WHEN THE NEED FOR IMMEDIATE HUMAN FACTORS ANSWERS CONFLICTS WITH "YOU WANT IT DONE RIGHT?"

David Olsen
Dynamics Research Corporation Orlando, FL

Stephanie A. Barnes
Dynamics Research Corporation Orlando, FL

Jeanine Williamson
Dynamics Research Corporation Orlando, FL

AUTHORS' BIOGRAPHIES

David Olsen is a Senior Systems Analyst for Dynamics Research Corporation in Orlando, FL. He has 14 years experience designing and developing military training systems. His work has included examination of cost, manpower and human factor issues impacting training system design and implementation. He has been involved in the design of numerous training systems utilizing various configurations of computer based instruction such as embedded training, multimedia, and virtual reality. He is currently supporting MANPRINT tasks for two major distributed simulation systems.

Stephanie Barnes is a Human Factors engineer with Dynamics Research Corporation in Orlando, FL. Stephanie has over 5 years experience providing Human Factors support to design teams of complex systems. This support has included system and user analysis, design support, and usability testing for a wide range of systems including chemical plants, computer peripherals, voice communication systems, and training simulation systems. She is currently providing Human Factors support for WARSIM 2000 concentrating on user needs analysis, user interface design support, functional allocation analysis, and usability testing. Stephanie has a B.S. in Psychology from Southwest Texas State University and M.S. in Human Factors and Ergonomics from the University of Idaho.

Jeanine Williamson is a Senior Human Factors engineer with Dynamics Research Corporation in Orlando, FL. She has over 15 years experience in analyzing and developing military training systems. As part of numerous training systems development, she has performed functional and system analyses for manpower allocations, high-level and low-level design of a wide variety of user interfaces, early user prototyping, usability studies and formal test and evaluation. Jeanine has a M.S. in Industrial/Organizational Psychology from the University of Central Florida.

ABSTRACT

In the human factors arena, the conflict between "we need answers now" and "you want it done right?" often results in trade-offs and, occasionally, heated discussions. This paper describes one such project in the context of a workload analysis conducted for a sophisticated training simulator under development. In response to a request to determine if workload will be within acceptable limits for various operators of the system, a MANPRINT team employed a stream-lined methodology in order to meet a rapidly approaching deadline. A computer modeling tool was used to help overcome the lack of a platform to obtain direct measures of workload for the operators. The use of computer modeling also helped to reduce the trade-offs between providing results quickly and providing quality, defensible results. The methodology employed enabled a quantitative comparison to a comparable existing training system. The results illuminated potential workload problems and alternatives to bring workload within acceptable limits. The methodology and results of the workload analysis are presented including how the computer modeling tool was integrated into the process. Discussion is provided on the limitations of the methodology and how it can be improved.

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INTRODUCTION

The increased sophistication of simulation based training systems has resulted in a number of challenges for system designers and architects. One of these challenges is keeping operator workload within manageable limits. While training system sophistication marches on, our understanding of manageable limits for operator workload lags behind, in particular, our ability to predict acceptable workload levels during design and even during development. Thus, when the end user of a simulation system under development asks: "Are you sure our operators will be able to manage the workload?" system developers scramble for the nearest human factors engineer for quick and defensible answers. The conversation proceeds something like this.

HF Team: (To System Developer) We understand your need and we should be able to give you answers. Do you have any data available on frequency or duration of task time?

System Developer: Are you kidding? I thought you guys had books on that stuff.

HF Team: Do you at least have task data?

System Developer: You can check with the logistics guys.

HF Team: (To Logistics) Do you have any operator task data?

Logistics: We have identified some maintenance tasks but the user is still determining how they want to use the system so we haven't defined operator tasks.

HF Team: (To System Developer) Task data is unavailable so we'll need your help to develop it. Once we've identified the tasks we'll collect some task frequency and duration data using any of your test scenarios. We'll also need to …

System Developer: Sorry for interrupting, but that's not possible. The scenarios don't exist. The hardware and software are configured within a testbed which is down for at least 4 weeks. Oh, by the way, I heard management say they need your objective and defensible answers for the customer in 6 weeks for their In-Process Review.

HF Team: Oh swell.

PROJECT BACKGROUND

The above conversation, while contrived, represents a recent challenge to a human factor's team supporting the development of a sophisticated training system currently being developed for a foreign military. The system will train battle procedures, tactics, and other collective tasks.

The main concern of the user was whether the simulation operators responsible for the control of semi-automated forces (SAF) would be able to handle the workload associated with the amount and variety of operator actions required. For the purpose of this paper and the project being discussed, workload is defined as the actions, both physical and mental, that the operator will experience while participating in a training exercise. The SAF operators are role players and their job is to control simulated vehicles on the battlefield and interact with simulators manned with soldiers in training. Essentially, the SAF operators need to do their job such that it appears that a real crew is controlling the simulated vehicle – the proverbial "Is it live or Memorex?" In this training system, these simulated vehicles are usually not controlled by the SAF operators at an individual (platform) level. Rather, they are controlled at an aggregate level, e.g., platoon, company, or battalion. While a single SAF operator has the option to control up to 64 individual vehicles, it is more likely that he/she will control vehicles at a platoon or company level. In addition to controlling the vehicles, the operator is playing a particular role, e.g., company commander, or in most cases multiple roles. This translates into multiple tasks, many of which

require monitoring and responding to radio communication on multiple channels. The workload demands on the SAF operators vary with the phase of battle, the particular role(s) assigned, and the need to emulate detailed vehicle behavior, e.g., a specified formation for movement.

If workload was determined to be a problem, options to reduce the load on the SAF operator would be needed. These options would include increased manning for the SAF position and software design changes to improve user interface design for role player performance. While both these options were not desirable because of cost and contractual implications, the prospect of a multi-million dollar training system not delivering an anticipated level of training was even less desirable.

METHODOLOGY

Ideally, workload should be assessed using both objective and subjective measures. The methodology would include a mock-up of the system in question and a process to assess workload such as having users perform a series of tasks under various conditions. A structured questionnaire would be used to supplement the objective task performance data. Since the simulation system being evaluated was not available from which to extract the workload data directly and answers were needed "now", we begrudgingly dismissed Plan A (the "do it right option") and considered alternative approaches that could be implemented quickly. The most promising approach involved developing a comparative model of workload between the system under development and a closely related existing training system. (For convenience throughout this paper, the System Under Development will be referred to as the **SUD** and the Existing Training System will be referred to as the **ETS**).

A key factor in taking this approach was that the operator tasks for both systems were essentially the same. Detailed discussions with subject matter experts for both systems confirmed that the operator tasks for both systems were almost identical. However, from discussions about how the ETS was utilized and how the SUD would be used, it was clear that the frequency and duration of the tasks would be different. Thus, predicting workload for the SUD could not be made based solely upon workload encountered in the ETS. However, the data from the ETS would provide the starting point for a comparison of workload for both training systems.

In order to assess workload for the ETS, a survey was developed that asked respondents to estimate the frequency and duration to perform various operator tasks. Respondents were asked to estimate frequency and duration of the various operator tasks involved in role playing SAF forces. These tasks included sending/receiving messages, coordinating with other role players, monitoring battle activities by viewing their map display, and making numerous computer inputs to the system. Since the specific activities within any given training scenario impact the frequency and duration of operator actions, a specific battle scenario lasting one hour was defined in ten minute blocks. A time line of events indicated the specific battle activities during each ten minute block. Based upon their experience as a SAF operator, respondents estimated the frequency. Eight surveys (out of 9) from experienced SAF operators were returned. While this sample size appears small, at the time it represented nearly 75 percent of the available ETS operators. The survey values for operator task frequency and duration were surprisingly consistent among the respondents for each of the 10 minute time periods which provided additional confidence in our survey approach.

In addition to the frequency and duration data, the respondents were questioned extensively on workload issues. For example, they were asked to describe what events or actions would result in excessive workload. They were also asked to estimate the maximum number of SAF units that could be controlled by an individual operator without experiencing excessive workload and how many radio nets could be monitored at one time. Follow-up phone discussions were used to clarify this narrative data and to identify other possible workload issues that could shed light on predicting workload in the SUD. One key finding from the narrative data was that operators for the current system were not experiencing excessive workload. This observation was unanimous among all respondents and, as will be discussed later, was a key piece of information in deriving workload results for the SUD.

Estimating the frequency and duration of tasks for the SUD was more subjective given the absence of an operational system from which to base estimates. A panel of experts was assembled consisting of subject matter experts and individuals familiar with the system configuration for both the ETS and the SUD. These two disciplines collectively possessed the knowledge to best quantify the differences in operator task frequency and duration between the two systems. Using the data collected from the survey for the ETS, the panel was asked to adjust the frequency and duration of the same tasks using the same battle scenario for the SUD. What we needed to know was how would the planned implementation of the new system and its system configuration/architecture impact the frequency and duration of operator tasks for the same battle scenario. In making their estimates, the panel was asked to

consider a number of factors. These included the following:

- Number of SAF units that the role player would control
- Level of control necessary to maintain training realism
- Number of roles that the role player must assume
- Number of radio nets that would have to be monitored
- Differences in the user interface and menus that might impact frequency and duration of tasks

A structured process was used to derive a consensus from the group for task frequency and duration for the SUD. For this process, worksheets were given to the participants and they were told to make estimates privately. Next, the participants were instructed to discuss their estimates and arrive at a consensus reflecting the total wisdom of the group.

INCORPORATION OF COMPUTER MODELING TO PREDICT WORKLOAD

As our deadline began to approach, the project team felt that computer modeling software would help to more efficiently make workload comparisons between the SUD and the ETS. The use of a stochastic tool would allow us to quickly perform "what if" analyses in order to uncover ways to reduce workload, if workload was determined to be excessive. Since our survey indicated that operators of the ETS were not experiencing excessive workload, our goal was to **objectively quantify** the workload levels for both system. If both were equal, or if workload for the SUD was less than the current system, we could say with some confidence that workload for the SUD most likely would be acceptable. The challenge at this point was formulating a methodology to objectively quantify workload.

Models of predictive workload have relied heavily on subjective measures and the theory remains largely undeveloped. A major problem has been the lack of reliability, and the lack of consistent correlation between estimates based on different approaches (Moray, 1988). In our opinion, some of the best work in predicting workload has been in predicting crew workload in new weapon systems. This work includes early efforts by McCracken and Aldrich (1984), and research by Aldrich, Szabo, and Bierbaum (1989). The thinking of these researchers builds upon the work of Wickens (1984) who theorized that workload is a multidimensional construct comprised of three workload components, sensory, cognitive and psychomotor. The sensory component consists of the complexity of the auditory and visual stimuli that the operator must attend to during task performance. Thus, a task can be evaluated for workload by evaluating four information processing channels, namely audio, visual, cognitive and psychomotor. For example, for an operator to input information into a computer using a keyboard, he/she must use the visual, cognitive and psychomotor information processing channels.

Through their research McCracken, Aldrich and colleagues derived values for each channel using a 0-7 scale. The scale reflects the complexity of the information processing. We referred to these values as benchmarks for workload. Table 1 is an example of the complexity values assigned to the visual channel. In their work, McCracken and Aldrich were also able to derive quantitative values that constitute excessive workload. If a given task exceeds the workload threshold for one or more of the information processing channels, workload was considered to be excessive. While these two researchers have been quick to point-out limitations in their methodology, a real advantage for the process is that it allows for refinement. In particular, as additional data are collected, the quantitative values or units that constitute the workload scale can be refined.

Table 1. Benchmarks for Visual Workload	
Scale Value	Descriptors
0	No Visual Activity
1.0	Visually Register/Detect (Detect Occurrence of Image)
3.7	Visually Discriminate (Detect Visual Differences)
4.0	Visually Inspect/Check (Discrete Inspection/ Static Condition)
5.0	Visually Locate/Align (Selective Orientation)
5.4	Visually Track/Follow (Maintain Orientation)
5.9	Visually Read (Symbol)
7.0	Visually Scan/Search/Monitor (Continuous Serial Inspection, Multiple Conditions)

For a computer modeling tool, we chose ProcessModel®. This tool is typically used for process analyses such as looking at the efficiency of the workers in an organization or on an assembly line. We had used ProcessModel on a project to evaluate staffing levels for a simulation system and felt it could be re-purposed to help quantify workload using the approach taken by McCracken, Aldrich and their colleagues. Our criteria in selecting the modeling tool included:

- Expanded capabilities such as the ability to evaluate individual information processing channels

- Minimal training time to get started

- Capability to create models through visual and graphical behaviors

- Flexible data collection and analysis capabilities

- Low cost

The ProcessModel® tool met all these criteria.

Figure 1 is a conceptualization of the workload model used. The top of the figure shows six, 10-minute time periods for the battle scenario. Workload data was calculated for each time period, as well as for the entire one-hour scenario. The operator tasks are shown along the left side. The frequency and duration of these tasks are input into the model for each of the six time period. Each task was assigned quantitative values for each of the four information processing channels (shown on the right) using the scales empirically derived by McCracken and Aldrich.
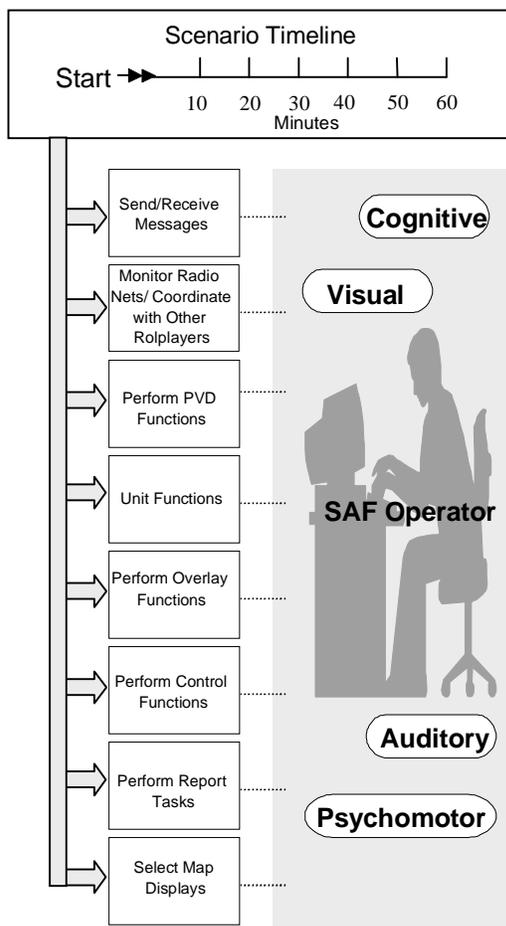
Figure 1. Basic Workload Model

Some subjectivity enters the process in assigning values since the complexity of a task will vary with the content/domain within which the task is performed. Our approach in assigning values was to first discuss the operator tasks with subject matter experts to clearly understand the complexity of information processing. Next, assign values most closely representing the information processing complexity of the task. Formulas were derived from this information and scripted into the model. The formulas provide boundaries in which the model runs. Boundaries reflect real-life capabilities and limitations of human performance. For example, the model was developed to restrict two keyboard tasks from occurring at the same time since this is not possible in real life. ProcessModel has extensive scripting capabilities and thus, no software programmers were required to build the models.

Initially, two workload models were built, one for the ETS and one for the SUD. The same one hour battle scenario was used for both systems, as were the operator tasks. However, the frequency and duration of operator tasks were different. The model was designed so the simulation would perform a number of specific operations. These included:

1. Randomly distribute operator tasks over the six, 10-minute battle time periods based upon their estimated frequency and duration derived earlier.

2. Model certain dependencies between tasks. For example, we designed the model to not allow more than one task involving radio communication to occur at the same time as this would not happen in the real world, i.e., a radio operator can only talk over one radio net at a time.

3. Calculate the average value of information processing resources that are being used for each information processing channel (i.e., cognitive, audio, visual, psychomotor). This was done every ten seconds.

4. Keep track of which tasks can't be performed because the operator is using the required information processing resources to perform another task.

5. Indicate when the total information processing resources exceed a defined value.

RESULTS

We felt several measures of workload were important for this analysis. First, we wanted to look at the total information processing units throughout the one hour battle scenario to determine if the workload thresholds suggested by McCracken and Aldrich had been exceeded.

Next, we felt it was important to look at a comparison of the average information processing values between the two systems. Finally, we were interested in tasks that had to be put on hold during the exercise.

Workload Threshold Results

Analysis of the workload threshold data (our first measure of interest) did not support McCracken and Aldrich's workload thresholds. Figure 2 depicts one view of the actual output from the model. It shows workload data for the cognitive channel for the ETS. The data indicates that the workload threshold (70). suggested by McCracken and Aldrich has been exceeded numerous times. (Note: We converted the scale values from 10 point to 100 points for convenience). However, the operators for the ETS unanimously reported during interviews that they did not consider their workload excessive.

So why the discrepancy? Were we using an inaccurate model? Was data collection flawed? Or, perhaps the operators had actually experienced excessive workload but had become desensitized to it and, thus, did not interpret the workload associated with their task activities as excessive. The possibilities are numerous and while this issue may have been a fruitful area for further investigation, our deadline did not allow us to pursue the issue further. It was felt that since job performance for the SAF operators appeared to be acceptable from all reports we were able to obtain, the workload level reflected in figure 2 was determined to be acceptable. This level of workload was compared to the SUD. As can be seen in Figure 3, the number of times the "70" level is exceeded is slightly greater. The magnitude of the spiking, however, is considerably greater for the SUD. The maximum spiking for the SUD was 138, and for the ETS the maximum was 114. This means that the operator for the SUD will experience periods of cognitive activity greater than the existing system. Similar results were found for the other information processing channels.
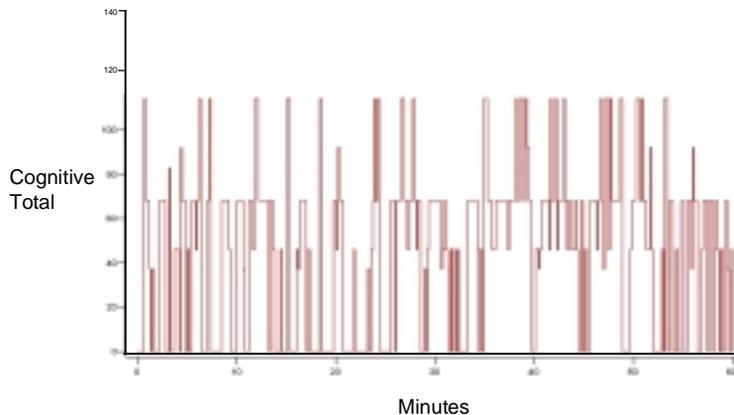

Figure 2. Workload Data for Cognitive Channel (Existing Training System)
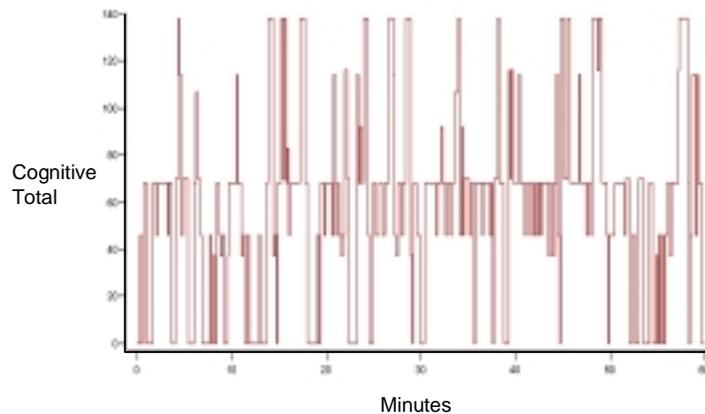

Figure 3. Workload Data for Cognitive Channel (System Under Development)

This first measure of workload was interesting, but provided little support for definitive conclusions concerning workload for the SUD.

Information Processing Resources

Our next measure involved determining the quantity of information processing resources being used. Figure 4 displays a comparison of the ETS and the SUD. The values along the "Y" axis denote the average number of information processing units that were used. To determine these units, we directed the simulation to calculate the average number of information processing units that were used for each information processing resource (i.e., cognitive, audio, visual, psychomotor). This was done every ten seconds for the 1 hour battle scenario using the scale derived by McCracken and Aldrich. The higher the number, the greater the information processing units that will be used by the operator at any given time during the training scenario.
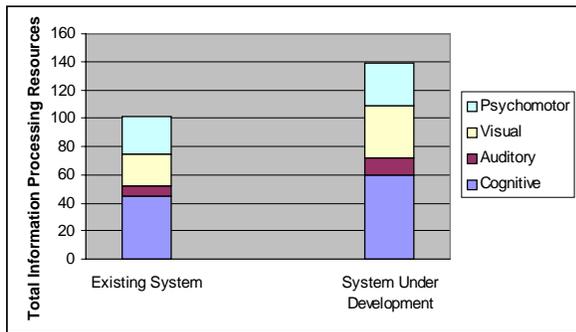
Figure 4. Comparison of Information Processing Values Between the Two Systems

The results indicated a substantial (28%) workload increase for the SUD, which we felt was likely to create operator workload problems. Admittedly, this was somewhat of a subjective conclusion because we did not have a measure to quantify the extent to which operators for the ETS were under their workload threshold. That is, while the operators for the ETS did not report excessive workload, we did not have the data to quantify how much additional workload they would be able to manage without experiencing problems. We felt a 28% increase was too much too ignore.

**Additional Models to Test Options for Reducing Workload**

Recognizing that both the customer and developer would be concerned, our goal was to identify and present potential options to reduce the workload for the operators. Following discussions with system engineers and subject matter experts, several viable options for system implementation were identified that

had the potential to reduce workload. For example, one approach was to add a person to assist with specific operator tasks. This additional person would handle radio tasks, thus relieving the primary operator of this job. Workload models were built to test these implementation options (see Table 2).

Table 2. Description of Workload Option Models

Model	Description
Option 1 Model	Models an additional person assisting the operator but with only one person actually making the keyboard or mouse inputs. In this model, the additional person performs 80 percent of the radio tasks. In addition, the model was adjusted to simulate the additional person coordinating extensively on other tasks.
Option 2 Model	Same as Option 1 Model except the additional person performs 80% of the radio tasks only.
Option 3 Model	This model was built around the premise that if an operator was nearing or exceeding workload, he/she could transfer some tasks to an operator at another workstation that was experiencing low workload at the time. The system architecture allowed for this possibility by providing a function to transfer control of SAF units from one workstation to another.

Figure 5 displays the results of the three optional models that were developed, as well as the two original models.
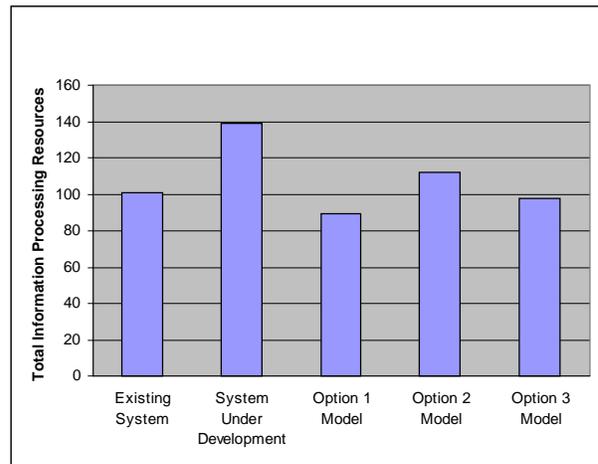
Figure 5. Comparison of Information Processing Resources for All Workload Models

Both models 1 and 3 decrease workload below that of the ETS. Each of these options had limitations from a systems operations perspective, including the added cost of additional personnel. These limitations would eventually become issues that the management and customer would consider extensively.

Tasks On Hold

The third measure of workload investigated involved tasks put on hold. The hold results from multiple operator actions that are required at one time. Through the script written for the simulation model, we determined if sufficient information processing resources were available to perform the task when it was time to be performed. If the necessary resources were not available, the simulation puts the task on hold until the resources became available. The simulation model calculated the "on hold" time.

Figure 6 identifies the total percentage of time that tasks will need to be put on hold for each of the 5 models (the two basic models and the 3 option models). For example, during a 60-minute scenario, tasks will be put on hold a total of 6 percent of the time, or approximately 3.5 minutes for the Option 1 Model. With the exception of Option Model 3, the percentage of time for tasks put on hold was nearly identical for all models. Initially, we felt that the amount of time that tasks would have to wait before being performed was significant. However, some additional analysis showed that the on hold time was always brief (12 seconds or less). These periods of hold were distributed throughout the scenario and usually involved keyboard inputs to the system. Subject matter experts indicated that if a task was put on hold for only 12 seconds, operator performance likely would not be degraded. Note that Option Models 1 and 2 show no benefit for reducing time for tasks put on hold even though an additional person is assisting the operator. This is because the bottleneck is in keyboard inputs, which are performed by one person only in these two option models. When an additional person is available (Option Model 3), the total time for tasks on hold is reduced greatly.
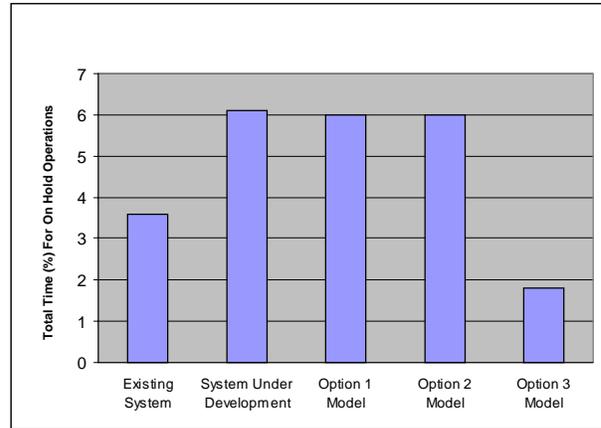

Figure 6. Model Comparison of Tasks Put on Hold

DISCUSSION

Our project team was able to provide a defensible, objective answer to the fundamental question asked by our customer by the specified deadline. Will workload be within acceptable levels for the SAF operators? We concluded that there was a high probability that operator workload thresholds would be exceeded unless an additional person was available to share operator workload. Through the workload modeling, we were also able to specify several options on how this work sharing could be done in order to bring workload within acceptable levels. Our work also illuminated several unforeseen issues that had the potential to impact workload. One of these was the experience level of the operators. The customer was hoping to use military personnel who arrived with the training audience as SAF operators. Based upon the experience level of the operators for the existing system and the challenges they noted in handling multi-tasking, we recommended that permanent staff be trained and assigned as SAF operators. While time did not permit, this implementation approach could also have been examined via modeling.

Immediate Answers Versus "You Want It Done Right?"

Studies to predict operator workload for evolving training systems are not routinely performed. The fact that the developer was willing to invest in answers concerning workload is noteworthy. Unfortunately, the need for immediate answers forced a less than ideal methodology to be implemented. One consequence was that not everyone was in agreement with our findings. Several members of the SUD engineering team felt an additional layer of analysis was needed in order to differentiate workload among the SAF operator roles. These members felt that certain SAF operators

would experience very low workload during certain types of scenarios. We could not agree or disagree. It was likely that they were correct, but the data was not available to build a case either way. While performing an additional layer of analysis seemed to be a viable next step, the need for quick answers to meet deadlines did not permit a more in-depth analysis.

While obtaining some workload answers is better than having no answers, the implications of limited results as described in the previous paragraph can be somewhat unsettling. Whenever possible, a sound methodology should not be compromised because of data collection and time constraints. An HF objective during similar efforts should be to work with management early on to help them understand the data interpretation limitations involved in taking shortcuts. As part of this process, it is important to define the limitations of the methodology and lay out the possible implications in clear terms for all to evaluate.

As is frequently the case in applied HF work, shortcuts taken to overcome time and resource restrictions tend to result in loose ends with respect to methodology. The consequence can be a lower than desired confidence level in the results as evidenced by the comments by the SUD engineers described above. To "do it right" we would have approached the problem in a more comprehensive manner. First, we would have conducted a simulated workload analysis versus a predictive analysis, or perhaps taken both approaches. With the simulated workload analysis approach, a mock-up of the system would have been used. A series of scenarios instead of only one would have been used to arrive at a greater wealth of data from which to examine workload, thus saving us from having to make generalizations about various workload situations. Operators with various experience levels would have been run through a series of tasks and scenarios. In our analysis, we only had data from highly experienced operators of the ETS. However, the designers for the SUD were anticipating that less experienced personnel would operate the SAF workstations. The impact of experience level on workload had to be estimated without benefit of hard data. Data collection using a mock-up of the system would have allowed both objective and subjective measures of workload to be taken. Our effort relied greatly on the ETS for establishing the benchmarks from which to make workload comparisons. Given the time, we would have relied less on workload benchmarks and thresholds established from ETS and established new criteria based upon the tasks performed using the SUD mock-up. In our "do it right" approach we would have compared various options for reducing workload such as adding personnel, streamlining the interface for keyboard intensive tasks, or adding automation to some operator tasks.

In the streamlined approach that we did take, we would have liked to conduct a follow-up analysis as the SUD progressed to a point where direct data collection measures could be utilized. Such an analysis would have confirmed the predicted workload for the system and/or illuminated additional workload issues that would have to be addressed.

Modeling Tool Advantages

A special note should be made concerning the modeling tool used for this effort. The use of ProcessModel proved invaluable. Without a tool to create workload models quickly, it is unlikely we could have produced defensible results in time to meet the project deadline. The graphical authoring nature of the tool allowed us to quickly model operator tasks and define task parameters. As a result, validation of the tasks and associated parameters with subject matter experts became easy and convenient. Changes to the model could be implemented "on the fly" and the results displayed immediately for analysis.

ProcessModel also proved to be an exceptional data visualization mechanism. The tool allowed raw data to be quickly converted to various graph formats resident within the application for analysis. We gained considerable insight into SAF operator workload by studying the graphs and looking for trends, patterns, and anomalies. The insights gained allowed us to refine the models to examine additional workload issues.

CONCLUSIONS

Predicting workload by quantifying information processing resources is a promising methodology, particularly when a platform does not exist, or is not available from which direct measures can be gathered. Additional research to validate predictive models of workload is needed. The need will continue since large systems engineering efforts tend to make important design and implementation decisions prior to when test beds or test harnesses are available for evaluating workload. Predictive models of workload would be of immense value in supporting user centered design efforts. Finally, it is our strong feeling that the use of a computer modeling tool helped us to close the gap between providing immediate results and providing defensible and quality results.

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