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HUMAN PERFORMANCE MODELING FOR DISCRETE-EVENT SIMULATION: WORKLOAD

John Keller

Micro Analysis & Design, Inc.
4949 Pearl East Circle, Suite 300
Boulder, CO 80301, U.S.A.

ABSTRACT

This tutorial will present a methodology for modeling of human performance using multiple resource theory within a discrete event simulation. Participants will gain an understanding of why modeling human performance can be important and how workload models can be used to support system design. This presentation will include the theoretical background as well as detailed the techniques for modeling workload. The techniques will be demonstrated through the development of a model to assess the workload associated with driving a car while talking on a cell phone. Finally, two case studies of how these techniques have been used to model human performance during the design of new military systems will be presented.

1 INTRODUCTION

Many systems are designed to enhance human productivity in one form or another. This is often done with new support systems designed to make the task easier or through increased automation. For example, a new cockpit system might be designed to help the pilot manage a landing or automation might support the navigation of a ship. Many of these systems are also designed to reduce the workload of the operators. However, in some cases, the tasks required to operate these new systems, while different, may actually increase the associated workload. The increased workload may then result in reduced performance and productivity. Such a result can be especially expensive if it is discovered following the development of the new system. Models that predict workload can be extremely useful and cost effective tools when applied during the system design stage.

This paper presents a technique for modeling workload using the multiple resource theory. A short background and description of its use with discrete event simulations is presented. An example model is then included to demonstrate the modeling techniques. The techniques are generic enough to be used with any of the available generic discrete event simulation tools. It is assumed that the reader has a basic understanding of these tools and of modeling techniques in general.

2 MODELING USING MULTIPLE RESOURCE THEORY

The term 'workload' refers to the total demand placed on a person as they perform a task. Chris Wickens developed a theory that workload was not the result of one central processing resource but was instead the use of several processing resources (Wickens 1984). For example, we can easily walk and chew gum at the same time but we cannot talk and listen at the same time. The argument was that there must be multiple resources for information processing. These processing resources are usually described by four components; visual, auditory, cognitive and psychomotor and are commonly referred to by the acronym VACP. Any task performed by a person can be broken down into these components. The visual and auditory components refer to the external stimuli that are attended to, the cognitive component refers to the level of information processing required and the psychomotor component refers to the physical actions. For example, the resources required for the task of dialing a phone number would include the cognitive component of retrieving the number from memory, the visual component of looking at the key pad, the psychomotor component of using fingers to press the buttons and the auditory component for hearing the feedback tones for each button press.

Rating scales have been developed (McCracken and Aldrich 1984, Szabo and Bierbaum 1986) for each VACP component. The scales provide a relative rating of the degree to which each resource component is used. They were developed by providing surveys containing matched pairs of verbal anchors to a range of human factors experts who were asked to indicate, for each pairing, which one required a higher level of effort. The pair comparison frequencies were used to develop interval scale values for each workload component (Bierbaum, et al 1987). **Table 1** includes the VACP rating scales. Each scale value includes a text description as an anchoring statement. The higher the scale value the greater the degree of use of the resource component.

Table 1: VACP Values and Descriptors

Scale Value	Scale Descriptor
	Visual
0.0	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)
	Auditory
0.0	No Auditory Activity
1.0	Detect/Register Sound (detect occurrence of sound)
2.0	Orient to Sound (general orientation/attention)
4.2	Orient to Sound (selective orientation/attention)
4.3	Verify Auditory Feedback (detect occurrence of anticipated sound)
4.9	Interpret Semantic Content (speech)
6.6	Discriminate Sound Characteristics (detect auditory differences)
7.0	Interpret Sound Patterns (pulse rates, etc.)
	Cognitive
0.0	No Cognitive Activity
1.0	Automatic (simple association)
1.2	Alternative Selection
3.7	Sign/Signal Recognition
4.6	Evaluation/Judgment (consider single aspect)
5.3	Encoding/Decoding, Recall
6.8	Evaluation/Judgment (consider several aspects)
7.0	Estimation, Calculation, Conversion
	Psychomotor
0.0	No Psychomotor Activity
1.0	Speech
2.2	Discrete Actuation (button, toggle, trigger)
2.6	Continuous Adjustive (flight control, sensor control)
4.6	Manipulative
5.8	Discrete Adjustive (rotary, vertical thumbwheel, lever position)
6.5	Symbolic Production (writing)
7.0	Serial Discrete Manipulation (keyboard entries)

For the previous example of dialing the phone, the visual component value could be estimated at 5 due to the level of focus required to align the fingers with the buttons. The auditory component could be estimated at 4.3 for the auditory feedback of the button tones. The cognitive component could be estimated at 5.3 for recalling the number from memory. Finally, the psychomotor component could be estimated at 7 to account for the keyboard-like nature of dialing the number.

In general, high workload occurs when excess demands are placed on a single resource component but less when workload occurs across components. That is, if the only task being done is to dial the phone, then there are no excess demands being placed on any one component. However, if another task is being performed at the same time that makes demands on similar components, the result may be excess workload. Excess workload can result in a number of problems or compensating behaviors including errors, slowing of the tasks, task shedding, or rapid task switching. While it may be important to understand these results, this paper will limit its focus to the modeling technique of predicting the workload itself.

3 MODELING WORKLOAD

As with any modeling effort, the process must begin with an understanding of the system or tasks to be simulated. For workload modeling, a task analysis is usually performed to develop a sequence of tasks performed by individuals or teams, timing and workload information associated with each task, and scenario information. The task analysis must define the tasks with enough detail to allow for the assigning of workload values from the scale tables. In addition, the sequence in which the tasks are performed, especially any simultaneous tasks, must be understood. Likewise, timing information for each task, usually in the form of mean time, standard deviation and a distribution, must be collected to allow the model to simulate variance across the tasks. While estimating workload values from the tables for each task can be done by experienced analysts, it can be helpful to have the feedback from one or more subject matter experts. This provides a higher level of validity to the workload estimates and the modeling results in general. Finally, scenario information is needed to allow the model to simulate the environment in which the tasks are performed.

The workload analysis for tasks that are performed sequentially isn't complicated and would not require the use of a discrete event simulation tool. It would simply be a matter of looking at the workload for each task individually. However, when tasks are performed simultaneously the workload must be aggregated to understand the demands on the person. The simplest method is to add up the workload within each component. If the person dialing the phone were also trying to drive their car then the cognitive value of 5.3 associated with the dialing task would be added to the cognitive value estimated for whichever driving task is also occurring. In addition, it can be useful to sum the individual workload component totals to get a value for the total workload. Finally, the analyst must determine what defines excess workload. This can be difficult and depends somewhat on the purpose of the analysis. For example, while it is certainly possible to do multiple tasks at once, it may be difficult to determine if there is some task degradation that might reduce the accuracy or safety associated with the task performance. In one analysis (Bierbaum, et al 1987), the analysts decided that any cumulative workload value greater than the highest value on the component scale tables represented excess workload. Any cumulative workload value of 8 or more was defined as an unacceptable workload level. This represents a conservative approach that may not be warranted in all cases as some level of task slowing, shedding or error occurrence may be deemed acceptable depending on the nature of the domain. The following workload modeling example with demonstrate the modeling techniques in more detail.

4 WORKLOAD MODELING EXAMPLE

For the purposes of this tutorial we will use a modeling problem that most everyone will understand. The tasks will involve talking on a cell phone while driving a car. The purpose of the modeling will be to determine the level of cumulative workload during any point in the scenario. The determination of whether or not the workload results in a dangerous situation will be left to the reader. Please note that the data used for this example is not the result of an actual task analysis and is being used purely for the purposes of demonstrating techniques of workload modeling. The Micro Saint modeling tool, developed by Micro Analysis & Design, is used as the modeling environment. Diagrams and code examples are taken directly from the Micro Saint model developed for this example.

The cell phone is a standard hand help phone with a digital readout. The scenario involves making cell phone calls while in stop-and-go city traffic. Assume that the task analysis has been done and has resulted in the following data describing the scenario:

- Traffic lights are encountered every 2 minutes with a 1 minute standard deviation and a 50% chance of needing to stop at each light
- If needing to stop, the stop time is an average of 30 seconds
- The driver has to dial the number then press send
- Each phone call lasts an average of 1 minute with a standard deviation of 40 seconds
- The model will include driving through 10 traffic lights.

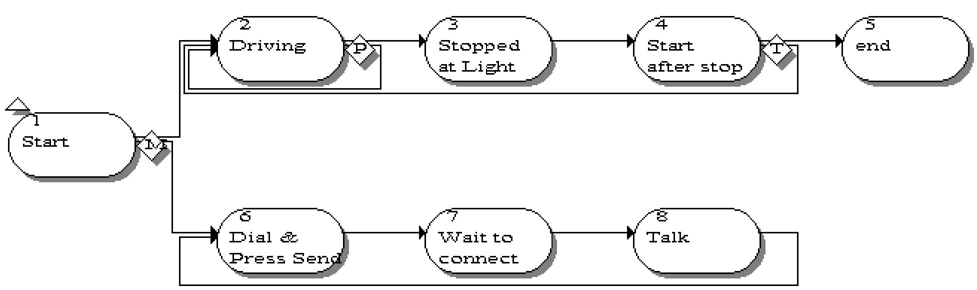

Figure 1: Network Diagram for Driving While Talking Model

In order to evaluate the simultaneous workload of driving and talking on the cell phone, we'll use two sequences of parallel tasks, one for driving and one for talking. Both sets of tasks will launch automatically and repeat until the process of passing through 10 traffic lights has been completed. At that point the model will stop. The specific tasks can vary depending on the level of detail of the task analysis. For this example, we will use three tasks for the driving sequence and three for the cell phone sequence. Figure 1 shows the network diagram from the model. Nodes 2 – 4 represent the driving sequence while nodes 6 – 8 represent the cell phone call. Model execution will start at node 1 and follow parallel paths using a multiple decision node shown by the symbol. The three driving nodes represent the process of driving, stopping and waiting at the light and starting again after the light. Node 2 has a path that loops back to itself and one that goes to node 3. This represents the possibility that the driver may or may not have to stop at the light. The symbol after node 2 represents the probability if stopping if the light is red or continuing through a green light. Node 4 has one path that goes back to node 2 and one that connects to node 5. Along with the symbol that allows a tactical decision, this represents repeating these tasks for the ten traffic lights before ending the simulation. The three cell phone call nodes represent the process dialing the number, waiting to connect and talking. The sequence simply repeats until the model is halted at node 5 after the 10 traffic lights have been passed. Note that this is a simplified version of this process. A higher fidelity model might include such enhancements as a more thorough breakdown of the driving tasks, a short period of time between one phone call and the next, a probability for not connecting during a call or losing the cell signal or incoming calls.

Table 2 contains the task times and standard deviations for each of the driving and calling tasks. **Table 3** contains the estimated values used in the model for each workload component and task.

Table 2: Task Times and Standard Deviations

Task	**Mean Time**	**Std. Dev.**
Driving	2 minutes	1 minute
Stopped at Light	30 seconds	5 seconds
Start after stop	2 seconds	
Dial and Press Send	10 seconds	5 seconds
Wait to connect	5 seconds	3 seconds
Talk	1 minute	40 seconds

Table 3: Task VACP Workload Values

Task	**Vis.**	**Aud.**	**Cog.**	**Psy.**
Driving	6	1	3.7	2.6
Stopped at Light	3	1	3.7	0
Start after stop	6	1	4.6	2.6
Dial and Press Send	5	4.3	5.3	7
Wait to connect	0	4.3	3.7	2.6
Talk	0	6	6.8	2.6

The workload level is increased at the beginning of each task and decreased at the end by the values assigned to the task. Using the simple additive workload calculation, the values are added to a variable for each workload channel at the beginning of each task and then subtracted at the end of the task. In addition, a total workload is calculated by summing the totals of all four channels. For example, the workload code for the beginning and end of the driving task represented by node 2 might look like this:

```
{Beginning of task}
Visual := Visual + 6;
Auditory := Auditory + 1;
Cognitive := Cognitive + 3.7;
Psychomotor := Psychomotor + 2.6;
TotalWorkload := Visual + Auditory + Cog-
nitive + Psychomotor;

{End of task}
Visual := Visual - 6;
Auditory := Auditory - 1;
Cognitive := Cognitive - 3.7;
Psychomotor := Psychomotor - 2.6;
TotalWorkload := Visual + Auditory + Cog-
nitive + Psychomotor;
```

When this code is included in each task with the associated workload values, it allows the model to predict the individual component and total workload of the combined driving and cell phone tasks at any point during the model execution. The variance in times across the two sequences of tasks and the stochastic nature of the model allows the workload to represent a range of driving and cell phone task combinations across the time period of the ten simulated stop light. As such, the workload prediction will represent a range of workload from the combinations of tasks.

Figure 2 and **Figure 3** show the graphed results of the cognitive and total workload values recorded every ten seconds of model time during execution. As you can see, the workload levels are often much higher than the scale values on the component tables. **Table 4** shows the maximum, mean and standard deviation for each of the recorded workload values. Focusing purely on the cognitive workload, the average of 10.50 is well over the maximum value assigned to the highest workload cognitive descriptor. While it is difficult to determine if this workload level relates to a dangerous situation, it is certainly true that a high level of cognitive effort is being expended. From a purely anecdotal point of view it is true that many people can drive their cars while talking on a cell phone. However, the high level of workload may limit their ability to adapt quickly to changing situations, such as distractions inside or outside the car, that require additional attention resources.

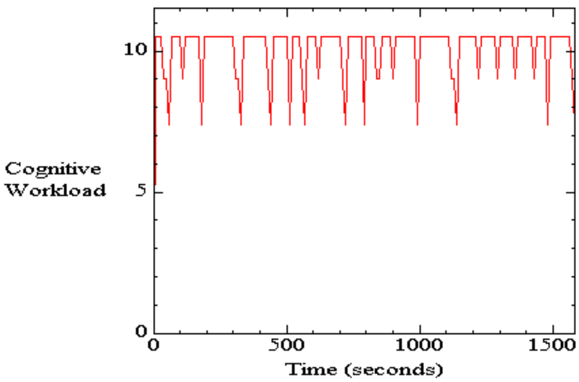

Figure 2: Cognitive Workload Results Graph

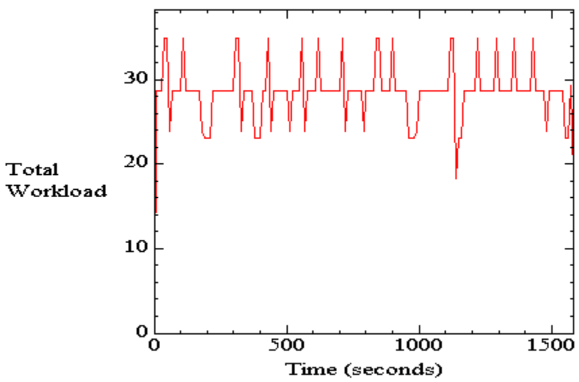

Figure 3: Total Workload Results Graph

Table 4: Workload Results

Workload	Maximum	Mean	Std. Dev.
Visual	11.00	6.26	1.97
Auditory	7.00	6.62	0.86
Cognitive	10.50	10.02	1.21
Psychomotor	9.60	5.43	1.73
Total Workload	34.90	28.33	3.86

5 CASE STUDIES

The example model represented the workload of an individual and was focused on identifying the workload incurred while performing a combination of two common tasks. In practice, it is common to use these techniques to model multiple people working together to perform tasks in team situations. In such cases, the models may also simulate the results of excess workload. This can include team interactions, task sharing, task shedding and errors. Such models can be used to determine required team size, evaluate new systems to support team size reduction, or to reallocate tasks across team members to balance workload levels.

In the mid '80s, these techniques were used to evaluate the workload associated with a proposed one-main attack helicopter. The proposed cockpit systems used a significant amount of automation. Along with other studies, it was determined that the workload was too high for a single crewmember to adequately perform all the required tasks. As a result, the Comanche helicopter uses a two-person crew. In a more recent project, the workload of watchstanders aboard naval ships has been modeled across a wide range of potential mission scenarios. The focus of the analysis includes:

- Improved affordability and mission effectiveness of naval ships
- Improved consideration of personnel performance in ship design
- Implementation of human simulations in rapid prototyping of ship designs.

The results include quantitative support for crew reductions, better task allocations and better use of shipboard automation.

6 SUMMARY

Many systems are designed to enhance human productivity in one form or another. However, attempts to enhance productivity do not always improve performance. The human performance associated with using a new system can be predicted using a simulation of the workload in much the same way a new manufacturing process can be tested by a simulation of its resources and throughput. The use of the multiple resource theory and the scale values of human resource components allow a simulation to provide quantitative predictions of workload during system development.

REFERENCES

Bierbaum, C. R., S. M. Szabo, and T. B. Aldrich. 1987. A comprehensive task analysis of the UH-60 mission with crew workload estimates and preliminary decision rules for developing a UH-60 workload prediction model. (Technical Report ASI690-302-87[B], Vol I, II, III, IV). Fort Rucker, AL: Anacapa Sciences, Inc.

McCrasken, J. H. and T. B. Aldrich. 1984. Analysis of selected LHX mission functions: Implications for operator workload and system automation goals (Technical Note ASI479-024-84). Fort Rucker, AL: Army Research Institute Aviation Research and Development Activity.

Szabo, S. M. and C. R. Bierbaum. 1986. A comprehensive task analysis of the AH-64 mission with crew workload estimates and preliminary decision rules for developing and AH-64 workload prediction model (Technical Report ASI678-204-86[B], Vol I, II, III, IV). Fort Rucker, AL: Anacapa Sciences, Inc.

Wickens, C. D. 1984. *Engineering psychology and human performance*. HarperCollins Pub.

AUTHOR BIOGRAPHY

JOHN KELLER is a Human Factors Engineer and modeler at Micro Analysis and Design, Inc. He has more than 10 years experience in the analysis and modeling of human performance issues related to systems design. During this time, he has led or worked on numerous modeling and system design projects including call center, crew workload, manufacturing, and human error analysis. In addition, Mr. Keller has taught modeling courses for both clients and conference participants.