

The Use of Behavior Models for Predicting Complex Operations

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ABSTRACT: Modeling and simulation (M&S) plays an important role when complex human-system notions are being proposed, developed and tested within the system design process. National Aeronautics and Space Administration (NASA) as an agency uses many different types of M&S approaches for predicting human-system interactions, especially when it is early in the development phase of a conceptual design. NASA Ames Research Center possesses a number of M&S capabilities ranging from airflow, flight path models, aircraft models, scheduling models, human performance models (HPMs), and bioinformatics models, among a host of other kinds of M&S capabilities that are used for predicting whether the proposed designs will benefit the specific mission criteria. The Man-Machine Integration Design and Analysis System (MIDAS) is a NASA ARC HPM software tool that integrates many models of human behavior with environment models, equipment models, and procedural / task models. The challenge to model comprehensibility is heightened as the number of models that are integrated and the requisite fidelity of the procedural sets are increased. Model transparency is needed for some of the more complex HPMs to maintain comprehensibility of the integrated model performance. This will be exemplified in a recent MIDAS v5 application model and plans for future model refinements will be presented.

1. Introduction

Complex system integration issues require that the model development process generally follow an iterative design philosophy that collaboratively leverages empirical human data (i.e., either human in the loop, HITL, simulations or real-time measurements) and concurrently feeds information to HITL simulation processes. Many organizations are faced with the goals of completing research as efficiently as possible while maintaining acceptable levels of safety to successfully complete a mission. NASA is no exception. Modeling and simulation techniques, particularly human behavior models, play an important role when complex human-system notions are being proposed, developed, and tested across many of the ten NASA centers. For instance, NASA Johnson Space Center (JSC) utilizes M&S to represent environments, physical structures and equipment components, crew stations, planets and planetary motions, gravitational effects, illumination, human anthropometric and biomechanics, among a host of other domains. NASA Ames Research Center also possesses a number of M&S capabilities ranging from airflow, flight path models (e.g., Airspace Concept Evaluation System, - ACES), aircraft models, scheduling models (e.g., Core-XPRT, Science Planning InterFace to engineering - SPIFe), human performance models (HPMs), and bioinformatics models, among many other kinds of M&S capabilities. One of the many NASA M&S capabilities, an ARC-related HPM

capability termed the Man-Machine Integration Design and Analysis System (MIDAS) is highlighted because of its relevance to the field of human behavior representation.

1.1 Human Performance Models (HPMs), Concept Development and Testing

Modeling can play a role in all phases of the concept development, refinement, and deployment process. Hybrids of continuous-control, discrete-control and critical decision-making models represent the 'internal models and cognitive function' of the human operator in complex control systems, and involve a coupling among humans and machines in a shifting and context sensitive environment. These models, known as HPMs, have arisen as viable research options due to decreases in computer costs, increases in representative results, and increases in model validity. They are especially valuable because the computational predictions can be generated early in the design phase of a product, system or technology to formulate procedures, training requirements, and to identify system vulnerabilities and where potential human-system errors are likely to arise. The model development process allows the designer to formally examine many aspects of human-system performance with new technologies to explore potential risks brought to system performance by the human operator (Gore & Smith, 2006). Often this can be accomplished before the notional technology exists for human-in-the-

loop (HITL) testing (Gore, 2000). This method possesses cost and efficiency advantages over waiting for the concept to be fully designed and used in practice (characteristic of HITL tests). Using HPMs in this manner is advantageous because risks to the human operator and costs associated with system experimentation are greatly reduced: no experimenters, no subjects and no testing time (Elkind et al., 1989; Gore, 2000). Hooley and Foyle (2008) outline that HPMs can be used to conduct system robustness testing to evaluate the system from the standpoint of potential deviations from nominal procedures to determine the impact on the performance of the human and the system ("what-if" testing).

1.2 The Man-machine Integration Design and Analysis Systems (MIDAS)

MIDAS is a dynamic, integrated human performance modeling and simulation environment that facilitates the design, visualization, and computational evaluation of complex man-machine system concepts in simulated operational environments (Gore, 2008). MIDAS combines graphical equipment prototyping, dynamic simulation, and HPMs to reduce design cycle time, support quantitative predictions of human-system effectiveness, and improve the design of crew stations and their associated operating procedures. HPMs like MIDAS provide a flexible and economical way to manipulate aspects of the operator, automation, and task environment for simulation analyses (Gore, 2008; Gore, Hooley, Foyle, & Scott-Nash, 2008; Hooley & Foyle, 2008).

Gore & Smith (2006) outline that MIDAS links a virtual human, composed of a physical anthropometric character, to a computational cognitive structure that represents human capabilities and limitations. The cognitive component is composed of a perceptual mechanism (visual and auditory), memory (short term, long term-working, and long term), a decision maker and a response selection architectural component. The complex interplay among bottom-up and top-down processes enables the emergence of unforeseen, and non-programmed behaviors (Gore & Smith, 2006). MIDAS can suggest the nature of pilot errors, and highlight precursor conditions to error such as high levels of memory demand, mounting time pressure and workload, attentional tunneling or distraction, and deteriorating situation awareness (SA).

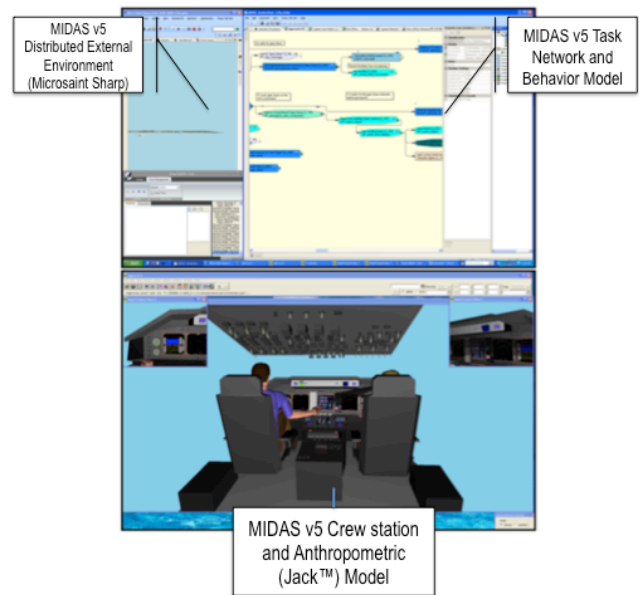


Figure 1. MIDAS' Environment, Task, and Anthropometric Models.

MIDAS can be used as a cognitive modeling tool that allows the user to obtain both predictions and quantitative output measures of human performance, such as workload and SA and as a tool for analyzing the effectiveness of crew station designs, information display concepts, operator roles and responsibilities from a human factors perspective (Gore, 2008). MIDAS has proven useful for identifying general human-system vulnerabilities and cross-domain error classes and for recommending mitigation strategies and job re-designs to account for the vulnerable areas, or risks, in system design (Gore & Smith, 2006). Fundamental design issues can therefore be identified early in the design lifecycle, prior to the use of hardware simulators and HITL experiments. In both cases, MIDAS provides an easy to use and cost effective means to conduct experiments that explore "what-if" questions about domains of interest.

1.3 The MIDAS User Interface Assists Comprehensibility

MIDAS v5 has a graphical user interface¹ (GUI) that does not require advanced programming skills to use. The GUI brings many of the previously embedded functions to the surface so that the model analyst can observe the underlying structure as well as the model's operation as it is run. The integrated GUI enables the user to build human procedures from MIDAS primitive tasks, create their own tasks, incorporate a series of nested procedures, change the SA context during the simulation and manipulate visual and auditory

¹ MIDAS uses Microsaint Sharp as its GUI which uses the C-Sharp programming language

attributes of equipment components. The MIDAS analyst can organize the human-system interactions visually, thereby greatly improving the model's transparency. Other features of MIDAS v5 include dynamic visual representations of the simulation environment, support for multiple and interacting human operators, distributed simulation, monte-carlo/stochastic performance, HPM timelines, task lists, workload, and SA, performance influencing factors (such as error predictive performance, fatigue and gravitational effects on performance), libraries of basic human operator procedures (how-to knowledge) and geometries for building scenarios graphically (that leverage heavily from Siemens' Jack software).

1.4 MIDAS Approach and Land Applications

The current air traffic control (ATC) system will not be able to manage the predicted two to three times growth in air traffic (JPDO, 2009). The Next Generation Air Transportation System (NextGen) is a future aviation concept that has as its goals to significantly increase the capacity, safety, efficiency, and security of air transportation operations (JPDO, 2009).

MIDAS v5 has been applied to examine a NextGen approach to land concept termed the very closely spaced parallel approach (VCSPA). In order to evaluate this concept, two MIDAS v5 models were generated. The first was a current day Simultaneous Offset Instrument Approach (SOIA) model that contained the current day procedures and the second was a NextGen VCSPA model that contained predictive displays in the cockpit and a modification to the roles and responsibilities of the flight crew and ATC modeled operators. This simulation involved over 500 tasks and culminated in a verifiable model of approach and land operations (vetted by Subject Matter Experts - SMEs). The SA model was augmented within MIDAS to represent how a cockpit crew builds SA of traffic, terrain, and weather information given the accessibility of sources of information. This model effort illustrated the "what-if" simulation capability within MIDAS. The "what-if" approach was completed when MIDAS was exercised with one set of displays and procedure sets designed to represent current day operations and roles followed by a second simulation with an alternate set of displays and procedures encoded to represent the NextGen displays and expected procedures. The model underwent an iterative verification/validation process that included examining: (1) the task sequences and the performance of the model as it executed; (2) the visual fixations, task timings, and workload relative to expected performance given the inputs to the model; and pilot performance according to SME evaluations.

Model comprehensibility is defined as understanding

the relationships that exist among the models being used in an application, the performance of the models in the application, which models are being triggered in the model architecture, and whether the model is behaving as the model analyst would expect. MIDAS v5's comprehensibility was greatly improved with the transparent model architecture (Gore, 2008). The operation of this complex model was verified throughout development and was validated according to SME evaluations. The verification phase of the model was improved given the visibility into the model's operations at any given point in simulation time combined with the cross checking of the jack visualization and the simulation runtime data that was output. The comprehensibility of this model would not have been possible without such a transparent architecture.

This MIDAS v5 effort lead to a greater awareness of potential parameters that should be included in system designs and enabled the research program to visualize the interactions that will be likely in future NextGen operations. It is anticipated that a formal validation approach will be developed and applied to the VCSPA model in an upcoming Federal Aviation Authority (FAA) task. This FAA task will require model refinement and validation, an increased number of alternative closely spaced operations for additional what-if scenarios including alternative pilot roles and responsibilities, and information requirements.

2. Conclusion

A number of significant challenges exist for the state of the art in HPMS, two of which will now be highlighted.

Transparency. The first challenge relates to model transparency. Model transparency refers to the ability to comprehend the relationships that exist among the models being used in the simulation, the performance of the models in the simulation, which models are triggering in the model architecture, and whether the model is behaving as the model developer would expect (Gore, 2008). Other researchers refer to this as model traceability, model behavior visibility, model verifiability, and model interpretability (Elkind et al., 1989; Napiersky, Young, & Harper, 2004; Gluck & Pew, 2005; Hooey & Foyle, 2008). Transparency in integrated HPMS is needed to support model verification, validation, and credibility. However, model transparency can be difficult to attain because of the complex interactions that can exist among the cognitive, physical, environment and crew station models, and because the cognitive models embedded within integrated HPMS produce behaviors that are not directly observable. Three types of transparency that the MIDAS researchers have found useful to understand, interpret, and increase the confidence in

the complex models' output include transparency of the input, transparency of the integrated architecture, and transparency of the output (Gore, Hooey, Foyle, & Scott-Nash, 2008). This paper illustrates how the augmentation to the MIDAS GUI has improved model transparency that has led to better model comprehensibility.

Validation. The second challenge facing the HPM community is validation. Validation remains a very large challenge for the HPMs community because statistical validation is oftentimes seen as the Holy Grail for determining whether a model is suitable but when models are deemed statistically valid, they are less generalizable, and less re-usable for applications in new contexts. This places the field of modeling into the conundrum of making models that are statistically valid (correlation, $r=.99$) but that lack the ability to generalize to other tasks or scenarios. When the generalizability of the model is limited, then its value as a cost-effective approach to predict complex human-system interactions is reduced.

Validation is further challenged when modeling future technology concepts where no or little HITL data exists upon which to statistically validate a model (as in the NextGen aviation systems or concepts being designed for the Space program). It is argued that our definition of model validation must be expanded beyond that of statistical results validation to be more representative of a model develop-model verify-model manipulate – model validate iterative process.

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Author Biography

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