# Man-machine Integration Design and Analysis System (MIDAS) v5: Augmentations, Motivations, and Directions for Aeronautics Applications

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Keywords: NASA, Human Error, Human Performance Modeling, MIDAS v5

## Abstract

As automation and advanced technologies are introduced into transport systems ranging from the Next Generation Air Transportation System termed NextGen, to the advanced surface vehicle Intelligent Transportations Systems, to future systems designed for space exploration, there is an increased need to validly *predict* how the future systems will be vulnerable to error given the demands imposed by assisted technologies. One formalized method to study the impact of assisted technologies on the human operator in a safe and non-obtrusive manner is through the use of human performance models (HPMs). HPMs play an integral role when complex human-system designs are proposed, developed, and tested.  One HPM tool termed the Man-machine Integration Design and Analysis System (MIDAS) is a NASA Ames Research Center HPM software tool that has been applied to predict human-system performance in various domains since 1986. MIDAS is a dynamic, integrated HPM environment that facilitates the design, visualization, and computational evaluation of complex man-machine system concepts in simulated operational environments. A range of aviation specific applications including an approach used to model human error for NASA's Aviation Safety Program, and "what-if" analyses to evaluate flight deck technologies for NextGen operations will be discussed. This chapter will culminate by raising two challenges for the field of predictive HPMs for complex human-system designs that evaluate assisted technologies: that of (1) model transparency and (2) model validation.

# Introduction

Human Performance Models (HPMs) have traditionally been used to predict sensory processes, aspects of human cognition, and human motor responses to system tasks. HPM tools are currently undergoing a developmental shift, now being more sensitive to situations that confront a virtual human in systems similar to human-in-the-loop (HITL) situations. HPMs and the human performance modeling process have attempted to integrate operator characteristics (cognitive, attentional, and physical) with environmental characteristics to more accurately represent human-system operations with new, augmented technologies. The growth in HPMs has been to examine human performance in systems including system monitoring (thereby taking information in from the environment) as opposed to the closed-loop view of the human as a mathematical relationship between input and output to a system. These hybrid models that combine closed-loop performance (continuous control), open-loop performance (discrete control) and critical decision-making have been undertaken to represent the "internal models and cognitive function" of the human operator in complex control systems. These hybrid systems involve a critical coupling among humans and machines in a shifting and context sensitive function.

## *Using Human Performance Models for Technology Development*

Modeling can play a role in all phases of new technology development from concept development, through the refinement, and deployment process. HPMs provide a flexible and economical way to manipulate aspects of the operator, automation, and task environment to represent the manner that a human engages with the technology under development. 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. Often this can be accomplished before the notional technology exists for HITL testing. More comprehensive conclusions can be drawn about technologies being introduced into complex operational environments when used in a cooperative and iterative fashion with HITL simulations. Furthermore, 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.

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 performance impact on the human and the system ("what-if" testing).

## The Man-machine Integration Design and Analysis System

The Man-machine Integration Design and Analysis System (MIDAS) is a dynamic, integrated human performance modeling environment that facilitates the design, visualization, and computational evaluation of complex man-machine system concepts in simulated operational environments [1]. MIDAS symbolically represents many mechanisms that underlie and cause human behavior. 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.

### History

MIDAS has undergone two paths in its development. The first path termed Air MIDAS focused on specific behaviors in complex human-system interaction and has been applied specifically to aviation operations. This development path was entirely code-based with no visualization capability. The second path, termed the NASA MIDAS and currently MIDAS v.5, focused on cross-domain capability, cognitive behavior model augmentations and has been validly applied to a variety of domains, which include rotorcraft, nuclear power plant, space, and commercial aviation operations [2, 3]. The MIDAS v5 path contains a comprehensive visualization capability associated with the physical and cognitive operations in their respective contexts. MIDAS v5 links a virtual human, comprised of a physical anthropometric character, to a computational cognitive structure that represents human capabilities and limitations. 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). MIDAS provides a flexible and economical way to manipulate aspects of the operator, automation, and task environment for analysis.

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## *MIDAS v5 Architecture*

Figure 1 illustrates the model's organization and flow of information among the model's components. MIDAS inputs (Figure 1, left column) include the operational environment (e.g., flight profiles, scenario objects and events, etc), the operator tasks and operator process models (e.g., algorithms that represent operator characteristics such as expertise). The MIDAS processing model (Figure 1, middle column) is comprised of a task manager model that schedules tasks to be completed, definitions of the state of models within the physical simulation, a library of "basic" human primitive models that represent behaviors required for all activities such as reach, and cognitive models such as operator perception. The cognitive component is comprised 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 MIDAS output model (Figure 1, right column) generates a runtime display of the task network, the anthropometry as well as mission performance.
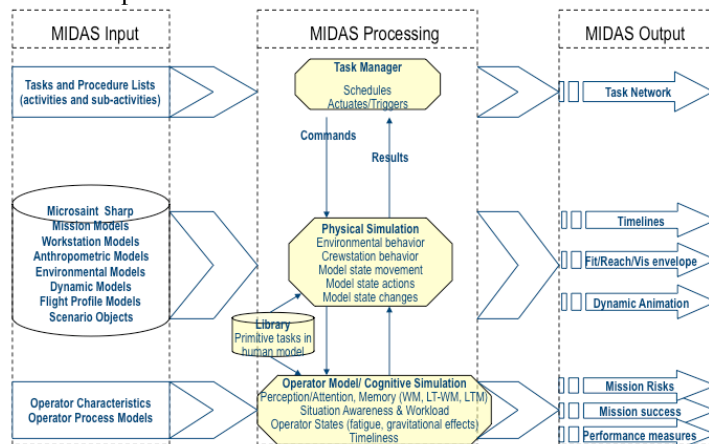


Figure 1. MIDAS structural composition and flow (adapted from [4]).

### MIDAS Input

Tasks are triggered by information that flows from the environment, through a perception model, to a task network representation of the procedures that then feeds back to the environment. Tasks are characterized by several defining parameters that include conditions under which the task can be performed (e.g., beginning, ending, and wait-for clauses), their priority relative to other tasks, their duration, their interruption specifications, and their required resource to perform the task defined according to the Modified TAWL [5, 6].

**MIDAS Processing**

MIDAS Perception

MIDAS represents *perception* as a series of stages that information must pass through in order to be processed. The perception model includes visual and auditory information. Visual perception in MIDAS depends on the amount of time the observer dwells on an object and the perceptibility of the observed object. The perception model computes the perceptibility of each object that falls into the operator's field of view based on properties of the observed object, the visual angle of the object and environmental factors. In the current implementation of MIDAS, perception is a three-stage, time-based perception model (undetected, detected, comprehended) for objects inside the workstation (e.g., an aircraft cockpit) and a four-stage, time-based perception model (undetected, detected, recognized, identified) for objects outside the workstation (e.g., taxiway signs on an airport surface). The model computes the upper level of detection (i.e., undetectable, detectable, recognizable, identifiable for external objects) that can be achieved by the average unaided eye if the observer dwells on it for a requisite amount of time. For example, in a low-visibility environment, the presence of an aircraft on the airport surface may be 'detectable' but the aircraft company logo on the tail might not be 'recognizable' or 'identifiable' even if he/she dwells on it for a long time.

MIDAS Memory

Tasks from the MIDAS input process also require knowledge held either in the operator's memory (working, long-term working, and long-term) or available from the environment to be consulted and used to determine subsequent tasks to be completed [2]. Memory is represented as a three stage, time decay model[1]. The stages are working memory (WM), long-term working memory (LT-WM), and long-term memory (LTM). The decay rates cause memory to be above or below a "retrievability" threshold based on the time since the information was last accessed. The retrievability thresholds incorporated into MIDAS are 5s for WM and 5 mins for LT-WM. The WM decay rate is faster than the LT-WM decay rate. Information that falls below the retrievability threshold is forgotten. This causes the perception level to be set to *Undetected* for external visual and auditory information or *Unread* for internal visual information. Newly perceived and recently refreshed attributes will be retained in LT-WM only if a node with newly updated or referenced attributes leaves WM before its attributes have decayed below the retrievability threshold. An operator may retain newly perceived information after it leaves WM, at least for a while, until it decays below the LT-WM retrievability threshold. If the information necessary for activity performance is available, and

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[1] In contrast to MIDAS v5, memory in Air MIDAS is represented as a two-stage model [7].

its priority is sufficient to warrant performance, then the schedule within the model operates according to heuristics that can be selected by the analyst. In most cases the heuristic is to perform activities concurrently when that is possible, based on knowledge and resource constraints.

MIDAS Visual Attention

MIDAS' attention-guiding model operates according to the SEEV model [2]. SEEV is an extensively validated model [8] that estimates the probability of attending, P(A), to an area of interest in visual space, as a linear weighted combination of the four components - salience, effort, expectancy, and value. Attention in dynamic environments is driven by the bottom-up capture of *Salient (S)* events (e.g., a flashing warning on the instrument panel) and inhibited by the *Effort (E)* required to move attention (e.g., a pilot will be less likely to scan an instrument located at an overhead panel, head down, or to the side where head rotation is required, than to an instrument located directly ahead on a head-up display (HUD) [9]. SEEV also predicts that attention is driven by the *Expectancy (EX)* of seeing a *Valuable (V)* event at certain locations in the environment. The four SEEV parameters drive the visual attention around an environment such as the dynamic cockpit in a computational version of this model. For example, the simulated eyes following the model will fixate more frequently on areas with a high bandwidth (and hence a high expectancy for change), as well as areas that support high-value tasks, like maintaining stable flight [10].

The integration of the SEEV model into MIDAS v5 allows dynamic scanning behaviors by calculating the probability that the operator's eye will move to a particular AOI given the tasks the operator is engaged in within the multitask context. It also better addresses allocation of attention in dynamic environments such as flight and driving tasks.

**MIDAS Output**

The MIDAS outputs include the task network, anthropometric, and Computer Aided Design (CAD) model visualizations (using the jack™ software), timelines of workload and SA, and risk vulnerabilities as inferred from timeline violation of optimal response times, workload spikes, or SA violations. MIDAS can suggest the nature of operator 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 SA. Figure 2 illustrates the integration of the different models in a recent aeronautics model completed with MIDAS v5.
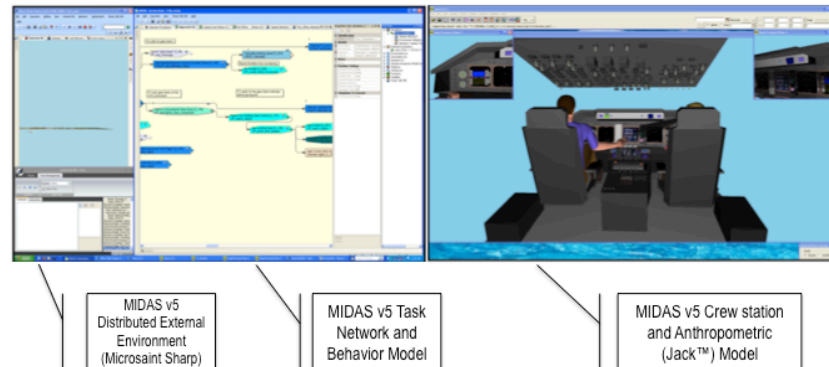
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Figure 2. MIDAS' environment, task, and anthropometric models.

## HPM of Next Generation Air Transportation Systems

The current air traffic control (ATC) system in the United States will not be able to manage the predicted two to three times growth in air traffic [11]. The Next Generation Air Transportation System (NextGen) is a future aviation concept that has as its goals to increase the capacity, safety, efficiency, and security of air transportation operations. Two MIDAS HPMs will be highlighted. The first illustrates a human error model of an aviation surface-related application that uses some candidate NextGen concepts as generated by Air MIDAS, and the second illustrates a recent application of NASA's MIDAS in the context of NextGen approach and land operations.

### *Human Error Modeling*

New conceptual designs especially those being developed for complex systems are likely to incorporate technologies that utilize or rely on a human's cognitive capabilities. New conceptual designs often incorporate automation to assist the human operator in their task performance. Automation increases precision and economy of operations but can have the unanticipated effect of increasing a human operator's cognitive, perceptual and attentional workload [12]. The increase in workload often negates some of the benefits afforded to the system from the use of automation. Operators may miss critical events in the environment due to a number of unexpected human-automated systems issues such as unevenly distributed workload, new attentional demands, and new coordination demands among operators. When critical physical events are missed, no response is possible and human errors occur. Model development of the human-system issues underlying human performance and human error is critical for conceptual systems being considered.

**Modeling Human Error**

An Air MIDAS flight deck model of ramp navigation and gate-approach at the Chicago O'Hare Airport (ORD) was developed to predict human error when technological introductions that took the form of augmented flight deck concept displays [13] were made to current day operations [14]. The control modes in Air MIDAS that had the potential of being sensitive to manipulations include memory errors and their effect on the simulated crew's internal representation. The first error type, declarative memory errors, included errors that occurred when virtual operators forgot the active procedure as a result of having too many procedures of the same type operating at the same time, which invoked the procedure scheduler (dropped tasks = memory loss). The second error type, memory load errors, included errors that occurred as a result of information competing for the capacity-limited WM space. Information was lost if it was not written down to a location from an actively available list from which the operator was able to visually encode the information (for example, a taxi clearance).

Environment triggers (e.g., turns, signs, ATC calls) elicited the human performance. Error rates as measured by missed turns, operator performance times, and workload were output from the HPM. This effort predicted that the model loading factors had an impact on the performance of the forgetting mechanism within Air MIDAS. The computational mechanisms within Air MIDAS replicated the operations of humans when humans forgot a piece of information. When there were a number of items occupying WM, one item in WM was shifted out of the limited capacity store by the subsequent information from the pilot or from the ATC communication. Each type of error emerged based on the environmental requirements and on the loads that were associated with the operator's performance. A prediction for increased auditory and cognitive demands as time in the scenario increased (as the virtual operator approached the second turn) was also found. The Air MIDAS model provided useful information about the risk factors that increase the probability of error and was useful for providing insight into mitigation strategies when errors occur.

**"What-If" Next Gen Approach and Landing Application**

MIDAS v5 has been applied to examine a NextGen approach to land concept termed the very closely spaced parallel approach/operations (VCSPA/O). Based on Raytheon's Terminal Area Capacity Enhancement (TACEC) parallel approach procedures, VCSPA/O requires that runway spacing be reduced [15]. This reduction in distance between the runways increases the likelihood of wake vortex incursion during independent simultaneous operations. VCSPA/O requires that a safe and proper breakout maneuver be calculated and presented via new displays to the cockpit crew [15]. In order to evaluate the VCSPA/O concept, two MIDAS v5 models were generated. The first was a Simultaneous Offset Instrument Ap-

proach (SOIA) model that contained the current-day procedures, and the second was a NextGen VCSPA/O model that contained advance displays of traffic and wake information in the cockpit and a modification to the roles and responsibilities of the flight crew and ATC modeled operators. The advanced technology in the "NextGen" VCSPA/O condition enabled closer separation in low visibility, lower landing minima, autoland capability, and enhanced wake and traffic data. The MIDAS model involved over 500 tasks and culminated in a verifiable model of approach and land operations (vetted during the model building process by Subject Matter Experts; SMEs). Performance profiles along the variables of operator workload, visual attention, and cockpit alert detection times for both the captain and first officer during the descent, approach, and land phases of flight were collected. Both conditions were run in Instrument Meteorological Conditions (IMC) with no out the window (OTW) visibility 100 times. The SOIA flight crew broke out of the clouds at 2100' and maintained separation from traffic and monitored runway alignment OTW. The VCSPA modeled flight crew monitored traffic separation and wake information on the ND throughout the approach and broke out of the clouds at 100'. This model effort illustrated the "what-if" 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 model with an alternate set of displays and procedures encoded to represent the NextGen operations and roles.

Important insights regarding the impact of NextGen VCSPA/O operations on pilot workload, visual attention, and alert detection times were revealed through this research. The MIDAS model predicted increased workload during descent and initial approach due to increased information available (traffic, weather, wake) on the flight deck but reduced workload during final approach and land due to automated landing procedures and ease of information retrieval (traffic and runway alignment) in the NextGen condition. Technologies that shift the workload demands away from the visual modality using auditory and haptic displays should be pursued as NextGen operations may tax the visual and cognitive-spatial channels to a greater extent than current day operations during specific phases of flight. Furthermore, the NextGen condition suggested a *more balanced workload* across the descent, approach, and land phases of flight than current day operations. In terms of visual attention, NextGen condition may draw visual attention to the ND, which suggest that the pilots will more likely be heads-down during the critical minutes before touchdown (TD). Increased head-down time within the cockpit due to the presence of additional, more salient, information, may draw pilots' attention into the cockpit at inopportune times leaving pilots vulnerable to external hazards (other aircraft or obstacles on the runway, terrain). It is important to remember that other instantiations of the VCSPA/O concept (with different operational requirements) may reveal different human-system vulnerabilities.

This MIDAS v5 effort led to a greater awareness of potential parameters such as the change in roles and responsibilities in the NextGen that should be included in system designs and enabled the research program to visualize the interactions

that are likely in future NextGen operations. It is anticipated that additional validation approaches will be developed and applied to the VCSPA/O model and that additional "what-if" scenarios including alternative pilot roles and responsibilities, and information requirements will be implemented.

## Conclusion

Automation often changes the nature of the human's role in the system. Therefore, as automation and technologies are developed, it becomes increasingly important to predict how the human operator perceives and responds to the automation. MIDAS has proven useful to identify general human-system vulnerabilities and cross-domain error classes and to recommend mitigation strategies and system re-designs to account for the vulnerable areas, or risks, in system design [4]. Fundamental design issues can therefore be identified early in the design lifecycle, often before hardware simulators and HITL experiments can be conducted. HPMs are most useful when used cooperatively with HITL simulations to supplement the HITL research. HPMs like MIDAS provide an easy to use and cost effective means to conduct experiments that explore "what-if" questions about concepts of operation in specific domains of interest.

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

### *Transparency*

Model transparency refers to the ability to comprehend the performance of the models, the relationships that exist among the models being used, which models are triggering in the model architecture, and whether the model is behaving as the model developer would expect. 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 [16].

## *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 generalize less, and are less re-usable for applications in new contexts. This places the field of modeling into the conundrum of making models that are statistically valid (i.e. a high correlation between predicted and actual data) 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 the 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, a process that is currently underway in MIDAS' FAA modeling of NextGen operations. The *model develop* phase of an HPM effort is one that is comprised primarily of model verification, where the inputs parameters such as the SEEV weights and workload primitives, are built from and operate as expected given the model's context. *Model verification* is the process of determining whether a model and its associated data behave as intended by the model developer / analyst. The model manipulate phase is where the model's conceptual parameters are manipulated to bring the overall model performance closer to expectations. The *model validation* phase determines the degree to which a model and its associated predictions are an accurate representation of the real world, from the perspective of the intended users of the model. Formalized 'develop-validate' iteration cycles are an important step toward increasing the credibility of HPMs particularly as the complexity of human-system operations increases.

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# Acknowledgment