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COMPUTER SIMULATION AS A TOOL FOR STUDYING HUMAN-CENTERED SYSTEMS

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ABSTRACT

Human performance is a critical aspect of system performance. Recently, tools and methods for modeling the human in systems have begun to receive widespread attention. These tools and methods are consistent with other types of models and simulations that are used to model other system components. In this paper, the basic approaches to modeling human performance are discussed along with a brief case study.

1 INTRODUCTION

Human performance is often a high risk element in the overall operational effectiveness of many types of systems. For example, approximately two thirds of aircraft accidents are now attributed to pilot error. Unfortunately, the traditional design process tends to put a disproportionate focus on the technical performance of equipment, with little regard for the human component.

In the past, it has been difficult to integrate human performance models within system performance models, because of the complexity of human behavior and the lack of computational power to address the variability in human performance. The techniques that have traditionally been used to examine the human performance issues have largely been manual and laborious in nature. However, modern tools and methods facilitate the transfer of this information in a format compatible with other system computer models and simulations. This provides a golden opportunity to ensure that problems associated with human performance are identified early in the design process to prevent costly changes and procurement delays.

Over the past few decades, tools and techniques for the modeling of human performance in systems have evolved and matured. These tools are now at a state of maturity where they could be effectively integrated into the systems engineering process. Outlining some of these methods and how they fit into the world of computer simulation is the purpose of this paper.

2 GENERAL CATEGORIES OF HUMAN PERFORMANCE MODELS

Laughery and Corker (1997) have separated the world of human performance models into two general categories that can be described as *reductionist* models and *first principle* models.

Reductionist models use human/system task sequence as the primary organizing structure. The individual models of human behavior for each task or task element are connected to this task sequencing structure. We refer to it as reductionist because the process of modeling human behavior involves taking the larger aspects of human system behavior (e.g., "perform the mission") and then successively reducing them to smaller elements of behavior (e.g., "perform the function, perform the tasks") until a level of decomposition is reached at which reasonable estimates of human performance for the task elements can be made. One can also think of this as a top-down approach to modeling human/system performance. Figure 1 presents the concept of reductionist models graphically.

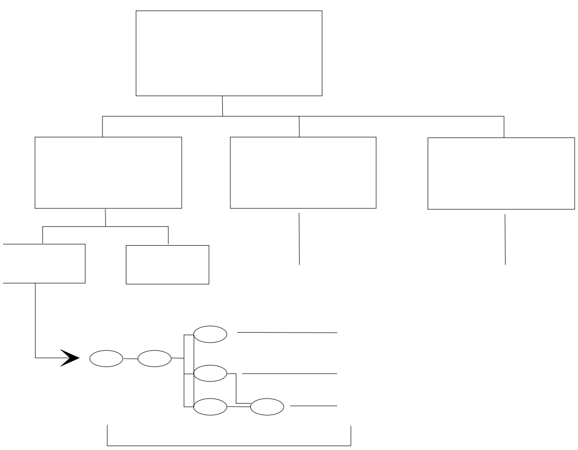
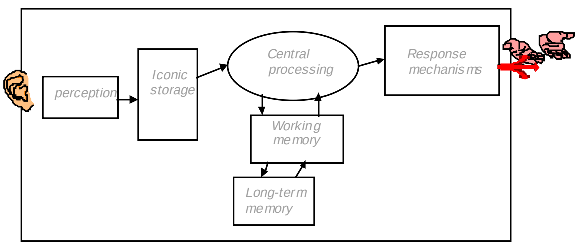


Figure 1: The Concept of Reductionist Models of Human Performance

First principle models of human behavior are structured around an organizing framework that represents the underlying goals and principles of human performance. Tools that support first principle modeling of human behavior have structures embedded in them that represent elemental aspects of the human. For example, these models might directly represent processes such as goal seeking behavior, task scheduling, sensation and perception, cognition, and motor output. To use tools that support first principle modeling, one must describe how the system and environment interacts with the modeled human processes. An example of a very simple structure to support a first principle modeling environment is presented in Figure 2. The best example of this type of tool is one that was developed and is being supported by the NASA-Ames Research Center, the Man Machine Integrated Design and Analysis System or MIDAS.

Figure 2: An Example of the Concept of First Principle



Models of Human Performance

It is worth noting that reductionist and first principle modeling strategies are not mutually exclusive and, in fact, can be mutually supportive in any given modeling project or environment. Often, when modeling using a reductionist approach, one needs models of basic human behavior to accurately represent behavioral phenomena and, therefore, must draw on elements of first-principle models. Alternately, when modeling human/system performance using a first principled approach, some aspects of human/system performance may be more easily defined using a reductionist approach.

In the remainder of this paper, we discuss an approach to modeling human performance, *task network modeling* that is primarily reductionist, but that has been used extensively as a platform for first principle modeling approaches.

3 A DISCRETE-EVENT SIMULATION APPROACH FOR MODELING HUMAN PERFORMANCE

Task network modeling is an approach to modeling human performance in complex systems that has evolved for several reasons. First, it is a reasonable means for extending the human factors engineering staple - the function and task analysis. Task analyses organized by task sequence are the basis for the task network model. Second, in addition to complex operator models, task network models can include sophisticated submodels of the equipment hardware and software to create a closed-loop representation of the human/machine system. Third, task network modeling is relatively easy to use and understand. Recent advancements in task network modeling technology have made this technology more accessible to human factors practitioners. Finally, task network modeling can provide reasonable input to many types of issues. With a task network model, the human factors engineer can examine a design (e.g., control panel redesign) and address questions such as "How much longer will it take to perform this procedure?" and "Will there be an increase in the error rate?" Generally, task network models can be developed in less time and with substantially less effort than would be required if a prototype were developed and human subjects used.

Task network models of human performance have been subjected to validation studies with favorable results (e.g., Lawless, Laughery, and Persensky, 1995). However, as with any modeling approach, the real level at which validation must be considered is with respect to a particular model, not with respect to the general approach.

Micro Saint is a tool for building task network models of human performance. Using Micro Saint as the basic building block, we at Micro Analysis and Design have developed a number of human performance modeling tools using the paradigm of “hybrid” human performance modeling (i.e., tools that take advantage of the simplicity and flexibility of a task network approach while also taking advantage of known first principles). For example, we have tools that include embedded algorithms representing the first principle of the multiple resource theory of workload and elements of the GOMS model (Gray, John, and Atwood, 1993). For a more complete description of some of our human performance modeling tools and research, please see our web site at www.maad.com.

4 TASK NETWORK MODELING FUNDAMENTALS

Task network modeling involves the extension of a task analysis into a predictive model based around a network representation of the human’s activity. This concept is illustrated in Figure 2, which presents a sample task network for dialing a telephone.

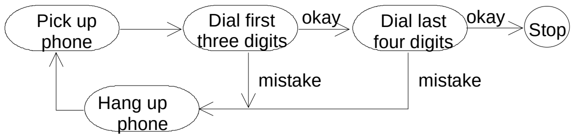


Figure 3: An Example of a Task Network Model Representing a Human Dialing a Telephone

Task network models of human performance have been subjected to validation studies with favorable results (e.g., Lawless, Laughery, and Persensky, 1995; Allender, *et al* 1995).

As stated above, a modeling environment that supports task network modeling is *Micro Saint.* The basic ingredient of a Micro Saint task network model is the task analysis as represented by a network or series of networks. The performance of the tasks can be interrelated through shared variables. The relationships among different components of the system (which are represented by different segments of the network) can then communicate through changes in these shared variables. For example, when an operator enters a command on a keyboard, this may initiate change in computer state or the information that is presented on an operator display. This task network is built in Micro Saint via a point and click drawing palette. Through this environment, the user creates a network as shown in Figure 4.

To reflect complex task behavior and interrelationships, more detailed characteristics of the tasks need to be defined. By pointing and double clicking on a task, the user opens up the Task Description Window as shown in Figure 5 whereby information describing task behavior and linkage with other system elements can be defined.

Another notable aspect of the Task Network Diagram Window shown in Figure 4 is the diamond-shaped icons that follow some tasks. These are present every time more than one path out of a task is defined. Implicitly, this means that a decision must be made by the human to select which of the following potential courses of action should be followed. By opening a window into the decision, decision logic and algorithms can be developed to any level of complexity. Micro Saint also offers many other features that facilitate the construction and use of task network models such as automatic error trapping, scenario development features, data gathering and analysis, and model animation features that allow the user to view the dynamic activities of the humans and system he or she is using. From these basic building blocks, a task network model can be built to describe human and system behaviors of any size or level of complexity.

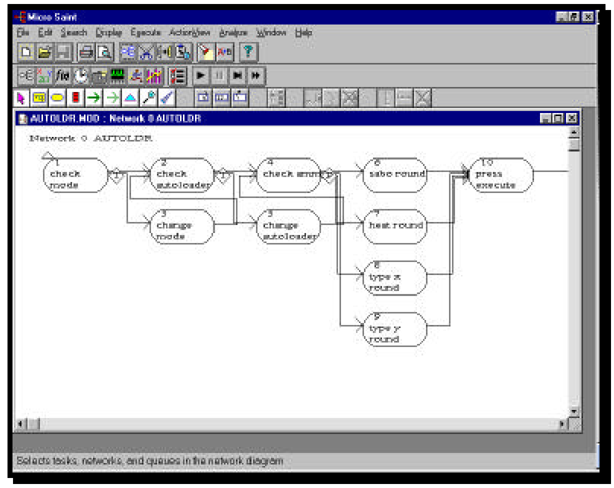


Figure 4: The Main Window in Micro Saint for Task Network Construction and Viewing

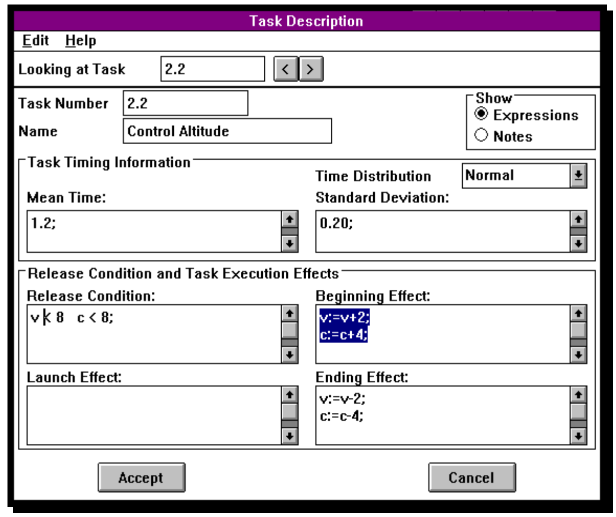


Figure 5: The User Interface in Micro Saint for Providing Input on a Task

6 A CASE STUDY USING TASK NETWORK MODELING TO EVALUATE AUTOMATED TELLER SYSTEM DESIGN

The above approach has been used to study many aspects of human performance in systems answering questions such as:

- how many people are needed to safely and effectively perform their job,
- what is the range of performance we might expect from the humans in the system and, therefore, how prone to failure is the system,

- how will the humans respond to stress
- what is the value of a new design or piece of equipment on human and, ultimately, system performance

In the remainder of this paper, we will discuss a project we performed looking at the value of an automated teller system on a Japanese bank. With this model, we were able to demonstrate the value of an equipment investment in enhanced human productivity and the resulting improvement in customer service.

The transaction completion process in the Japanese banking industry has many areas that could be improved to better meet customer and bank needs. The current transaction completion process at Japanese banking institutions includes several tasks that are time-intensive, inefficient, and may prevent tellers from keeping up with customer demand. Potential methods that could be used to decrease the time required for each transaction and improve accuracy include hardware improvements (e.g., ATMs), software enhancements (e.g., the design of the ATMs), and process redesign. A provider of equipment to the Japanese banking industry determined that a cost-effective and efficient method to 1) investigate the Japanese banking industry problems and 2) evaluate potential solutions was simulation.

One purpose of the Japanese banking project was to identify the effects of changing various parameters on the overall transaction process. In particular, it was desired to obtain results from the effects of changing system, personnel, timing, and/or resources. The output desired included time per transaction, average transaction time for each transaction type, total customer time in the bank, customer wait times, teller utilization, transaction queue times at the teller stations, and the maximum queue lengths.

The basic sequence of events for most transaction types is as presented in Figure 6. More detailed models of each of these transactions were developed in the model. Each transaction had its own unique set of steps that were required.

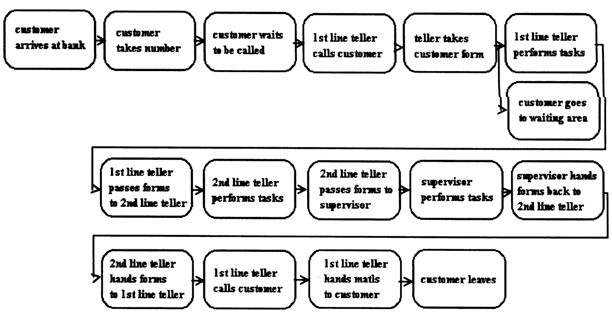


Figure 6: The Basic Sequence of Events for Most Transaction Types

For the base Japanese banking model, a graphical animation was constructed along with the simulation to show the general layout of the bank along with various output parameters. While the model executes, the animation is updated to represent the current state of the system. The animation background is shown in Figure 7.

The model was constructed so that certain system input parameters could be easily manipulated. For example, the user can easily modify customer arrival rates based on branch and type of day, transaction type ratios, number of tellers, probability of transaction types such as the percentage of customers who require change and percentage of customers who withdraw more than 1,000,000 Yen.

The output data collected from the model includes time per transaction, average transaction time for each transaction type, total customer time in the bank, customer wait times, teller utilization, transaction queue times at the teller stations, and the maximum queue lengths.

Proposed transaction process changes were evaluated and analyzed in order to understand, identify, and test opportunities for process improvement or reengineering including cross training of tellers to eliminate the multi-tiered system and bank automation (e.g., automated teller machines) on resource requirements (e.g., tellers) and customer throughput.

In sum, simulation provided a tool to evaluate the payoff of human factors improvements on employee productivity and customer service.

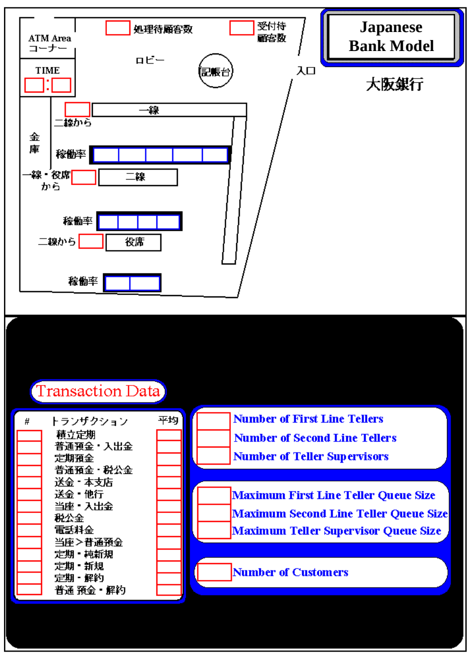


Figure 7: Graphical Animation Background

7 SUMMARY

Task network modeling provides one way to assess the value of human-computer interface designs in the operating environment. Together with usability analysis to ensure model accuracy and systems analysis to define how the system will be used, a better assessment of the value of the human interface can be gained.

REFERENCES

Gray, W.D., John, B.E., and Atwood, M.E. 1993. Project Ernestine: Validating a GOMS Analysis for Predicting and Explaining Real-World Task Performance. Human-Computer Interaction, Vol.8, pp.237-309.

Laughery, K.R., and Corker, K. 1997. *Computer Modeling of Human/System Performance*. In the Handbook of Human Factors, G. Salvendy Ed., Wiley Publishing.

Lawless, M.L., Laughery, K.R., and Persensky, J.J. 1995. *Micro Saint to Predict Performance in a Nuclear Power Plant Control Room: A Test of Validity and Feasibility*. NUREG/CR-6159, Nuclear Regulatory Commission, Washington, D.C.