INL/CON-06-11170
PREPRINT

Modeling Human Reliability Analysis Using MIDAS

International Workshop on Future Control Station Designs and Human Performance Issues in Nuclear Power Plants

Ronald L. Boring

May 2006

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Ronald Laurids Boring, PhD
Human Factors, Instrumentation and Control Systems Department
Idaho National Laboratory
Idaho Falls, ID 83415, USA
{ronald.boring,tuan.tran}@inl.gov

Abstract – *This paper documents current efforts to infuse human reliability analysis (HRA) into human performance simulation. The Idaho National Laboratory is teamed with NASA Ames Research Center to bridge the SPAR-H HRA method with NASA's Man-machine Integration Design and Analysis System (MIDAS) for use in simulating and modeling the human contribution to risk in nuclear power plant control room operations. It is anticipated that the union of MIDAS and SPAR-H will pave the path for cost-effective, timely, and valid simulated control room operators for studying current and next generation control room configurations. This paper highlights considerations for creating the dynamic HRA framework necessary for simulation, including event dependency and granularity. This paper also highlights how the SPAR-H performance shaping factors can be modeled in MIDAS across static, dynamic, and initiator conditions common to control room scenarios. This paper concludes with a discussion of the relationship of the workload factors currently in MIDAS and the performance shaping factors in SPAR-H.*

I. INTRODUCTION

The Man-machine Integration Design and Analysis System (MIDAS) is a simulation modeling environment developed by NASA Ames Research Center over a 20-year period [1]. MIDAS combines in a single environment a dynamic simulation scenario builder, a 3-D graphical environment modeling system, an ergonomically correct virtual human, and a series of cognitive and perceptual models [2]. Using this interplay of components, it is possible to create high-fidelity simulations of humans interacting with systems, including human performance modeling over repeated simulation trials.

While MIDAS has to date been used extensively in aerospace to model astronautic crew performance in microgravity, it also holds considerable promise for the simulation of control room scenarios in nuclear power plants. The Idaho National Laboratory (INL) is currently working with NASA Ames Research Center (ARC) to develop this control room simulation capability. These efforts center on incorporating CAD models of control rooms, modeling advanced instrumentation and functionality in these control rooms, developing realistic crew interaction scenarios, and implementing human reliability analysis logging techniques within MIDAS.

Currently, MIDAS includes a series of cognitive models that provide an estimation of crew workload across modeled scenarios. These cognitive models are based on Wickens' Workload Model [3], which groups mental abilities into four functional areas: Visual, Auditory, Cognitive, and Psychomotor (VACP). The visual and auditory elements map perceptual processes, while the psychomotor element maps the execution of thought into action or behavior. As depicted in the on-screen lower-lefthand window in Figure 1, VACP is modeled dynamically throughout simulated task executions, allowing cognitive modelers to identify key scenarios in which acceptable workload thresholds are exceeded, thereby potentially degrading performance to unacceptable levels.

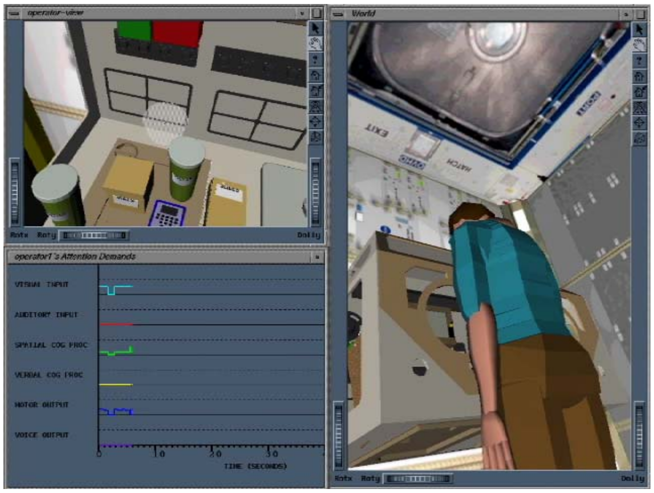

Figure 1: MIDAS simulation depicting dynamic workload calculations in lower-lefthand window

Initial collaborative efforts between the INL and ARC are focusing on incorporating human reliability analysis (HRA) models into MIDAS (for a full review, see [4]). HRA is commonly used to estimate the human error probability (HEP) of overall system risk. Numerous formal HRA methods exist to identify potential sources of human error, incorporate them into overall risk models, and quantify the corresponding HEPs [5]. To achieve a quantitative estimate of the HEP, many HRA methods utilize performance shaping factors (PSFs), which characterize significant facets of human error and provide a numerical basis for modifying default or nominal HEP levels [6].

Initial efforts are currently capturing aspects of human performance along the eight shaping factors modeled in the SPAR-H HRA method [7]. These eight PSFs include: *the ratio of required time to available time, stress and stressors, task complexity, experience and training, quality of procedures, ergonomics and human-machine interface, fitness for duty,* and *work processes.* SPAR-H provides assignment levels for each of these PSFs, which have been calibrated to error likelihood rates found across other HRA methods. This paper highlights initial efforts to model the SPAR-H PSFs in MIDAS.

Modeling these PSFs within MIDAS allows simulation-based assignment of non-nominal levels, which may be mapped to the PSF levels provided in SPAR-H and subsequently quantified to produce an estimated human error probability (HEP). Because MIDAS permits Monte Carlo style multiple runs of scenarios, it is also possible to adopt a frequentist approach to HEP calculation, in which simulated errors may be mapped back to the PSF states at the time the error occurred. It is also possible, in this manner, to calculate HRA dynamically across scenarios. PSFs from other methods, including the 15 PSFs identified in the *HRA Good Practices* guide [8], are planned for future implementation. In most cases, these additional PSFs represent a refinement of the SPAR-H PSFs to a greater level of analytic granularity.

II. CONSIDERATIONS FOR MODELING PERFORMANCE SHAPING FACTORS

II.A. Static vs. Dynamic HRA

Most HRA models, including SPAR-H, are designed to capture human performance at a particular point in time. These models can be considered *static HRA models*, in that they do not explicate how a change in one PSF affects PSFs and the event progression downstream. Of course, most HRA methods do account for dependency, which is the effect of related events on the HEP calculation. Generally, if two events in a sequence are related, it is assumed the dependent likelihood of the downstream errors is greater than if they were not preceded or primed by an error-enhancing system. Dependency, however, is typically based on an overall HEP and does not systematically model the progression of PSF levels across events. *Dynamic HRA*, as afforded by simulation environments such as MIDAS, needs to account for the evolution of PSFs and their consequences to the outcome of events.

An issue related to dependency in static HRA is the level of granularity accounted for in the task decomposition. In HRA, events are decomposed into a series of subevents, steps, actions, or goals. Most HRA follows general task analysis guidelines for event decomposition, but there is significant variability in the level of decomposition adopted across analyses and analysts. While one analysis may focus on a detailed step-by-step breakdown of human actions and intentions (e.g., the approach adopted in GOMS-level task analyses), another may cluster human actions at a high level according to resultant errors (e.g., the approach often adopted in probabilistic risk assessment). This inconsistency is particularly problematic in making headway on dynamic HRA, because:

- Most simulation systems offer a highly detailed level of task decomposition that may be incompatible with certain HRA approaches;
- Adjustments to HEPs for dependency based on human action clusters may be artificially inflated when used with a highly detailed level of task decomposition, because there is no granularity adjustment on dependency calculations;
- No current HRA method offers guidance on the treatment of continuous time-sliced HEP calculation as is afforded by dynamic HRA.

Another important aspect of dynamic HRA is the need to consider PSF latency and momentum. *PSF latency* refers to the phenomenon that a PSF, once activated, will retain some activation across tasks in a scenario. The PSF activation may degrade over successive tasks, but the PSFs for a particular point in time cannot be determined without consideration of the antecedent PSF states. Likewise, the dynamism of antecedent PSF states must be considered. *PSF momentum* refers to the propensity of the antecedent PSF to change. A PSF momentum may mean that the effects of a PSF such as stress may actually continue to increase when emerging from an increasingly stressful task situation. This information can be accounted in part by tracking the history of task outcomes in the scenario. Positive actions and recovery are credited by a progressive decrease in the negative effect of a PSF. In contrast, unsuccessful actions and human errors serve to increase the negative effect of a PSF. Once a positive or negative effect of the PSF is underway, a reverse in outcome will not instantly wipe out the positive or negative momentum of the PSFs.

Efforts are ongoing in the current SPAR-H mapping exercise to address these dependency, decomposition, latency, and momentum considerations to a degree appropriate for dynamic HRA. In the current approach, HEPs are calculated according to SPAR-H with a Bayesian update on the individual PSF levels. Thus, dynamic HRA is approximated by calculating HEPs at discrete, static time slices using SPAR-H and updating preceding HEPs. Future efforts will attempt to achieve dynamic HRA modeling by validating the appropriate adjustments to SPAR-H for dynamic dependency and task decomposition.

II.B. Types of PSF Adjustments

In order to understand how PSFs may be adjusted in a simulation, it is necessary to understand scenarios. MIDAS executes scenarios, which are scripted to encompass the predictable as well as unpredictable series and progression of events. The simulated operators are equipped with a rich collection of laws of human performance, thereby closely approximating human behaviors across all events that comprise a scenario. The scenario simply serves as a figurative roadmap to guide the activities of the simulated operators. Operators respond to the scenarios according to their defined behavioral repertoire, incorporating minute variations in behavior in each run of a scenario. To capture the breadth of human behavior, it is therefore necessary to run multiple trials of each scenario using the simulated operators.

Not only are the actions and outcomes by the simulated operators important, it is also important to capture and manipulate the PSFs that affect those actions. A realistic simulation is comprised not only of the normal aleatory span of human behavior for a given situation but also the range of PSFs that influence and result from the situation and the actions throughout the course of a scenario.

Table 1 depicts the three types of modifications to PSFs that may occur throughout a particular scenario. In a *static condition*, the PSFs remain constant across the events or tasks in a scenario. For example, in many scenarios, the operator's fitness for duty—the operator's physical and emotional health with regard to performing the required tasks—is set at the onset of the scenario and is not expected to change throughout the scenario. Across the progression of the scenario, the operator is not expected to suffer a lapse in physical health or psychological state of mind that would affect the outcome of the scenario. In a *dynamic progression*, PSFs evolve naturally across events or tasks in a scenario. Again, using the example of fitness for duty, there are circumstances in which fitness for duty would naturally degrade throughout the scenario. Such would be the case, for example, during an unusually long work shift, in which fatigue—a negative contributor to fitness for duty—would be expected to set in. Finally, when there is a *dynamic initiator* (cf. "initiating event" in the traditional parlance of HRA), a sudden change in the scenario causes changes in the PSFs. For example, a sudden change may be introduced into the environment that would decrease the operator's fitness for duty. The operator may be physically injured, or the operator may receive "bad news" that interferes with his or her ability to concentrate on the tasks at hand. Note that while a dynamic progression may encompass both positive and negative outcomes on the PSF, the dynamic initiator is assumed to have a negative outcome. The likelihood of unanticipated hardware failure, for example, is assumed to be greater than the likelihood of the spontaneous recovery of a failed hardware system.

Table 1: Types of PSF modifications

Static Condition	**Dynamic Progression**	**Dynamic Initiator**
PSFs remain constant across the events in a scenario.	*PSFs evolve across events in a scenario.*	*A sudden change in the scenario causes changes in the PSFs.*

It is crucial in MIDAS modeling of HRA to consider all three types of PSF modifications. The MIDAS simulation must:

- Include the nominal effects of a PSF for static conditions
- Feature the full range of PSF effects, from performance enhancing to performance decreasing effects
- Incorporate the natural cause-and-effect relationship of one task on another in terms of the PSF progressions
- Consider PSFs over time, in terms of diminishing effects (i.e., the natural decay of an effect) and effect proliferation (i.e., the natural increase of a PSF over time, even if it begins as a latent effect)
- Reconfigure PSFs in the face of changing scenarios while retaining PSF latency and momentum states from the scenario forerunner for a suitable refractory period (e.g., if the operator is stressed prior to a scenario switch, the stress PSF should remain active despite the new scenario because of the operator's inability to release built-up stress instantly).

Table 2 presents modeling considerations for the eight SPAR-H PSFs across static, dynamic progression, and dynamic initiator conditions. As well, Table 2 provides considerations related to the effect of the SPAR-H PSFs on VACP workload modeling. Some high-level considerations include:

- All PSFs should be set at the appropriate level at the initiation of the scenario. Several PSFs represent typically static conditions across the scenario. These PSFs include: *experience/training, fitness for duty,* and *work processes.*

Table 2: SPAR-H PSF modeling considerations for MIDAS

SPAR-H PSF	Considerations for Static Condition	Considerations for Dynamic Progression	Considerations for Dynamic Initiator	Considerations for VACP Model
Available Time	May be set initially for scenario if there are time limits in place.	As scenario progresses, available time will diminish unless actions are taken that effectively buy time to successfully complete required actions in the scenario.	Situational changes (e.g., sudden hardware failure) may diminish available time.	Inadequate time may lower overload threshold for VACP activities by requiring more rapid sequencing of information and actions. It is assumed that a generous allotment of time does not significantly increase the overload threshold for VACP activities beyond the default threshold found for adequate time.
Stress/Stressors	May be set initially for scenario. In most cases, stress/stressors assumed to be nominal at the outset of a scenario.	In the presence of stress, it is assumed that the outcome of tasks will affect the severity and continuance of stress. Successful actions and recovery may serve to decrease stress gradually, while unsuccessful actions and errors may increase stress over successive actions.	Situational changes (e.g., sudden hardware failure), environmental changes (e.g., excessive heat), and psychological factors (e.g., sudden adverse event that negatively impacts state of mind) may increase stress.	Stress and stressors lower the overload threshold for all VACP activities. Sustained high VACP levels may induce stress.
Complexity	May be set initially for scenario or sequence of events within a scenario.	Complexity may vary from task to task. Successful actions and recovery may decrease subsequent task complexity, while unsuccessful actions and errors may increase subsequent complexity and recovery.	Situational changes (e.g., sudden hardware failure) may increase task complexity.	Task complexity may lower overload threshold for visual, auditory, and especially cognitive activities.
Experience/Training	May be set initially for scenario, as individual's experience and training will not vary throughout scenario.	Unlikely to change throughout the scenario, although may change if task switches to less familiar or more familiar domain.	Situational changes (e.g., sudden hardware failure) may move individual into a less trained and experienced domain.	Low experience may lower the overload threshold for VACP activities, while high experience may increase the overload threshold for VACP activities.
Procedures	Overall quality of procedures may be set globally at the initation of the scenario.	Assuming screened and edited procedures of at least nominal quality, deviations in quality of procedure (e.g., omitted step) are task specific and will vary from task to task.	Situational changes may introduce cases for which the procedures are deficient.	Assumed nominal overload threshold for VACP activities. Simultaneous utilization of several procedures will elevate visual and cognitive activity levels. Multiple annunciators requiring separate procedural response may elevate visual, auditory, and cognitive activity levels.
Ergonomics/HMI	Overall quality of ergonomics may be set globally at the initiation of the scenario.	Poor ergonomics or HMI may appear in specific tasks.	Situational changes (e.g., sudden hardware failure including instrumentation failure) may reduce the quality of the ergonomics or HMI.	Poor ergonomics may especially elevate the level of psychomotor activity by requiring greater physical effort by the individual. Poor HMI may elevate the visual, auditory, or cognitive activity levels.

Table 2: SPAR-H PSF modeling considerations for MIDAS (continued)

Fitness for Duty	Individual brings fitness for duty to work environment; may in most cases be set and kept static at initiation of scenario.	Long duration scenarios may degrade fitness for duty through fatigue. Environmental conditions (e.g., excessive heat) may degrade fitness for duty.	Sudden change in the environment (e.g., radioactive release), physical injury, or psychological shock may be introduced to significantly degrade fitness for duty.	Degraded psychological state may lower overload threshold for visual, auditory, and cognitive activities. Degraded physical state may lower overload threshold for psychomotor activity.
Work Processes	Work processes represent precipitating circumstances that are unlikely to change across the scenario and may be set at the initiation of the scenario.	Unlikely to change through the scenario unless new individuals are introduced into the scenario with different work processes.	Sudden introduction of novel individuals or novel punitive consequences to actions may result in poor work processes.	Work processes—particularly communication—are likely manifest in the visual and auditory activities. Poor work processes may lower overload threshold for these activities.

- The SPAR-H PSFs are not truly orthogonal, a consideration that is particularly important when modeling the dynamic progression of PSFs. For example, as *available time* decreases, there is usually a related increase in the individual's *stress*.
- As noted earlier, dynamic initiators rarely work to decrease the error likelihood of a situation. Often dynamic initiators serve to change the scenario parameters significantly. At the introduction of a dynamic initiator, all PSFs should be refreshed to reflect the new scenario characteristics.
- The impact of nominal or positive PSFs is generally treated by setting the default overload thresholds in the VACP model in accordance with Keller [9].
- With regards to VACP components, the negative impact of PSFs is reflected in the VACP model either by a lowering of the overload threshold or an increasing the VACP activation level. To the extent that the PSF can be ascribed to the individual and results in significant PSF latency, it is assumed that the threshold is lowered. When the PSF represents transient situational factors, it is assumed that these may act on a particular VACP channel by increasing workload but not by affecting the individual's threshold. For example, low *fitness for duty*—an individual characteristic—may be reflected in lower attentional abilities and a lower workload overload threshold in that individual. In contrast, a poor *human-machine interface* is expected to increase the attentional demands of the individual but not lower that individual's threshold.

III. DISCUSSION

This paper characterizes initial efforts to translate HRA to human performance simulation. These efforts require a reconsideration of several fundamentals of HRA, ranging from dependency to PSFs. In this paper I have outlined how the INL has recrafted a few of these fundamentals to achieve dynamic HRA, a prerequisite to HRA in simulation. I have also provided a first glance at how SPAR-H PSFs are being incorporated into MIDAS scenarios. This work is ongoing, both in terms of mapping static HRA to dynamic HRA and in terms of implementing a specific HRA method within a simulation system. Future research will provide case study illustrations of the implementation of these concepts, validate the utility of PSF and HEP generation by simulated operators, and demonstrate a full-scale control room scenario of MIDAS utilizing SPAR-H. It is anticipated that these successive steps will pave the path for MIDAS as a cost-effective, timely, and valid human performance screening tool for current and next generation control room configurations (see [4]).

REFERENCES

[1] S.G. Hart, D. Dahn, A. Atencio, & K.M. Dalal, "Evaluation and application of MIDAS v2.0," *Proceedings of the 2001 Aerospace Congress*, Paper 2001-01-2648 (2001).

[2] B.F. Gore & P.A. Jarvis, "New integrated modeling capabilities: MIDAS' recent Behavioral Enhancements," *Proceedings of the 2005 Aerospace Congress*, Paper 2005-01-2701 (2005).

[3] C.D. Wickens, *Engineering psychology and human performance*, Harper Collins (1984).

[4] R.L. Boring, D.D. Dudenhoeffer, B.P. Hallbert, & B.F. Gore, "Virtual power plant control room and crew modeling using MIDAS," *Joint Halden Reactor Project and CSNI Special Experts' Group on Human and Organisational Factors Workshop on Future Control Station Designs and Human Perfromance Issues in Nuclear Power Plants*, Paper 5.3:1-5 (2006).

[5] D.I. Gertman & H.S. Blackman, *Human Reliability & Safety Analysis Handbook*, Wiley-Interscience (1994).

[6] R.L. Boring & D.I. Gertman, "Atomistic and holistic approaches to human reliability analysis in the US power industry," *Journal of the Safety and Reliability Society*, 25(2), 21-37 (2005).

[7] D. Gertman, H. Blackman, J. Marble, J. Byers, & C. Smith, *The SPAR-H Human Reliability Analysis Method, NUREG/CR-6883*, US Nuclear Regulatory Commission (2005).

[8] A. Kolaczkowski, J. Forrester, E. Lois, & S. Cooper, *Good Practices for Implementing Human Reliability Analysis (HRA), Draft Report for Comment, NUREG-1792*, US Nuclear Regulatory Commission (2004).

[9] J. Keller, "Human performance modeling for discrete-event simulation: Workload," *Proceedings of the 2002 Winter Simulation Conference*, 157-162 (2002).