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MODELING THE EFFECTS OF CREW SIZE AND CREW FATIGUE ON THE CONTROL OF TACTICAL UNMANNED AERIAL VEHICLES (TUAVS)

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ABSTRACT

The field element of the U.S. Army Research Lab (ARL) at Fort Huachuca, Arizona is concerned with the manning required to operate the close-range Tactical Unmanned Aerial Vehicle (TUAV). The operational requirements of the TUAV operators may include extended duty days, reduced crew size and varying shift schedules. These conditions are likely to reduce operator effectiveness due to fatigue. The objective of this study was to analyze how fatigue, crew size, and rotation schedule affect operator workload and performance during the control of a TUAV. The conclusions from executing the models indicate that reducing the number of operators currently recommended for the control of TUAVs results in 1) 33% more aerial vehicle (AV) mishaps during emergencies, 2) a 13% increase in the time it takes to search for targets, and 3) an 11% decrease in the number of targets detected. Over 400 mission scenario replications of the model were executed allowing statistically reliable predictions to be made of the effect of operator fatigue on performance. Discrete Event Simulation (DES) models may provide a cost effective means to estimate the impact of human limitations on military systems and highlight performance areas needing attention.

1 INTRODUCTION

Changes in military contingencies in the last decade have led to reduced funding for expensive field exercises and training. Consequently, planners have increasingly turned to modeling and simulation efforts for war gaming and to estimate the operational impact of new systems. Evaluating the human impact on complex systems has lagged behind and has resulted in a decrease in system outcome fidelity. Small-computer derived network simulation models are ideal for these studies and can address a wide variety of human interface solutions and the effects of operator workload. DES models describe a process as a sequence of events, each with a distinct beginning and end and a variety of outcome solutions. Micro Saint is a commercially available DES software package for constructing models that emulate real-life processes. Simple and complex models can be built that include dynamically changing variables, probabilistic and tactical branching logic, conditional task execution, and extensive model data collection (Laughery 1999). These models provide predictive validity for systems without resorting to expensive human studies in prototypes (Lawless et al. 1995, See and Vidulich 1998). Unlike human studies, hundreds of model executions are possible providing enough outcome variance to allow statistically-based estimates of human performance (See and Vidulich 1998). DES models are valuable for military systems that frequently change to adapt to new technologies and that often have important human operator issues (Pew et al. 1997). Verification and validation studies have been conducted favorably comparing Micro Saint-based simulation timing and workload predictions to real world military operations (McMahon et al. 1995, See and Vidulich 1998).

Computer models are frequently used to estimate theater losses due to nuclear, chemical or biological events. However, other threats may be amenable to computer evaluation that would enhance the realism of modeling or war-gaming exercises. Fatigue induced by sleep deprivation or poor sleep has always played an important role in the effectiveness of troops. The impact is not lessened by the increase in night operations and high intensity, round the clock operations expected in near future threats. Fatigue is arguably one of the most persistent threats to mission success during sustained or continuous operations. A great deal is known about the effects fatigue has on performance. The effects have been consistently demonstrated in multiple sleep deprivation studies. For example, cognitive capacity can decline about

60% after two nights of sleep deprivation (Angus and Heselgrave 1985). Decreases in asymptotic performance between 10-20% are reported during extended performance of less than 24 hours duration (Benline et al. 1997). Recently, Dawson and Reid (1997) proposed that performance after 21 hours of sleep deprivation was comparable with performance degradation following legal levels (0.1%) of intoxication.

This report describes a study conducted by Micro Analysis and Design, Inc. for the U.S. ARL HRED Field Element at Fort Huachuca, Arizona. One area of research examined at the Field Element is the manning required to operate close-range TUAVs. Computer models were developed using the Micro Saint DES software to simulate the tasks operators' performance when controlling a TUAV. These models contained system-specific attributes of the Shadow 200 TUAV. Also included in the models were workload values associated with each task.

The objective of this study was to analyze how fatigue and crew size affect operator workload and performance during the control of a TUAV. It was predicted that as fatigue increased and crew size was reduced, operator performance would be degraded. One of the goals of the project was to use the predictions generated by these models to help determine the crew resources necessary to support Operating Tempo (OPTEMPO) requirements.

2 METHOD

2.1 Fatigue Algorithm Development

A fatigue algorithm was developed for this project that predicts human response capability for tasks over an extended period of sleep deprivation. The main focus of the algorithm is the interaction of prolonged sleep deprivation with circadian disruption on performance. It is based on data collected at Brooks Air Force Base using USAF pilots as subjects during a 52-hour sleep deprivation study. The algorithm is based on one of the tasks used, the Maniken task of the Attention Switching task. This task was selected because it is a complex visual task; it required the subject pay attention to a signal on the screen while performing one of two tasks to know when to switch to and from one task to another. It is an intellectually challenging test that has consistently proven sensitive to fatigue and other stressors in a number of experiments. It is similar to the kinds of visual and performance demands placed on radar operators.

The data from the task were plotted as shown in Figure 1. A cosine curve was fit to the data to unmask the circadian features of performance (Naitoh et al. 1985). This involved a complex demodulation function to separate the linear aspects of the data. The remainder is the

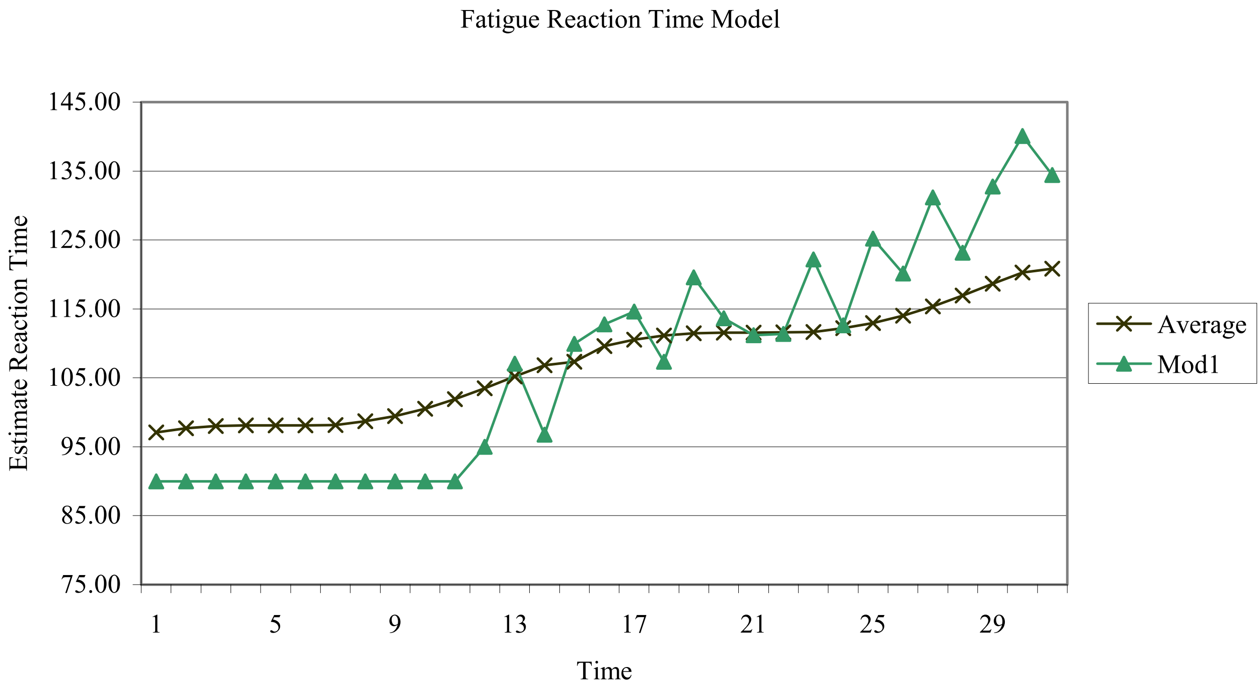

Figure 1: The Maniken Data Used to Make the Algorithm (Mod 1) and the Predicted Response Time Capability (Average) Expressed as Percent Baseline Response Time

circadian function that allows oscillating performance levels to be reliably predicted for extended periods of time over several days (Redmond et al. 1983). The algorithm accounts for a significant amount of the variance; although most of the variance is linear (0.89%), the cosine fit provides an important oscillating function to estimate performance at different circadian times of day.

2.2 DES Model Development

Subject matter experts (SMEs) from Fort Huachuca provided the list of tasks involved in controlling a TUAV (during normal operations and emergencies), the order of these tasks, and the visual, auditory, cognitive, and psychomotor workload values associated with each task. These data were supplemented with information obtained from the Operational Model Summary/Mission Profile for the Shadow 200, a Mapping Exercise that took place at Fort Huachuca in March of 2000, and previous TUAV models and studies (Barnes et al. 2000). The model simulates the Tactical Operations Center (TOC) and the Launch/Recover Station (LRS) [Mission Commander (MC), Aerial Vehicle Operator (AVO) and Mission Payload Operator (MPO) duties] and the following functions: Launch, Recovery of the TUAVs, Mission Support, Emplacement, Displacement, Emergencies, mishaps, and some maintenance tasks that affect the model's timeline.

The TUAV models were developed to simulate an 18-hour surge. A surge is 18 hours of flight over a 24-hour time period, for three consecutive days. Different weather, terrain, search, and emergency conditions were also programmed into the models. The model simulates five TUAV launches per day, regardless of crew rotation schedule. For each launch, three different types of target searches were performed. This resulted in 15 different types of searches per day. These missions were repeated every day (72 hours) in the model using 2, 3, 4, and 6-hour rotation schedules. During times when they are not in the shelter or moving, soldiers may be either resting, eating, performing guard duty, or mission planning. A TUAV spends five hours in the air: four hours of surveillance and one hour to fly to and from its destination. The model simulates three TUAVs and one Float.

Different conditions can affect the time it takes to perform a task, flying the TUAV, and target detection rates. Emergencies cause operators to perform specific tasks that take away from search time. The following conditions are simulated in the model: 1) the type of search being performed (e.g., area search), 2) emergencies that can occur (e.g., generator failure), 3) weather conditions (e.g., gusty winds), and 4) terrain (e.g., high vegetation). The output produced by the model includes performance times and target detection rates and AV mishaps under each of the simulated conditions.

Workload was estimated from a scale developed by McCracken and Aldrich (1984) and later enhanced by Szabo and Aldrich (1987) and Aldrich et al. (1989). Their scale was originally developed to provide a workload estimate compatible with Wickens (1984) in which mental workload is viewed as consisting of multiple cognitive resources. The scale was originally designed for use in discrete task network tools. There are four resources or components typically used in mental workload models; visual, auditory, cognitive, and psychomotor. Typically, the visual, and auditory components refer to the information processing of stimuli surrounding a mission task event. The cognitive component consists of the information processing synthesis. The psychomotor component is directed by the physical responses required of a mission event. The scale for each component ranges from 0 (very low workload) to 7 (very high workload).

In the model, crew size and rotation schedule affect the soldiers' sleep/rest cycles, which in turn affect their fatigue, circadian rhythms, workload, and performance. The more time an operator spends on a task (vigilance) such as monitoring, the greater the decrease in his/her performance over time. As fatigue and workload increase, target search time, target detection rate and human errors increase – thus, increasing the likelihood of TUAV crashes. In the model, the times to perform the tasks were generated from SMEs. These values were then adjusted using the fatigue algorithm and the time into the scenario.

To determine the amount of power necessary to detect a difference in experimental conditions, a power analysis table within Keppel (1991 pp. 72) was referenced. With an alpha level of .05 and a small effect size (.01), it was necessary to obtain 354 data points per cell to obtain 90% power. Thus, the model was run 400 times for each rotation schedule to obtain slightly over 90% power.

3 RESULTS

An Analysis of Variance (ANOVA) was performed on the model output to see how different crew sizes and fatigue affect three dependent variables: 1) the number of AV crashes that occur during emergencies, 2) the amount of time operators spend searching for a target, and 3) the number of targets detected during a 72-hour period. The results show a significant effect for crew size on all three dependent variables: ($F(3,1396) = 51.17$; $p<0.01$), ($F(3,1396) = 12759.24$; $p<0.01$), and ($F(3,1396)=7379.29$; $p<0.05$) respectively. Scores for the 2 and 3-hour rotation schedules were combined because they were not significantly different from each other and they used the same number of crewmembers. A post-hoc analysis (the Tukey Honest Significant Difference Test) showed that decreasing the crew size results in more AV mishaps when emergencies occur (see Figure 2). For example, reducing the crew from 6 to 4 produces 33% more mishaps.

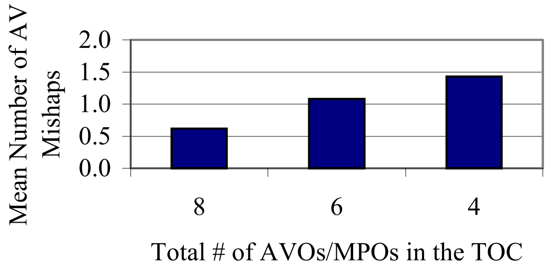

Figure 2: Mean Number of AV Mishaps by Crew Size

Post-hoc analyses also revealed that decreasing the crew size also results in an increase in the amount of time it takes to detect a target (see Figure 3) and a decrease in the number of targets detected (see Figure 4).

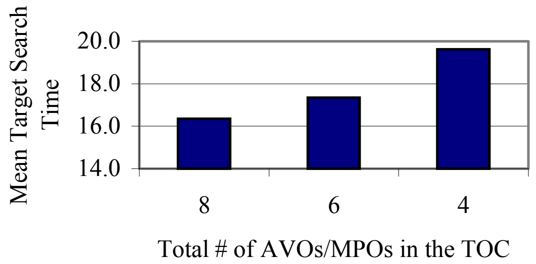

Figure 3: Mean Target Search Time by Crew Size

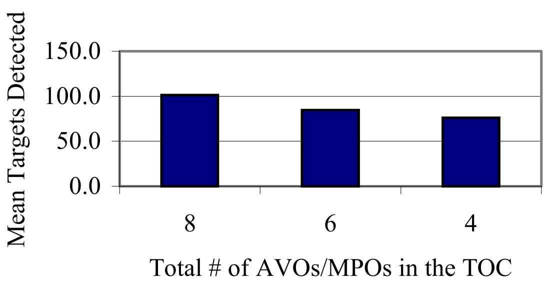

Figure 4: Mean Targets Detected by Crew Size

Finally, analysis of the workload data produced by the model showed that when there was no MC in the LRS, the TOC MC was interrupted approximately 50% of the time with tasks that would have been performed by the LRS MC. When there was one MC in the LRS, he would work for 6.5 hours, have 8 hours of rest, and then work for 6.5 hours (this is for an 18-hour surge with one move). This resulted in the TOC MC being interrupted approximately 20% of the time with tasks that would have been performed by the LRS MC. Overloading the TOC MC can result in a number of events (e.g., degraded supervision of maintenance problems) that might lead to the loss of an AV.

4 SUMMARY

Fatigue is arguably one of the most persistent threats to accelerated mission requirements. When the number of crewmembers on a team is reduced, the same number and type of tasks still need to be performed. This often requires the crewmembers to be awake and performing the same duties for longer periods of time, thus increasing their fatigue and workload. The results of this study indicate that reducing the current recommended number of crewmembers can result in:

- More AV crashes during emergencies
- An increase in the time it takes to search for targets
- A decrease in the number of targets detected.

The model is an attempt to simulate important human limitations into complex models of human performance to increase the fidelity of the predictions. The fatigue algorithm may have applications in other modeling and simulation areas where human limitations would affect the capabilities of friendly and hostile forces. It is hoped that further development of the algorithm will improve the realism of the outcome of these computer-generated exercises.

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