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THE HUMAN SIMULATION: RESOLVING MANNING ISSUES ONBOARD DD21

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ABSTRACT

The limitations that human operators impose on task execution are rarely integrated into simulations of complex systems, resulting in considerable loss of outcome fidelity. A discrete-event simulation tool, Micro Saint, was used to stochastically model the impact of human interactions in a comprehensive model of the next generation US Navy destroyer, DD21, to support the Blue contract competitor team. Mission essential tasks performed by a 3-operator and a 4-operator configurations were modeled during a demanding 2.5 hour land attack scenario. Estimates of utilization rate for the two configurations revealed that two of the operators were tasked more frequently during the 3-operator configuration compared to a 4-operator configuration. Workload estimates showed that Operator 2 was working with significantly increased workload for the smaller watchteam configuration. The workload for Operator 2 dropped 36% when Operator 4 was added to the mission. This over tasking likely contributed to the finding that the smaller configuration could not respond to a call for fire in support of ground forces before 179 seconds whereas the 4 operator team responded within 61 seconds. The DD21 model suggests that the small watchteam configuration might not be acceptable, particularly during missions lasting over several days.

1 INTRODUCTION

The impact of human behavior in computer simulations of complex systems is often disregarded, resulting in a loss of outcome fidelity and realism. Including human behavior issues early in the development of sophisticated design strategies often reveals systems better suited to automation than human intervention. Similarly, a variety of human interface solutions and the effects of operator workload can be evaluated. Small-computer derived network simulation models are ideal for these studies and provide an economic alternative to constructing full-scale prototypes and testing a large number of human operators under different conditions (Laughery 1999). Task network simulation tools are gaining importance and are particularly useful for military systems that can be costly and can require frequent design changes to accommodate advances in technology (Pew and Mavor 1997).

Micro Saint is a discrete-event task network simulation tool that stochastically models the impact of human interaction in system operations of varying complexity and can provide realistic outcome expectations (See et al. 1997). It was developed as an engineering tool to reduce complex tasks to smaller individual networks of tasks. It is ideally suited to similarly reducing complex human operator tasks so that different solutions and timing strategies to task completion can be devised (Laughery 1989). Task timing is user defined from average times and standard deviations provided by subject matter experts and is estimated to be normal, gaussian or rectangular distributions. These pathways and probability levels at key points in the network designs allow for multiple routes to the same solution through the networks. The variability associated with different outcome times allows for multiple executions of the network to emulate variable human response characteristics suitable for subsequent statistical analysis (Lawless et al. 1995; See et al. 1998). Verification and validation studies have been conducted favorably comparing Micro Saint-based simulation timing and workload predictions to real world military operations (McMahon, Spencer and Thornton 1995; Allender et al. 1997).

The US Navy is considering designs for a new generation of Zumwalt-class destroyers (DD-21) that will increase mission capability while dramatically reducing the manning from current operations. Blue team is one of two contract competitors for the ship design and has an integrated human systems interface approach. The DD21 Micro Saint model represents a significant part of that effort. The entire ship's complement is expected not to exceed 95 personnel, a reduction of about 66% overcurrent destroyer manning (O'Brien 2000). Micro Saint was selected to assist in determining the adequacy of integrating the reduced manning with the ability of the ship to perform its mission. A comprehensive Micro Saint model of all of the warfare and maintenance areas of the ship was designed. Thus all of the operator tasks involved in land attack, undersea warfare, air defense, surface warfare and information warfare excursions were modeled. The DD21 simulation is completely autonomous and includes proactive as well as reactive mission events such as responding to threats, altering course and re-directing fire. The model was given five standard operational scenarios to negotiate to determine the adequacy of the number and organization of the crew. Additionally, the effect on crew mental and physical workload was estimated to determine if the operators were unrealistically tasked by the mission activities.

A demanding high operational tempo mission was utilized so that extreme conditions estimate of manning requirements could be obtained. The hypothesis to be tested consisted of comparing two different watchteam configurations in the completion times to engage in a 168 minute battle involving land support, ship defense and target strikes. Specifically, a smaller team of three watchteam officers was expected to take far longer to complete the mission than a four watchteam configuration. Further, the smaller watchteam configuration was expected to experience much greater mental workload demands than the larger watchteam.

2 METHODS

Subject matter experts for the five warfare areas provided the Micro Saint timing means and probabilities for all of the DD21 tasks during a series of meetings. A small part of one of the Land Attack networks for the model is shown in Figure 1. The entire DD21 model consists of 740 such tasks of which 306 require human intervention. The remaining tasks were representations of automated tasks. Tasks are typically called hundreds of times during a scenario.

Workload was estimated from a scale developed by McKracken et al. (1984) and later enhanced by Szabo, et al. (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 4 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).

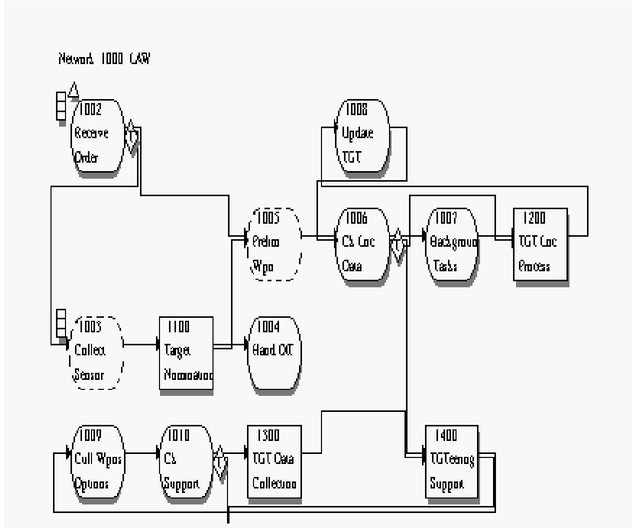

Figure 1: A Very Small, Abridged Example of a Micro Saint Task Network for the Land Attack Warfare Area (LAW) of the DD-21 Model; the Ellipses Have a User-Defined Probabilistic Outcome whereas the Rectangles Contain or Refer to Other Task Networks; the Dashed Ellipses are Automated Tasks

The scenario that was evaluated for the purposes of this analysis focused on a Land Attack engagement, which took place in the littoral environment of the DD21 simulation. It consisted of a 2 hour and 48 minute land attack mission to support ground troops advancing on the beach. It begins with the first of two calls for fire support commands to DD21 located about 20 nautical miles off shore. In addition, a coastline defense shore battery fires on DD21 with missiles that must be defeated. The second call for fire command is executed within 15 minutes of the first. Finally, the scenario calls for planning and execution of a missile strike against 7 on-shore targets. The timing of these mission events is shown in Figure 2. In the figure, Tactical Land Attack Missiles (TLAM) and Advanced Gun System (AGS) rounds (RNDS) operations were simulated. The DD21 model also accounted for the ship's position as it navigated through the scenario. Only the Land Attack Warfare area was considered in this report.

The DD21 model was run 30 times to provide a power of 0.86 for a between group Analysis of Variance with significance levels set at an alpha level of 0.05.

Comparisons were made between the two watch team configurations for each of the workload areas and utilization rates, followed by the Scheffe test for post hoc analyses. Data for Utilization levels (0-100%) were collected every second during the engagement. Operator workload rates were collected for each watch position every time they were tasked in the mission.

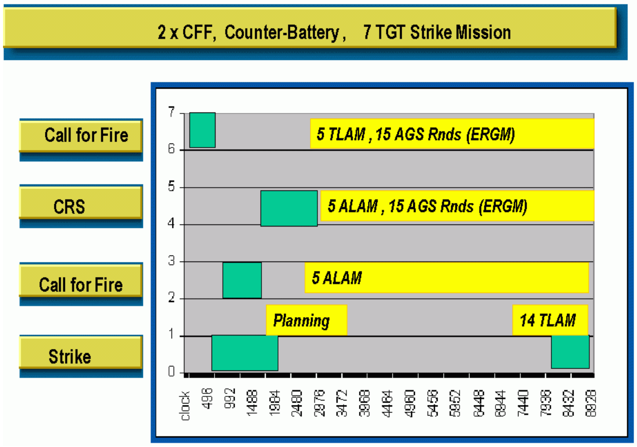

Figure 2: The Land Attack Scenario used in the 2.48 Hour, DD-21 Mission; there were 2 Call for Fire (CFF) Epochs, Counterfire from Shore (CRS) Epochs, and One Strike Epoch Involving 7 Targets (TGT)

3 RESULTS

During the 30 runs of the DD21 model for the Land Attack scenario for each of the two configurations, the average response latency was 61 seconds for the 4-operator configuration and 179 seconds for the 3-operator configuration after the two CFF's.

The utilization rate for Operator 2 is shown in Figure 3. These data refer to a second by second percentage of utilization capacity. The data collected for all operators during the mission were used to generate the graph in Figure 4. An average utilization frequency, the number of times in seconds each operator was tasked, shows that Operator 2 and 3 were significantly more tasked in the 3 operator configuration than in the 4 operator configuration.

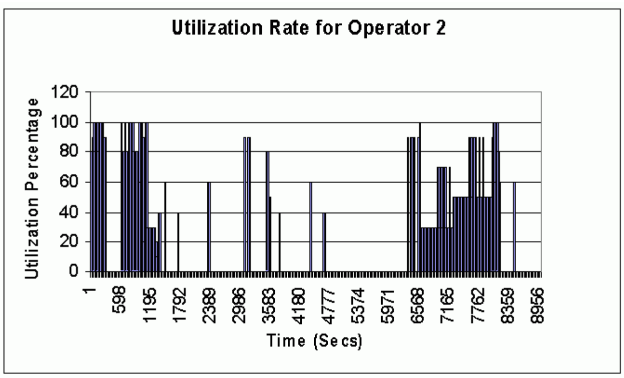

Figure 3: Example of Utilization Rate for an Operator During the Land Attack Warfare Scenario; note the Example Does Not Contain Situation Assessment Events (Information Gathering Tasks) and Only Refers to Operation Events

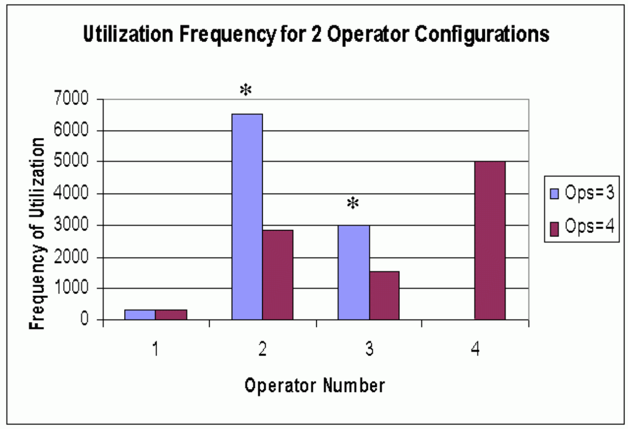

Figure 4: The Frequency with which Operators are Tasked in the 3 Operator (Ops=3) and 4 Operator (Ops=4) Conditions during the DD21 Land Attack Scenario; Operator 2 and 3 Utilization Frequencies (*) were Greater with 3 than with 4 Operators

Workload data were collected for 4 mental resources; visual, auditory, cognitive and psychomotor. All 4 resource areas demonstrated a significant increase in workload for Operator 2 in the 3 operator configuration compared to the 4 operator configuration. These results are demonstrated in the overall workload data shown in Figure 5.

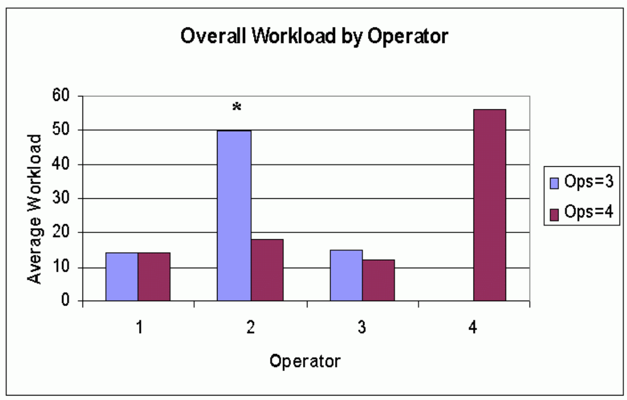

Figure 5: The Average Overall Workload (Combined Visual, Auditory, Cognitive, Psychomotor) with which the Individual Operators are Tasked in the 3 Operator (Ops=3) and 4 Operator (Ops=4) Conditions during the DD21 Land Attack Scenario; Operator 2 Workload (*) was Greater with 3 than with 4 Operators

4 DISCUSSION

Land attack fire support is the most important mission of DD21. If an operator cannot immediately get to a task, it waits in a queue until there is time. These provide an estimate of how long it would take an operator in a high workload environment to get to a task. The DD21 model assigns a priority to task completion as well, allowing higher priority tasks to advance in the queue beyond less priority tasks, so it is unlikely that less demanding tasks could account for a slowed response time.

Using the response time for a CFF as the primary operational measure of performance, the 3 operator configuration may not be ideal. The high workload associated with operator 2's utilization rate and overall workload suggests that unusually high tasking is associated with the demands of this position. It may be possible to distribute the workload to less utilized operators during intense combat scenarios. These options will be tried in subsequent tests of the model.

Micro Saint seems to be a satisfactory tool for identifying high workload conditions by operator. In a study of the operational relevance of two different discrete network simulation packages, See (1997) found that compared to Task Analysis/Workload (TAWL) simulations in a simulated attack on a Scud missile site, Micro Saint was more flexible and versatile.

System analyses, such as the DD21 model, often reveal tasks better suited for automation than human intervention. In one iteration of the model for example, a 4 second task was executed over 100 times in a brief period of time. Such a task might involve considerable distraction for the operators and would perhaps be amenable to automation.

The utilization rates in the DD21 model used for the analysis did not capture an important tasking of the operators, that of information gathering as the mission unfolds. Most of the operator time would be spent collecting information about targeting, threats and mission objectives. Current versions of the DD21 model consider this type of situational assessment and account for a substantially greater, more realistic, utilization rate.

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