workload
D-OMAR BBN Technologies	A flexible modeling environment comprised of a discrete-event simulator and languages that instantiate models of human perceptual, cognitive, & motor. Focus: Multi-task behavior, Teamwork, Procedural Integration
A - SA University of Illinois	Predicts pilot attention and SA based on the salience, effort, expectancy, and value of information and a Belief Module which decays with time. Focus: Situation Awareness, Attention Allocation
IMPRINT/ ACT-R Micro Analysis & Design	ACT-R, a bottom-up validated cognitive model represents the human combined with IMPRINT, a task network model that represents the environment. Focus: Learning Behavior (of new procedures / adaptation to new technology)

The NASA HPM Project: Goals

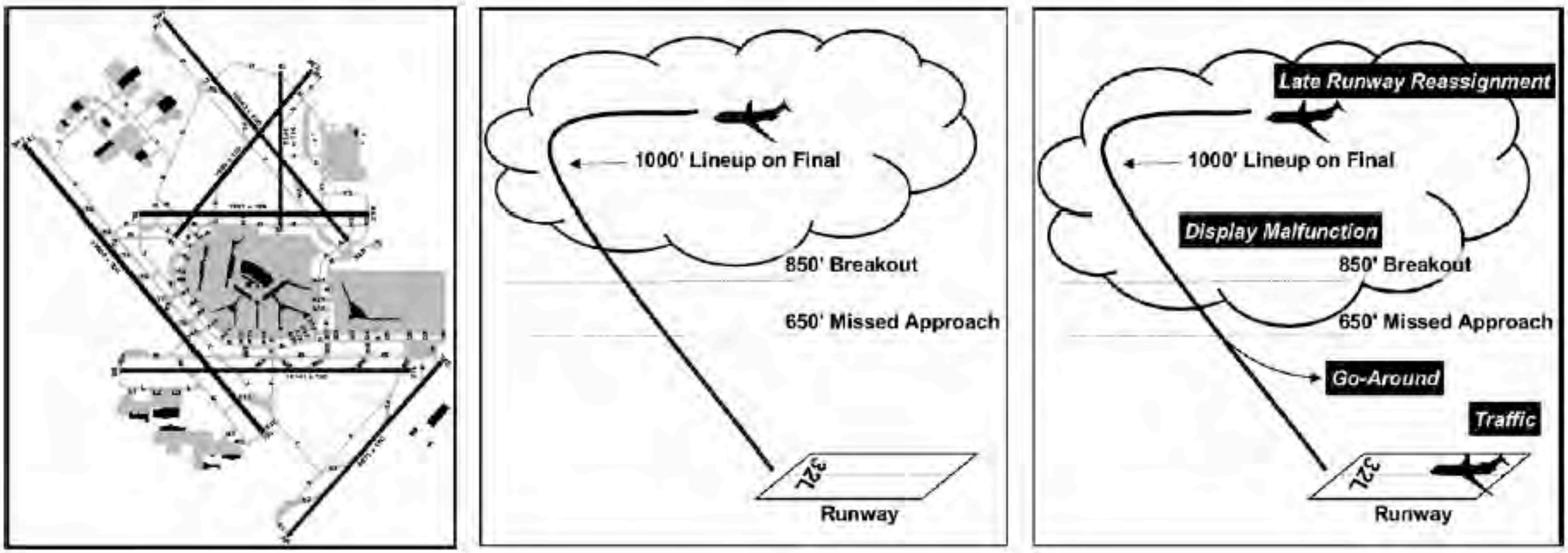
- Address real aviation safety problems
- Develop and extend human modeling capabilities for aviation applications
- Determine how human-in-the-loop simulations and human performance modeling work synergistically in system design and evaluation

Address real aviation safety problems

Airport
Surface Operations
Taxiway Errors

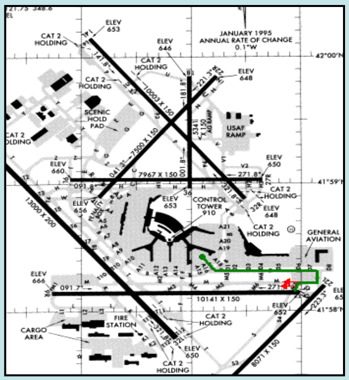
SVS
Approach & Landing
(Nominal)

SVS
Approach & Landing
(Off-Nominal)



System Design Implications: Surface Operations

Full-Mission Pilot-in-the-loop Sim



- 18 crews
- 54 current-day land-and-taxi trials
- Low visibility at Chicago O'Hare

Data Set

- Taxi clearance, airport geometry
- Task analysis
- Sample OTW visuals, signage
- Error Description
  - Taxi route taken
  - Error classification
  - Communication transcripts

Human Performance Model Tools

ACT-R
University of Illinois
Rice University

Air MIDAS
San Jose State University

D-OMAR
BBN Technologies

A - SA
University of Illinois

IMPRINT/ ACT-R
Micro Analysis & Design

Risk factors that increase Pr (Error)

- Memory decay rate
- Memory capacity overload
- Workload
- Decision heuristics
- Worldview inconsistency
- Situation awareness
- Procedural interference
- Perceptual inaccuracies

Implications

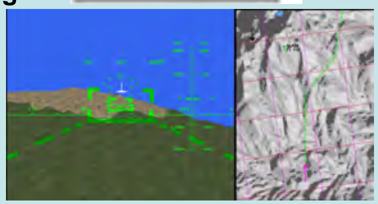
- Inform cockpit display design
- Inform airport design
- Revise cockpit procedures
- Revise ATC procedures
- Identify training needs

System Design Implications: SVS for Approach & Landing

Full-Mission Pilot-in-the-loop Sim

NASA ARC Part-Task Sim
SVS Approach & Landing

Boeing / NASA ARC
Approach/Landing Sim
(Mumaw, 2000)



U.Illinois SVS Sim
(Wickens, 2004)

Data Set from nominal and off-nominal scenarios

- Performance data
- Eye-tracking scan data
- Control inputs (MCP, Throttle)
- Video w/ audio

Other Information

- Cognitive Task Analysis (with/without SVS)

Human Performance Model Tools

ACT-R
University of Illinois
Rice University

Air MIDAS
San Jose State University

D-OMAR
BBN Technologies

A - SA
University of Illinois

IMPRINT/ ACT-R
Micro Analysis & Design

Issues Identified

- SVS altered scan pattern
- SVS delayed initiation of flight control action
- SVS yielded increase in visual workload
- Potential for attentional tunneling

Implications Identified

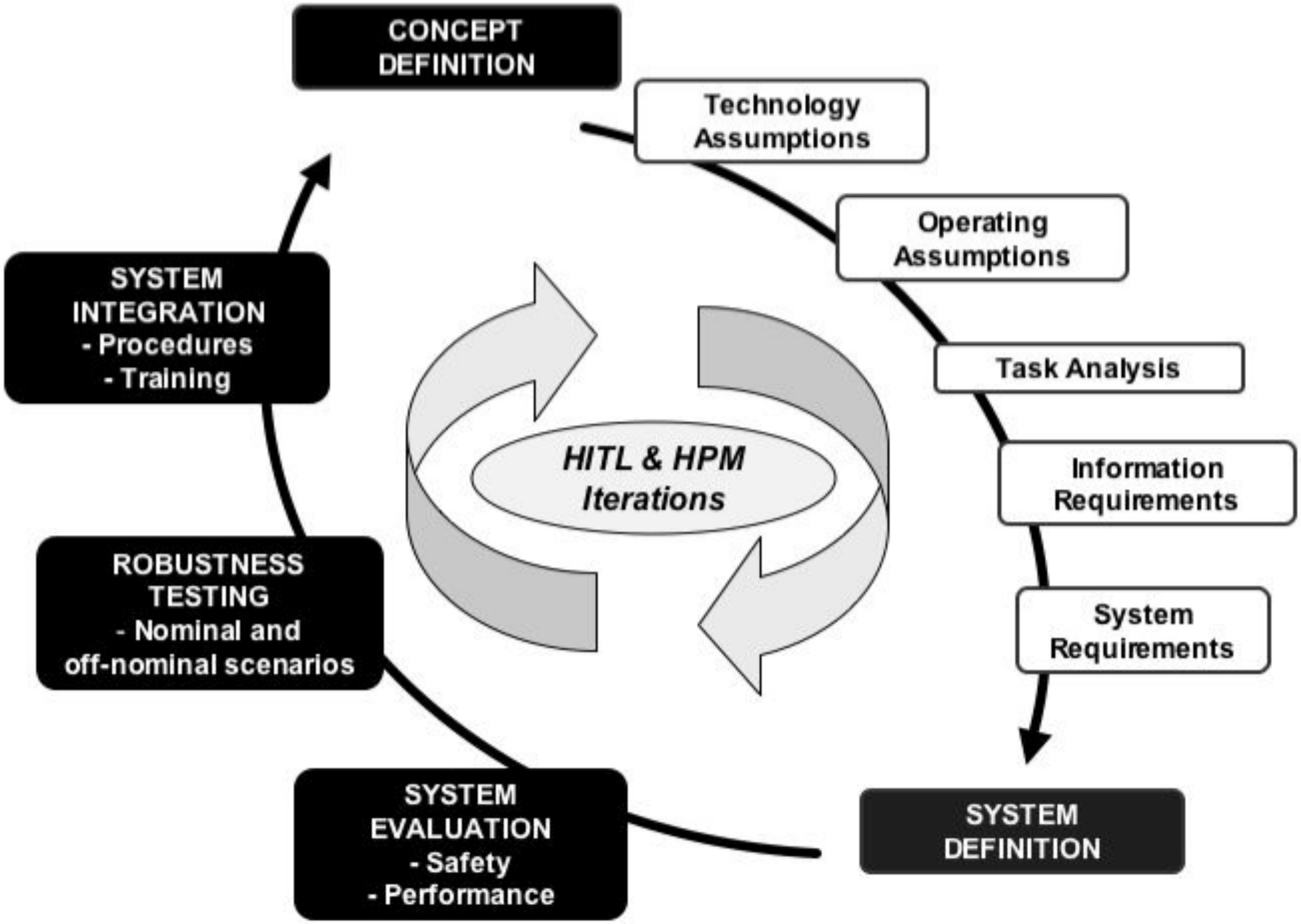
- SVS design
  - redundancy vs. integration
  - symbology overlay
- Concept of Operations
  - SVS as primary or secondary display
- Pilot training
  - Gold standard for visual scan

Develop/Extend HPM Capabilities for Aviation Applications

Model Capability	Specific Advance	Modeling Team
Human-Environment Interactions	- Enabled closed-loop behavior by integrating HPM with desktop simulator	ACT-R; Air MIDAS
	- Integrated a task network model with a cognitive model	IMPRINT/ACT-R
Visual Attention	- Replicated information seeking behavior of pilots	ACT-R; Air MIDAS; D-OMAR
	- Implemented model-learning of scan patterns	IMPRINT/ACT-R
	- Predicted visual scan due to top-down and bottom-up factors /developed scanning optimality score	A-SA
Situation Awareness (SA)	- Demonstrated how SA changes as a function of time and distraction	A-SA
Human Error	- Identified error vulnerabilities due to memory deficits	IMPRINT/ACT-R; Air MIDAS
	- Identified error vulnerabilities due to pilots heuristics, biases, and strategies	ACT-R; D-OMAR
	- Identified error vulnerabilities due to SA deficits	A-SA

Integrated HITL/HPM Approach

Value added at each stage of the design and evaluation lifecycle



Integrated HITL/HPM Approach

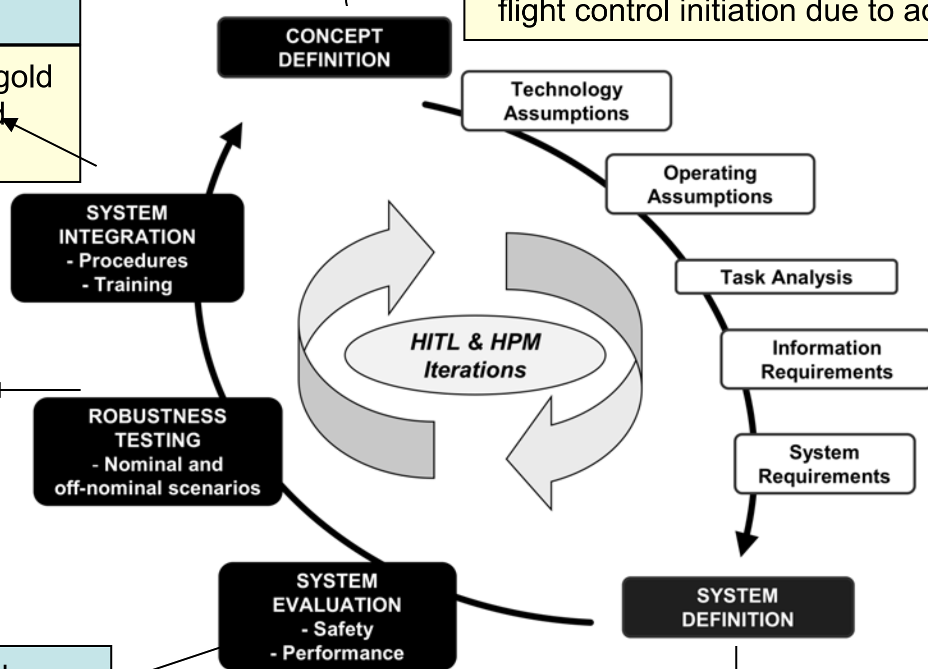
Value added at each stage of the design and evaluation lifecycle

HITL: Revealed pilot usage of displays, user acceptance of procedures and requirements

HPM: Showed that ConOps resulted in delayed flight control initiation due to added cross-check

HITL: Used to evaluate SOPs, checklists, and training programs

HPM: Models such as the optimal scanning "gold standard" metric can guide pilot training and procedures



HITL: Evaluate human responses to off-nominal events but often limited to a single off-nominal per study.

HPM: Uncover low-probability latent errors. Can be used to identify off-nominal scenarios for further HITL study

HITL: Data such as frequency of errors, and error context (taxiway geometry, concurrent tasks) were used to inform models

HPM: Systematic manipulation of variables such as memory capacity and decay rate revealed vulnerabilities (e.g., workload spikes, clearance exceeded memory limits, clearance contradicted expectations)

HITL: Physical mock-ups provide greater specificity of displays and algorithms - but slower, more costly

HPM: Fast, inexpensive 'what-if' redesign and evaluation of displays, operations, and procedures

Revealed Future Challenges

Model Selection

- Fidelity (e.g., process-level vs. task-level, cognitive structures, open- vs. closed-loop modeling, etc.)
- Assumptions (e.g., cognitive process instantiation, output metrics [workload, SA], etc.)
- Philosophy (e.g., cognitive theory, etc.)

Model Development (esp. for complex environments)

- Requires intensive knowledge engineering
- Need for techniques for populating models (parameters, task sequences and strategies)
- Need for "shared libraries" of common tasks for complex environments (such as aviation, nuclear, etc.)

End-user issues

- Need for increased model interpretability
- Improved visualization and documentation tools
- Capture and understand model assumptions, parameters, "hidden assumptions"

Validation (esp. for modeling new, emerging systems)

- What constitutes validation for a new, not yet totally defined system?
    - Results validation (observed vs. predicted) is a standard, but may not be relevant for an emerging system