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A Comparison of Alphanumeric, Direct Manipulation Graphic, and Equivalent Interface Design for a Production Scheduling Task

Ann C. Fulop
Old Dominion University

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by

Ann C. Fulop

B.A. May 1987, Boston College, Chestnut Hill, MA

M.S. December, 1989, Old Dominion University, Norfolk, VA

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Glynn D. Coates (Chairperson)

ABSTRACT

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Ann C. Fulop
Old Dominion University
Chairperson: Dr. Glynn D. Coates

Scheduling is an essential factor influencing the efficiency of any production system. The effectiveness of the scheduling system depends upon the interaction of the human and machine. Thus, to effectively design the interface between the human and the machine, the human factors professional must understand scheduling behavior and the information requirements of the scheduling task. The present study modeled human scheduling behavior and determined the information requirements of the scheduling task. The study also compared alphanumeric, direct manipulation graphic, and equivalent interfaces to determine which interface best supports scheduling. The results of the study show that schedulers monitor the current system state and preview to future system states to test scheduling options and make scheduling decisions. Thus, current state, goal state, future state, and discrepancy between goal state and future state information help schedulers. In addition, the analysis suggests that a mixed format interface design best supports the human in the scheduling system. Recommendations for interface design and future research are discussed.

ACKNOWLEDGEMENTS

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INTRODUCTION

Scheduling is an essential factor in determining overall manufacturing performance. With the increased implementation of advanced manufacturing systems and automation, the scheduling task is given to the machine. However, even with high levels of automation, humans monitor, supervise, and perform rerouting functions. An understanding of the human's planning and scheduling role in the system is necessary for two reasons. (1) Advanced manufacturing systems experience as much as 60% downtime thus, humans must reschedule and reroute jobs (Ammons, Govindaraj, Mitchell, 1988). Therefore, they need to be supported in this role. (2) The programmed algorithms and heuristics used in automated systems are limited to well-defined problems that occur on a regular basis, whereas the human is capable of solving intermittent ambiguous problems and unplanned changes in production requirements.

To respond effectively to problem situations, the human requires knowledge of the manufacturing system properties and constraints, and a mental picture of the current system state (Sanderson, 1989). A system model can be presented via a graphical interface. In interactive man-machine scheduling systems the interface provides support for the human. Thus, interface design needs to be based on an analysis of the scheduling task and an analysis of the decision processes the human uses to perform this task.

Specifically, the human factors professional needs to know the information requirements of the scheduling task, so that the appropriate information can be made available to the scheduler at the proper time. In addition, the human factors professional must understand the decision making strategies involved in scheduling. Studying schedulers' decision strategies will enable researchers to find flaws or biases in the strategies. Thus, well-designed systems or interfaces can compensate for these biases and improve the quality of a scheduler's decision.

In addition, the human factors professional needs to know how to display the required information so that it is easily understood and interpreted by the scheduler. Display format of information affects either positively or negatively the quality of schedules produced. The appropriateness of a display style such as, direct manipulation graphic, alphanumeric, or equivalent depends on the decision strategies and information the human uses to create schedules. Therefore, the development of interfaces that adequately support the human in the planning and scheduling role require knowledge of the human's understanding of the system, knowledge of the human's decision processes when scheduling, and the information the human uses to make scheduling decisions. The purposes of the present research are to determine which display: alphanumeric, direct manipulation graphic, or equivalent best supports scheduling, to determine the type of information that facilitates effective scheduling, and to acquire an understanding of the decision processes the human uses when scheduling. In addition, this study examines which display is most appropriate for scheduling under a time pressure.

Scheduling problem.

The scheduling task is a problem solving task in which the scheduler must create a schedule, within the constraints of the environment, that will accomplish production goals (e.g. minimize average job completion time, maximize machine utilization) while minimizing costs (e.g. inventory and labor requirements). Production scheduling problems occur whenever the same materials and resources must be used to make a variety of products during the same time period. Creating a schedule involves specifying a sequence of operations to complete a job, designating resources, and assigning start and finish times for the job (Rodammer & White, 1988). Job priorities, due-dates, resource requirements, and resource availabilities impose constraints upon the scheduler when creating a schedule (Rodammer & White, 1988). Furthermore, the scheduler must create schedules in dynamic, uncertain environments. Equipment failures, worker absenteeism or tardiness, late inventory arrivals, changes in production demand, and inadequate supplies all contribute to the instability of the scheduling environment. Schedules must be frequently changed and updated to accommodate the changes in the environment and meet production goals in a timely manner. Thus, creating the optimal schedule is improbable, if not impossible. Any scheduling problem has an enormous number of solutions. In 1964, Dutton analyzed a scheduling task in a shoe box factory. He estimated the number of possible scheduling solutions to fill 20 orders to be 4×10^{15}. The scheduler's task is to optimally designate resources and sequence operations to achieve production goals, minimize costs, and account for constraints in a dynamic unstable environment.

Currently, several techniques exist to help the scheduler meet the demands of the scheduling task (see Table 1). However, these scheduling systems do not necessarily aid the human in making good decisions or provide the human with appropriate information. These approaches include artificial intelligence (Bruno, Elia, & Laface, 1986; Jackson & Jones, 1987; Vere, 1983), control theory (Gershwin, Hildebrant, Suri & Mitter, 1986), discrete-event simulation (Amar & Gupta, 1986; Baker & Dzielinski, 1960), machine sequencing and scheduling (Conway, Maxwell & Miller, 1967), resource-constrained project scheduling (Davis, 1973), stochastic optimization (McClain & Thomas, 1985) and conventions of industrial practice (Jacobs, 1984).

Each of these approaches to the scheduling problem have

TABLE 1
Advantages and disadvantages of scheduling systems.

	Advantages	Disadvantages
Artificial Intelligence Bruno, 1986 Jackson, 1987 Vere, 1983	Ability to solve complex problems.	Expensive, Slow Based on expert humans.
Control Theory Gershwin, 1986	Appropriate for use in continuous manufacturing environments.	Not useful for discrete manufacturing environments.
Database Systems WIP, JIT MRP, OPT Jacobs, 1984	Provides philosophy for reducing costs and improving quality. Determines & tracks material req's.	Does not prescribe a scheduling method. Expensive. Cannot handle random events. Ignores available production capacity.
Discrete-event Simulation Amar, 1986 Baker, 1960	Allows schedules to be tested before implementation.	Need human to interpret simulations.
Machine Sequencing and Resource Constrained Project Scheduling Davis, 1973 Conway, 1967	Algorithms based on known scheduling rules. Optimize schedules.	Need better algorithms. User needs extensive training. Project scheduling has to be adapted for production scheduling.
Stochastic Optimization McClain, 1986	Applies queuing and reliability theories to scheduling. Estimates system performance.	Requires simplified models of the system. Cannot handle random events.

unique advantages and disadvantages, but all require a human scheduler for successful implementation. Artificial intelligence solutions, such as expert systems, offer solutions to computationally complex problems, yet they are costly, slow, and are based on the imperfect scheduling strategies of humans. Stochastic optimization models or queuing models are ill-equipped to handle disruptions such as machine failures. Discrete-event simulation allows the human to test options before executing them. However, the success of the system depends on the human's ability to interact with simulated models and the human's knowledge of the system. Control theory describes scheduling in continuous environments, but is not well suited to discrete manufacturing environments. Continuous process environments involve an uninterrupted flow of inputs to outputs. For example, the cooling system in a nuclear reactor requires a continuous flow of water through the plant. Discrete manufacturing involves the sequential assembly of separate inputs to produce an output. Even with these varied approaches for scheduling, much scheduling is still done by a human aided with a paper, pencil, graphical aid (e.g. Gantt chart) and a software and database package such as optimized production timetables or just-in-time production systems.

These systems reduce the need for the scheduler to maintain the constraints and changes in memory. However, these systems do not necessarily provide the scheduler with needed information such as, demands and constraints, in a usable form. Few studies question whether these scheduling techniques present usable information to the user. Fewer studies analyze the information humans use to schedule. Research comparing unaided human scheduling with scheduling systems (Ben-Arieh & Moodie, 1987; Dunkler, Mitchell, Govindaraj & Ammons, 1988), investigating human-computer interactive scheduling behavior (Ferguson & Jones,1969; Godin, 1978; Hurrion, 1978; Sharit, 1985), examining human scheduling with enhanced human-computer interactive interfaces (Laios, 1978; Mitchell, 1983), or modeling the human to create intelligent systems captures the policies the human uses but does not adequately describe the scheduling behavior.

It appears that man-machine scheduling systems are superior to either man or machine alone because humans add flexibility to the system (Mitchell, Govindaraj, Dunkler, Krosner, & Ammons, 1986; Nakamura & Salvendy, 1988; Sanderson, 1989). For example, humans have the unique ability to change performance goals and perform tradeoffs among conflicting goals (Dunkler et al, 1988). An effective scheduling system appropriately allocates functions between the human and computer and presents to the human needed information in the appropriate form. Results from these studies suggest production scheduling with man-machine systems requires the human to perform three tasks, monitoring, predicting, and problem-solving (see Figure 1).

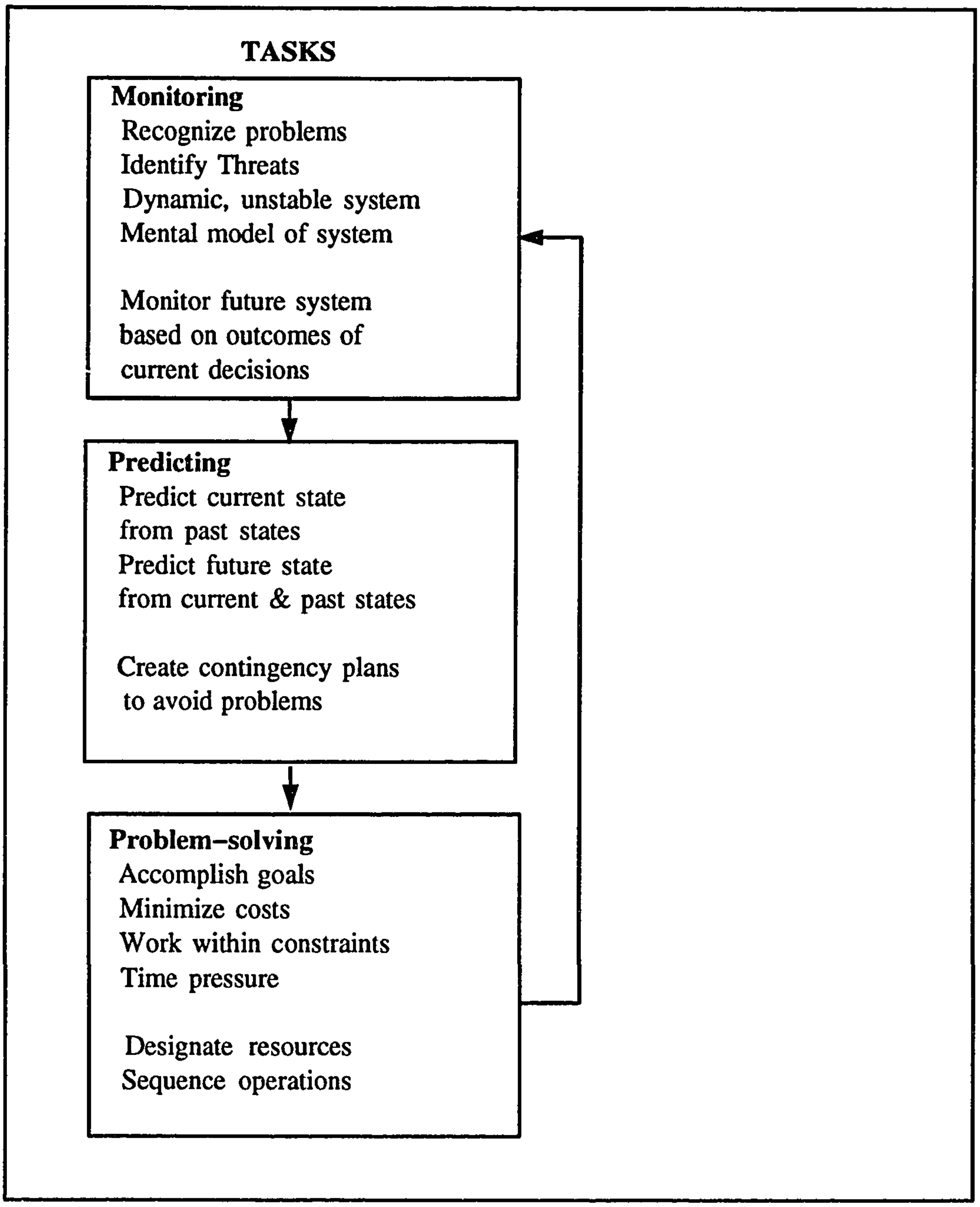

Figure 1. Human scheduler's tasks.

Monitoring task.

Analysis of various scheduling situations reveals that schedulers spend a large proportion of time monitoring the system in order to identify problem constraints and create plans to prevent breakdowns and problems (Fox & Smith, 1984; Thurley & Hamblin, 1962). Therefore, to schedule successfully, the scheduler must prepare ways to identify threats, identify possible threats to goal attainment, and invent contingency plans.

The human must also monitor the current system in order o try to predict future system states from current and past states. Monitoring also helps the scheduler to estimate the current system state from previous system states in order to prevent or detect failures to maintain a smooth system flow. Effective monitoring depends on the scheduler's understanding of a system which includes a model of the sources of task-relevant information (Sheridan, 1988). Thus, the scheduler must have an understanding of the spatial and temporal relationships among the inputs, outputs, and processes of a system. Detecting the relationship between inputs and outputs is complicated when changes in system state occur far apart in time or when feedback that explains the relationships is delayed by hours or days. Furthermore, complexity of the task increases when system components are interactive and highly coupled.

Problem solving and predicting.

The scheduler makes decisions to designate resources and sequence operations in order to accomplish production goals and minimize costs. The scheduler is faced with a discrepancy between the current system state and a desired goal state. To solve the problem, the scheduler develops a schedule to achieve the goal state within the constraints of the system. Several possible problem-solving strategies exist. A forward chaining strategy involves reasoning from the current problem state working forward to the goal state. Backward chaining involves reasoning backward from the goal state to the initial problem state. Means-end analysis strategy solves the major parts of the problem first and then solves smaller problems for the entire solution. Barfield and Robless (1989) investigate problem-solving strategies managers use to solve a production problem. Experienced managers predominately use forward chaining and means ends analysis strategies while novice managers do not engage in a particular strategy. For example, managers in Barfield and Robless's study used a means-end analysis to check solutions against constraints using both forward and backward chaining strategies.

If schedulers engage in forward chaining, backward chaining or means-end analysis, then the interface of a scheduling system should display information about the current system state, the desired goal state, and the discrepancy between the current system state and goal state. In addition, the interface should include information about future system states to help the scheduler predict future situations and plan ahead.

The ability to predict the future system allows the scheduler to test various alternatives before making a decision to implement an alternative. If the scheduler is provided with a view into the future, testing options and predicting the future state of the factory will be a less difficult task enabling the scheduler to make better decisions. Suresh (1975) suggests that predictive displays improve performance because the user can view possible outcomes of many scheduling alternatives and eliminate ineffective alternatives. Schedulers also use predictive displays as error-correction devices (Smith and Crabtree, 1975). They use the display to determine future problems and output states from current inputs before making decisions.

Laios (1978), studying the scheduling of entry and exit of hot steel ingots in a soaking pit, found that dynamic Gantt chart predictive displays improved performance when arrival times of ingots needed to be estimated. When participants estimated arrival times using an alphanumeric predictive display performance was poor. Adding an analogue representation of the interval in which the arrival time was likely to occur to the predictive display improved performance because the picture provided a perceptual solution to the estimation problem. Laios concluded that creating a perceptual solution by adding an analogue display of the estimation problem reduced the cognitive workload of the users.

Wickens, Pizzaro, and Bell (1991) compared the decision strategies of participants who were given a preview display with those participants who did not view a preview. Participants given preview information were more likely than their counterparts to make decisions based on concrete information rather than utilize probability information. These researchers concluded that a limited amount of preview information is helpful. However, the cognitive processing required to extract information from preview displays made decision making a more difficult task.

Often, schedulers reduce the complexity of the task by looking for similarities among past production jobs and the current production job (Sanderson, 1985). Schedulers group or classify jobs based on their similarities. They use the categories to assess the situation in order to estimate the current system state and predict the future system state. The human's ability to make predictions about future system states relies on an adequate assessment of the situation.

Effective schedulers monitor the system state and decide how to designate resources and sequence operations in order to accomplish production goals while minimizing costs. The human monitors the system in order to create contingency plans to avoid problems and to try to predict the future state of the factory. Based on the prediction of future factory states the scheduler decides how to allocate resources. The scheduler must also monitor the future system state based on current decision outcomes to avoid future problems. Figure 2 summarizes the information requirements of the scheduling tasks. To effectively monitor the system, the scheduler needs to know the normal operational status of equipment and other system parameters, needs to know abnormal parameters or when equipment is not working, needs to remember past system states, needs to understand the current system state, and needs to understand or predict the future system state. To effectively make decisions, the scheduler must know the production goals, current state of the goals, constraints, resources, future constraints, and future resources. In addition, knowing the discrepancy between the goal state and current state should help the scheduler decide how to allocate resources to accomplish goals.

Interface display styles.

The form of information display can influence the ability to perceive relevant information and relationships among data points (Brooke & Duncan, 1981; Woods, 1984). Laios (1978) and Howell (1984) show that providing a spatial representation of non-spatial information improves user comprehension because the picture reduces the difficulty of the task by changing a cognitive task to a perceptual task. For example, two-dimensional data is presented effectively in

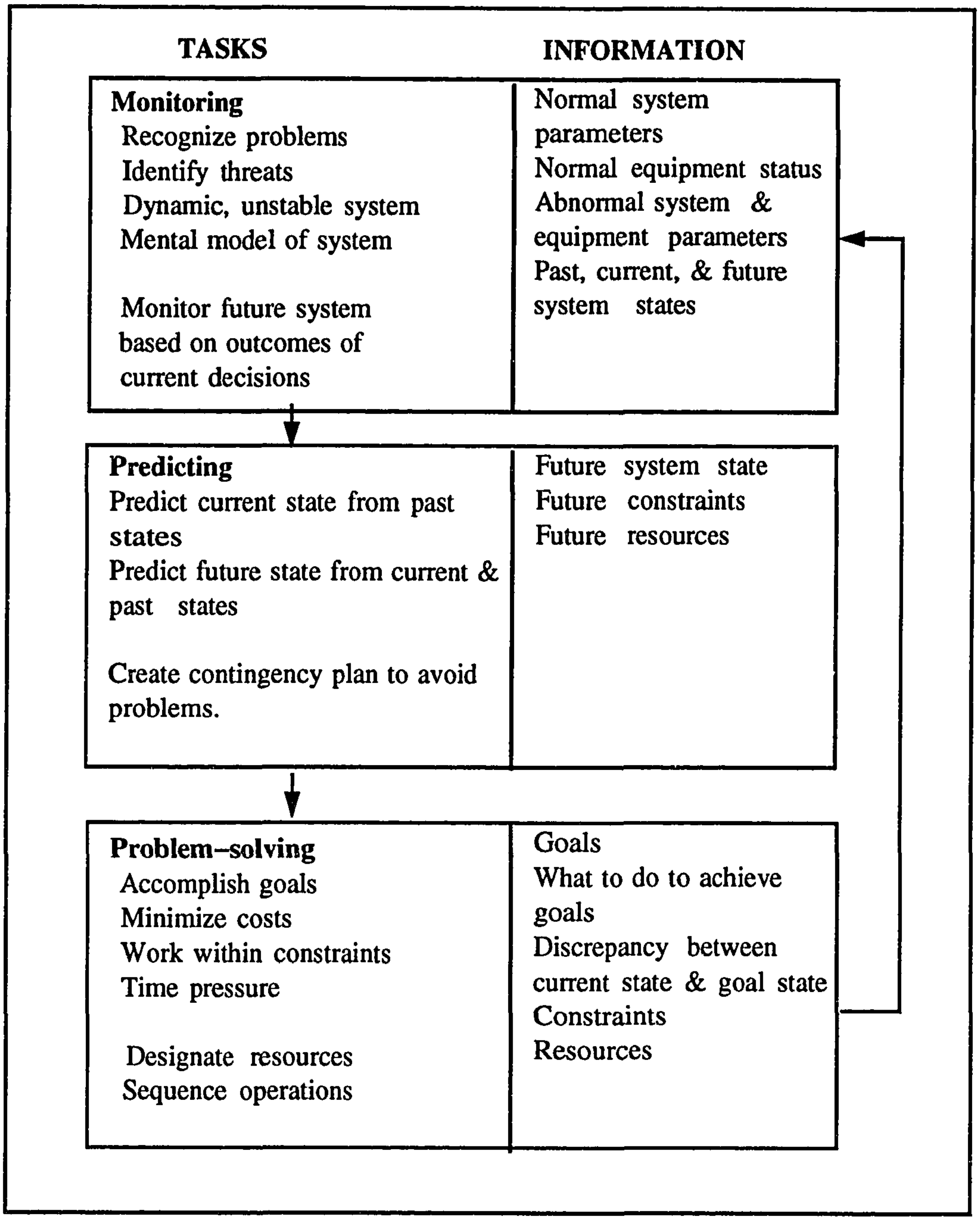

Figure 2. Human scheduler's tasks and information requirements.

bar charts, scatter plots, and histograms.

Graphic or analogue displays chunk information, thus reduce the cognitive demands on the user. Woods (1984) argues that analogical representation, a map of the system, reduces memory demands and the need to make inferences about relationships between inputs and outputs, by making information location and integration a perceptual process. The structure of the analogue display provides information about the structure of the system. Analogue displays also provide spatial cues that are readily perceived and serve as retrieval cues for content-related information about the system state. Therefore, analogue displays facilitate the synthesis of information by integrating information and spatially depicting the relationships within a system. Thus, an analogue or pictorial display can aid the decision maker in assessing a problem situation.

Jones and Maxwell (1986) developed an interactive scheduling system that combined Gantt charts and graphic representations of the components of a system. The system was received favorably by the individuals who tested it during development; however, it has not been tested empirically.

While graphic displays are beneficial when integrating data or analyzing aggregate level data, they are not beneficial in displaying "granular level" data or specifics. The user is required to hold specific information in "working memory" while creating schedules. The scheduler must mentally simulate different scheduling alternatives, and must "juggle" many items in memory. Thus, the graphic display could make the scheduling task more difficult because of the added load in memory.

Alphanumeric displays show all the specific data points simultaneously, thus decreasing the bits of information that the scheduler needs to keep in memory. However, the scheduler loses the possible advantage of spatial cues, integration of data, and ease of location of information.

Equivalent display of information is a dual-screen technique in which the user can see equivalent information in alphanumeric and graphic forms (Andriole, 1986). Equivalent displays offer a solution to the problems of alphanumeric and graphic displays by combining both displays into a single display. Three formats exist for equivalent displays: (1) Two monitors can be used, with the alphanumeric display presented on one monitor and the graphic display presented on the other monitor. (2) One monitor can be used, with the alphanumeric display presented on one half of the screen and the graphic display on the other half of the screen. (3) A toggle button with one monitor can be used enabling the user to toggle between two full-screen displays. Equivalent displays allow users to create displays that are compatible with the mental models they manipulate. It is possible that equivalent displays can improve scheduling performance because the two kinds of information displays reinforce each other.

The alphanumeric display reduces the amount of information that needs to be held in memory, and the graphic display "chunks" this information into higher order units. Yet, it is unknown whether equivalent displays are superior to alphanumeric or graphic displays.

The superiority of an alphanumeric, graphic, or equivalent display is task dependent. Tasks requiring serial processing of information such as data entry or text editing benefit from an alphanumeric display. Problem-solving tasks requiring visualization of a problem benefit from analogue representations of the problem space or graphic displays. Problem-solving tasks benefit most from equivalent displays because both serial and holistic processing of the information is required. It is assumed that the scheduling task is a problem solving task, thus the equivalent display should facilitate scheduling. Unfortunately, no empirical studies have compared alphanumeric, direct manipulation graphic, and equivalent displays with a problem-solving task. Most research comparing display styles explore text editing and data entry tasks.

Research comparing direct manipulation graphical interfaces with menu systems to command languages suggests that graphical interfaces facilitate text editing tasks that are done under time pressure (Shneiderman & Margono, 1987). Graphical interfaces lead to faster performance (Card, 1983) and faster learning time (Ziegler, Vossen, & Hoppe, 1986 as cited by Helander, 1990). Subjective ratings suggest that users prefer graphical interfaces to other interfaces (Shneiderman & Margono, 1987). Shneiderman (1983) states that the advantage of direct manipulation interfaces is the consistency of the display across various applications and tasks. For example, all windows are sizable and movable and command buttons perform an action. It is plausible that a graphical interface will facilitate scheduling in a time pressured scheduling situation because graphic interfaces are easy to learn and facilitate text editing tasks done under time pressure. However, research does indicate that more errors are made when using a mouse. For example, incorrect number of button activations and incorrect positioning of the mouse are common errors. Users become frustrated when they cannot access information that they need or cannot input information into the system correctly using the mouse. The equivalent display may be the best display for scheduling under time pressure because the system has the advantages of direct manipulation and the ease of keyboard entry.

Hypotheses.

Aiding the scheduler in monitoring, predicting, and decision-making requires the human factors engineer to develop comprehensive, integrated displays. These displays should facilitate the detection of trends over time and should show the user how past and current inputs will affect future system states. The design of comprehensive integrated displays requires the human factors specialist to depict the user's mental model, goals, resources, constraints, system states, and the results of the scheduler's actions. Information which supports the human's decision-making strategy should be displayed in an appropriate form. Graphic displays help the scheduler because graphic displays allow holistic processing of information. Alphanumeric displays are appropriate, because alphanumeric displays facilitate serial processing of information. However, equivalent displays provide information in both alphanumeric and graphic forms so that the presentation of the information is compatible with the user's mental model of the system.

It is hypothesized that the equivalent display provides the best support for scheduling because it has the advantages of both the alphanumeric and graphic displays. It provides specific information and chunks this information into higher order units to depict relationships within the system.

It is hypothesized that information that depicts the current system state, future system states, goal state, and the discrepancy between the current and the goal state should help the scheduler to make decisions. It is also believed that future state information will help the scheduler to avoid errors by allowing the scheduler to monitor future system states.

It is hypothesized that in a time pressure situation users with a graphical or equivalent display will produce better schedules than users of the alphanumeric display.

Task Requirements.

To test the above hypotheses, a simulated manufacturing environment (cookie factory) was created. Figure 3 outlines the task requirements for the study. In order to study monitoring behavior, the task is dynamic and occurs in real time. Participants in the study monitor equipment (ovens and mixers) and resources (cookie dough). The task includes equipment failures, and resource shortages. In addition, participants monitor an inspector to determine if all cookie batches pass inspection.

In order to study decision-making behavior, participants are given goal information (customer's orders), resource information (cookie dough inventory), and constraint information (equipment limitations). Participants are also given future inventory and constraint information. To mimic the complexity of scheduling tasks, the goals change during the task. That is, customer's orders change during production.

Participants create a schedule to bake cookies in a cookie factory. They control the ovens in the factory and will have to determine the sequence of cookie batches through the ovens and the start and finish time of each batch. To schedule a batch, participants determine the oven, the temperature, the number of cookies to be baked, the type of cookie to be baked, and the baking time of the cookies.

A cookie factory was chosen because the experimenter

TASKS	INFORMATION	REQUIREMENTS
Monitoring Recognize problems Identify threats Dynamic, unstable system Mental model of system Monitor future system based on outcomes of current decisions	Normal system parameters Normal equip. status Abnormal system & equip. parameters Past, current,& future system states	Recipes Ovens & mixers All information
Predicting Predict current state from past states Predict future state from current & past states Create contingency plans to avoid problems	Future system state Future constraints Future resources	Preview all information Preview equipment Preview inventory
Problem-solving Accomplish goals Minimize costs Work within constraints Time pressure Designate resources Sequence operations	Goals What to do to achieve goals Discrepancy between current state & goal state Constraints Resources	Customer's orders Total cookies baked Remaining cookies to bake Equipment Inventory

Figure 3. Human scheduler's tasks,information requirements, and experimental task requirements.

assumed that most college undergraduates have a similar understanding of the cookie baking procedure which is,ingredients are mixed, placed on baking trays, and baked. It is also assumed that most college students understand the purpose and operation of a mixing machine and an oven.

METHOD

Independent Variables and Experimental Design.

Two independent variables display type and time pressure were manipulated. Type of display was a between-subjects factor with 3 levels; alphanumeric, direct manipulation graphic, and equivalent displays (see Figures 4, 5, & 6). The displays and information presented in the displays is discussed in Appendix A.

Time pressure was a between-subjects factor with 3 levels. Participants were required to generate a schedule in 60 minutes, 75 minutes, or 90 minutes. The experimental design was 3x3 between subjects design.

Participants.

One hundred eighty undergraduate and graduate students were assigned to conditions with a stratified random sampling technique. Each cell had five male participants and 15 female participants. Undergraduate students received extra credit points for participating in the study.

Task.

Participants were told that they were the bakers in a cookie factory. They controlled the ovens in the factory. Their job was to fill customers' orders within 2 hours. Participants decided the sequence of batches through the ovens

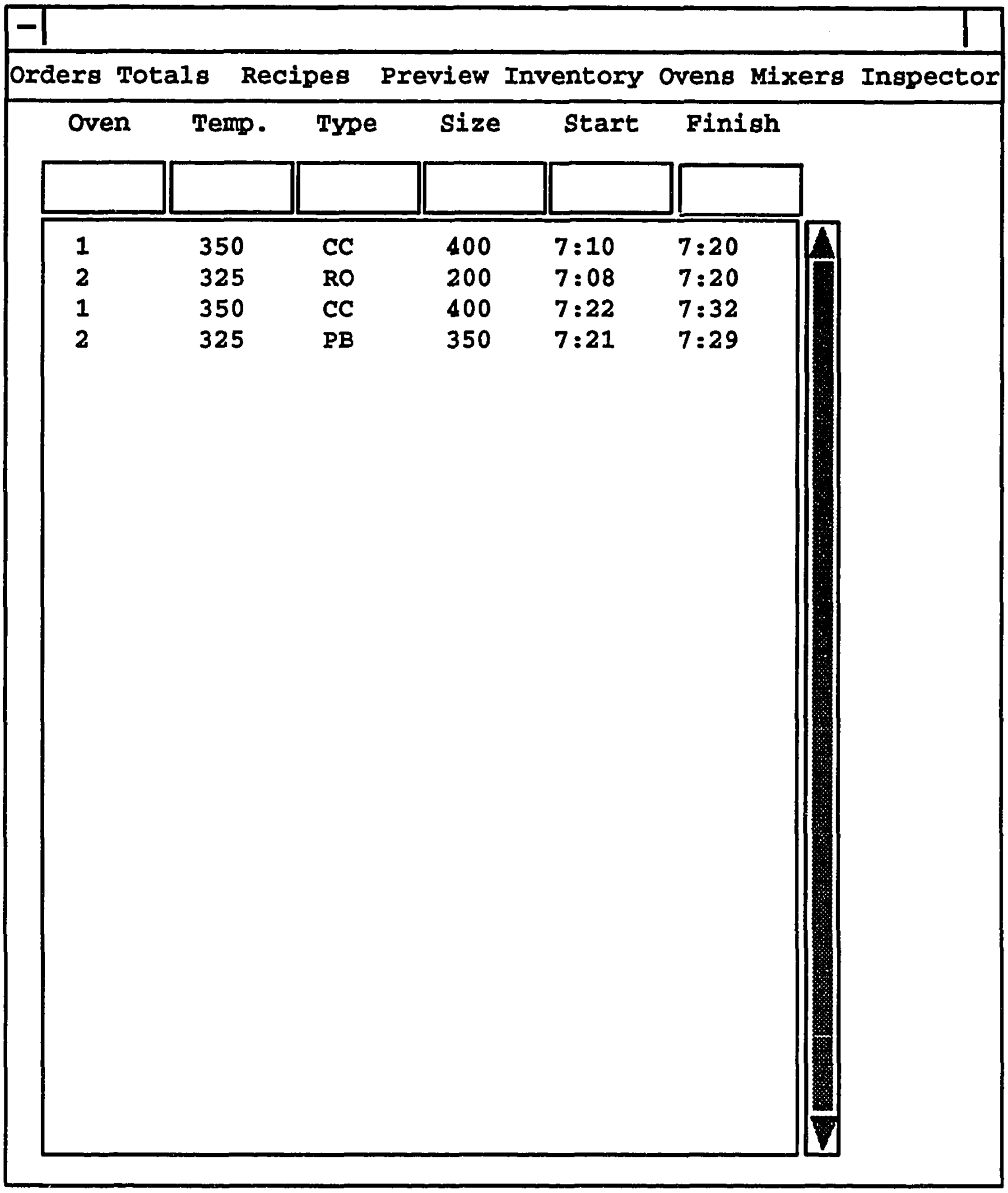

Figure 4. An example of the Alphanumeric Interface.

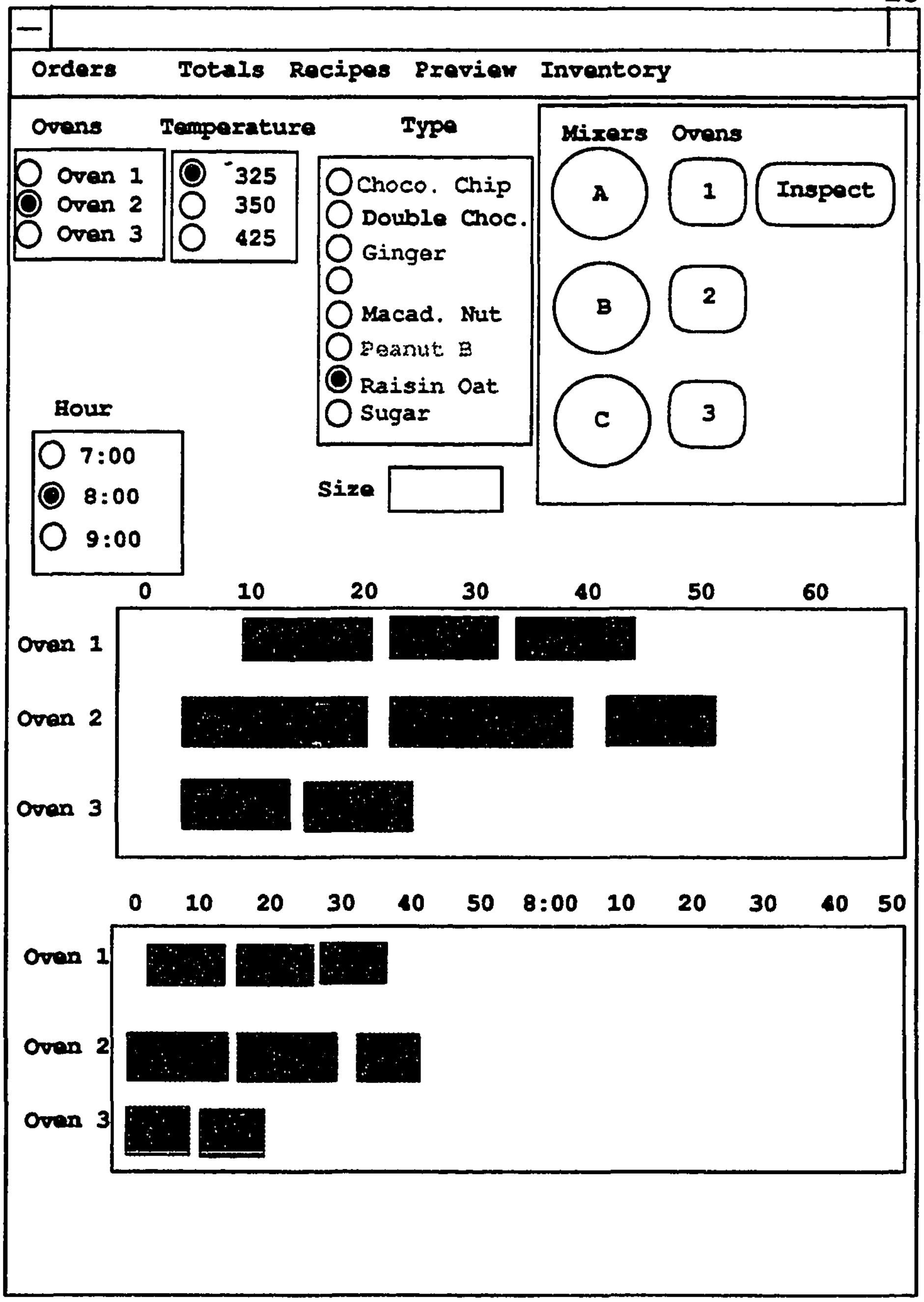

Figure 5. An example of the Direct Manipulation Graphic Interface

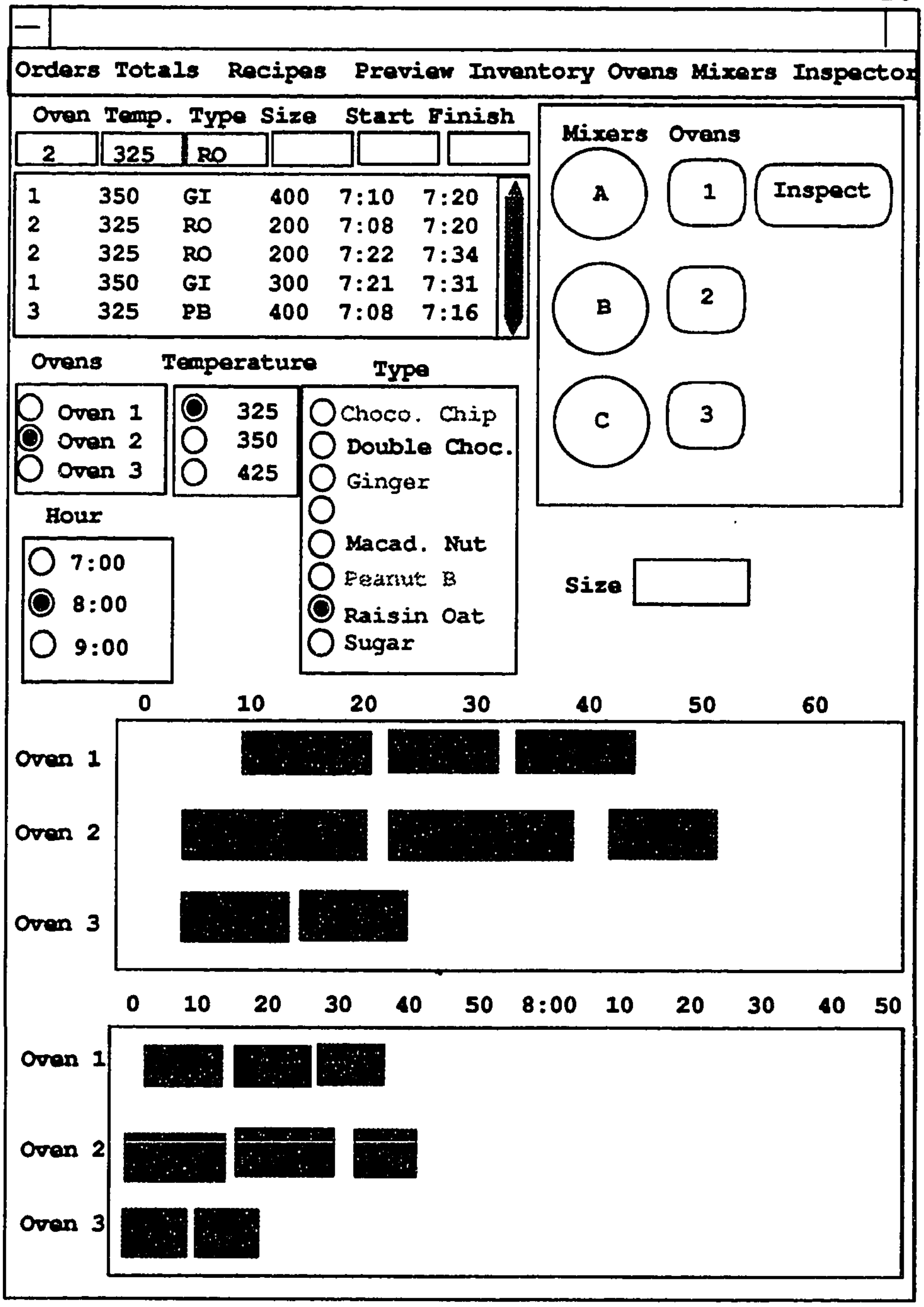

Figure 6. An example of the Equivalent Interface.

and decided the start and finish times of each batch. To perform the task, participants monitored mixing machines so that they knew which batch types were being mixed at what times and monitored inventory to determine the amount of cookie dough supply available from the mixing machines. In addition, participants had to monitor current time, inspector, and ovens and mixers for equipment failures.

Participants were given three production goals. They had to fill each order on time, maximize time of oven use, and minimize waste or ingredient use.

Participants created schedules by entering into the computer the oven in which to bake a batch, temperature, type of cookie, number of cookies in a batch, and start time and finish time of the batch.

Procedure.

Participants were treated in accord with the ethical guidelines of the APA. The experimenter read the instructions to participants, as participants read along, and demonstrated the use of the display. Instructions are reproduced in Appendix B. Participants were shown where and how to access information from the display and how to enter information into the system. Then, participants performed a 15-minute practice task to familiarize themselves with the display followed by the experimental task. During the practice task, participants received error messages when they made errors. Participants did not receive error messages during the experimental task because error messages could have masked data that revealed information the subject found helpful for error discovery and error recovery. If participants made three of the same type of error during the 15-minute practice task, they were excused from further participation in the study. Two participants were excused from the study at this point.

After the task, participants responded to several Likert scales and were debriefed. During the experimental task, 70 decibels of white noise was played to mask extraneous sounds.

Scheduling task.

The scheduling task was dynamic; order changes, inventory shortages, and equipment failures occurred. Two order changes occurred. The first order change occurred 20 minutes into the task and required fewer lemon cookies to be baked. The second change occurred 35 minutes into the task and required more peanut butter cookies to be baked.

Ten minutes into the task a mixer failed. The mixer failure resulted in a shortage of chocolate chip cookie dough for a ten minute time period. The mixer became operational 20 minutes into the task.

There was a .45 probability that oven 3 would fail. However, oven 3 never failed. None of the ovens failed.

Messages from the inspector told the participants the functionality of a line. Very few production facilities have production lines in which 100% of the products produced pass inspection. Schedulers rely on quality control or inspectors to know the functionality of a line. During the first 15 minutes of the task, the inspector displayed a message stating that there was a 15% probability that a batch will be rejected in oven 1. Between 15 minutes and 30 minutes, the message stated the there was a 25% chance that a batch will be rejected from oven 3. After 30 minutes, the message stated that there was a 5% probability that a batch will be rejected from oven 2. However, a batch was never rejected. These messages varied so that participants were motivated to monitor the inspection messages. The influence of the messages on scheduling behavior could therefore be measured. If the inspector message had remained static it would have been difficult to know whether a participant remembered the information or was not monitoring the information.

Inventory changed every 10 minutes throughout the task as the mixers mixed dough. Therefore, all the dough was not available as schedulers needed it. The task was designed this way to add realism to the task and to test the use of the predictive display. For example, chocolate chip, raisin oatmeal, and peanut butter dough was available at the start of the task. Sugar and macadamia nut became available at 8:40 am. Therefore, participants had to use the predictive display to determine when inventory became available for these cookies. The lemon became available during the first hour of the task, therefore it was available in real time for the 60 minute, 75 minute and 90 minute conditions. Double chocolate became available after 8:00, therefore participants in the 60 minute condition were required to use the predictive display, but 75 minute and 90 minute subjects did not need to use the preview. Ginger became available after 8:15, therefore both the 60 minute and 75 minute conditions required the use of the predictive display in order to schedule these cookies.

Information Display.

Participants were provided the essential information needed to schedule (see Appendix A). All the display types provided order information, recipe information, discrepancy information, the current time, and inventory information by selecting items from the menu bar. In the alphanumeric and equivalent displays, (see Figure 7) information about the mixers, ovens, and inspector were also available by selecting an item from the menu bar. In the graphic and equivalent display, (see Figures 2 & 8) equipment and inspector information was available by clicking on a command button that represented the piece of equipment or the inspector.

In all the displays the predictive or preview information was accessed from the menu bar. The participant entered the time to which they wanted to preview and could access information about the future state of the system from the preview menu (see Appendix A).

To schedule batches, participants with the alphanumeric display typed information into text boxes. Participants with the graphic displays selected the oven, temperature, and

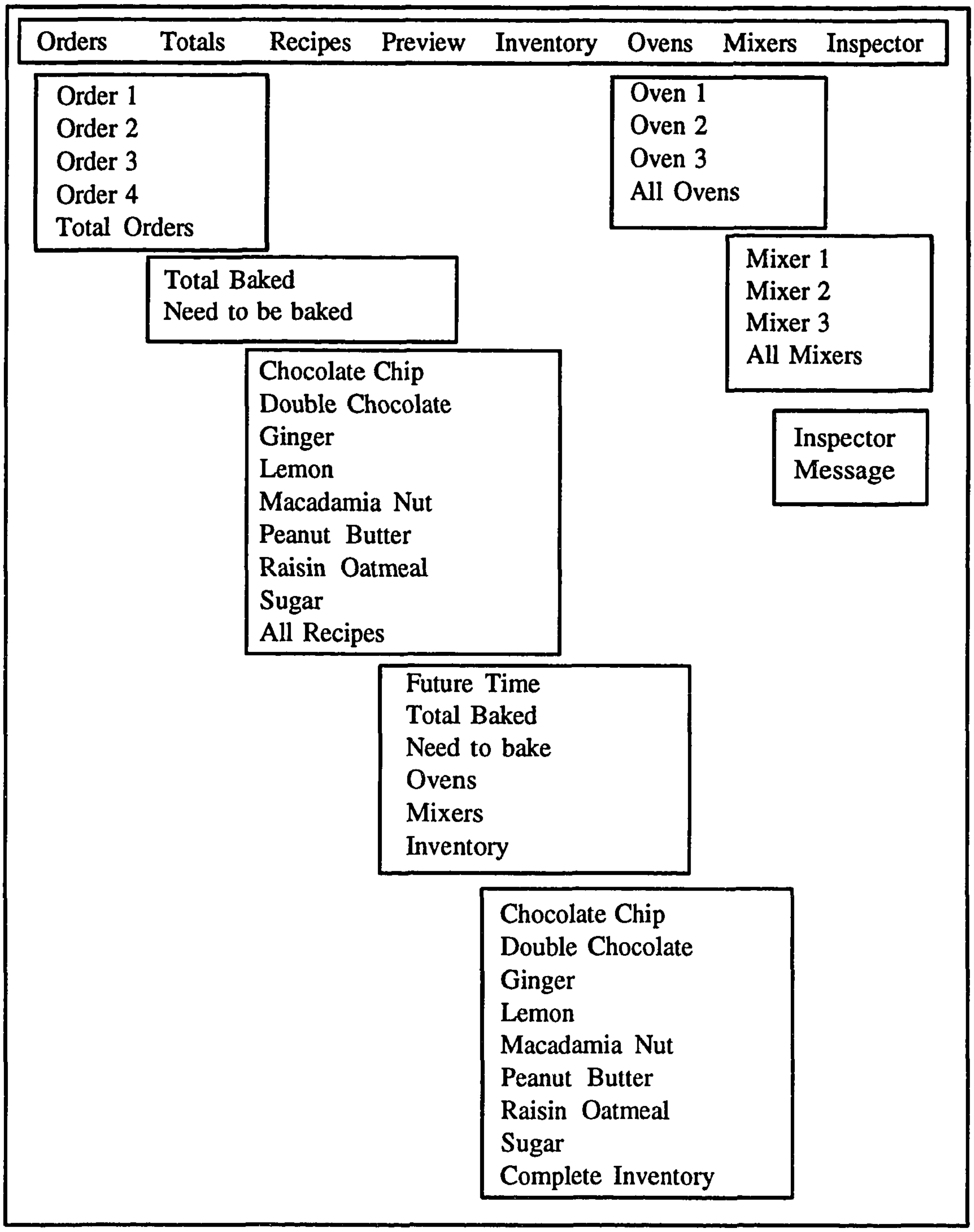

Figure 7. The Menu Structure of the Alphanumeric and Equivalent Interfaces.

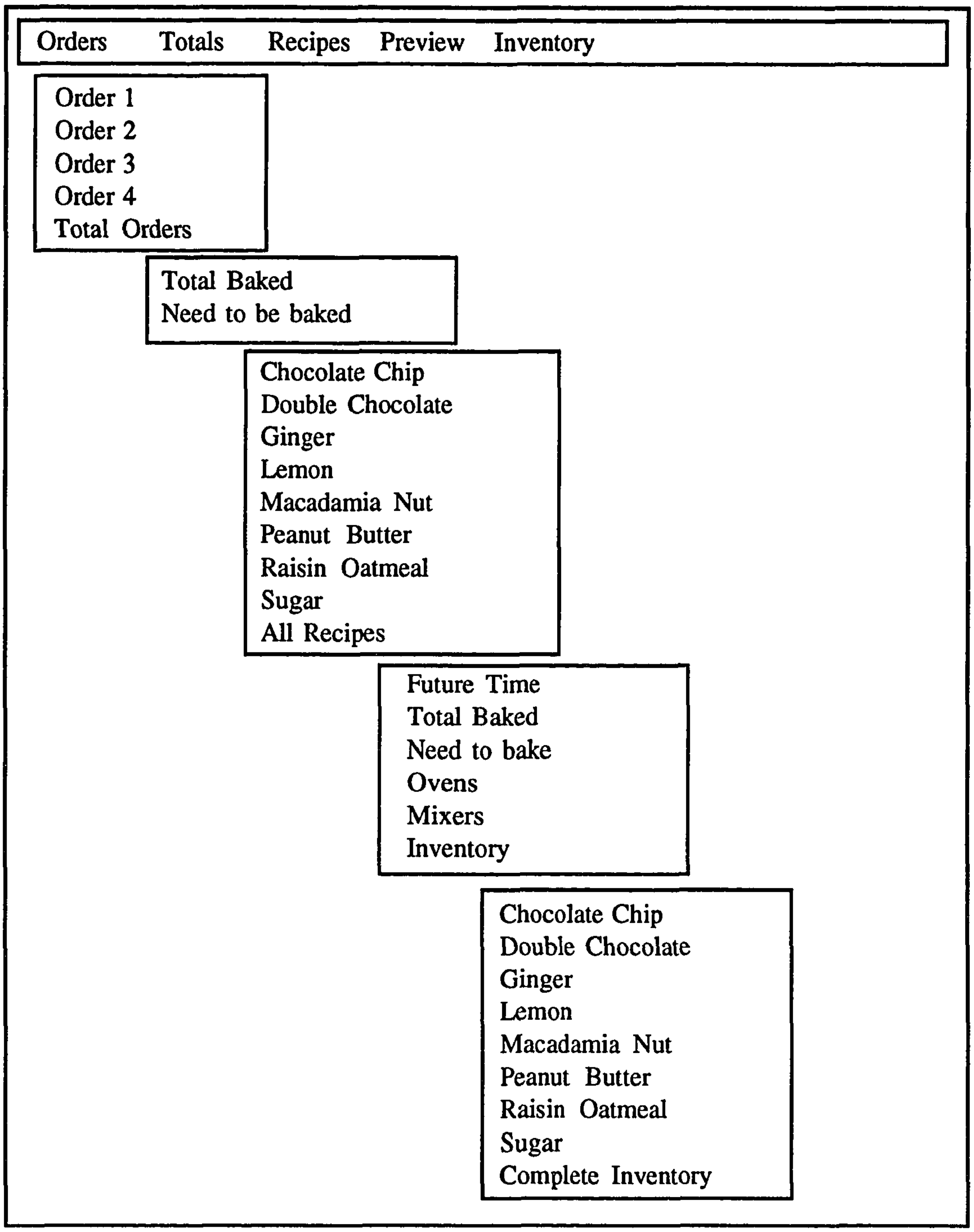

Figure 8. The Menu Structure of the Direct Manipulation Graphic Interface.

cookie type by clicking on a radio button. They entered size into a text box and with the mouse drew the start and finish times into a Gantt chart. Participants in the equivalent display could input information with methods available to both the alphanumeric and graphic displays.

Control variables.

It was assumed that all participants had the same experience and training level with the scheduling task. Participants were not trained except for the instructions and practice trial. The feedback participants received from the program was always in alphanumeric form for all conditions. Participants were not asked to provide justification for their actions. All participants received the same instructions except for instruction in interacting with the display.

Dependent measures.

Performance measures. Performance measures were type of information accessed, frequency of information accessed, time of information accessed, responses, time of responses, number of errors, type of errors, time required to fill orders, number of cookies baked, time of oven use, and amount of inventory. The above measures were collected sequentially by the computer program as a subject scheduled.

The quality of the schedule produced was measured according to the three production goals: filling the orders on time, maximizing oven use, and minimizing inventory. Number of errors was also measured. Oven use was measured as the time ovens were in use on a scale of 0 minutes - x minutes. The times computed were adjusted for the number of cookies that were overbaked. The greater the time the better the schedule.

Orders filled was measured as the number of cookies baked. Schedules that filled orders while accounting for batches rejected were considered better than those schedules that baked excess cookies or failed to fill orders. Number of cookies baked was measured on a deviation scale from -y to +y, with 0 indicating that the correct number of cookies was baked. Therefore, -y indicates a shortage of cookies and +y indicates extra cookies. Schedules with scores close to 0 indicated better schedules. Amount of inventory used is directly related to number of cookies baked. That is, those participants who baked extra cookies wasted inventory. Thus, amount of inventory used did not need to be measured directly.

Subjective measures. Subjective measures included Likert scales measuring the confidence participants had in their schedules, concentration required, difficulty of the task, confidence in the information provided by the display, trust in computers, and frustration experienced. Also open-ended questions about scheduling strategies, like or dislike about the display, information that they would have found helpful, information they did not find helpful, and how the probability information influenced their strategies were asked while participants were debriefed (see Appendix C).

RESULTS

General task analysis.

Information accessed by participants.

The information provided during the task was categorized into groups according to current state, future state, goal state, and discrepancy information. The categorization and frequency counts for each type of information is shown in Table 2. The ranges were determined based on the frequency distributions of the items and were determined to provide expected cell counts of 5 in each category.

Order, recipe, and inventory information were the most frequently accessed pieces of information for current and future states. Inventory was frequently accessed because it changed often and was not available for all types of cookies during the entire task. Therefore, different types of cookies had to be baked at different times. Inventory for some of the cookie types was available only by accessing inventory preview or mixer preview. For example, participants in the 90 minute condition needed to use future state information to determine inventory for sugar and macadamia nut cookies. Participants in the 75 minute condition had to use future state information to determine inventory for sugar, macadamia nut, and ginger cookies. Participants in the 60 minute condition needed

TABLE 2
Information categories and frequency counts.

Information	Range	Frequency	Percent	Mode
Current system state				
Total cookies baked	0-20	115	63.89	0
	21-42	47	26.11	
	43-87	18	10.00	
Current time	0-5	154	85.56	0
	6-23	26	14.44	
Mixer Information	0-20	143	79.44	0
Contents and status	21-43	25	13.89	
of mixer	44-88	12	6.67	
Oven Information	0-14	152	84.44	0
Probability of failure	15-30	25	13.89	
and temperature	31-47	3	1.67	
Inventory	0-58	74	41.11	28
	59-118	61	33.89	
	119-179	34	18.89	
	> 179	11	6.11	
Inspector - Probability	0-10	171	95.00	0
batch would be rejected	11-33	9	5.00	
Goal State				
Orders	0-32	51	28.33	
	33-65	79	43.89	42
	66-98	29	16.11	
	> 99	21	11.67	
Discrepancy information				
Need to bake - # of	0-15	153	85.00	0
cookies remaining	16-32	22	12.00	
to be baked	33-50	5	3.00	
Future Need to bake	0-24	142	78.90	0
	25-49	32	17.80	
	50-16	6	3.33	

(Table 2 cont.)

Future State				
Future time	0-23	134	74.44	1
	24-48	34	18.89	
	49-99	12	6.67	
Total cookies baked by future time	0-13	158	87.80	0
	14-45	22	12.22	
Future Need to bake	0-24	142	78.90	0
	25-49	32	17.80	
	50-100	6	3.33	
Contents of mixer	0-6	167	92.78	0
	7-16	13	7.22	
Future oven temperature	0-4	173	96.00	0
	5-13	7	4.00	
Future inventory	0-24	133	73.89	0
	25-49	35	19.44	
	50-100	12	6.67	
Static Information				
Recipes	8-33	69	38.30	28
	34-60	75	41.70	
	61-87	32	17.80	
	88-115	4	2.20	

future state information to determine available inventory for sugar, macadamia nut, ginger, and double chocolate. Current state information could be used in all displays to determine inventory for chocolate chip, raisin oatmeal, peanut butter, and lemon cookies.

In order to fill the orders, participants in the 60 minute condition needed to be more adept with using the preview display than participants in the 90 minute condition. Ninety minute participants could schedule in real time until the last 30 minutes of the task when they needed the preview display to finish scheduling. However, this strategy would not have worked with the 60 minute participants because they needed to rely on the future state information to schedule.

A comparison of the number of cookies baked across time conditions revealed that participants did not effectively use the future state information. Table 3 shows the number of participants who were able to schedule to cookies to bake. A negative number indicates that cookies were not scheduled. A positive number indicates the number of cookies that were overbaked. Table 3 shows that 111 participants did not schedule sugar cookies to bake and 103 participants did not schedule macadamia nut cookies to bake. Table 3 also shows that most participants did not schedule ginger cookies, particularly the 60 minute condition in which 43 participants did not schedule ginger to bake. Ginger became available during the last 15 minutes of the 90 minute task. Therefore,

TABLE 3

Frequency counts of the number of sugar, macadamia nut, ginger, and double chocolate cookies baked by time condition.

Sugar

Range	60 min	75 min	90 min	**Totals**
-300 to -140	40	35	36	**111**
-139 to 0	6	6	4	**16**
1 to 300	14	19	20	**53**

Macadamia Nut

Range	60 min	75 min	90 min	**Totals**
-255 to -98	37	31	35	**103**
-97 to 60	21	23	22	**66**
61 to 375	2	6	3	**11**

Ginger

Range	60 min	75 min	90 min	**Totals**
-350 to -88	43	24	12	**79**
-87 to 174	15	29	28	**72**
175 to 500	2	2	3	**7**

Double Chocolate

Range	60 min	75 min	90 min	**Totals**
-1750 to -88	33	24	12	**69**
-87 to 174	20	26	37	**83**
175 to 500	7	10	11	**28**

participants in the 90 minute condition did not have to use the future inventory information to schedule, however, they did have to allow enough time to schedule. It appears that 50% of the participants in the 90 minute condition did not have enough time to schedule and bake ginger cookies thus, these participants adapted the strategy of scheduling in real time rather than ahead of time.

Participants in the 75 and 60 minute conditions had to use the future inventory information to schedule ginger cookies. Approximately 50% of participants in the 75 minute group and 72% of participants in the 60 minute group were able to schedule ginger cookies thus, showing that these participants used the future inventory information more than the 90 minute group. However, the 60 minute group effectively used the preview to schedule ginger cookies but not to schedule double chocolate cookies. The order for ginger cookies was much smaller than the order for double chocolate. It is likely that 60 minute participants ran out of time before they could schedule the double chocolate cookies. To summarize, approximately, 50% of participants in the 75 and 90 minute conditions effectively used the future information. They had more time to figure out an appropriate strategy to use the preview than those in the 60 minute condition.

Inspector information was infrequently accessed by participants. A possible explanation for this finding is that inspector information was provided as probability information, not as specific information. That is, participants were given the probability that a batch would be rejected, not the exact number of cookies rejected. If the information had been specific such as, "2000 cookies have been rejected" rather than "15% chance that cookies will be rejected", participants may have used this information. Probability information may not have meaning for university students. Or, participants may not have known how to incorporate this information into their schedules. Participants could have adapted the strategy of waiting for cookies to be rejected before taking action rather than planning on the cookies to be rejected and compensating ahead of time. It is also possible that participants were too busy scheduling to check this information.

Information provided from the menu bar was either specific or global. Specific menu items displayed specific pieces of information. Global menu items displayed grouped information. For example, the menu item for orders included an item for each individual order and an item that showed all four orders combined (see Figure 7). Menus for recipes, inventory, and equipment included specific and global items (see Figure 7). Table 4 shows the frequency that each of these menu items was accessed. Participants accessed global information for inventory, order, and equipment information more frequently than the specific information. They accessed the specific recipe information more than the global recipe

TABLE 4

Chi-Square analysis of global and specific menu items for orders, inventory, ovens, mixers, and recipes.

Order menu items, $X^2(4, N = 830) = 180.029$, $p<.01$

	0 accesses	>0 accesses
Order 1	42	124
Order 2	93	73
Order 3	112	54
Order 4	53	113
All Orders	7	159

Inventory menu items, $X^2(8, N=1495) = 135.896$, $p<.01$

	0 accesses	>0 accesses
All cookie types	6	160
Chocolate Chip	31	136
Double Chocolate	45	121
Ginger	73	93
Lemon	72	94
Macadamia Nut	89	77
Peanut Butter	59	107
Raisin Oatmeal	47	119
Sugar	55	111

Oven menu items, $X^2(3, N=664) = 47.89$, $p<.01$

	0 accesses	>0 accesses
Oven 1	136	30
Oven 2	138	28
Oven 3	137	29
All ovens	93	73

Mixer menu items, $X^2(3, N = 664) = 75.319$, $p<.01$

	0 accesses	>0 accesses
Mixer 1	126	40
Mixer 2	139	27
Mixer 3	143	23
All mixers	81	85

(Table 4 cont.)

Recipe menu items, $X^2(8, N=1494) = 209.055, p<.01$

	0 accesses	>0 accesses
All Recipes	58	108
Chocolate Chip	16	150
Double Chocolate	18	148
Ginger	40	126
Lemon	15	151
Macadamia Nut	74	92
Peanut Butter	9	157
Raisin Oatmeal	10	156
Sugar	71	95

information. Inventory and order information is used to make planning decisions and changes as the state of the factory changes, whereas recipe information is static and applies to specific types of cookies. Global information may be more useful when system states are dynamic and participants need to compare components to make scheduling decisions.

<u>Errors made by participants.</u>

Type of errors made by schedulers included incorrect bake time, incorrect temperature, not enough inventory or no inventory available to bake cookies, filling ovens beyond oven capacity, specifying cookies to begin baking when the bake time was in the past, and putting different types of cookies in the same oven simultaneously. Table 5 summarizes the errors with range, mode, and frequencies of each error. The modal values of the errors indicate participants made few errors. Incorrect bake time and incorrect temperature were the most frequently made errors. Participants scheduled approximately 20 batches to bake during the entire experimental task. Thus, errors greater than 20 suggest that participants made an error in almost every batch they scheduled. Approximately 20% of the participants made incorrect temperature and incorrect bake time errors.

<u>Interaction with the displays.</u>

To assess whether text box input or mouse input was used more frequently, interaction with the equivalent display was examined. The equivalent display (see Figure 6) included both

TABLE 5

Error Frequencies.

Error Type	Mode	Range	Frequency	(Percent)
Incorrect Bake time	2	0	8	(4.40)
		1-16	141	(78.40)
		17-48	31	(17.22)
Incorrect Temperature	0	0	43	(23.90)
		1-6	98	(54.43)
		7-21	39	(21.67)
Inadequate Inventory	0	0	30	(16.7)
		1-16	141	(78.33)
		17-35	9	(5.00)
No inventory available	0	0	102	(56.70)
		1-19	76	(42.22)
		20-30	2	(1.00)
Ovens filled beyond	0	0	137	(76.10)
capacity		1-9	41	(22.77)
		10-30	2	(1.00)
Start time in past	0	0	49	(27.20)
		1-11	123	(68.33)
		12-24	5	(2.78)
		25-38	3	(1.67)
Different types of	1	0	32	(17.80)
cookies in oven simultaneously		1-12	142	(78.88)
		13-20	6	(3.33)

methods of interaction therefore, participants using this display could choose the mode of interaction. To input bake times participants could use either the text boxes or draw in the times on a Gantt chart. Table 6 shows that most of the participants used the text boxes to enter the bake times. One subject entered bake times exclusively with the Gantt chart.

Participants in the equivalent display condition also had a choice to use either radio button input or text box input to specify in which oven a batch would bake, the temperature of the batch, and the type of cookie. Figure 6 shows the three radio buttons specifying each of the three ovens, three temperature buttons for each of the temperatures and eight radio buttons for each of the cookie types. To enter cookie type in a text box, participants had to enter a 2 letter code for each cookie type. However, with radio buttons, using the codes to enter cookie type was not necessary. Table 7 includes the contingency tables comparing text box input and radio button input for participants in the equivalent display condition. The oven input table shows that subjects used the radio buttons exclusively to choose in which oven a batch would bake. Analysis of the column and row totals of temperature input show that within the range of 25 - 39 interactions, 24% of the participants chose the text boxes while 67% chose radio buttons. Participants more frequently interacted with the radio buttons than with the text boxes.

TABLE 6

Frequencies for text box and Gantt chart input in equivalent display.

Input Field	Range	Frequency
Start time text box	17-28	23
	29-55	37
Finish time text box	17-31	30
	32-65	30
Gantt chart	4-22	59
	23-39	1

TABLE 7

Three contingency tables comparing input mode for oven, temperature and cookie type.

Oven Input

Text Box Ranges	Radio button input Ranges: 18-30	31-44	45-57
0	22	25	7
>0	1	0	0

Temperature Input

Text Box Ranges	Radio button input Ranges: 10-24	25-39	40-53	**Totals**
0-12	3	23	7	**33**
13-24	3	5	1	**9**
25 - 39	1	9	3	**13**
Totals	**7**	**37**	**11**	

Cookie Type Input

Text Box Ranges	Radio button input Ranges: 15-27	28-40	41-53	**Totals**
0-13	5	23	5	**33**
14-27	6	4	0	**10**
28-40	3	6	3	**12**
Totals	**14**	**33**	**8**	

This same result can be found by examining the contingency table for cookie type input. In the range of 28-40 cookie type interactions, 22% of the participants chose text boxes, and 60% chose radio buttons. Radio buttons were used more than the text boxes. The consistency across the tables suggests that those few participants that chose text boxes to input information always used the text boxes. While, the remaining participants mixed input modes, using the mouse to select from radio buttons and the keyboard to enter bake times.

Interview information collected during debriefing of the participants suggests that those individuals in the alphanumeric display condition did not know that they had a third oven. Thus, they did not schedule in the oven. Both the equivalent and graphic displays included a physical representation of the factory. This can be seen by comparing Figures 4, 5, and 6. It was immediately perceptible to these participants that they had three ovens in which to bake. This information was hidden in a menu from the alphanumeric participants. Analysis of the number of times the oven menu was accessed shows that more than 60% of the participants in the alphanumeric condition never accessed the oven information. The frequencies are shown in Table 8. Participants in the equivalent display had both menu items and push buttons representing the physical layout of the factory. Analysis of the oven menu items and oven push buttons in the

TABLE 8

Frequency counts for number of times oven menu information was accessed by alphanumeric participants.

	Menu item for oven 1	
Accesses	Frequency	Percent
0	36	64.3
1	16	28.3
2	2	3.6
4	1	1.8
6	1	1.8

	Menu item for oven 2	
Accesses	Frequency	Percent
0	35	62.5
1	12	21.4
2	5	8.9
3	3	5.4
5	1	1.8

	Menu item for oven 3	
Accesses	Frequency	Percent
0	37	66.1
1	13	23.2
2	3	5.4
3	1	1.8
4	2	3.6

equivalent display, shown in Table 9, suggest that push buttons resulted in more frequent access of equipment information. Eighty-two percent of the participants in the equivalent display never accessed the menu items for oven information. Whereas, 40% of the participants never accessed the push button for oven information. Approximately 33% of the participants in the equivalent display never accessed oven information, whereas 60% of the participants in the alphanumeric display never accessed oven information.

Conclusions of general task analysis.

Inventory information was frequently accessed by participants but not effectively used by all participants. Many participants inappropriately used current inventory information to scheduled batches into the future. These data suggest that concrete, grouped information is more helpful when scheduling in a dynamic system.

Participants scheduling with the equivalent display were given a choice to use mouse and/or keyboard input. Participants generally chose the means that resulted in the fewest number of errors. They used the keyboard to enter quantities and bake times, and the mouse to select items from a list.

Hypotheses.

The research hypotheses were: (1) Participants scheduling with the equivalent interface would create the best schedules. (2) Goal state, current state, future state, and discrepancy

TABLE 9

Contingency tables for oven push buttons and oven menu items for equivalent display.

Push Button for Oven 1

Menu Item	0	1-6	7-21	**Total**
0	13 (23.64%)	30 (54.55%)	2 (3.64%)	**45 (81.82%)**
1-4	5 (9.09%)	5 (9.09%)	0	**10 (18.18%)**
Total	**18 (32.73%)**	**35 (63.64%)**	**2 (3.64%)**	**55**

Push Button for Oven 2

Menu Item	0	1-8	**Total**
0	18 (32.73%)	30 (54.55%)	**48 (87.27%)**
1-6	4 (7.27%)	3 (5.45%)	**7 (12.73%)**
Total	**22 (40.00%)**	**33 (60.00%)**	**55**

Push Button for Oven 3

Menu Item	0	1-6	**Total**
0	18 (32.73%)	27 (49.09%)	**45 (81.82%)**
1-4	4 (7.27%)	6 (10.91%)	**10 (18.18%)**
Total	**22 (40.00%)**	**33 (60.00%)**	**55**

information would be the most useful information. (3) Graphic and equivalent interfaces would support scheduling best under a time pressure. The above hypotheses were tested with loglinear analysis. Loglinear analysis is a technique that allows construction of n-dimensional contingency tables. Loglinear analysis tests various models, similar to ANOVA models, to find the model that best represents the data. However, rather than differences among cell means, the expected cell frequencies are compared to the observed cell frequencies to find the best fitting model. Statistically significant Chi-squares for terms in the model and a nonsignificant likelihood ratio are the criteria of "goodness of fit" of a model.

Hypothesis I.

To test the hypothesis that the best schedules would be created with an equivalent display, schedule quality was measured according to three criteria, number of errors made, number of cookies baked, and length of time ovens were in use.

Loglinear analysis, $X^2(14, \underline{N} = 180) = 24.56$, revealed that participants in the graphic condition made more bake time errors than participants in the other display conditions (see Table 10). With the direct manipulation graphic display, participants had to draw in the bake times with a mouse on a Gantt chart. This is a more difficult motor task than keying in the bake times from the keyboard. The difficulty of

TABLE 10

Loglinear analysis of bake time error by display with contingency table.

Source	df	Chi-Square
Bake time Error	1	64.72*
Bake time Error * Display	2	26.22*
Likelihood Ratio	14	24.56

Bake time Errors	Alphanumeric	Graphic	Equivalent
0-16	57	33	59
17-48	3	27	1

* indicates signifance at alpha .05.

interacting with the mouse explains the increase in errors.

Loglinear analysis revealed that participants scheduling with the alphanumeric display made more incorrect temperature errors than participants in the graphic display. Alphanumeric and graphic displays are illustrated in Figures 4 and 5. The loglinear analysis, shown in Table 11, suggests participants using the graphic display had to access recipe information more frequently from the menu than participants in the alphanumeric display. With the graphic display, temperatures were chosen by selecting a radio button from a list of available temperatures. Once the batch was scheduled the button would clear for input for the next batch. With the alphanumeric display, temperatures were keyed in, then added to a list of previous batches. Thus, once participants keyed in a temperature, they scanned the list for the temperature the next time they needed to schedule a batch of the same cookie type. Consequently, once they entered the temperature incorrectly, they repeated this error in later batches. Participants in the graphic display had to repeatedly access the recipe information from the menu in order to determine the correct temperature for a batch of cookies. According to the criteria of number of errors made, the equivalent display is the best display because it resulted in the fewest number of errors made.

Analysis of order completion or the number of cookies baked showed few differences among the displays. Table 12

TABLE 11

Loglinear analysis of incorrect temperature errors, recipe information, and display with error by recipe information and recipe information by display contingency tables.

Source	df	Chi-Square
Recipe	2	12.32*
Temperature Error	1	41.88*
Recipe * Temp	2	13.24*
Display * Recipe	4	21.24*
Likelihood Ratio	8	12.56

	Recipe Information		
Temperature Error	8-33	34-60	61 and greater
0-6	44	64	33
7-21	25	11	3

	Recipe Information		
Display	8-33	34-60	61 and greater
Alphanumeric	30	24	6
Graphic	9	32	19
Equivalent	30	19	11

* indicates significance at alpha .05.

TABLE 12

Mode number of cookies baked and range of cookies baked by display.

Cookies Ordered		Alphanumeric Mode (Range)	Equivalent Mode (Range)	Graphic Mode (Range)
Choco.Chip	2500	0 (-1200, 1900)	0 (-1600, 2000)	0 (-2000, 2500)
Dbl Choco.	1750	0 (-1750, 1050)	0 (-1750, 2000)	-1750 & 0 (-1750, 1000)
Ginger	350	-350 (-350, 700)	-350 (-350, 250)	-350 (-350, 200)
Lemon	150	0 (-150, 300)	0 (-150, 300)	0 (-150, 300)
Macad. Nut	225	-225 (-225, 225)	0 (-225, 275)	-225 (-225, 375)
Peanut Bt.	1700	0 (-1300, 3500)	0 (-1200, 1800)	0 (-1300, 1900)
Raisin Oat	1150	0 (-750, 2100)	50 (-550, 2400)	0 (-750, 1750)
Sugar	300	-300 (-300, 250)	-300 (-300, 300)	-300 (-300, 300)

shows the mode number of cookies baked for each cookie type and display. A mode of zero indicates that participants baked enough cookies to complete the orders. Positive values indicate overfilling an order. Negative values indicate an incomplete order.

Participants in the equivalent and alphanumeric conditions over-baked chocolate chip cookies and raisin oatmeal compared to the graphic condition. Chocolate chip and raisin oatmeal cookies were the "easiest" to schedule, because inventory was available when the task began and was steadily supplied until baking was completed. Furthermore, chocolate chip inventory was replenished every 10 minutes, except for a 10 minute mixer breakdown, and chocolate chip required a 10 minute baking time, therefore no timing adjustments needed to be made to bake chocolate chip cookies. It appears that participants in the alphanumeric and equivalent conditions baked inventory as it was provided rather than using only the inventory necessary to fill the orders. According to the criteria of number of cookies baked, it appears that there is not much difference among the display types. Those using the graphic display did not over bake as many cookies as those using an alphanumeric or equivalent display, therefore they did not use more inventory than necessary. This display may result in more efficient use of supplies.

Analysis of variance of the baking times of the three ovens shows participants using the alphanumeric display used oven 1 significantly more than participants in the graphic display. Participants in the alphanumeric and equivalent display conditions used oven 2 significantly more than the graphic condition. However, participants in the graphic and equivalent displays used oven 3 more than the alphanumeric display. The source of variation tables are shown in Table 13. The means and standard deviations for minutes of oven use are shown in Table 14.

Overall, equivalent and alphanumeric participants used the ovens for the longest amount of time. According to the criteria of maximizing oven time in use, these displays resulted in better schedules than the graphic display. The best display for scheduling varies according to the criteria used to define a best schedule. To reduce errors and increase ease of use, the equivalent display appears to be the best display. To reduce inventory waste and have efficient use of equipment, the graphic display appears to be the best display. There is not a difference in displays for satisfying the criteria of completing orders.

Hypothesis II.

It was hypothesized that information that depicts the current system state, the goal state, and the discrepancy between the current and goal states should be useful. It was also hypothesized that future state information would be useful for error avoidance. Analysis of the total number of cookies baked (see Table 12) suggested that some participants

TABLE 13

Analysis of variance for time ovens were in use by display.

* statistically significant at Bonferroni alpha = .0125

Oven 1

Source	df	MS	F	eta
Display	2	5185.17	7.30*	.077
Time	2	88.94	.13	
Display * Time	4	378.21	.53	
Error	171	709.85		

Oven 2

Source	df	MS	F	eta
Display	2	7617.27	12.46*	.1259
Time	2	446.29	.73	
Display * Time	4	77.79	.13	
Error	171	611.08		

Oven 3

Source	df	MS	F	eta
Display	2	5633.82	5.08*	.0525
Time	2	6326.02	5.71*	.0589
Display * Time	4	266.33	.24	
Error	171	1108.18		

TABLE 14

Means and standard deviations for minutes of oven use by display.

	Alphanumeric Mean (sd)	Equivalent Mean (sd)	Graphic Mean (sd)
Oven 1	107.45 (28.98)	95.68 (20.56)	89.10 (28.44)
Oven 2	95.83 (25.88)	91.45 (22.60)	74.50 (25.36)
Oven 3	50.63 (37.93)	69.92 (23.28)	58.60 (27.77)

continued to schedule cookies to bake as inventory was produced rather than baking enough cookies to fill the orders. This suggests that participants accessed inventory information more than total baked information. A loglinear analysis of inventory information and total baked information shows those participants who frequently accessed inventory information infrequently accessed total baked information. The analysis is displayed in Table 15.

Scheduling cookies when there was not enough inventory was a common error made by participants. Yet, inventory information is the most frequently accessed piece of information. It is possible that participants were scheduling ahead of the current time, or in the future, but using current inventory information. A loglinear analysis of current and future inventory information, shown in Table 16, shows that 60% (33.8% + 24.80%) of the participants used current inventory information. These results suggest that participants developed a strategy for scheduling into the future with current inventory information. Or, participants were not able to resolve the discrepancy between current and future inventory states.

Table 2 shows that participants did not frequently access future state information. It is quite possible that the strategy or method participants used to schedule with future information did not require frequent accessing of this information. It is also plausible that participants developed

TABLE 15

Loglinear analysis of inventory and total baked information with contingency table.

Source	df	Chi-Square
Total Baked	2	58.79*
Display * size response	2	7.17*
Inventory * Total Baked	4	28.08*
Likelihood ratio	45	46.05

	Inventory			
Total Baked	0-58	59-119	> 120	**Totals**
0-20	62 (34.0%)	32 (17.8%)	21 (11.6%)	**115 (63.4%)**
21-42	8 (4.40%)	22 (12.2%)	17 (9.40%)	**47 (26.0%)**
43-87	4 (2.20%)	7 (3.80%)	7 (3.80%)	**18 (9.80%)**
Totals	**74 (40.6%)**	**61 (33.8%)**	**45 (24.8%)**	

* indicates significance at alpha .05.

TABLE 16

Loglinear analysis of current and future inventory information and contingency table of current by future inventory information.

Source	df	Chi-Square
Current Inventory	1	4.39*
Future Inventory	2	73.66*
Current * Future	2	30.97*
Likelihood Ratio	12	9.04

Current Inventory	Future Inventory 0-24	25-49	50-100	**Totals**
0-60	37 (20.55%)	27 (15.0%)	10 (5.5%)	**74 (41.05%)**
> 60	96 (53.33%)	8 (4.40%)	2 (1.1%)	**106 (58.88%)**
Totals	**133 (73.88%)**	**35 (19.4%)**	**12 (6.6%)**	

* indicates significance at alpha .05.

a method for scheduling that allowed them to use current inventory information to estimate appropriate times to schedule future batches. The frequency of errors made specifying cookies to bake when there was no inventory suggests that an estimation strategy was faulty.

Hypothesis III.

It was hypothesized that the direct manipulation graphic display would improve performance when scheduling with a time pressure. There were no significant findings among the 60 minute, 75 minute, and 90 minute conditions.

Task analysis of best and worst schedulers.

A fourth purpose of this study was to determine how effective schedulers used the predictive display compared to ineffective schedulers. The nine best schedulers were selected because they completed baking at least seven of the types of cookies. Of the nine best schedulers four of them scheduled with the alphanumeric display, four of them scheduled with the direct manipulation graphic display, and one with the equivalent display. The six worst schedulers were selected because they either over baked orders or failed to complete any orders.

A task analysis examined the pattern of information that the schedulers accessed before making a particular response and examined the pattern of responses. The specific information that the participants accessed and the time of access was analyzed. In addition, the specific response and time of response was analyzed. Thus, the activity of the participants was reproduced on a time line. Figure 9 is a sample of a task analysis time line. Five or 6 minute segments of the scheduling behavior were sampled at the start of the task, at 15-20 minutes, 30-45 minutes, 55-65 minutes, 75-80 minutes, and 85-90 minutes. For the best schedulers, the behavior became consistent at 20 minutes. Thus, the task analysis showed a consistent pattern of responding for the duration of the task. The worst schedulers never created a consistent response pattern. The decision processes of the schedulers were inferred from the results of the task analysis. The information collected during the debriefing of these participants was also used to interpret the task analysis.

The task analyses of the nine best schedulers were compared and contrasted to the six worst schedulers. Figure 10 illustrates the decision model and behavior of the nine best schedulers. No information was accessed before schedulers chose which oven to schedule. Verbal and written reports collected during the debriefing show that the best schedulers chose the oven based on a first available rule. Three of the worst schedulers also chose the oven based on this rule.

After entering the oven, the best schedulers then previewed to the time that the oven would become available and checked projected inventory supply for that time. They then

```
7:11:04 Future  NTB
7:11:24 Future  Mixers
7:11:38 Future Minute of 7:21
7:11:46 Future  Inventory
7:11:59 Future Minute of 7:24
7:12:18 Future Minute of 7:30
7:12:31 Future  Inventory
7:12:59 Current  Complete  Inventory
7:13:32 Future  Ovens
7:13:40 Future  Mixers
7:13:51 Future Minute of 7:25
7:14:00 Future  Inventory
7:14:23 Future Minute of 7:21
7:14:34 Future  Inventory
7:14:53 Current Total Baked
7:15:09 Future Minute of 7:30
7:15:18 Future  Inventory
7:15:30 Chocolate Chip Recipes
7:15:35 Radio Button Oven 2
7:15:36 Radio Button 350
7:15:38 Radio Button Chocolate Chip
7:15:45 Size 400
7:15:54 Draw in baking time from 7:30 - 7:40
```

Figure 9. Sample Task Analysis from Graphic Participant

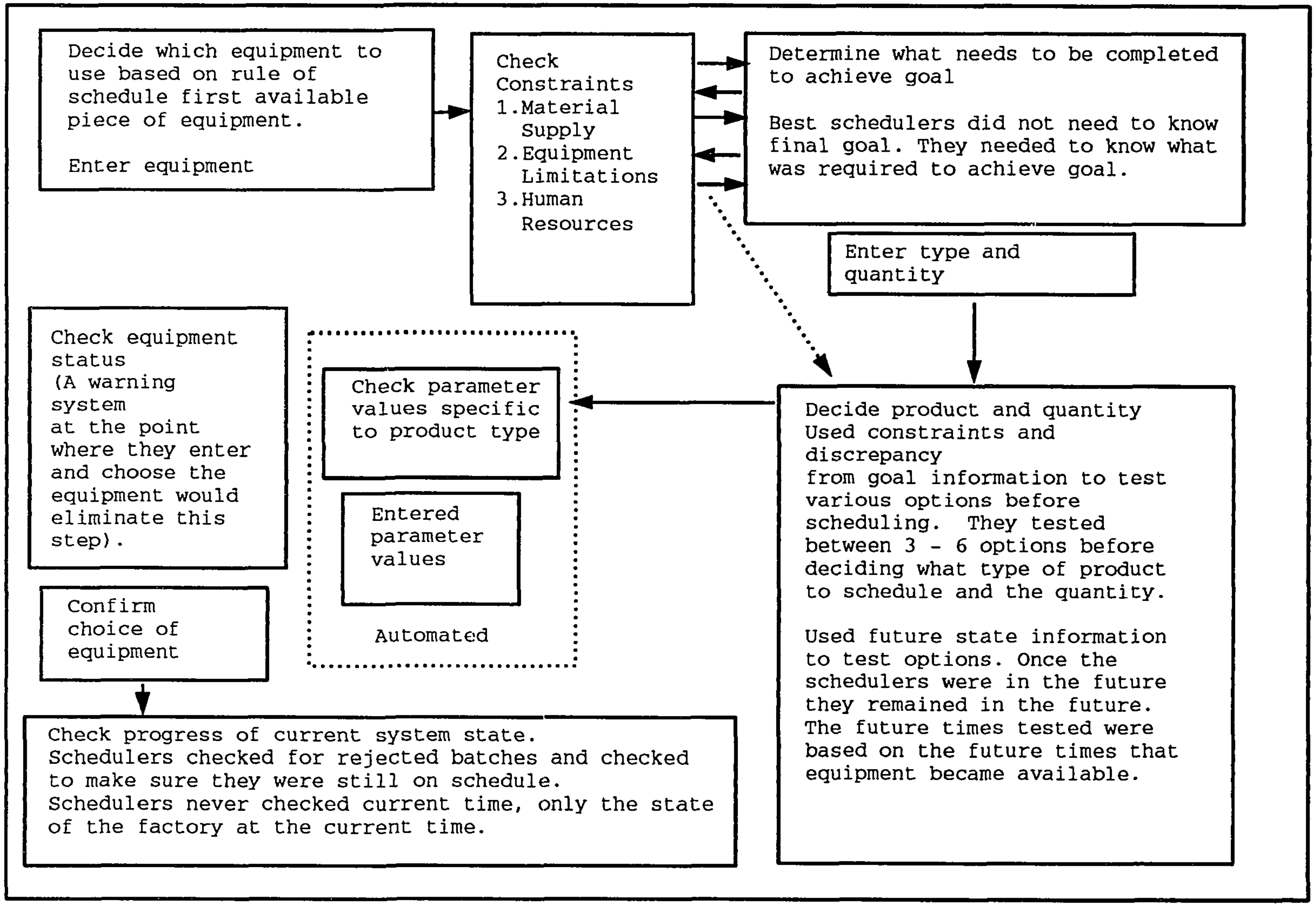

Figure 10. Model of Efficient Schedulers' Behavior.

checked what cookies would need to be baked to complete the orders. The best schedulers would check inventory and need to be baked information for several types of cookies and sometimes for different future times. They previewed the future times each oven would become available. Or, they previewed to a time they thought inventory would become available. Once they found a cookie that was needed to complete an order and had available inventory they would enter the cookie type and the size of the batch. The schedulers then checked the recipe information to enter the temperature and bake time.

The worst schedulers did not frequently check inventory or "need to bake" information. They did not preview to future inventory but scheduled using current inventory information, even if the batch was scheduled into the future. However they did check order information and total baked information. At times they previewed to future total baked information. Unlike the best schedulers, the worst schedulers did not have a consistent pattern of previewing to the future to check total baked and order information against inventory available. They did not use the preview function to test options and determine the best type of cookie to bake. Rather, they baked the inventory that was available, consequently they over baked a number of cookies.

After entering the information for a batch, the best schedulers checked the status of the factory or the progress of previously scheduled orders by checking the inspector or checking current total baked information to determine that cookies were continuing to bake. They also checked the status of the equipment to make sure that it was operational. The worst schedulers never checked the inspector. However, they did occasionally check the status of equipment.

The nine best schedulers performed the task in the same manner and created a consistent strategy 15 or 20 minutes into the task. The worst schedulers did not perform the task in a similar manner and took much longer to create a consistent strategy. Furthermore, the strategies that they created were not optimal.

DISCUSSION

The purposes of the present research were to determine the decision processes, problem-solving strategies, and information humans use to perform the scheduling task. In addition, the present compared alphanumeric, direct manipulation graphic, and equivalent interfaces. The research hypotheses were: (1) Participants scheduling with the equivalent interface would create the best schedules. (2) Goal state, current state, future state, and discrepancy information would be the most useful information for schedulers. (3) Graphic and equivalent interfaces would support scheduling best under a time pressure.

<u>Hypothesis I.</u>

It was hypothesized that participants scheduling with the equivalent interface would create the best schedules. The results of this study show that one display design is not necessarily better than another display design. There were no differences among the displays according to the criteria of number of cookies baked and amount of inventory used. According to the criterion of number of errors made, the equivalent display provided the best support for the users. The equivalent interface allowed users to choose either the keyboard, mouse, or both methods to interact with the display. Results of this study provide information that is valuable to the display designer. Figure 11 illustrates a recommended interface design for the scheduling problem based on the

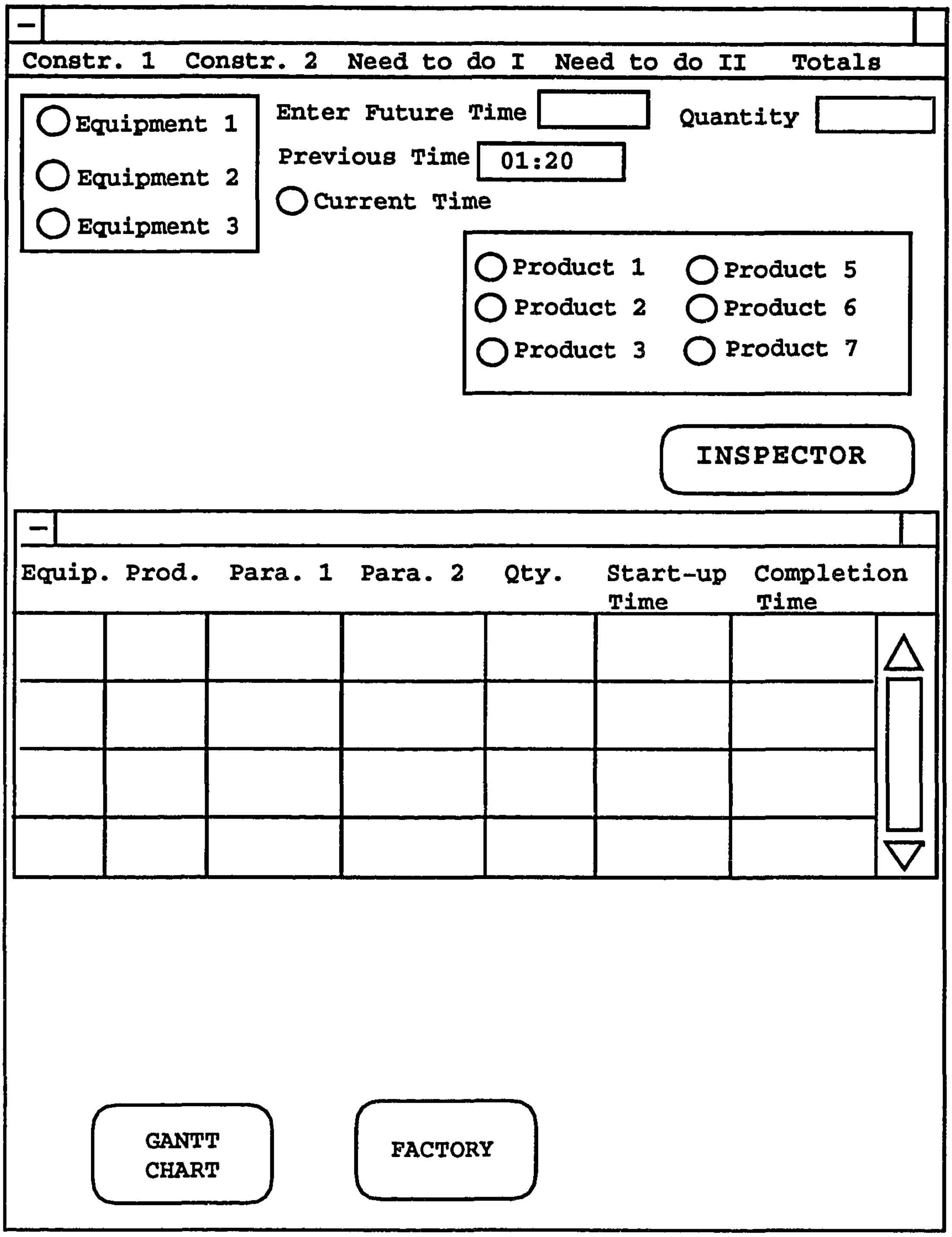

Figure 11. Recommended Interface Design for Scheduling Task.

results of this study. The menu should include constraint information and discrepancy information. The information should be grouped or aggregated in a meaningful manner for the scheduler so that the scheduler does not have to mentally arrange or group information. For example, inventory could be categorized by vendor. The menu should also include information that will allow the scheduler to monitor the progress of the schedule. Generally, menus allow a user to set defaults or perform actions. With a complex task such as scheduling, the menu should also provide constraint, discrepancy, and current system state information particularly if the information is dynamic.

The interface should allow the user to open a spreadsheet window or a Gantt chart window to schedule. It may be beneficial in complex systems to have a separate spreadsheet or Gantt chart window for each line or product family. The results of the present study suggest that the spreadsheet format should be the default option because participants in the equivalent display condition preferred to enter quantities and times in the spreadsheet rather than in the Gantt chart.

Parameters that are specific to a given product, such as temperature, or parameters that change infrequently should be entered into the system automatically. This would reduce errors made when entering this type of information into the system. It would also reduce the amount of work required of the scheduler. Participants in the alphanumeric display made more temperature errors than participants in the other displays because they were required to type temperatures rather than select a radio button. This research showed that participants in the equivalent condition chose to enter equipment and product information with radio buttons. Thus, radio buttons should be used or the scheduler should be allowed to choose an item from a list to enter information into the system.

The schedulers should be able to open a window that provides a physical representation of the line or factory. This window should open on default because results of this study show that this information was infrequently accessed when hidden from view in a menu. This supports Woods' (1984) argument that an analogical representation, or a map of the system, makes information location a perceptual process rather than a cognitive process. That is, the user can see in a picture the equipment and processes in the factory rather than needing to remember and mentally depict the processes. Information about any equipment or process in the factory should be available by clicking on a push button or an icon that represents equipment. This research showed that this information was more likely to be sought if accessible by a push button. Furthermore, the inspector information should not be hidden from view in a window. The inspector information should be in view at all times. This information must be monitored by the scheduler and therefore should have a push button accessed from the main interface window. The button should signify when an emergency has occurred or products have been rejected. Warning messages could also display information about emergency situations.

To summarize, the display designer should include constraint, discrepancy, and current system state information in the menu. The user should be able to select items from a list or use radio button to enter equipment and product information into the system. The user should be able to use text boxes to enter specific parameter information into the system. When parameter information can be automatically entered into the system, the system should perform this function. A pictorial representation of the factory and process should be easily accessible and always available to the user. Inspector information should be prominently and constantly displayed to the user. Finally, the user should be given a choice between spreadsheet and Gantt chart input of information.

Hypothesis II.

It was hypothesized that information that depicts the current system state, the goal state, and the discrepancy between the current and goal states should be useful. It was also hypothesized that future state information would be useful for error avoidance.

Barfield and Robless (1989) suggest that problem-solvers require current state information, goal state information, and discrepancy between goal and current state information. The task analysis shows that good schedulers only need the discrepancy information. However, the discrepancy between the current point in the schedule and the goal state is needed, rather than current system state and the goal state. Barfield and Robless (1989) found that experienced managers in a production task used a forward chaining problem solving strategy. They defined forward chaining as working from the problem state toward the goal state. The good schedulers in this study also adapted a forward chaining strategy. They worked forward from the latest batch scheduled to the goal state. However, the goal state was defined as the discrepancy from what they had scheduled to what remained to be done to complete the orders. Thus, the best schedulers adapted a forward chaining strategy using this information. Scheduling interfaces should display this information.

Scheduling research (Fox & Smith, 1984; Thurley & Hamblin. 1962) suggests that the scheduler needs to identify threats to goal attainment, prepare ways to identify threats, and invent contingency plans. Schedulers identify threats by monitoring the system to estimate current system states from past system states. Providing the scheduler with preview information should allow them to test current scheduling options before committing the system to them. Thus, the use of future state information may cause the monitoring task to change from estimating the current system state to checking the progress of the current system and estimating future system state information. Smith and Crabtree (1975) found that schedulers used preview information to avoid errors and test options. Results of the present research suggests that good schedulers adapted the same strategy by previewing to options to avoid problems, monitoring the progress through the factory using current state information, and monitoring the inspector information. For example, the best schedulers in the present study did not make errors. They checked to make sure that they would have enough inventory at a future time before scheduling a batch. They checked the operational status of equipment and checked recipe information before scheduling a batch. They monitored the current progress of the schedule to make sure that cookies were baking as scheduled.

Sanderson (1989) states that the scheduler requires a mental picture of the current system constraints and properties. The results of the task analysis of the best schedulers suggests that the scheduler, if given preview information, will rely on system state information to the time at which they are currently scheduling, not necessarily the current system state. Thus, if they are scheduling into the future, then the time at which they are currently scheduling will be ahead of the current system state. The best schedulers operated from three time frames, the current system, the time at which the schedule is being currently created, and the future. Once these schedulers began scheduling ahead of time they did not rely on current state information to schedule. However, if they had not been given the ability to preview to the future, they would need knowledge of current system constraints. Good schedulers did use the current state information to monitor the implementation of the schedule and to monitor progress. Providing schedulers with the ability to "see" into the future, changes the time frame from which they operate.

Results from this research showed that good schedulers entered future time frequently. They used future information to test options before making a scheduling decision. The interface needs to convey to the user the time frame of the information displayed. The scheduler needs to know which information describes the current system, the future system, and the state of the factory to the time scheduled. The display should be consistent with the scheduler's time frame. Several possible methods exist for conveying the time state of the information presented. Dynamic menuing systems could update the information in the menu when the scheduler enters a future time into the system. Previous future times that the scheduler entered should be displayed so that the scheduler is not required to remember the times. The scheduler could request by selecting a radio button that the system return to the current time. The title of the window could tell the scheduler what time frame is being displayed. Clocks could show future and current times. A color change of the window or menu items could convey to the user which time frame is currently displayed. A box next to the menu could show the time frame. For example, a filled box indicates current system state information an unfilled box future state information. It is also possible to use two menus, one for future state information and one for current state information. One menu bar at the top of the window and another at the bottom of the window. However, two menus should be used only if the scheduler needs to simultaneously view current and future factory states. With a highly complex scheduling system, it is possible that the scheduler will be scheduling into the future for one product family but not for another. Thus, the interface needs to clearly convey which time frame is being displayed.

Hypothesis III.

It was hypothesized that the direct manipulation graphic display would improve performance when scheduling with a time pressure. There were no differences among the time pressure conditions in the quality of schedules created. However, analysis of the use of the preview display showed that participants in the 90 minute condition did not use the preview display. They scheduled in real time, unlike the 60 minute and 75 minute participants who needed to use the preview display to schedule.

Future research.

Future research between current time, time as currently scheduled, and future time should explore how readily people can switch among these states and the types of errors that occur when people lose their place in time. This research suggests that most of the participants had difficulty switching among these time frames. Many of the participants did not figure out a strategy for keeping their location in time until the end of the task. The interface needs to clearly mark or display to the user the time frame of the information displayed.

This research supports providing future state information to schedulers. As automation technology improves and scheduling is given to the machine, the human must monitor the situation and intervene when necessary. Future research should explore how future state information can help the human in monitoring intelligent scheduling systems. Glimpses into the future may help the human intervene to avoid problems. Enabling schedulers to compare both current and future system states could help them see into the future to determine when and where a problem will occur and to look to the present to determine the cause of the problem. Furthermore, this research shows that people will use the future display to test interventions before committing them to the system.

In this study, the inspector provided probability information, that is the probability that a batch would be rejected. The inspector information was not important to the participants in this study because the probability information did not have consequences. That is, cookies were never rejected. Exploring the usefulness of probability information when predicting problems and inventing contingency plans should be studied. Participants in the present experiment simplified the task by creating rules and minimizing the amount of information needed to solve the problems. Whether information is concrete or is in the form of probability information may influence how schedulers simplify information and the rules that they create. Furthermore, there was little variability among the rules that participants created in this study. Poor schedulers adapted the same rules as good schedulers. This suggests that the display of information is a strong determinant of which rules will be used by schedulers.

Summary.

Results of the present study suggest that future state information is essential to aid the scheduler in monitoring, predicting, and decision making. The interface should facilitate testing the future outcomes of past and current inputs. Information should tell the user what needs to be accomplished to fulfill goals. A mixed display format may be the most appropriate interface design for the scheduling problem. Both a spreadsheet and a Gantt chart should be made available to the user so that the user can choose the preferred display.

The design of comprehensive integrated displays for a scheduling task requires the human factors specialist to depict the factory and process, current and future system states, dynamic information in aggregate form, and discrepancy information between what is currently scheduled and the goal state. This information will allow the user to test options, before making the scheduling decision and avoid errors. Thus, the interface design will best support the human in the scheduling role.

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Appendix A

Information Content of Displays

Information in the alphanumeric displays is presented in the menu bar and the list box (see Figure 4). The order menu item (see Figure 7) includes the number of orders, the number and type of cookies in each order individually, and the total number of cookies in all the orders combined. There was a menu item for each individual order and a menu item for the orders combined.

The four orders were:

(1) 500 chocolate chip, 1000 double chocolate, 250 ginger, 50 lemon, 450 peanut butter, 100 macadamia nut, 250 sugar;

(2) 300 chocolate chip, 100 ginger, 300 peanut butter, 450 raisin oatmeal;

(3) 1000 chocolate chip, 750 double chocolate, 450 peanut butter, 200 raisin oatmeal, 50 sugar;

4) 700 chocolate chip, 150 lemon, 500 peanut butter, 500 raisin oatmeal, 125 macadamia nut.

Recipe menu item includes the baking time and temperature for each type of cookie individually, and all the cookie types combined.

Totals menu item includes discrepancy information. The "total baked" menu item displays the number of cookies baked at the current time, and the "need to bake" menu item displays the number of cookies remaining to be baked in order to fill the orders.

Inventory menu item includes the amount of cookie dough available to be baked for each type of cookie individually, and a complete inventory menu item that includes inventory for all the cookie types.

The time item displays the current time in the cookie factory. In the factory, it was always between 7:00 am and 9:00 am. The task simulated real time, therefore a minute was 60 seconds.

In the alphanumeric and equivalent displays, information about the mixers, ovens, and inspector were presented in the menu bar . Mixer information included the number of mixers, types of cookie being mixed and how long the cookies were being mixed. The menu included an item for each mixer and an item that displayed the activity of all the mixers. This menu also told the subject when a mixer had failed.

Oven information included the number of ovens, the current temperature of each oven, and the probability of an oven failure. The menu included an item for each oven and an item that displayed the temperatures for all the ovens.

Inspector information included the probability that a batch would be rejected.

To use the preview display, participants enter the time to which they want to preview by selecting the future time menu item. Then by selecting any other menu item under the preview display participants can see information for the future time. "Total baked" menu item shows the number of cookies that should be baked at the future time. "Need to bake" menu item shows the number of cookies needed to be baked to fill the orders. Mixers show what the mixers should be mixing at the future time. Ovens show the future temperatures of the ovens. Inventory shows the amount of inventory that should be available at that future time. The Gantt chart in the graphic and equivalent displays also automatically drew in oven activity to the future time. From this chart, participants could determine which type of cookie would be baking in which oven at a certain time. They could also see how much time remained to schedule batches in each oven. The participant had to compute this by means of mental arithmetic when using the alphanumeric display.

To interact with the alphanumeric display and schedule a batch, participants typed the information into text boxes. After they scheduled a batch and hit the return key, the batch was displayed in a list box. The information in the list box was redundant with some of the menu items. For example, a participant could look in the list for recipe information, totals baked, and times when ovens would become available. However, determining this information required mental arithmetic and scanning of the list. Participants could also select a batch from the list in order to edit or change a batch. However, once a batch went into the oven participants could not change it.

Information presented in the graphic display is presented in the menu bar, radio buttons, pictorial representation of the factory and the Gantt charts (see Figure 5). The orders, totals, recipes, inventory, and preview menu items are identical to the alphanumeric menu structure (see Figure 8). However, the participants in the graphic display accessed information about the mixers, ovens, and inspector by clicking on the item with their mouse. The mixers, ovens, and inspector are displayed to represent the physical layout of the factory. The participant immediately perceives the number of mixers and ovens available and has a representation of the process in the factory. This information is not readily available from the alphanumeric display. However, the participants could not see what all three mixers were doing at the same time.

Participants chose the oven, temperature, and cookie type by selecting a radio button. The radio buttons in the display allowed participants to recognize the appropriate temperature and cookie type, while participants in the alphanumeric display were required to remember and recall this information. The graphic display drew a picture of oven activity, so that participants could readily perceive when an oven became available and when it was being used. In addition, participants could see oven activity in each oven simultaneously. The Gantt chart also showed the type of cookie baking in an oven. However, participants in the graphic display did not have the sizes or temperatures of the batches in a list. They needed to rely upon the information presented elsewhere in the display. Cookie types were color coded with the radio buttons enabling participants to recognize the type of cookie scheduled in the Gantt charts. Participants were required to recognize color coding of cookie types in order to know what type of cookie was baking in an oven. The graphic and equivalent displays included a second Gantt chart that updated oven activity each minute. They could use this chart to monitor the passage of time. The second Gantt chart also updated to a preview time when participants entered a future time. This allowed them to view oven activity at the future time. Participants double clicked to erase the display back to the current time.

When using the graphic display, participants selected the oven, temperature, and cookie type by selecting the appropriate radio button with the mouse. They typed in the size of a batch and drew, with the mouse, start and finish times on a Gantt chart. To edit a batch, participants using the mouse erased the batch and rescheduled the information.

Participants using the equivalent display had all the information in the alphanumeric and graphic displays and could interact with the system by using a mouse or the keyboard (see Figures 6 and 7). Table 17 summarizes the information displayed in each of the interfaces.

TABLE 17
Types of information provided in the scheduling task.

	Alphanumeric	Graphic	Equivalent
Menu	Order Info. Recipe Info. Discrepancy Current Time Inventory Mixer Status Oven Status Inspector Future Info.	Order Info. Recipe Info. Discrepancy Current Time Inventory Preview Info.	Order Info. Recipe Info. Discrepancy Current Time Inventory Mixer Status Oven Status Inspector Preview Info.
Push Buttons		Mixer Status Oven Status Inspector	Mixer Status Oven Status Inspector
Gantt Chart		Current Time Future State	Current Time Future State
Input	Text Boxes Keyboard	 Radio Buttons Gantt Chart Mouse	Text Boxes Radio Buttons Gantt Chart Keyboard Mouse
Advant.	List box is memory aid. View all equipment at once	See Equipment See time remaining in ovens	Advantages of both
Disadvant.	Cannot see equipment Scan List	High memory load	Redundant & Cluttered

Appendix B

Instructions

<u>General Instructions for alphanumeric, graphic, and equivalent displays</u>.

You are the baker in a cookie factory. The cookie baking process in the factory works likes this:

A mixer person mixes the batter for the cookies in the mixing machines.

You do not control the mixing machines.

After the batter is mixed, the mixer person places it in inventory.

You bake the cookies that the mixer person has mixed and placed in inventory.

You control the ovens.

After the cookies are baked, the inspector inspects the cookies to see if they are good enough to ship to the customers. The inspector will reject cookies if they are too big, too small, too crunchy, or too moist. Do you have any questions?

Your job, as the baker, is to fill the customers' orders by 9:00 am.

You begin work at 7:00 am. Therefore, you have 2 hours to bake the cookies necessary to complete the customers' orders.

You also want to minimize the amount of batter that is used to bake the cookies. The mixer may mix more batter than you need to fill the orders. You want to use only the batter than you need to use.

You want to maximize the time ovens are baking cookies because, it is expensive to turn the ovens off and on. Once an oven is on you want to try to leave it on for the entire two hours.

You create a schedule to bake cookies. The schedule must be completed in ( ) minutes.

To schedule a batch of cookies you must specify:

the oven the cookies will bake in

the temperature of the oven

the type of cookie to be baked

the size of the batch (the number of cookies)

the start time (the time cookies will enter the oven)

the finish time (the time cookies will be removed from the oven).

Your job is to create a schedule that specifies when cookies will bake in the ovens. The cookies can be scheduled to bake until 9:00 am. However, the schedule specifying this has to be done by ( ).

Do you have any questions?

All the information you need to bake the cookies is available by selecting an item from the menu, clicking on a piece of equipment, or displayed in front of you.

The orders menu includes items for each order and a total order item. This tells you the number of orders that have to be filled and how many cookies have to be baked to fill an order. The total order menu item adds all the orders together to show all the cookies that you have to bake.

The totals menu has two items, total baked and need to bake. Total baked tells you how many cookies you have currently baked. Need to bake tells you how many cookies you need to bake in order to fill the orders.

The recipes menu item includes items for each cookie type. These items tell you the time and temperature required to bake the cookies. The complete recipes item summarizes in a table all the baking times and temperatures for each cookie type.

The time menu item displays the current time. In the factory, it is between 7:00 am and 9:00 am, therefore your watch is not helpful.

The inventory menu includes items for each cookie type and all the cookie types. Inventory tells you how much batter you have available to bake for each cookie type at the current time. It tells you how much batter the mixer person has mixed at the current time. You have no control over amount of inventory. As the mixer person makes cookie batter it is placed in inventory. As cookies enter the ovens it is removed from inventory. Therefore, inventory is constantly changing. You cannot bake cookies unless you have inventory for the cookies. It would be impossible to bake chocolate chip cookies, unless chocolate chip batter was mixed.

The mixer menu (Or mixers) includes items for each mixer and an item for all the mixers. The mixer menu tells you the type of cookie currently mixing in a mixer. It also tells you when a mixer has gone down.

The oven menu (Or oven buttons) tells you the current temperature of an oven. It also tells you the probability that the oven may breakdown.

The inspector menu (Or button) tells you the probability that a cookie batch will be rejected.

Do you have any questions?

The preview menu allows you to see what will be happening into the future. This allows you to schedule ahead of time. The menu provides the same information as above except it tells you for a future time. Thus, it tells you according to your schedule the number of cookies you will have baked, the number of cookies you need to bake, what the mixers will be mixing, what the oven temperatures will be, and the amount of inventory at the future point in time.

To use the preview menu, you must first select "future time" from the preview menu. Type in the time you want to preview to into the box at the bottom of the box. For example, if the current time is 7:10 and you want to bake cookies at 7:30 then enter 7:30 into the box. Then you may select any of the following items (total baked, need to bake, mixers, ovens, inventory) from the preview menu and it will display what the factory will be like at 7:30.

<u>Preview instructions for the graphic and equivalent displays.</u>

The bottom chart updates each minute. It shows what type of cookie is baking in each oven. When you select the preview display and enter the time, the bottom chart automatically displays to the future time. This is so you can see what the ovens will be baking in the future.

To return the picture to its pre-preview state. Move into the chart and double click the left mouse button. The experimenter will show you how to double-click.

Do you have any questions?

<u>Interaction instructions for the alphanumeric display.</u>

To schedule cookies:

Move your mouse over the box labeled oven. When the mouse pointer changes from to click the left mouse button. A line should be blinking in the box.

Type in the number of the oven you want to turn on.

Tab to the next space.

Type in the temperature of the oven.

Tab to the next space.

Type in the 2 letter code for the cookie type. The codes can be found in the complete recipe menu item under recipes.

Tab to the next space.

Type in the size of the batch.

Tab to the next space.

Type in the start time. The correct format is h:mm.

Tab to the next space.

Type in the finish time. The correct format is h:mm.

Hit the tab key.

The information that you have typed in the boxes pops into the list below the boxes. The boxes are cleared so that you can enter your next batch. The list keeps track of all the batches you have entered.

Do you have any questions?

To correct a mistake. Move the mouse to the row in the list you want to change.

Click the left mouse button.

Click on yes button if you want to change something in the row. Click No if you do not.

After you click yes, the items will appear in the appropriate boxes above the list.

Click in the box you want to change.

Type in the change.

Click in the finish time box, re-enter the finish time.

Hit the tab key. The edited item is placed in the top of the list. The old item is removed from the list. The boxes are cleared.

Do you have any questions?

Before you begin there are a few rules:

1. Fill the orders on time, that is by 9:00 am.

2. Minimize inventory waste. Use only the inventory you need to use.

3. Maximize the time ovens are in use. Keep the ovens busy for 2 hours.

4. Must always type in oven number first before typing in other information. Must always enter finish time last.

5. 400 cookies fit in an oven at a time. You may bake less that this, but not more than this. Your maximum batch size can be 400 cookies.

6. Can only bake one type of cookie in an oven at a time. For example, you cannot bake 200 Chocolate chip and 200 Double chocolate in the same oven at the same time.

Do you have any questions?

When you are ready to begin, click the box labeled start. You will have a 15 minute practice task and then the experiment will begin. Good Luck.

<u>Interaction instructions for the graphic display.</u>

To schedule cookies:

To choose the oven, move the tip of the arrow into the circle next to the oven, click the left mouse button.

To choose the temperature click in the circle next to the temperature.

To choose the cookie type click in the circle next to the cookie type.

To enter size move the mouse over the box labeled size when the changes to click the left mouse button. A line should be blinking in the box. Type in the size of the batch (number of cookies you want to bake). Do not push the enter button.

Choose the hour by clicking in the circle next to the hour.

Draw in the minutes by moving the mouse so that the tip of the arrow is at the start time of the batch. Push the left mouse button and hold your finger down. Move the mouse until the tip of the pointer is at the finish time then lift your finger up.

Each type of cookie is a different color. Each cookie type will draw in a different color. Try to finish the last batch of the hour close to 60, because you cannot draw from 7:55 to 8:05.

Do you have any questions?

To correct a mistake:

Click in the box next to correction. Then position your pointer at the start time of the batch you want to correct. Push the left button down, hold your finger down. Move your mouse to the finish time and lift up your finger. You have erased the batch and can now re-enter the correct oven, temperature, type, size, hour and minutes.

Do you have any questions?

Before you begin there are a few rules:

1. Fill the orders on time, that is by 9:00 am.

2. Minimize inventory waste. Use only the inventory you need to use.

3. Maximize the time ovens are in use. Keep the ovens busy for 2 hours.

4. Must always type in oven number first before typing in other information. Must always enter finish time last.

5. 400 cookies fit in an oven at a time. You may bake less that this, but not more than this. Your maximum batch size can be 400 cookies.

6. Can only bake one type of cookie in an oven at a time. For example, you cannot bake 200 Chocolate chip and 200 Double chocolate in the same oven at the same time.

When you are ready to begin, click the box labeled start. You will have a 15 minute practice task and then the experiment will begin. Good Luck.

Interaction instructions for the equivalent display.

To schedule using the keyboard:

Move your mouse over the box labeled oven. When the mouse pointer changes from to click the left mouse button. A line should be blinking in the box.

Type in the number of the oven you want to turn on.

Tab to the next space.

Type in the temperature of the oven.

Tab to the next space.

Type in the 2 letter code for the cookie type. The codes can be found in the complete recipe menu item under recipes.

Tab to the next space.

Type in the size of the batch.

Tab to the next space.

Type in the start time. The correct format is h:mm.

Tab to the next space.

Type in the finish time. The correct format is h:mm.

Hit the tab key.

The information that you have typed in the boxes pops into the list below the boxes. The boxes are cleared so that you can enter your next batch. The list keeps track of all the batches you have entered.

Do you have any questions?

To correct a mistake. Move the mouse to the row in the list you want to change.

Click the left mouse button.

Click on yes button if you want to change something in the row. Click No if you do not. After you click yes, the items will appear in the appropriate boxes above the list.

Click in the box you want to change.

Type in the change.

Click in the finish time box, re-enter the finish time.

Hit the tab key. The edited item is placed in the top of the list. The old item is removed from the list. The boxes are cleared.

Do you have any questions?

To schedule with the mouse:

To choose the oven, move the tip of the arrow into the circle next to the oven, click the left mouse button.

To choose the temperature click in the circle next to the temperature.

To choose the cookie type click in the circle next to the cookie type.

To enter size move the mouse over the box labeled size when the changes to click the left mouse button. A line should be blinking in the box. Type in the size of the batch (number of cookies you want to bake). Do not push the enter button.

Choose the hour by clicking in the circle next to the hour.

Draw in the minutes by moving the mouse so that the tip of the arrow is at the start time of the batch. Push the left mouse button and hold your finger down. Move the mouse until the tip of the pointer is at the finish time then lift your finger up.

Each type of cookie is a different color. Each cookie type will draw in a different color. Try to finish the last batch of the hour close to 60, because you cannot draw from 7:55 to 8:05.

Do you have any questions?

To correct a mistake:

Click in the box next to correction. Then position your pointer at the start time of the batch you want to correct. Push the left button down, hold your finger down. Move your mouse to the finish time and lift up your finger. You have erased the batch and can now re-enter the correct oven, temperature, type, size, hour and minutes.

Do you have any questions?

To schedule with either the keyboard or the mouse:

You may schedule cookies in any manner that you wish. For example: you could use the mouse to select the oven, temperature, and type of cookie, and use the keyboard to type in the size, start time and finish time. You can correct mistakes with either method.

Do you have any questions?

Before you begin there are a few rules:

1. Fill the orders on time, that is by 9:00 am.

2. Minimize inventory waste. Use only the inventory you need to use.

3. Maximize the time ovens are in use. Keep the ovens busy for 2 hours.

4. Must always type in oven number first before typing in other information. Must always enter finish time last.

5. 400 cookies fit in an oven at a time. You may bake less that this, but not more than this. Your maximum batch size can be 400 cookies.

6. Can only bake one type of cookie in an oven at a time. For example, you cannot bake 200 Chocolate chip and 200 Double

chocolate in the same oven at the same time.

When you are ready to begin, click the box labeled start. You will have a 15 minute practice task and then the experiment will begin. Good Luck.

Appendix C
Questionnaire

Subject Id# ____________________

1. Mouse 1 2 3 4 5 6 7
Mouse was difficult to use — Mouse was easy to use

2. Keyboard 1 2 3 4 5 6 7
difficult to use — easy to use

3. The schedule I created will bake all the cookies required to fill the orders.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

4. The schedule I created has:

1 2 3 4 5 6 7
No Errors — Many errors

5. I used more inventory than necessary to fill the orders.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

6. The schedule I created maximizes the time ovens were in use.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

7. The schedule I created accounts for cookies the inspector may have rejected.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

8. The scheduling task was very frustrating.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

9. Order changes interrupted my chain of thought.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

10. The information displayed was accurate.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

11. I found the information I needed when I wanted it.

1 2 3 4 5 6 7
Always Found — Never Found

12. Equipment failures interrupted my train of thought.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

13. The task was enjoyable.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

14. Computers always give accurate information.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

15. The time limit was in the back of my mind.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

16. I was easily distracted.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

17. I developed a plan or strategy for scheduling.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

18. The information changed too quickly for me to keep track of it.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

19. I did not know what I was doing. I did not develop a plan.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

20. I felt rushed.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

21. I corrected any errors that I made.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

22. I changed my plan or strategy during the task.

1 2 3 4 5 6 7
Strongly Agree — Strongly Disagree

23. I had to remember several pieces of information at a time.

1	2	3	4	5	6	7
Strongly Agree						Strongly Disagree

24. I forgot information after I looked at it.

1	2	3	4	5	6	7
All the time						Never

25. Correcting errors made me change my strategy.

1	2	3	4	5	6	7
Strongly Agree						Strongly Disagree

Questions:

1. What did you like about the display?

2. What did you dislike about the display?

3. When you scheduled a batch how did you do it?
   How did you decide which oven? temperature? type? size? start time? finish time?

4. Did you use the inspector information?
   How did you use it?