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Team-Computer Interfaces in Complex Task Environments

Michele Terranova

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ABSTRACT

This research focused on the interfaces (media of information exchange) teams use to interact about the task at hand. This report is among the first to study human-system interfaces in which the human component is a team, and the system functions as part of the team. Two operators dynamically shared a simulated fluid flow process, coordinating control and failure detection responsibilities through computer-mediated communication. Different computer interfaces representing the same system information were used to affect the individual operators' mental models of the process. Communication was identified as the most critical variable, consequently future research is being designed to test effective modes of communication. The results have relevance for the development of team-computer interfaces in complex systems in which responsibility must be shared dynamically among all members of the operation.

INTRODUCTION

The behavior of human operators typically has been studied from the perspective of individual performance. Attempts to reduce human error in complex environments, such as aircraft systems, have been synonymous with providing the operator with redundant information (Foushee, 1982). However, many of the problems and mishaps in these and other systems seem to be more a function of the communication and coordination of teams, than of individual operator performance. Lack of adequate coordination of crews, and poor management of human resources have been connected to several aircraft disasters in the past two decades (Chambers & Nagel, 1985). It is not a coincidence, therefore, that momentum is building in the public sector for research on the effectiveness of teams in complex systems. In September 1988, Congress passed a bill mandating that the Federal Aviation Administration (FAA) spend $25 million for human factors research. One of the main concerns of the FAA is group dynamics within complex systems (Human Factors Society, 1989). The American National Standards Institute formalized the importance of team work in a requirement that Nuclear Power Plant operators be skilled not only in individual performance, but also in team communication (American Nuclear Society, 1987). The research reported in this article is among the first studies in the field of human factors that addresses the role of the computer as part of the operating team. The communication and the visual display interfaces used by the teams were examined to ascertain the most effective operating dimensions.

Mental Models of Complex Environments

Automation technology has made an important contribution to the design of advanced systems as well as to the revitalization of current systems. Designers of complex systems, such as those involved in air traffic control, aircraft piloting, and nuclear power plant operations, are striving to incorporate automated system features into designs to decrease human operator error. The human operator is no longer involved in direct manipulation of the process itself, but interacts with computer controls. Therefore, increases in system effectiveness are often related to issues of computer interfaces that display the task environment effectively to the operator. The ability to cope with complex environments is related the operator's ability to develop appropriate *mental models* and to shift levels of abstraction as needed (Rasmussen, 1986). A mental model is assumed to include knowledge of the system, principles according to which it is operated, and its relationship with the environment (Morris & Rouse, 1985). It must also contain knowledge and understanding of the dynamic physical relationships within the system. This advanced level of thinking involves an understanding of the system's internal structures and processes - the "how-it-works knowledge." (Kieras & Bovair, 1983, 1984). The mental model enables the operator to assume proper procedures when past experience or training do not apply.

Major issues in mental models research are the formation, use and update of the mental model in the system environment (Zhang & Wickens, 1987). The comparison of human performance on different computer displays representing complex systems provides information about the effectiveness of different mental models of those systems (Sanderson, 1986).

The developers of the system used for the research in this study, Coury and Pietras (1989), looked at the merits of graphic and alphanumeric displays for representing process-plant data and information in a dynamic process monitoring and control environment. They based their selection of screens on the assumption that there was some correlation between the information displayed, and models of the process that could be in the operators' minds. The graphic display provided an overall, physical representation of the structure of a fluid processing plant, representing the organization but not the function of the system components. Coury and Pietras also designed an alphanumeric display that presented the specific values of process variables; the relation between process data and components; and some knowledge of the impact that a change in a particular process variable might have on other components in the system. This display provided more detailed information about the underlying relationships between the function of components and the concomitant changes in attribute values. Unlike the graphic display, the alphanumeric display did not show the organization of the components. When both displays were presented, the operator was given a more complete representation of the system. Coury and Pietras (1989) predicted that the graphic display would produce better system optimization performance under normal conditions, and that the alphanumeric display would provide a better interface for the detection and location of failures. They also hypothesized that the overall performance on both tasks would be superior if both representations were available. Because of the way in which the system isolated the significant variables of mental models and system representation, the system developed by Coury and Pietras (1989) was selected for the research reported here. The interfaces of visual display and communication in the experimental task environment are examined to get a better understanding of sources of failure in team coordination for the performance of complex tasks.

Mode of Communication

Communication is an important variable in the effectiveness of interactions between operators. Communication measures have been shown to predict group performance better than measures such as individual knowledge or skill (Lanzetta & Roby, 1960). Because of concern in this study for effective team performance some serious attention was paid to selecting the mode of communication. A literature review has revealed two studies of group decision-making with respect to the mode of communication used (Siegal, Dubrovsky, Kiesler & McGuire, 1986; Kiesler, Siegal, & McGuire, 1984). Siegal and associates (Siegal et al., 1986) used three-member groups to compare the

communication efficiency of computer-mediated communication with face-to-face communication. Their measures of efficiency included the number of remarks exchanged by group members; the number of task-oriented remarks as a fraction of total remarks; and the number of decision proposals as a fraction of total remarks. The computer-mediated group took more time to reach a decision, and they exchanged fewer remarks than the face-to-face. However, the longer decision intervals for computer-mediated communication seemed to have resulted from factors other than the time required for typing the input (Kiesler et al., 1984). The number of task-oriented remarks was generally the same for both groups, however, the computer-mediated communicators made more decision proposals as a fraction of the total remarks made.

The internal group hierarchy and structure that usually emerge in face-to-face meetings do not emerge so clearly in written and computer-mediated communication. Whereas, participation in group processes usually reflects social status and the real or assumed expertise of individuals, computer communicators usually participate equally (Siegal, et al., 1986). Face-to-face communication might be associated with increased feelings of control which detract attention from the task, while the lack of non-verbal cues in computer communication might force the participants to pay closer attention to information verbalized rather than to the individual.

Kiesler et al., (1984) offer the following reasons for decision-making difficulties encountered by groups using computer-mediated communication. First, the absence of informational feedback makes it hard to know when one's point of view is accepted or understood, and participants feel that they have to exert more effort to get their point across. Second, because of a equal distribution of responsibilities among people, no individual takes responsibility for coordinating and controlling activities. The lack of centralization makes coordination more difficult.

For the current study computer, communication was selected because equal participation of team members was expected to contribute to better performance. The operators were required to communicate in order to share responsibilities on the task. It was expected that more communication and equal participation would be related positively to system performance.

Present Research

The research reported here was designed to study team computer interfaces on a dynamically shared task between two operators. This study addressed the relationship of system representations as modelled by the computer displays and communication efficiency on team performance. Each of the subjects in the research served as a team member with independent access to a computer interface that represented system information either in an graphic format, in an alphanumeric format, or in both. Members of the same team either had the same or different interfaces.

Subjects were required to share problem-solving in order to optimize the flow of fluid through a simulated system and to monitor and diagnose failed components (Coury & Pietras, 1989). The configuration of the simulation required that one team member served as the primary operator, responsible for actually finalizing and implementing decisions. The second subject was the support operator serving as an advisor, recommending plans to the primary operator. Communication between team members was computer-mediated.

The following questions were examined: (1) What is the relationship between the communication efficiency and distribution of communication and team performance? (2) What effect do the computer displays of the individual team members have on the ability of the team to control the process, detect failures, and utilize the displayed information? and (3) What is the relationship between the computer displays of the individual team members and the communication efficiency and the distribution of communication within the teams?

METHOD

Subjects

Fifty Navy and Marine reservists from the Navy and Marine Reserve Center in Knoxville, Tennessee served as subjects for this study. Of the 50, two were female. Ages of the subjects ranged from 21 to 59, with a mean age of 34 years. Subjects were selected by the respective commanding officers of the reserve center from among reservists who were making up a previously missed drill weekend. Twenty-five teams of two subjects each were assembled.

Task

A computer-simulated dynamic task was used. The task is a generic, dynamic production process, known as SARPI (Simulation for Assessing Representation of Process Information), developed by Bruce Coury and his associates at the University of Massachusetts (Coury and Pietras, 1989). SARPI is a version of Production Levels and Network Troubleshooting (PLANT) software, a computer-based process control task (Morris, Rouse, & Fath, 1985). SARPI has a graphic display and an alphanumeric display which present the same system information in two different formats. The graphic display uses a 13 inch color monitor, the alphanumeric display uses a 13 inch monochrome VT 100 terminal (a picture of the two screens appears in Figure 1). For the present study, a configuration was utilized which enabled two operators to view the simulation via the graphic, alphanumeric, or both screens from separate workstations. Only one operator, the primary operator, was able to control the process.

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Figure 1. Pictures of the SARPI Graphic Display (Left) and the Alphanumeric Display (Right) Formats.

The system simulates a fluid flow process through a nine tank matrix. A pump forces fluid out of each tank, and three valve connections can be made from each tank to tanks in neighboring columns. An operator can manipulate these valves to control the fluid process. The objective is to keep fluid levels in each tank between the range of 0-99, and as close as possible to an optimum level of 50.

At the beginning of each production run, the fluid level in each tank is set at 50, and all horizontal valves are open. Total system input and output, as well as the flow rate for connections, are set by the experimenter when the production run is initialized. Input to the system (set at 30 for this experiment) is evenly divided among the first three tanks (1, 2, and 3). Total output (set at 30 for this experiment) flows from the last three tanks (7, 8, and 9). The flow rate (set at 10 for this experiment) is the amount of fluid that flows out of each open valve to the next tank as the system is updated by the subject.

Randomly occurring system failures (either valve, pump, or simultaneous pump and valve) can be set by the experimenter. For the purpose of this experiment, system parameters were set so that approximately 7% of the iterations contained valve failures, 7% contained pump failures, and 7% contained both types of failures. Thus, a total of six failures, two of each type, occurred during each production run. If the operator suspects a failure, the pump or valve can be checked (system check); if the operator correctly diagnoses a failure, the "repair team" is automatically sent out by the system to the valve or pump.

If the fluid in any tank exceeds or falls below a certain height, warnings are displayed so that the subjects can adjust input to these tanks. If fluid continues to rise or fall and reaches critical limits, an automatic safety system assumes control of input and output to that tank until the fluid levels return to normal. Valves leading to a critical tank are either opened or closed by the system in order to correct the deviation. The safety system functions to prevent damage to the system and to keep the system under control.

SARPI is a subject-paced simulation; the system updates the displays after operators have responded to the prompts. The user commands issued between successive system updates constitute one iteration. In this experiment, the number of iterations was set at 30 for two production runs, one without failures and one that included failures.

Experimental Design and Measures of Performance

Subjects, scheduled for the experiment in groups of two, were randomly assigned as primary operator or support operator. The team was then randomly assigned to one of five conditions: (1) primary and support operator with graphic representation (GRGR); (2) primary and support operator with alphanumeric representation (ALAL); (3) primary and support operator with both representations (BOTH); (4) primary operator with

graphic representation and support operator with alphanumeric (GRAL); or (5) primary operator with alphanumeric representation and support operator with graphic representation (ALGR).

Three categories of dependent measures were used to measure system performance, and two categories were used to measure communication in the system:

(1) System Performance. The dependent measures chosen to reflect the performance of the teams on the simulation included: *process control*, *failure detection*, and *information utilization* strategies.

> *Process Control*. Operators were instructed to control the system by maintaining tank heights as close to 50 units as possible. This performance was measured by the mean deviation from the tank setpoint height of 50 for the 9 tanks averaged over the 30 iterations. This measure, mean deviation, was computed for a session of 30 iterations without failures and for a session of 30 iterations with failures. In order to determine changes in process control over time, this variable will be computed in six blocks of five iterations. Other dependent measures of process control were the number of system warnings and safety system takeovers that occurred during the No Failure condition and during the Failure condition.
>
> *Failure Detection*. Measures of failure detection were assessed during the 30 iterations of the failure session. Failure detection was measured by the percent of failures detected, the average number of iterations between the occurrence of a failure and its detection by the operator, and the number of times an operator checked the operation of a pump or valve.
>
> *Information Utilization*. Utilization of information measures how well the operators used the information presented on the screens (Coury and Pietras, 1989). This measure was assessed only during the 30 iterations of the session where failures were present. Information utilization (IU) is computed as the ratio of the number of connections made between tanks, to the number of system checks. The number of tank connections reflects the ability of the operator to control the system. The ratio indicates the number of connections made before checking the status of a component. Large IU ratio operators are characterized as effective information users. These operators do not query the system about the status of the various subsystems, do not send out the repair team unless a failure is detected, and make a relatively large number of fluid flow connections. They effectively use the displayed information to control the system and to diagnose system failures.

(2) Communication. The dependent measures chosen to analyze the communication that occurred during the simulation were: *communication efficiency* and *communication distribution*.

Communication Efficiency. The efficiency of communication was estimated with the following measures: the number of remarks of the primary operator, the number of remarks of the support operator, and the number of remarks combined. The greater the number of comments, the more the operators communicated.

Communication Distribution. Communication distribution is related to the social equalization measures of communication defined by Siegal et al. (1986). It is a measure of how communication is partitioned between the operators of the team. This measure is determined as the ratio of the number of communication remarks for the primary operator to the number of communication remarks for the support operator. Equal distribution of communication results in a ratio equal to one. A ratio greater than one is indicative of more communication on the part of the primary operator, and a ratio less than one indicates that the support operator communicated more.

RESULTS

Relationship of Communication Efficiency and Distribution to Team Performance

Correlations were computed in order to determine whether the measures of communication were related to team performance as measured by process control, failure detection, or IU. These correlations are presented in Table 1. For the failure conditions combined, three measures of communication efficiency (number of remarks communicated by the primary operator, the number of remarks communicated by the support operator, and the total number of remarks) and one measure of communication distribution were correlated with the three measures of process control (mean deviation, system warnings, and system takeovers).

As reported in Table 1 for process control, the total number of remarks was correlated negatively with mean deviation (-.44). As the number of remarks increased, the mean deviation decreased. The total number of remarks was correlated negatively with system warnings (-.29) and system takeovers (-.44). Communication distribution was not correlated significantly with any of the process control measures.

Correlations were also computed in order to examine the relationship between the measures of failure detection (percent of failures detected, average number of iterations to detection, average number of checks), and the indices of communication efficiency and communication distribution. As Table 1 displays, none of the failure measures were correlated significantly with the measures of communication, and the measures of IU were not related significantly to the communication measures.

Table 1

Relationship Between Communication and Team Performance

Process Control	Efficiency: Primary Remarks	Efficiency: Support Remarks	Efficiency: Both Remarks	Distribution: Ratio of Primary/Support
Deviations	-.46*	-.43*	-.44*	-.08
Warnings	-.30	-.41*	-.29*	.03
Takeovers	-.38*	-.45*	-.44*	-.01
Failure Detection				
% Detect	-.21	.07	-.16	-.21
Iterations	-.01	-.12	-.08	.04
Checks	-.09	-.20	-.18	-.01
Information Utilization IU	.16	.16	.20	.07

*p<.05

Relationship between Computer Displays and Team Performance

In order to determine the relationship between display type and team performance, a multivariate analysis of variance (MANOVA) was conducted. There were three dependent measures of process control: mean deviation from the setpoint of 50, system warnings, and safety system takeovers. The grouping factors were team Display Type (GRGR, ALAL, BOTH, GRAL, ALGR), Blocks of Iterations (in groups of 5: Block 1, Block 2, Block 3, Block 4, Block 5, Block 6), and the levels of the Failure condition (No Failure, Failure). A summary of these data collapsed across Blocks of Iterations is presented in Table 2.

There was a significant multivariate effect for Blocks of Iterations ($F(15,271) = 9.32$, $p < .05$), by the Wilks' Lamda Criterion. The examination of the univariate F tests showed the Blocks of Iterations effect to be significant for the mean deviations ($F(5,100) = 35.08$, $p < .05$) and safety system takeovers ($F(5,100) = 8.17$, $p < .05$). The MANOVA showed that the main effect for Failure was also significant ($F(3,17) = 51.42$, $p < .05$). All three of the dependent variables contributed significantly to this effect ($F(1,19) = 154.19$ (mean deviations), 113.40 (system warnings), 38.97 (system takeovers), $p < .05$). The multivariate effect for Display Type was not significant.

Among the two-way interactions, Failure by Blocks was significant ($F(15,257) = 4.62$, $p < .05$). The univariate tests showed that both mean deviation ($F(5,95) = 12.99$, $p < .05$) and system takeovers ($F(5,95) = 6.02$, $p < .05$) contributed to this effect. The interactions of Display Type by Failure, Display Type by Blocks, and the three-way interaction of Display by Failure by Blocks were not significant.

The mean fluid deviation data for the effects of Blocks of Iterations and Failure conditions are presented in Figure 2. In the graph, the data are averaged across Display Type. For the No Failure and Failure conditions combined, teams stabilized performance at 16-17 deviation units from the optimal setpoint. There was also a significant decrease in the ability of the team to control the fluid deviation over the last 20 iterations during the Failure condition.

A single factor MANOVA was computed with Display Type as the grouping factor and the following failure detection variables: the percentage of failures detected, the number of iterations between the occurrence of a failure and its detection, and the average number of times the team checked the system for failures. The multivariate test revealed no significant effect. The means for these data are presented in Table 3.

A one-way Analysis of Variance (ANOVA) was computed on the IU ratio (Number of Tank Connections/Number of System Checks) with Display Type as the grouping factor (GRGR, ALAL, ALGR, GRAL, BOTH). This analysis yielded a significant difference across the groups on IU ($F(4,20) = 3.24$, $p < .05$). The means for the groups are displayed in Table 3. Recall that the larger this ratio, the better the team used the

Table 2

Fluid Deviation Means for Process Control

Display Type	Mean Deviation		System Warnings		System Takeovers	
	No Failures	Failures	No Failures	Failures	No Failures	Failures
BOGR	11.6	20.8	9.4	22.0	5.2	12.8
BOAL	9.7	22.5	6.4	22.8	0.6	23.0
BOTH	11.4	21.1	9.7	20.2	3.0	23.0
ALGR	8.7	19.3	4.0	18.8	1.2	9.8
GRAL	11.0	19.4	8.8	19.0	3.2	11.8
Means	10.42	20.53	7.58	20.56	2.62	16.08
Standard Deviations	5.04	4.90	8.08	6.48	4.98	12.80

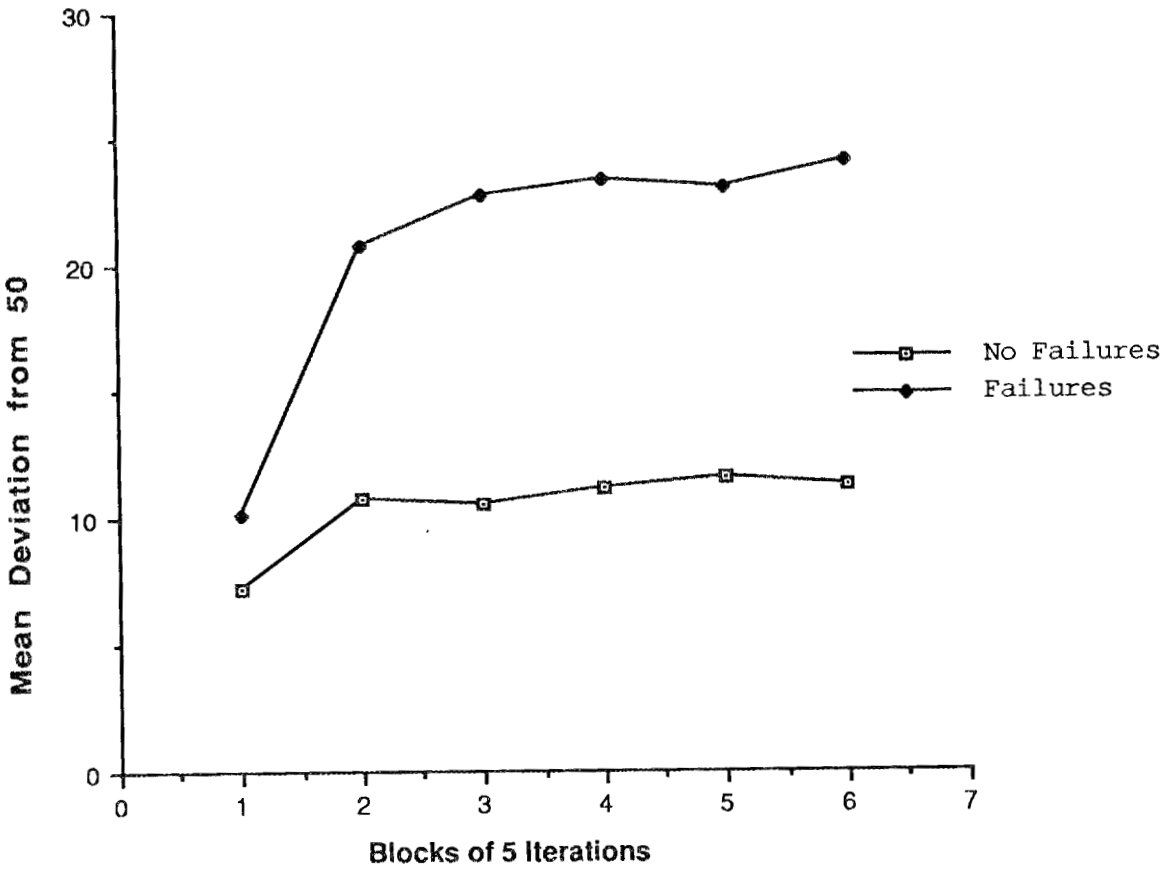

Figure 2. Mean Fluid Deviation from Setpoint: All Teams Combined

Table 3

Means for Failure Detection & Information Utilization by Display Type

Display Type	Percentage of Failures Detected	Number of Iterations to Detect	Information Utilization (IU)
BOGR	55.0	4.3	2.3
BOAL	38.6	5.6	2.1
BOTH	56.4	4.7	1.7
ALGR	45.0	3.6	5.3 *
GRAL	50.0	5.3	2.1

*Mean is significantly different from all other means ($p < .05$)

information displayed. The Newman Keuls test revealed a significantly higher mean for the ALGR team (5.3) than the mean for each of the other teams ($p < .05$).

Relationship of Computer Displays to Communication Efficiency and Distribution

In order to determine the relationship between computer display type and communication efficiency, a two-factor repeated-measures MANOVA was computed with Display Type (GRGR, ALAL, ALGR, GRAL, BOTH) and Failure condition (No Failure, Failure) as the grouping factors. The dependent variables were the number of remarks communicated by the primary operator and the number of remarks communicated by the support operator. There was a significant multivariate effect for Failure condition ($F(2,19) = 6.38$, $p < .05$) by the Wilks' Lamda Criterion, with both of the dependent variables significantly contributing to a drop in communication during the Failure condition ($p < .05$). Neither, the multivariate effect for Display, nor the Display by Failure interaction effect were significant. The means for communication efficiency are presented in Table 4.

Another two-factor repeated-measures MANOVA was computed for measures of communication distribution. The dependent variable was the ratio of the number of remarks communicated by the primary and the support operators. The greater the deviation of this ratio from 1, the more unequitable the distribution is. None of the multivariate effects were significant.

The means for communication distribution are presented in Table 4. The table illustrates a similar distribution between the No Failure (.7757) and the Failure condition (.6429).

DISCUSSION

In order to gain perspective on the results of this study, comparisons were made to data obtained from individual subjects in the research of Coury and Pietras (1989). As in the study reported here, Coury and Pietras (1989) found an increase in mean deviation during the Failure condition across blocks of iterations. In their No Failure condition, the mean deviation stabilized around 4-6 units from the setpoint of 50. In the current study, it was surprising to find that the mean deviation stabilized around 10-12 units from the setpoint of 50. This might indicate that the teams either had a more difficult time stabilizing the system, or merely selected a higher criterion for stabilizing the system.

Comparison with the failure detection data of Coury and Pietras (1989) revealed that the teams did not detect as many failures (49.00) as the individuals (58.03) and took more iterations (4.7) to detect them than did the individual operators (3.2). However, the teams did not check the system (14.48) nearly as much as the individual

Table 4

Means for Communication Efficiency and Distribution

Display Type	Efficiency		Distribution	
	NO FAILURES	FAILURES	NO FAILURES	FAILURES
BOGR	113.0	92.4	.59	.54
BOAL	109.0	79.0	.80	.88
BOTH	141.0	90.8	.76	.54
ALGR	168.0	84.2	.79	.65
GRAL	147.4	68.6	.91	.59
Means	135.84	83.00	.776	.643
Standard Deviations	66.88	37.05	.449	.545

operators did (23.00). The overall mean for IU was, however, lower for the team data than for the individual operators. The exception to this was the ALGR team, with a higher mean IU than both Coury and Pietras' (1989) Graphic groups and Alphanumeric groups.

These comparisons indicate that the subjects in the present study were not as effective as Coury and Pietras' (1989) individuals in optimizing the process, and that teams detected fewer failures, required more iterations to detect them, and made fewer tank connections than individuals. However, the teams did not make as many system checks as the individuals, suggesting that they were better able to detect failures from information displayed on the screen. The teams, with the exception of ALGR, did not utilize information as effectively as the individuals.

Several factors need to be considered in accounting for the differences between the results of this study and Coury and Pietras' (1989). First there are differences in subject population. Coury and Pietras (1989) used industrial engineering college students, whereas this study used subjects from the general population serving in a military installation. This probably translated into differences in age, education levels, and work experience. Second, the communication and coordination efforts of the teams in this study contributed to higher workloads. In a study of pilot workload, Hart et al. (Hart, Hauser, & Lester, 1984) found that communication contributed to a significant proportion of subjective ratings of workload, and might even serve as an objective indicator of workload. The communication mode in the current study might also have increased the subjects' perceptions of workloads. Beith (1987) compared the subjective workload demands of individuals performing a complex cognitive task with another person under conditions of face-to-face communication and obstructed communication. Under restricted communication, perceptions of workload increased almost 50%. Third, the differences between the teams in this study, and the individuals in Coury and Pietras (1989) could have been due to difficulties associated with coordinating team activities. Team performance could be less effective in this dynamic situation. This might be due to teams having more difficulty in coordinating activities in order to stabilize the system. Some team members reported that they concentrated on trying to help their teammate rather than optimizing system performance, with communication taking precedence over the control of the system. Finally, perhaps the lower team performance could be explained by a tendency for teams' responsiveness to be triggered at a higher point than individual responsiveness. In other words, if an individual attempted to keep the fluid level around 50 units, a team might tend to be satisfied as long as the level was stabilized around 70. Likewise, failures might be diagnosed earlier by individuals. This might be due to a psychological diffusion of responsibility when there is more than one controller (Foushee, 1982). One team member might assume that the other one is attending to certain functions of the process. These findings are counterintuitive to expectations that team performance would be better than individuals. Close attention should be paid to this. In light of the widespread interest and mandates of improved performance in teams, future research should address this.

The current research shows that the performance of teams related to the amount of communication between its members. Communication or interaction processes among members of a group might serve to prevent errors that occur in individual performance (Foushee, 1982; Hackman & Morris, 1975). In fact, in flight crews it has been observed that there is a tendency for poorer performing crews to communicate less (Foushee & Manos, 1981).

In the current study the amount of communication was not related to the ability of the teams to detect failures. In fact there was a significant drop in the amount of communication when failures were present. One subject in this study commented that the communication was effective for the No Failure condition but was ineffective for the Failure condition.

The presence of failures significantly degraded the performance of the teams in controlling the flow process. This was true for the all the measures of process control: the optimization of flow around the setpoint, the number of system warnings, and the number of takeovers that the teams incurred. The Failure condition placed additional workload on the teams. The workload of communication may have been too much to handle when the additional workload of failures was added to the task.

The ability of the teams to optimize flow decreased as a function of time. The process was more difficult for the teams to control as the number of iterations progressed. Increases in iterations usually mean more valve connections and more flow through the system. In the Failure condition, unless failures were recognized immediately, this decrease might also result from failures disrupting the system. While optimization performance did stabilize, it remained at a relatively large deviation from the setpoint. This appears to be a function of the increase in failures in the system, since performance remained fairly stable when failures were absent.

The way in which the teams utilized the information they were provided varied as a function of team Display Type. The IU ratio was significantly higher for the ALGR. It would appear from these results that these teams were able to employ the displayed information and the information obtained from each other more effectively. In studying cooperation, or lack thereof, between humans and computers, Rouse (1976) found that not all actions are planned in response to what the other controller is doing. He (1976) termed this "competitive intelligence." Controllers compete with each other to complete the task, with severe consequences for performance. The setting of this study might have facilitated competitive intelligence. The subjects were motivated highly throughout the experiment, and every subject displayed enthusiasm to participate in the research. This might have contributed to an ambitious effort rather than a cooperative one between team members.

In the current study, there was no difference among the team Display Types for communication efficiency or communication distribution. In previous research (Cook, 1987), equality of participation in computer-mediated communication has been shown to

be practical for tasks requiring creative solutions, or during brainstorming. This equality in participation might not be functional during task-oriented or dynamic performance such as in the present study. In a dynamic, although subject-paced, system such as SARPI, answers to system questions are needed relatively quickly. A more "unequitable" form of communication, where the primary or the support operator took more control and facilitated the communication process, might have contributed to better results. In complex problem-solving tasks, especially under time constraints, face-to-face communication might be more effective (Cook, 1987). In the present study, when questioned about the effectiveness of the computer communication, most of the respondents felt that it was effective. However, two subjects felt that a more direct form of communication such as oral would have improved performance on the task. Further research addressing this issue is currently being conducted.

When asked about their support operator, several primary operators commented that they did not utilize the support operator as much during the Failure condition as during normal operations. Other research suggests that if a potentially dangerous situation occurs during an aircraft flight, many pilots tend to take over control from co-pilots (Foushee, 1982). Foushee suggests that it might actually be best for the captain to resign control to the co-pilot. This would free the resources of the captain to make decisions and delegate responsibility, while the co-pilot carries out the decisions. The configuration of the current study did not allow for the support operator to take control of the system. Only the primary operator could input decisions into the system. Future research will allow the actual control of the system to be dynamic between the team members.

CONCLUSIONS

In many complex systems it is desirable to include the resources of more than one specialist. However, the results of this study have shown degraded performance when teams controlled a dynamic complex system, as compared to individuals in previous research (Coury & Pietras, 1989). While population variables and experimental control might have played a role in these differences, the workload of computer-mediated communication also took its toll. By its nature, computer-mediated communication adds to the workload of the task. Team members may have used the communication medium to instruct their teammate. Also, teams might select different, and more stringent, criteria than individuals to report problems. This phenomenon would be especially dangerous in systems with increased automation. Systems that include automation tend to perpetrate a psychological sense of diffusion of responsibility (Foushee, 1982). Operators are not as likely to take control when a disaster is imminent, or even to interpret a potentially dangerous situation as a threat. It is expected that this effect would be magnified when teams are a part of the automated system.

The knowledge-based behaviors demanded by complex systems require computer interfaces that enhance the operator's mental model of the system. The importance of this model is critical when the operator is required to rely on internal resources to guide performance. Different computer representations of system information affect the operator's model of that system. This study attempted to determine the best computer display configuration for teams working together to control a process. The results are inconclusive and additional research is ongoing with other communication modes.

Today's complex systems increasingly mandate the use of teams, however, much remains to be learned about how teams can be used to their fullest potential. Previously attention had been focused on the individuals, especially where system performance depended on support for the human operator. Although many aids and improvements for individual operators have been built into these systems, human errors are still in evidence. Modern systems depend on team operators, and computer interfaces must be designed to accommodate these teams. One of the significant results of the research reported here is that optimal team performance for problem-solving tasks that are being shared dynamically relies heavily on communication. Applications of results from future studies of human performance will assist operators in communicating and interpreting system information, while optimizing the representation of information for manipulation by teams not individuals.

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