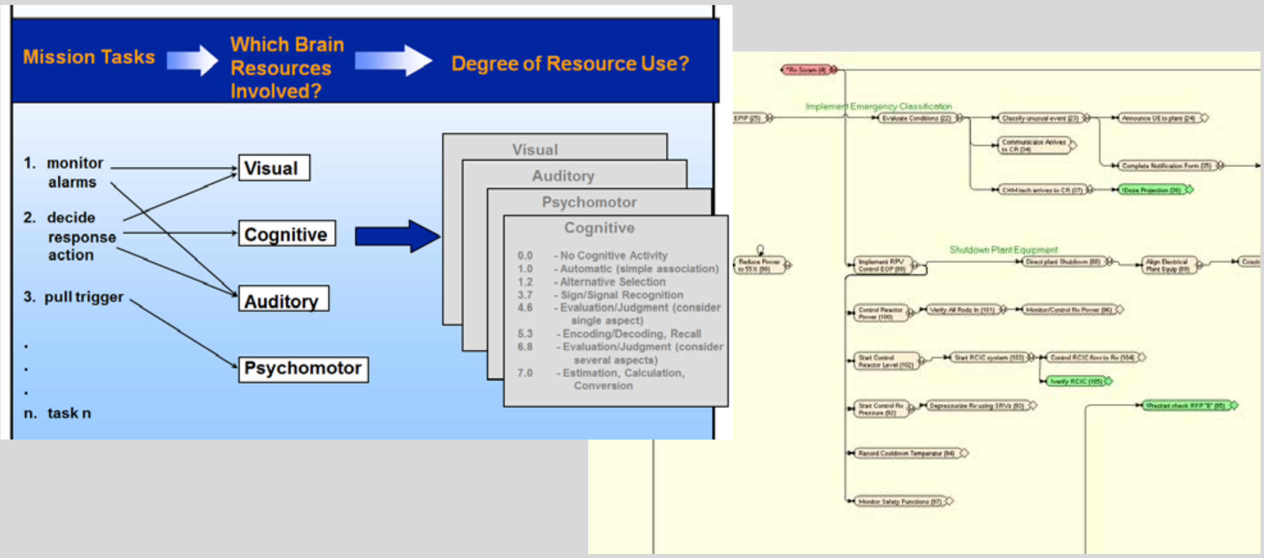
USE OF DISCRETE EVENT SIMULATION TO MODEL HUMAN PERFORMANCE



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For the past twenty years, Micro Saint simulation software has been helping the military and other commercial companies answer human performance related questions. Micro Saint Sharp, the next generation Micro Saint simulation tool, includes the ability to allow the user to add built-in parameters and reports that are specifically related to human performance modeling. With a well-designed model, users can easily represent who the operators are, what functions and tasks they perform, what visual, auditory, cognitive, and psychomotor demands are placed on them, and what their utilization is. There are a number of user-defined reports that can be generated based on the simulation execution. This demonstration will provide an overview of Micro Saint Sharp and present some of its new human performance modeling capabilities.

OVERVIEW

Discrete event simulation has been a standard technique in the analysis of systems, particularly manufacturing, for many years. Simulation has been recognized as a valuable tool for evaluating alternative strategies in a timely and cost effective manner. Simulation is now being used to evaluate and improve efficiency in a myriad of areas, including: process definition, quality measurement and control, process re-design, employee workload, safety and productivity. With simulation technology being applied to a wider variety of problems, the need for general-purpose simulation tools that are capable of addressing all of these needs has increased. Micro Saint Sharp, a task network based modeling tool, is recognized to be an efficient and cost-effective tool for simulating the complexities of systems within a variety of industries ranging from the military to health care.

The purpose of this demonstration will be 1) to provide a basic understanding of the principles of modeling with Micro Saint Sharp, and 2) to demonstrate how Micro Saint Sharp can be used to aid human performance professionals.

HUMAN PERFORMANCE MODELING

Perhaps the greatest contributor to human error in many systems is the extensive workload placed upon the human operator. The inability of the operator to cope effectively with all of his or her information and responsibilities contributes to many accidents and inefficiencies. In recognition of this problem, new automation technologies have been introduced to reduce workload during periods of high stress. Some of these technologies are in the form of enhanced controls and displays, some are in the form of tools that “push” information to the operator and alert the operator in order to focus attention, and still others consist of adaptive tools that “take over” tasks when they sense that the operator is overloaded. Unfortunately, these technical solutions often introduce new tasks to be performed that affect the visual, auditory, and/or psychomotor workload of the operators.

There are limited opportunities to empirically examine the performance of different combinations of equipment and crew composition in a realistic scenario, or context. Additionally, high workload is not typically caused by a single task but by situations in which multiple tasks must be performed or managed simultaneously. It is not simply the quantity of tasks that can lead to overload, but also the composition of those tasks. For example, two cognitive tasks being performed in parallel are much more effortful than a simple motor task and an oral communication task being performed together. The occurrence of these situations will not typically be discovered through normal human engineering task analysis or subjective workload analysis until there is a system to be tested. That is often too late to influence design.

To rectify this problem, there has been a significant amount of recent research and development aimed at human workload *prediction* models. Predictive models allow the designers of a system to estimate operator workload *without human subject experimentation*. Several Micro Saint Sharp human performance models have been developed to help address this need.

Any system or process that can be drawn as a flow chart can be represented as a model in Micro Saint Sharp. This is a useful feature for human factors professions because the task network diagrams mimic the task analysis data collected. The degree of model complexity is flexible. A simple, functional model can be built just by drawing a network diagram and filling in the task timing and operator assignment information. Also a more complex model that includes dynamically changing variables, probabilistic and tactical branching logic, sorted queues, conditional task execution, and extensive data collection can be built in Micro Saint Sharp. Micro Saint Sharp includes a fully functional programming language (Microsoft C#). This sophisticated programming language makes it more efficient to write code especially for large, complex models.

Whether the model is simple or complex, the process of running the model and generating statistics and graphs from the collected data is relatively simple. The user simply selects the execution settings and the variable data he/she wants collected and executes the model. Micro Saint Sharp symbolically animates the network diagram as the model executes and, using a random number seed the user provides, generates task times and routing choices specific to the current run.

Micro Saint Sharp includes features that allow it to communicate with other human performance or system simulations. This allows the human performance model to share data with other tools. A real time mode is available to ensure the simulation clocks remain in sync. This is a powerful new capability not found in most human performance tools.

MODEL DEVELOPMENT

Micro Saint Sharp uses a methodology known as task network modeling. Activities are represented in a diagram as nodes and the arrows between the nodes represent the sequence in which the activities are performed. This approach allows users to develop models using the same techniques they would use to define a flow diagram of the activity. Each activity, whether it is a human activity or a system activity, is defined using the same method. This forms the "backbone" of the model.

A Micro Saint Sharp model is composed of "networks" which may be a sequence of tasks to be performed by a human or a series of processes that define an organization. Networks are composed of either lower-level networks or "tasks." Tasks represent the lowest level in the model and have specific parameters (timing information, conditions for execution, beginning and ending effects).

For defining task times, Micro Saint Sharp supports more than 22 distribution types including normal, rectangular, exponential, gamma, Weibull, Poisson and others. The task time may be determined by the current state of the system or by an attribute of the process itself. In human performance modeling, the mean time to perform a task may be influenced by such conditions as how long the human has been working, the skill level of the human, or the current workload.

Task sequencing is also defined from the task description dialog. Users can enter the conditions that control the branching; this includes tasks with just one exiting path or multiple exiting paths. Micro Saint Sharp provides the following decision types to ensure that all real-world situations may be represented in the model:

<u>Probabilistic</u> – The following task conditions are evaluated and the next task to execute is determined by the relative probabilities of all tasks listed. Only one of the following tasks will be executed with probabilistic decisions.

<u>Multiple</u> – The following task conditions are evaluated and all of the tasks whose conditions evaluate to true will execute.

<u>Tactical</u> – The following task conditions are evaluated and the next task to execute is the task whose condition evaluates to the highest value.

Variables and algebraic expressions can be used anywhere in the model and the value of the variables can be changed by conditions in the model. This gives the user complete control and manipulation of the network flow.

ANALYSIS AND RESULTS

Simulation models are built to provide insight to, or to answer specific questions about, a system or process. Some information can be gained by watching the Micro Saint Sharp model run. Micro Saint Sharp's symbolic animation capability provides an animated view of the network diagram as the model is running. Users can watch as entities flow through the network or wait in queues before being processed. This type of animation is particularly useful in debugging the model.

Sometimes it is sufficient to save the state of the system at the end of the run. Sometimes the final state of the system does not allow the user to fully understand the dynamic aspects of that system as it executes, Micro Saint Sharp allows users to "take snapshots" of the model variables at any time during the run. These "snapshots" of data can be analyzed by importing them into another statistical analysis package. Data can be collected at any time during the model run. Task and queue data files can be collected automatically.

Micro Saint Sharp includes a real time graphing capability. This graphing capability allows the user to watch data be dynamically graphed onto any type of chart. These charts can then be printed or saved as separate files for later analysis. Using the insights gained from the results of the simulation analysis, users can assess the relative merits of alternative solutions. Additionally, users can predict the impact of these solutions that subsequently leads to a better understanding of the costs and benefits.

Micro Saint Sharp also has an image-based animation capability called Animator. This allows custom animations of the model to be built. The background scene can be a three-dimensional diagram from a CAD package, a digitized diagram of a factory floor, or a bitmap from any drawing package. The creation and movement of the animation is driven by events that take place in the model. Animator allows descriptions of the model to be shown while the model is executing and is an extremely valuable tool for presenting the model. It can also be run in real time. Using Animator, the user can have annotations, labels, plots, graphs and images all on the same screen. Images can be scaled and rotated with ease.

EXAMPLE APPLICATION OF MICRO SAINT SHARP TO MODEL HUMAN PERFORMANCE

Since Micro Saint Sharp is a general-purpose discrete event simulation tool, certain additions need to be made to a Micro Saint Sharp model before it can be easily used as a human performance-modeling tool. These additions to any Micro Saint Sharp model are in the form of user-defined functions and data collection snapshots that allow the user to easily define: operator assignment, task location requirements, and workload level (visual, auditory, cognitive, and psychomotor).

In this section a sample human performance model developed using Micro Saint Sharp will be discussed. The goal of this modeling effort was to examine the effects of various staffing levels on nuclear power plant crew performance. Through modeling, the current and proposed processes can be evaluated and analyzed in order to understand, identify, and test opportunities for process improvement or reengineering. Models can quickly be built and modified to reflect system, personnel, timing, and resource changes.

To develop the models, the human performance and scenario event task analysis data was entered into Micro Saint Sharp as a series of individual tasks. Then the interrelationships amongst the tasks were defined in the form of a task network. The interrelationships that were used to develop the models include: which tasks were a result of another task (what was the task sequence), which tasks were performed due to plant conditions, and which tasks were caused directly or indirectly by events in the scenario. Any interrelationship data that was not obvious from the data collection timeline was obtained from the plant documentation and/or subject matter expertise. Attributes of each task were then defined in terms of what was the task name, what operator type performs the task, where is the task performed, and how long each task takes to perform. A portion of the task network is show in Figure 1.

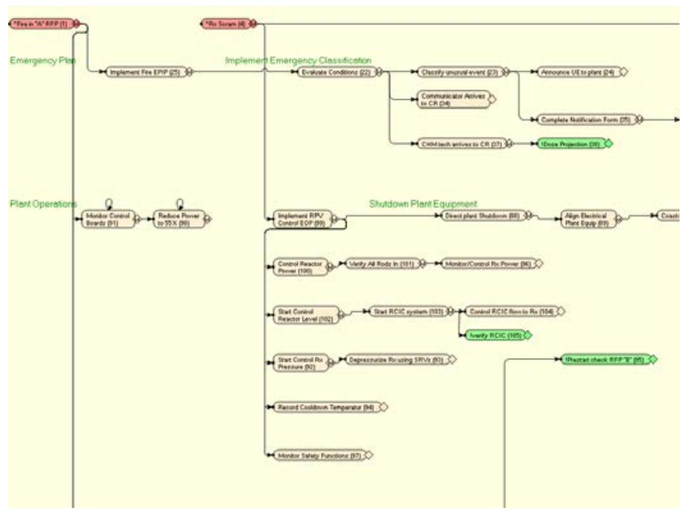

Figure 1 – A portion of the Nuclear Power Plant Human Performance Model

The tasks were divided and grouped into six categories: point events, emergency plan tasks, plant operation tasks, fire response tasks, emergency operating procedure tasks, and administrative tasks.

The majority of the work in developing a human performance model in Micro Saint Sharp is done using the task description dialog (Figure 2). Each task has several attributes that users can define including: timing information (distribution, mean, standard deviation), operator type assignment, mental workload level (visual, auditory, cognitive, and psychomotor), queue information, sequencing information (under what conditions will each potential path be followed), and appearance parameters (size, shape and color).

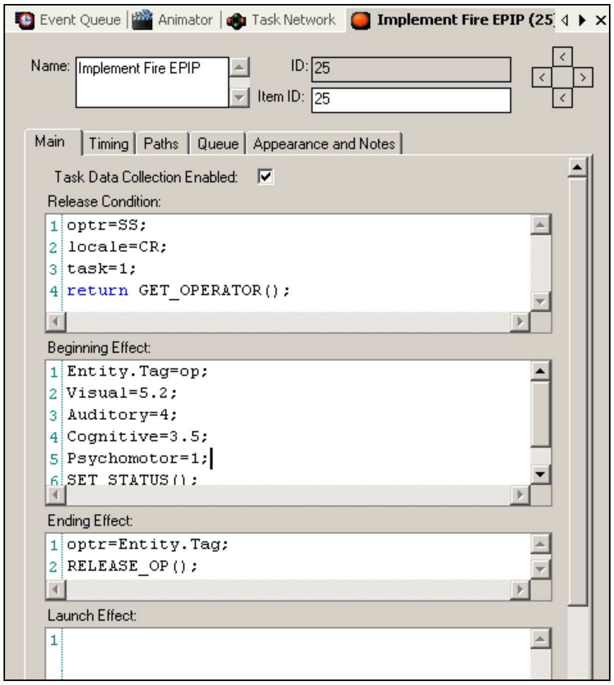

Figure 2 – Task Description Window

The following parameters are defined for each operator task:

Task ID: Micro Saint Sharp assigns the task ID when the task is created. The user can change it.

Task Name: The task name is a textual description of the task

Mean Time: The mean time field shows either a number or expression that describes the length of time that the task will normally last. The data was supplied from either the on-site data collection or from a subject matter expert.

Standard Deviation: The standard deviation field shows a number or expression that describes the spread of task times. The data was supplied from either the on-site data collection or from a subject matter expert.

Release Condition: Release conditions in Micro Saint Sharp are used to describe the conditions that must be true in order for the task to execute. In the models built for this project, the release condition is used to assign each task to the operator type who would perform the task, and check if the operator is available.

Beginning Effect: In the task beginning effect the operator is marked as unavailable and the tag is set to the operator identification number.

Launch Effect: The launch effect field in Micro Saint Sharp is used to execute graphic animation (Animator) commands.

Ending Effect: In the task ending effect the operator is marked as available.

For each task to be performed in the nuclear power plant human performance model, an operator type and a location were defined. The operator type defines the skill set required to perform the task. During model execution, when a task is scheduled to be executed, a user defined function entitled "GET_OPERATOR()" determines which operator is available and in the correct location to perform the task. If an operator is not available, the task cannot be started.

The user-defined function "SET_STATUS()" is called in each task beginning effect field. This function is responsible for updating the operator's status and calculating the current workload for the operator performing the task being executed. As more and more tasks are assigned and executed by the operators in the model, each operator's workload will determine how the model will execute and how long tasks will take to finish. At the beginning and end of a task, an operator's workload will increase and decrease.

The model was constructed so that certain system parameters could be easily manipulated. The user can easily modify any of the following parameters:

- Number of operators of each type (Shift Supervisors, Reactor Operators, Shift Technical Advisors, Auxiliary Operators, etc.)
- Operator assignments (which operators are on the fire brigade)
- Operator initial locations (inside the control room, outside the control room)

The final addition to a Micro Saint Sharp model is to define the specific human performance results. These results files will be created using the Micro Saint Sharp function "Model.TriggerSnapshot()". This function call allows users to define where in the model they want data collection to occur and gets the specific information needed for human performance modeling such as: operator utilization, operator workload, and number of bottlenecks. Once these specific additions have been made to any Micro Saint Sharp model, a user has all they need to develop their human performance model.

Three snapshot files were created to collect data for the nuclear power plant model. The first file contains the simulation time that significant events occurred during model execution. For example, the snapshot file contains data on what time the fire started, what time the fire brigade response occurred, what time the blowdown lineup occurred, etc. The second result file contains the frequency and total amount of time that a task delayed starting due to operator unavailability. The third records data on operator workload and utilization.

By comparing the model output with the data collected on-site, it was determined that reasonable models can be built in a short amount of time that can simulate nuclear power plant control room personnel for different plant types and scenarios. Comparison of task start times and of tasks that would be delayed due to operator unavailability showed that the model output was closely aligned with the data collected on-site.

CONCLUSION

The features included in Micro Saint Sharp provide an environment for the model developer that is easy to learn and easy to use. Once the basic concepts are understood, any system or process can be modeled using Micro Saint Sharp. In addition, users can build models of any level of complexity. The human performance capabilities allow human factors professionals to quickly and easily build models that incorporate the operators, the functions and tasks they perform, and the basic workload incurred. Reports can be generated to help the user analyze the human system in terms of utilization and workload. During the demonstration, Micro Saint Sharp will be shown in a hands-on format.