Modeling Algorithms for Predicting the Effects of Human Performance in the Presence of Environmental Stressors

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For military systems, environmental stressors (e.g. motion, temperature, noise) must be considered during decision making related to manpower requirements, workload determination, design tradeoffs, and mission effectiveness/sustainability early into and throughout the system acquisition process. Current human performance modeling techniques may have limited predictive utility and have not been fully validated against operational human in the loop (HIL) data. As a result, they may lack sufficient fidelity to support systems engineering needs to predict the individual and interactive effects that environmental stressors may have on human performance. The purpose of this paper is to describe an approach for developing performance shaping function (PSF) algorithms for environmental stressors that can be integrated into human performance modeling tools. These high fidelity plug-in algorithms are anticipated to provide an enhanced level of predictive validity when compared to current discrete event modeling tools. The algorithms will address environmentally induced limitations that are levied on human performance and enhance decision making in defense acquisition system design and cost versus performance tradeoffs.

INTRODUCTION

Within the current defense acquisition design climate, realization of reduced manning initiatives must be tempered by limitations of human performance that may affect mission effectiveness, sustainability, and safety. Environmental factors may induce onset of a number of physiological and biomechanical events that can quickly reduce human capabilities to a fraction of what they would be within a stable environment. For example, ship motions can limit a crews' ability to perform essential command, control, and communications functions, navigation tasks, and emergency procedures (Stevens & Parsons, 2002).

Currently, validated impacts of environmental stressors (e.g., motion, temperature, fatigue) on human performance are not fully considered during defense system design tradeoffs, workload estimation, and manpower determination. Further, algorithms used for human performance modeling may have limited predictive utility and have not been fully validated against operational human performance data. As a result, they may lack sufficient fidelity to accurately predict the individual and interactive effects that these stressors have on human performance.

Assessing the effect of these stressors on human performance is not a novel idea; there are currently many modeling tools designed specifically for this purpose. All modeling tools, however, are dependent upon the quality and fidelity of the algorithms embedded within them. The current effort aims to enhance the predictive capability of these algorithms.

The user's guide of one such modeling tool, Improved Performance Research Integration Tool (IMPRINT), states the need for updating and adding new algorithms as something that should be considered for improving utility (Alion Science & Technology, 2009). This enhancement of human performance shaping function (PSF) algorithms would provide a basis for improved decision making early into and throughout the defense

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14. ABSTRACT

For military systems, environmental stressors (e.g. motion, temperature, noise) must be considered during decision making related to manpower requirements, workload determination, design tradeoffs, and mission effectiveness/sustainability early into and throughout the system acquisition process. Current human performance modeling techniques may have limited predictive utility and have not been fully validated against operational human in the loop (HIL) data. As a result, they may lack sufficient fidelity to support systems engineering needs to predict the individual and interactive effects that environmental stressors may have on human performance. The purpose of this paper is to describe an approach for developing performance shaping function (PSF) algorithms for environmental stressors that can be integrated into human performance modeling tools. These high fidelity plug-in algorithms are anticipated to provide an enhanced level of predictive validity when compared to current discrete event modeling tools. The algorithms will address environmentally induced limitations that are levied on human performance and enhance decision making in defense acquisition system design and cost versus performance tradeoffs.

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acquisition design process. The current effort can help enhance the total system picture (i.e., hardware, software, human, and environment) by enhancing accuracy of estimates for task time, task accuracy, manpower, workload, fatigue, effectiveness, and sustainability. This integrated picture will result in more precise predictions of total system performance and ownership cost and could reduce the need for costly redesign by considering environmentally induced limitations to human performance during the design process.

HUMAN PERFORMANCE MODELING

An Office of Naval Research (ONR) funded research effort consisting of team members from government, industry, and academia is currently underway to develop processes for improving the predictive capabilities of PSF's. The goals of this effort are threefold: increase fidelity of existing PSFs, create new PSFs, and implement PSFs within discrete event modeling tools to improve predictiveness of human performance within the presence of environmental stressors. The PSFs will be applied in the form of mathematical algorithms and implemented as plug-ins to relevant task network models within off- the-shelf software.

The initial modeling effort is relevant to tasks performed aboard a Navy ship. The modeling environment, or implementation software, will be chosen based upon the type of human performance question being asked. Some examples of potential candidates for the modeling environment are described briefly below.

IMPRINT can be used to apply environmental stressor algorithms in real time during a mission simulation, or allow the insertion of a preprogrammed stressor into a model (Alion Science and Technology, 2009). The software uses these encoded algorithms to determine the impact of environmental stressors (e.g., heat, cold, motion) on task time and accuracy. IMPRINT is used primarily to analyze crew effectiveness and predict human performance decrements.

Alion has also developed the Total Crew Model (TCM) is used to assess the adequacy of proposed manpower levels by evaluating system effectiveness. TCM can evaluate task throughput by assigning functions to individuals while applying constraints, such as fatigue, to manpower. The output may include a timeline of allocated tasks, time spent on tasks, task failures, or fatigue levels.

A third modeling tool is one which allows the user to schedule appropriate numbers of crew members and their sleep/wake cycles to generate optimized watchbills. The Fatigue Avoidance Scheduling Tool (FAST), developed by the United States Air Force, utilizes a biomathematical fatigue model and individualized performance prediction algorithms to quantify the effects of various work-rest schedules on human performance. The graphic input-output display shows cognitive performance effectiveness as a function of time (Eddy & Hursh 2001).

Each of these modeling tools can be used to accomplish different human performance modeling objectives; however, they all rely upon one common thread. In order for them to predict human performance impacts accurately they must utilize valid task networks and performance shaping algorithms as input. The models' output can then be compared to human in the loop (HIL) data to assess validity against an established benchmark. As the adage goes, "garbage in, garbage out" hence, higher fidelity data and algorithms yield more accurate predictions. The Naval Air Warfare Center Training Systems Division (NAWCTSD) Human Systems Integration (HSI) PSF Team set out to improve the outputs of predictive human performance modeling by increasing the fidelity and validity of these algorithms.

APPROACH

The algorithm development approach adopted by the team involved obtaining data relevant to individual and interactive impacts of environmental stressors on human performance, development of human performance models, development of PSF algorithms, and validation of modeled output against HIL performance data.

Obtain Data

An extensive literature review was conducted to assess the current state of research related to the impact of a range of environmental stressors on human performance. Operational definitions were refined for environmental stressors including illumination, motion, vibration, fatigue, G-force, and temperature.

Over 250 environmental stressor documents (e.g., experimental studies, literature reviews, meta-analyses) were reviewed and relevant data were extracted and arranged into a comprehensive database that included independent and dependent variables, statistical results, effect sizes, and pertinent notations explicit to the validity of the study. Topical content addressed topics such as vehicle motion, motion sickness, uncoupled motion, whole-body vibration, multi-axis vibration, combinations of vibration frequencies and amplitudes, sleep deprivation, shift work, thermal regulation, thermal comfort, ambient temperatures, illumination, sustained acceleration, workload, and fatigue. Based on ONR guidance, data availability, and preliminary analyses of programmatic requirements the initial stressors of focus were determined to be motion, fatigue, and thermal stress.

Develop Models

Fundamental to algorithm development is the iterative process of integrating performance data into task network models. Task data were derived from documentation for our initial transition platform (e.g., test reports, risk assessments, hazard control records, and training documents). Data collected and analyzed were aligned with previous and ongoing research to create initial task network models. Gaps in the literature and available data were indentified and are being supplemented through implementation of a data acquisition approach that includes additional experimental and operational evaluations designed to bridge these gaps.

Based upon analysis of ship design documentation, ONR guidance, data availability, and SME input it was determined that motion would be chosen as the initial stressor of interest. It was also decided that the initial modeling effort would be focused on the manual material handling (MMH) aspect of vehicle launch and recovery (L&R). It is anticipated that there will be a more prevalent effect of motion on manual tasks vice cognitive tasks. Therefore, this direction may provide a more sensitive model within which to investigate the approach, processes, and algorithm application.

Based on the question being asked (e.g., how many people does this task take; how effective is this crew) and the software capabilities mentioned previously, the appropriate modeling environment can be chosen. Once the models are constructed, algorithms are plugged into the modeling architecture (e.g., IMPRINT, TCM) and applied to the task networks for human performance effects. Impacts are evaluated in terms of variables such as task time, task accuracy, manpower, workload, fatigue, effectiveness, and sustainability of tasks.

Develop Algorithms

The algorithm component development approach is based upon findings and data obtained from laboratory, simulation, and HIL experimental data. Critical algorithm component determination involves consideration of the potential influence of several confounding and affecting variables on human performance. For example, it is anticipated that the magnitude and direction of observed effects may be influenced by task/stressor type, task/stressor duration, or stressor dosage (Cheung, Brooks, & Hoofer, 2002; Hancock, Ross, & Szalma, 2007; Hancock & Vasmatzidis, 2003; Muth, 2006; Pilcher, Nadler, & Busch, 2002; Stevens & Parsons, 2002). Hence, not all tasks are equally demanding and some tasks may be more susceptible to stressors than others. Additionally, there is inherent variability between individuals (e.g., gender, age, and exposure history) and therefore some may be more susceptible to environmental stressor exposure than others (Bos, Damala, Lewis, Ganguly, & Turan, 2007; Stevens & Parsons, 2002).

Efforts are being aimed toward identifying as many influencing factors as possible and determining gaps for representative data, constants, equations, performance curves, or ranges. Some of these factors include platform location, adaptation, susceptibility score, onset cues, recovery times, etc. Initially, base algorithms are being developed which will be enhanced iteratively as additional data is acquired and analyses are performed. Since initial modeling is being focused on motion stressor effects, an example of the current state of a base equation for the motion stressor is presented below

$$HP_{(SS)} = f\,(TT \times TD \times D \times I \times MSI \times MSDV \times PH_{(z)})$$

where HP is human performance, SS is sea state, TT is task type, TD is task difficulty, D is duration of exposure, I is individual differences, MSI is motion sickness incidence, MSDV is motion sickness dose value, PH is placeholder, and $_z$ is human performance factor. The relationships and weightings of the component effects are still being determined, these base formula examples are not meant to imply a multiplicative relationship.

The MSI and MSDV components were incorporated to predict the occurrence of motion sickness based on the amplitude, frequency, and duration of exposure to ship motions. There are two existing models for predicting the occurrence of motion sickness: the MSI Model and the Vomiting Incidence (VI) Model (Stevens & Parsons, 2002). Both models express findings in units of percent of the population that has vomited after exposure of a specified duration. A "motion sickness dose value" is also defined, which may be used to predict the percentage of persons likely to vomit after exposure to known magnitudes and durations of vertical oscillation in the frequency range 0.4 to 0.5 Hz. The motion sickness dose value is defined as:

$$MSDV_z = \left(\int_0^T a_z^2\,(t)dt\right)^{1/2}$$

where a_z is the frequency-weighted z-axis acceleration and T is the period. Using the motion sickness dose value, the actual number of adults who are likely to vomit may be approximated by

$$MSI = K_m \cdot MSDV_z$$

where K_m is a constant which may vary according to the exposed population. For a mixed population of unadapted male and female adults, $K_m = 1/3$ is suggested. The standards identify the large variability in the susceptibility among different individuals, e.g., females are more prone to motion sickness than males and that the prevalence of symptoms declines with age. Therefore, it is noted that K_m should be adjusted accordingly (Stevens & Parsons, 2002).

The base algorithms are also being developed with placeholders for factors with unknown effector values. The algorithms will obtain increased fidelity through iterative enhancement as additional data is acquired and analyses are performed.

Validate Model Output

The data validation plan includes identification of HIL data type requirements, anticipated data sources, data collection methods, measures of performance, and statistical approaches to analysis. This plan will serve as a roadmap for the acquisition, testing, and evaluation of algorithms for predictiveness and validity. Models based on HIL experimental and operational data along with algorithm influenced modeled data will be assessed for validity. These criteria include range checking, causal dependencies, temporal validity, stability check, cross-validation, and SMEs corroboration.

Model predictions will be validated against the HIL data collected during performance of tasks in an operational environment and/or laboratories. Boring, Hendrickson, Forester, Tran, and Lois (2010) recommend using three levels of validation to accurately assess human performance models: (a) successful task completion, (b) subtask correspondence, and (c) quantitative performance. Within these levels, efforts should span from coarser, qualitative to finer, quantitative levels of granularity. For qualitative validation (task characteristics such as triggering events, release events, subtask composition, etc.), analysts will utilize a combination of SME input, consistency with existing literature, and evaluation of similar models. Validation parameters for quantitative comparison will include time to complete tasks and performance accuracy (e.g., error rate, errors of omission).

An inspection approach will be used to check that HIL and model output data match within the benchmark of 75 ± 10 %. This validation goal was an estimate determined by a NAWCTSD team of human factors engineers, training specialists, and senior research psychologists with significant experience in human performance studies and research. It was based on past research and sound human performance research best practices as determined by the human performance SMEs. Based on pass/fail assessment against the benchmark, algorithms will either be adopted within the PSF modeling architecture or iteratively recalibrated until they achieve the benchmark (NAWCTSD, 2011).

CONCLUSION

The purpose of this project is to develop processes for improving the predictiveness of PSF algorithms for environmental stressors, either alone or in combination with other stressors. The goal of this work is to enhance the capability to perform quantitative assessments of human performance within affected operational environments (e.g., varying sea states, protective posture, or extreme heat/cold). It is expected that these predictions will provide defense acquisition leaders, decision makers, and design teams with a more complete picture of total system performance and an improved capacity to make predictions that support increased capability, effectiveness, safety, and sustainability.

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