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An experimental study of dialogue-based communication for dynamic human–computer task allocation

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The allocation of tasks between human and computer and the merits of a dynamic approach to this allocation are discussed. Dynamic task allocation requires efficient human–computer communication. This communication may be accomplished in an implicit, model-based, or explicit, dialogue-based, manner. A framework for the study of dialogue-based human–computer communication is introduced and a study exemplifying the use of the framework is presented. This study investigated the effects of two input media and four task allocation strategies on the performance of a human–computer system. The task environment represented a simplified version of an air traffic control scenario wherein computer aid could be evoked by the human controller to accomplish task sharing between the human and the computer. Dedicated function keys proved to be a more effective input medium than the standard Sholes QWERTY keyboard in terms of both objective performance and subjective preference measures. Of the task allocation strategies considered, spatial assignment, contingency-based assignment, and assignment by designation achieved the highest levels of overall system performance, while temporal assignment achieved a significantly lower level of performance. Subjective ratings indicated an overall preference for assignment by designation, followed by spatial assignment and contingency-based assignment. Spatial assignment was the most powerful, but the least specific strategy. Assignment by designation was the least powerful strategy, but the most specific and most flexible strategy.

Human–computer task allocation

Function allocation has always been central in the design of any complex human-machine system. Systems engineers distinguish between "function" and "task". "Function" is defined as "a general means or action by which the system fulfills its requirements" (DeGreene, 1970, p. 21). "Task" is described at the behavioural level, and is construed to be "a composite of related (discriminatory-decision-motor) activities performed by an individual, and directed toward accomplishing a specific amount of work within a specific work context" (DeGreene, 1970). Now that the computer is capable of human behavioural-like activities, allocation of responsibilities between human and machine can be extended to a lower system level. Both function and task allocation between human and machine should be considered. For the sake of this discussion, function and task allocation are intermingled.

LIMITATIONS OF THE CLASSICAL APPROACH

With the desire to enhance productivity, past practice has been to mechanize everything possible. Mechanization extends the physical capabilities of the human, though it

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entails physical displacement of some workers. Despite human versatility, the bounds of human physical capabilities are extremely limited. Well-conceived machines can readily take over human labour, and even out-perform the human in the physical domain, although the human is still prized for versatility and cognitive abilities. For such reasons, traditional task allocation between human and machine has been relatively straightforward. Rieger & Greenstein (1982) outline some of the classical methods of task allocation. In essence, the classical approach dissects system function into its constituents (subsidiary functions, tasks and subtasks), and then allocates tasks to either human or machine according to some generalizations regarding human and machine abilities (e.g. Fitts, 1962). This allocation is necessarily "static"; once implemented, it is largely situation-independent and unchanging with time.

Computerization has increased in sophistication to a level capable of mimicking or enhancing many functions that have traditionally been performed by humans. The implications for task allocation between human and machine are intriguing. First, the computer has not become the cognitive equivalent of the human; it excels in some abilities but is deficient in others. Automation tends, therefore, to displace rather than replace the human. This occurs, for example, when a human operator is replaced by a computer and then becomes the supervisor of the computer. As the development of the computer continues, assigning the human the correct tasks, and at the same time providing for human needs is a particularly arduous endeavour.

Second, generalizations regarding human and machine abilities are becoming increasingly inadequate. They are non-quantitative, subjective, overly general (Rieger & Greenstein, 1982); they do not reflect other important situational considerations, such as trade-offs of the various system costs (Chapanis, 1965); and they do not consider the integration and collaboration of human and computer within systems (Bainbridge, 1982). Hence, systems engineers should exercise discretion when using these general guidelines as a basis for task allocation.

Third, most machines have traditionally been designed with a static role in mind, and have been used in relatively static environments. Because the machine performed only one function, static task allocation was adequate. However, the computer, with its abilities analogous to human cognitive abilities, can be more flexible in its role and in the tasks it performs. Classical methods of task allocation do not permit systems engineers to exploit this flexibility.

Finally, allocation of functions in human–computer systems might in large part be determined by other considerations than comparisons of human and machine abilities. These considerations include social, economic, political, psychological and philosophical criteria (Chapanis, 1965; Nickerson, Myer, Miller & Pew, 1981). It is not only a matter of which entity will perform the task better; there are larger issues beyond this. The systems engineer must be sensitive to these more encompassing organizational issues as well.

ADVANTAGES OF A DYNAMIC APPROACH

Several approaches to this predicament have been suggested (e.g. Nickerson *et al.*, 1981, pp. 71–74). Despite different opinions on task allocation, there is a consensus that the human and computer relationship should be complementary (Hormann, 1971; Jordan, 1963; Licklider, 1960; Rouse, 1975). Rouse (1977, 1981) identified an approach to achieving an adaptive complementary relationship. In multiple-task situations where human and computer possess overlapping capabilities, responsibilities (functions, tasks and subtasks) can be dynamically allocated to the human or computer. This approach is particularly appropriate for the control of dynamic systems. A dynamic allocation approach assigns a particular task to the decision-maker that has at that moment the resources available to perform the task. Dynamic allocation is adaptive in that the allocation depends on the state of the system as well as the states of the decision makers. Rieger & Greenstein (1982) showed that by incorporating dynamic allocation in the overall task allocation process, the systems engineer is able to tackle the allocation

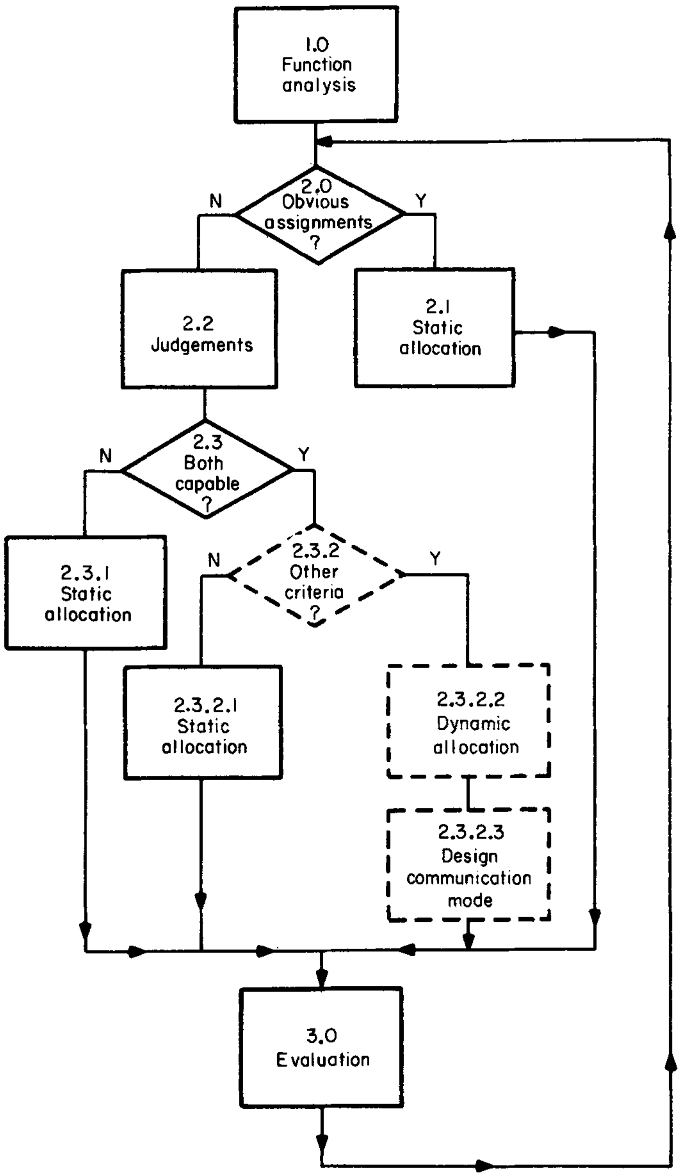

FIG. 1. The task allocation process.

problem in a more flexible, comprehensive, and systematic manner. The procedure for this task allocation process is depicted in Fig. 1. Those stages which particularly require further research to enable implementation are depicted with a broken line, while the stages which may be implemented more directly are depicted with a solid line.

Dynamic task allocation is advantageous from the system and human perspectives (Rouse, 1975, 1977). The human and computer resources available within the system are more effectively utilized. This can be visualized using a queueing theoretic analysis wherein waiting customers (in this case, the tasks) are more promptly served when servers (the human and computer) can move freely among queues. With dynamic task allocation, the human and computer are active simultaneously and each has knowledge about the other's current state. Systems with such parallel components are more fault-tolerant than those without them. Moreover, the human is not separated from some system subtasks; he is thus able to retain necessary knowledge and skill about system operation which can be evoked in case of need (e.g. upon computer failure or malfunction). This contributes to overall system fault tolerance and mitigates human motivational problems as well. The need for periodic retraining and the variability of human workload are also reduced.

Human–computer communication

Dynamic allocation of responsibilities can be initiated by the human or computer, though intuitively it would be more motivating (but more work) for the human to assume the active role. In either case, human-computer communication is essential to inform the other party when and where one will allocate attention. Two types of communication that can be utilized to convey the messages are model-based communication and dialogue-based communication.

MODEL-BASED COMMUNICATION

Model-based communication uses models of human performance to enable the computer to work cooperatively with the human in a reasonably conflict-free fashion. The computer uses these models to predict what the human is likely to do next. The computer then attends to tasks which are likely to be neglected by the human. Communication is implied, and the computer utilizes these implicit messages to complement the human by averting conflicting or redundant actions.

There is an important advantage to the design of a human-computer coupling such that the computer actively seeks to accommodate the human. The human's role retains initiative and primacy, and the computer remains the human's aide (Greenstein, 1980). Rouse (1981) provides two additional reasons for employing an implicit form of communication. The first is to avoid the extra human workload associated with explicit communication. Second, implicit communication may be useful for tapping information which the human is unable to supply explicitly. For instance, a model may be used to predict that the human will devote an inordinate amount of attention to instruments which are irrelevant to the current task set.

A series of recent studies illustrates some interesting properties and the potential utility of model-based communication. In a simulation investigation, Greenstein & Revesman (1981) demonstrated: (1) the importance of the computer using the correct algorithm to act upon model-based communication—use of a poor algorithm resulted in poorer performance than that obtained with no model at all; (2) when an appropriate algorithm was used, system performance increased as the predictive validity of the model increased; (3) for the conditions simulated, explicit communication achieved better system performance than model-based communication. However, as the time-cost associated with explicit communication increased, the differences in system performance achieved with the two communication approaches became less distinct. Greenstein & Revesman concluded that the trade-offs between the two types of communication for dynamic task allocation can and should be carefully considered. Ensuing studies (Greenstein & Revesman, in press; Revesman & Greenstein, in press) demonstrated further the feasibility of model-based communication by the development, validation and implementation of a mathematical model of human performance for human-computer communication in a process control environment.

DIALOGUE-BASED COMMUNICATION

Dialogue-based communication focuses upon the process in which the human uses some kind of computer input device to explicitly relate intentions to the computer. This form of communication is relatively simple to implement, and it averts conflicts of responsibilities between the human and computer with a high degree of certainty. Model-based communication entails a time cost for development and verification of models, an ambiguity cost (the model will not be perfectly predictive of human performance), and an increased load on the computer (when the model demands a great deal of computation). A model must also be capable of representing the human behaviour in question, the computational complexity of the model must be amenable to real time implementation, and the parameters concerned must be measurable (Rieger & Greenstein, 1982; Rouse, 1981). Dialogue-based communication entails direct entry time cost and imposes additional work upon the human. There are likely to be situations in which one method of communication will be superior to the other.

A conceptual framework

To understand better and utilize dialogue-based communication for dynamic task allocation, one can study the factors that generally define interaction between human and computer. These factors include the human user, the computer and system, the task, the task environment and the human-computer interface. The human-computer interface is of particular interest to system designers because in most systems the other factors are either given or relatively fixed; interface design becomes the most flexible tool for enhancing dialogue-based communication.

The interface factor can be further delineated into four subfactors, each amenable to investigation and variation. These subfactors include the medium—the directly communicative hardware used in any human-computer interaction (e.g. dedicated function keys and voice recognition equipment); the mode—the directly communicative software used in the interaction (e.g. menu selection and command language); the style of information presentation used within a particular mode (e.g. the use of colour and formatting); and the strategy—the goal-directed decision-making and choice of action from among various alternatives. Strategies may be task- or task-allocation-related. Task strategy pertains to the ways a given task and mission can be fulfilled by the human-computer system. Task allocation strategy concerns how tasks are allocated between human and computer and is particularly important to the specification of dialogue-based communication for dynamic task allocation.

This framework provides a structure for systematic investigation of dialogue-based communication for dynamic task allocation. A four-dimensional array composed of different combinations of the interface subfactors can be constructed. The goal is to identify those subfactor combinations which specify appropriate interface designs for a given application. A study was conducted (1) to exemplify the use of the framework to conceptualize and delineate the dialogue-based communication problem, and (2) to determine how system performance is affected by different input media and task allocation strategies.

A study of input media and task allocation strategies

METHOD

Experimental task

A Generic ENvironment for Interactive Experiments (GENIE), designed for behavioural research on human–computer interaction in real-time multiple-task situations, was employed (Lindquist, Fainter, Guy, Hakkinen & Maynard, 1983). The task environment represented a simplified version of an air traffic control scenario wherein computer aid could be evoked by the human controller to accomplish task sharing between human and computer.

The primary display monitor showed a radar-like screen with moving aircraft, a guide path and runway, aircraft status, approach information, and remarks (Fig. 2). Also displayed was feedback regarding the total number of planes landed and lost. Planes that followed the designated flight path and landed on the cross hatch were scored as successful landings. Planes flown out of the displayed control area were

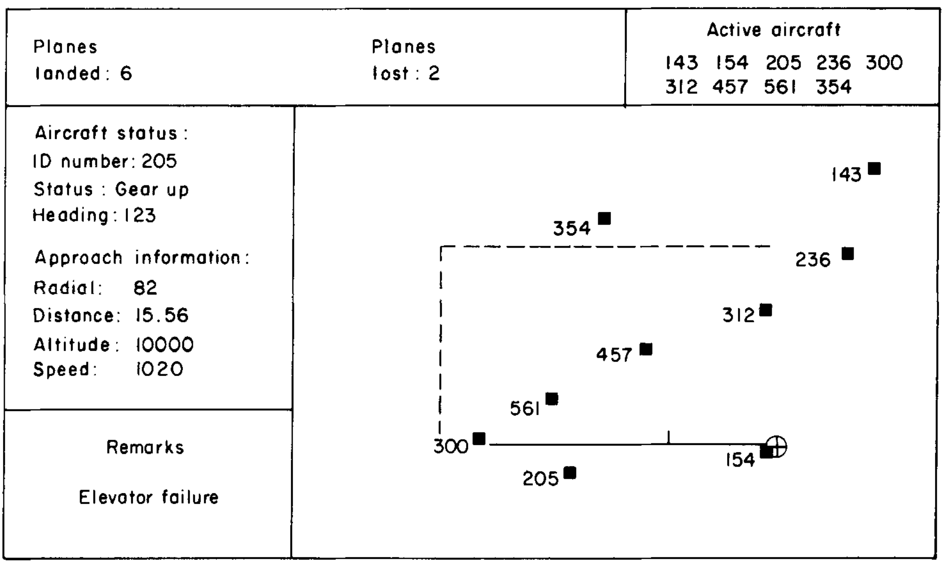

FIG. 2. The primary display.

scored as lost. The dotted path served as a navigation guide for normal landings. A secondary display monitor was used to echo-print human command inputs, and to display messages from the computer (e.g. error messages and requested information).

Planes entered onto the upper right corner of the primary display monitor at a pre-determined rate. The human was to direct and land these planes safely and efficiently onto the runway according to one of two landing patterns. Identification numbers of "normal" planes were displayed in white (against a blue background) in the active aircraft window, and were to be landed adhering to the normal landing path. Identification numbers of planes encountering emergency situations were coded in red; these planes could abandon the guide path and land via the shortest route onto the runway. Ideally three "TURN" commands would be sufficient for each normal landing, and two for each emergency landing. In actual practice, more commands were necessary due to imperfect specification and timing of commands by the human controller. In four of the five conditions studied, computer aiding was made available when the human issued specific "TAKE" commands. The computer-assisted planes would then be coded as round blips instead of square ones, and they would be landed by the computer without further human involvement.

Thus, the scenario represented a high workload, moderately complex, frequent (i.e. the tasks are performed frequently), open (i.e. the tasks are open to the influence of external parameters), and dynamic multiple-task system.

Subjects

Five male and five female college students participated in the study. Prospective subjects were screened for corrected 20/20 vision using a Bausch & Lomb Ortho-Rater. They were also given a 1-min typing test to determine that they could type at a rate of at least 20 words per min.

Apparatus

The basic hardware consisted of a Digital Equipment Corporation GIGI keyboard (model VK100) and two Barco Model GD33 colour monitors interfaced to a Digital Equipment Corporation VAX 11/780 computer. The right monitor was the primary graphics display and the left monitor was the secondary command display. A protractor was attached to the keyboard to provide directional information.

Independent variables

In the context of the proposed framework for the study of dialogue-based communication, the present study was two-dimensional: only input media and task allocation strategies were investigated. Either dedicated function keys or the standard Sholes QWERTY keyboard was used as the medium to input task commands (e.g. "TURN") and allocation commands ("TAKE"). Figure 3 depicts the dedicated function key arrangement employed.

Four allocation strategies plus a control condition were studied.

(1) Control condition, wherein no computer aid was available and the human performed all tasks.

(2) Assignment by designation, wherein the computer might be requested to take over certain tasks pinpointed by their associated identification numbers. The human

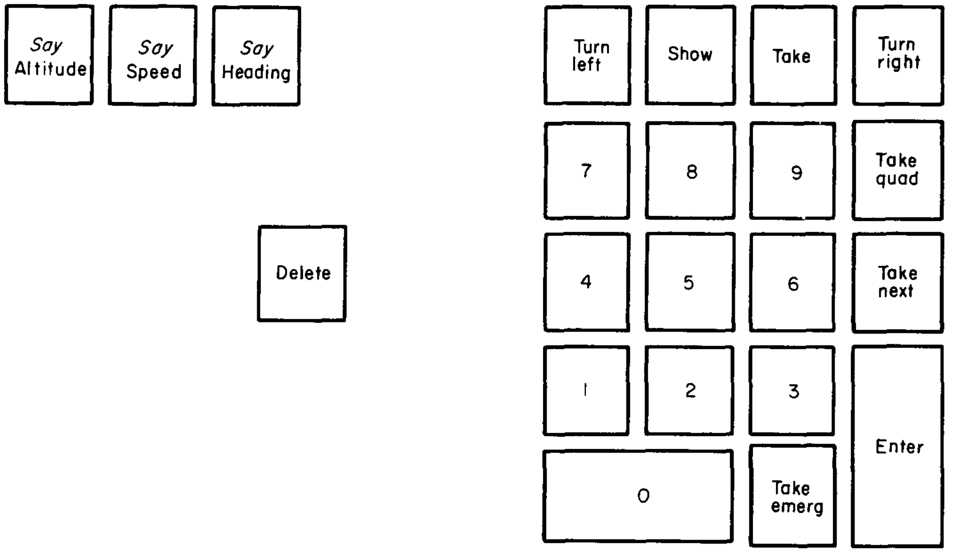

FIG. 3. The dedicated function key arrangement.

could issue, for example, the command "TAKE 200" to ask the computer to take control of the plane numbered "200". One to four planes could be allocated to the computer with one command invocation.

(3) Spatial assignment, wherein tasks within a certain spatial confine were assigned to the computer. The control area was partitioned into four indexed quadrants, and the human could issue, for example, the command "TAKE QUAD 1" to signify that planes within quadrant 1 were to be controlled by the computer. A maximum of two quadrants could be assigned to the computer with one command invocation.

(4) Temporal assignment, wherein tasks occurring within a certain time frame were assigned to the computer. Using the "TAKE NEXT" command, the human could assign up to the next four planes entering the control area to the computer with one command invocation.

(5) Contingency-based assignment, wherein responsibilities for certain contingencies (here, emergencies) were assigned to the computer. One invocation of the "TAKE EMERG" command would effect computer control of all planes on the screen currently encountering emergencies.

It was hoped that this delineation of task allocation strategies might be generalizable to other multiple-task situations. Clearly there are other possible strategies or combinations of strategies that might be incorporated in future studies. It shall be argued in the following discussion of results that there are important idiosyncratic differences in the selected strategies.

Experimental design

There were 10 treatment conditions resulting from the crossing of the two input media with the four task allocation strategies and one control condition. Each of the ten subjects received all the treatments in a balanced Latin square design.

Dependent variables

Fourteen performance measures were metered on-line during the study. These measures can be grouped into five clusters, each reflecting a different aspect of system performance, as presented in Table 1. Subjective ratings were also elicited from the subjects at the end of the experiment.

TABLE 1
Performance measures

Overall system performance measure	
% landed by system	The percentage of planes entering the control area that were landed by the human-computer system
Human performance measures	
% landed by human	The percentage of planes entering the control area that were landed by the human
% correct commands	The percentage of commands entered by the human that were syntactically correct
Computer performance measures	
% landed by computer	The percentage of planes entering the control area that were landed by the computer
# TAKE commands	The number of TAKE commands issued
# planes to computer	The number of planes assigned to the computer
Human error measures	
# errors	The number of action and syntax errors committed by the human
# planes lost	The number of planes lost by the human
# approaches missed	The number of landing approaches missed by the human
# syntax errors	The number of syntax errors committed by the human
Human workload measures	
# commands	The total number of commands issued by the human
# TURN commands	The number of TURN commands issued
# SAY commands	The number of SAY commands issued
# SHOW commands	The number of SHOW commands issued

Procedure

Three 3-h sessions were conducted over 3 consecutive days. The subject was briefed and trained on the first day. Firstly the subject read through a training manual, paced by a tape recording. Then 15-min practice trials were given, with short breaks between trials. These trials represented balanced experience with the two input media and the four task allocation strategies and control condition. The subject was required to demonstrate the ability to land at least two planes to qualify for further participation in the study. In the following sessions, five 30-min counterbalanced trials were given to the subject on each day. These trials were separated by brief rest breaks. Upon completion of the final session, the subject was asked to rate the different input media and task allocation strategies and to supply justifications for the ratings.

RESULTS

Analyses of variance revealed significant input medium and task allocation strategy effects on a number of performance measures. However, no significant interaction effects were found.

TABLE 2
Mean performance measures by input medium

Measure	QWERTY keyboard	Function keys	% difference	F ratio	p
% landed by system	58·87	64·67	+9·85	4·60	0·0353
% landed by human	32·33	37·80	+16·91	6·03	0·0165
% correct commands	88·35	93·33	+5·64	38·98	0·0001
% landed by computer	26·53	26·87	+1·26	0·02	0·8785
# TAKE commands	4·98	5·30	+6·43	0·44	0·5108
# planes to computer	9·88	9·68	−2·02	0·08	0·7768
# errors	25·40	19·26	−24·17	15·06	0·0002
# planes lost	4·70	3·18	−32·34	8·14	0·0057
# approaches missed	5·66	5·60	−1·06	0·01	0·9111
# syntax errors	16·50	10·54	−36·12	17·62	0·0001
# commands	134·40	146·50	+9·00	10·08	0·0022
# TURN commands	94·90	108·16	+13·97	16·36	0·0001
# SAY commands	0·20	0·32	+60·00	0·80	0·3750
# SHOW commands	17·66	22·06	+24·58	15·51	0·0002

Table 2 summarizes the differences in performance obtained with the QWERTY keyboard and function keys conditions. As was expected, there was a significant effect of input medium on performance. Both performance and subjective preference measures indicated that function keys were the more desirable tool for input communication. In general, when function keys were used, more planes were landed and fewer errors were made. The use of function keys had the greatest effect on human perform-

TABLE 3
ANOVA summaries for performance measures by allocation strategy

Measure	df	F-ratio	p
% landed by system	4, 72	21·91	0·0001
% landed by human	4, 72	9·62	0·0001
% correct commands	4, 72	2·27	0·0699
% landed by computer	4, 72	62·76	0·0001
# TAKE commands	4, 72	47·40	0·0001
# planes to computer	4, 72	64·84	0·0001
# errors	4, 72	7·06	0·0001
# planes lost	4, 72	15·25	0·0001
# approaches missed	4, 72	33·24	0·0001
# syntax errors	4, 72	3·75	0·0079
# commands	4, 72	7·60	0·0001
# TURN commands	4, 72	6·87	0·0001
# SAY commands	4, 72	1·30	0·2800
# SHOW commands	4, 72	3·49	0·0117

ance. The effect on computer performance was not significant. Eight of the 10 subjects preferred function keys, mainly for their keying efficiency. Subjects entered commands at a faster rate, accomplished more tasks, felt a greater sense of control, and experienced less stress in the function keys condition. Subjects also issued significantly more commands using function keys. When function keys were used, subjects clearly exerted more frequent control of the tasks.

Table 3 summarizes the results of the analyses of variance for the performance measures as a function of task allocation strategy. Significant differences ($P<0 \cdot 05$) were noted for all but two of the performance measures. *Post-hoc* least significant difference (LSD) tests were performed to determine the loci of significance. Representative results of these tests are presented in Table 4, which shows the control condition, in which computer aiding was not available, resulted in the fewest planes landed and the most planes lost. This condition was also the least preferred by the subjects. Of the four different task allocation strategies considered, spatial assignment (QUAD), contingency-based assignment (EMERG), and assignment by designation (ID) achieved the highest levels of overall system performance. Temporal assignment (NEXT) was significantly poorer in this regard, as Fig. 4 indicates. Subjective ratings revealed an overall preference for assignment by designation, followed by spatial

TABLE 4
Results of selected LSD tests on performance measures by strategy

% landed by system				
Control	NEXT	ID	EMERG	QUAD
40·33	55·17	68·50	68·84	76·00
% landed by human				
QUAD	NEXT	ID	Control	EMERG
22·33	33·50	38·00	40·33	41·17
% landed by computer				
NEXT	EMERG	ID	QUAD	
21·67	27·67	30·50	53·67	
# TAKE commands				
EMERG	QUAD	NEXT	ID	
4·40	4·85	6·05	10·40	
# planes lost				
QUAD	ID	EMERG	NEXT	Control
2·35	2·75	2·85	3·75	8·00
# commands				
QUAD	EMERG	NEXT	ID	Control
126·30	134·10	138·30	146·75	156·80

Bracketed means are not significantly different ($P>0 \cdot 05$).

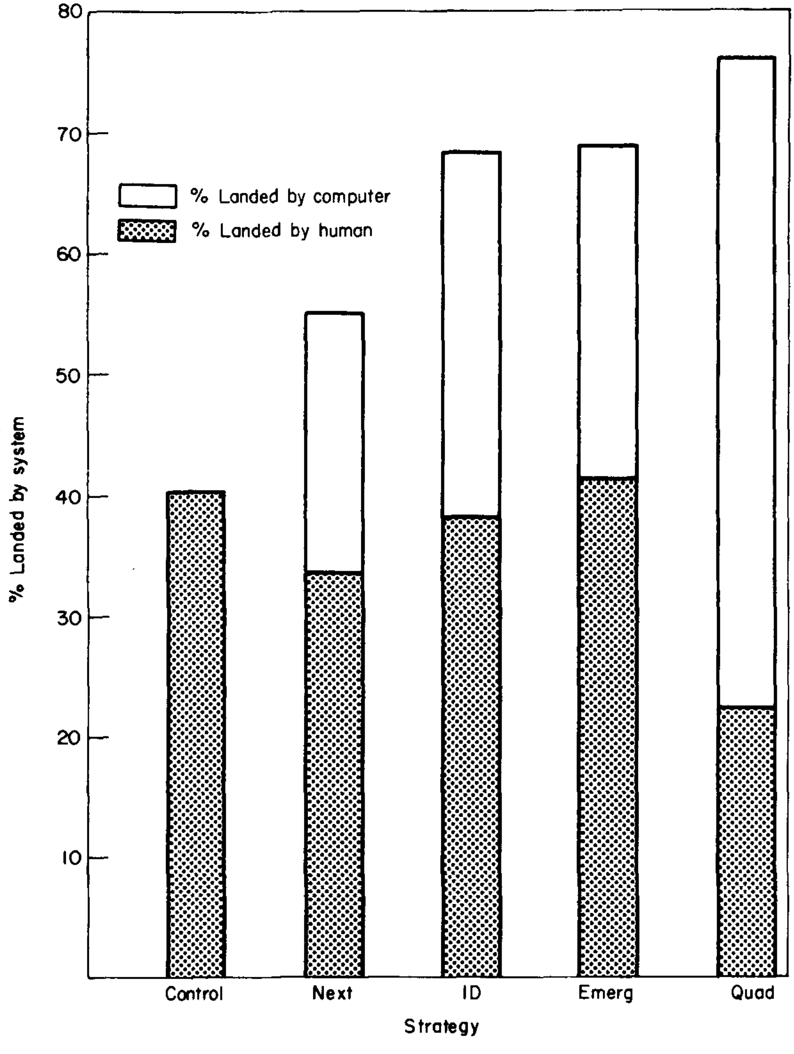

FIG. 4. Percentage of planes landed by the system.

assignment and contingency-based assignment. Subjects rated assignment by designation the most flexible strategy, while they considered spatial assignment to be the most powerful strategy.

DISCUSSION

Function keys may represent a better input medium than the QWERTY keyboard because they permit a faster input rate and convey structured input cues to the user that demand less cognitive processing. Function keys are especially desirable in situations where the tasks, subtasks and commands are relatively simple, the number of possible commands is relatively small, and the input rate is of considerable importance. When the task environment becomes more open and complex, and when the total number of possible commands increases, selecting and locating the correct function keys may become taxing.

Subjects who preferred the QWERTY keyboard mentioned its inherent flexibility. As the number of possible commands increases in a situation, there is likely a point beyond which the QWERTY keyboard becomes a better input medium than function keys. Another comment made by those who preferred the QWERTY keyboard was that the longer keying time imposed by it enabled them to contemplate the appropriateness of their command and objective before the command was issued. As a result, erroneous or inadequate commands could be averted. It is possible that this enforced delay may be beneficial in some situations because it increases the time opportunity for cognitive participation. The performance measures tabulated in this study do not support this hypothesis, however.

The four task allocation strategies possessed diverse characteristics. First, the strategies differed in degree of specificity. Assignment by designation was the most specific strategy in that it could be used to pinpoint particular planes for assignment to the computer. Temporal assignment and contingency-based assignment were the next most discriminative, and spatial assignment was the least.

Assignment by designation was also the most flexible strategy in that it could be used to assign virtually any proportion of the planes currently on the screen to the computer. This was reflected in the comments of the subjects who participated in the experiment. Spatial assignment ranked next in flexibility, followed by contingency-based assignment and temporal assignment.

Due to its flexibility and specificity, assignment by designation may instill a greater sense of control in the human. This feeling of control diminishes as the human moves to spatial assignment, contingency-based assignment, and temporal assignment.

The four strategies also differed in power. Power is taken to denote the average number of planes that can be allocated to the computer with one command invocation. Spatial assignment was the most powerful strategy. This is reflected by the fact that while spatial assignment was among the strategies associated with the smallest number of task allocation commands, the percentage of planes landed by the computer was greatest in this condition. Depending on the total number of emergency planes on the screen, contingency-based assignment might have been equally powerful at times. Temporal assignment was not as powerful, and assignment by designation was least powerful. The powerful strategies tend to reduce the number of task allocation commands issued by the human. This trend is reflected in Fig. 5.

The four strategies referred to different dimensions. Spatial assignment concerned the dimension of space, temporal assignment, the dimension of time, and assignment by designation and contingency-based assignment some particular cases within a certain time and space. The different reference dimensions varied in their degree of abstraction. Time would seem to be a more fluid and abstract concept than space, while referring to specific planes or contingencies is probably least abstract. If so, temporal assignment entailed manipulation of the most abstract concept.

Temporal assignment possesses two additional shortcomings. The human does not know what will come next or what will be taken care of by the computer component. This uncertainty might induce a diminished sense of control in the human. Further, a problem with temporal assignment may occur when the human believes that a command is still active (when in fact it is not) and that the computer will continue taking care

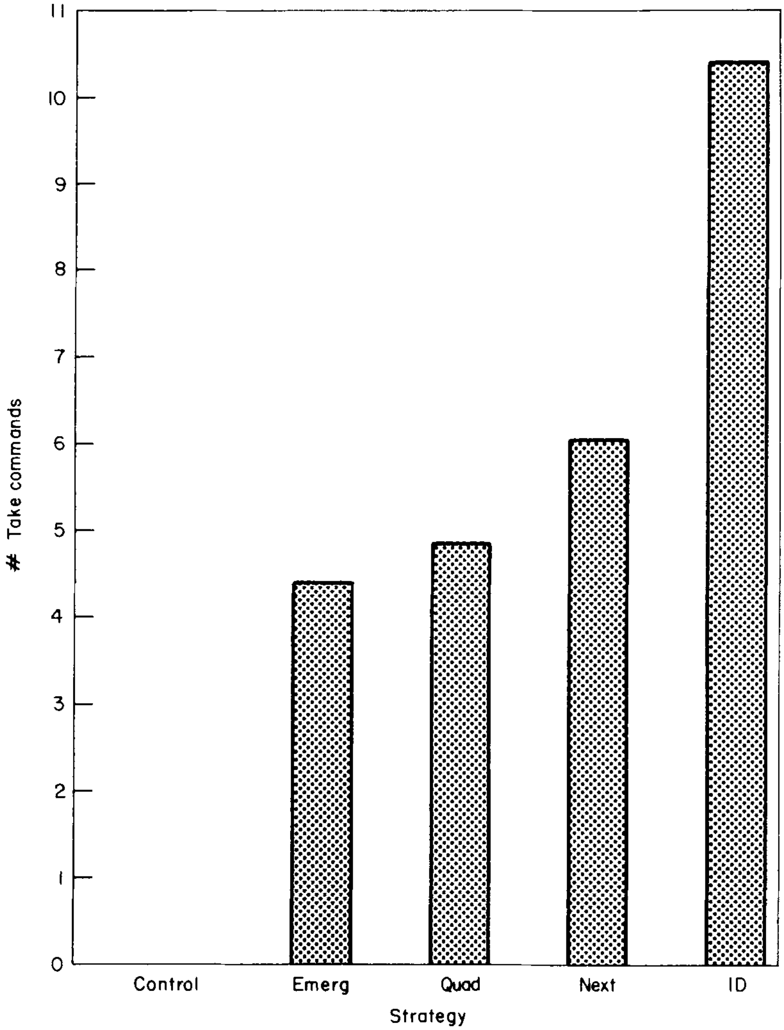

FIG. 5. Number of task allocation commands issued by the human.

of future tasks. When the tasks are not taken care of, the human will have a difficult time keeping up with the flow of tasks. Hence, using temporal assignment entails the extra labour of keeping track of the tasks assigned to the computer component to determine what has and what has not been done.

Spatial assignment was the most powerful and least discriminative strategy. Assignment by designation was the most flexible and specific, and was also most preferred by subjects. In terms of system performance and system adequacy data, the two strategies were comparable. Although no interaction effect was found between input media and strategies, it might be speculated that when the QWERTY keyboard is used, spatial assignment may be the more appropriate strategy. This is because the QWERTY keyboard is a slow input medium while the spatial assignment strategy is powerful, requiring few invocations. In this instance, QWERTY keyboard input and spatial assignment strategy may be complementary. However, when function keys can be used, assignment by designation may become the preferred strategy. Assignment by designation can be used in this case to boost the human's sense of control, with the increased number of task allocation commands compensated by the use of a faster input medium.

Conclusion

The strengths of dialogue-based communication relative to model-based communication for dynamic task allocation are that it is relatively simple to implement and it averts conflicts of responsibilities between human and computer with a high degree of certainty. Dialogue-based communication imposes, however, a communication task upon the human, increasing workload in a situation already involving multiple tasks. Given that there are situations in which dialogue-based communication is the method of choice, a reasonable research goal is the development of guidelines for the design of efficient task allocation dialogues.

The development of such guidelines can begin with a study of the factors that generally define interaction between human and computer: the human user, the computer and system, the task, the task environment, and the human-computer interface. The design of the human-computer interface in particular offers the greatest opportunity for realizing efficient dialogue-based communication. The interface factor can be addressed in terms of four subfactors: (1) the medium, consisting of the hardware employed for human-computer communication; (2) the mode, composed of the software developed for communication; (3) the style of information presentation used within a particular mode; and (4) the strategy, the goal-directed decision-making involved in accomplishing the tasks. In situations involving dialogue-based communication for dynamic task allocation, the overall task strategy depends in part upon a strategy for the allocation of tasks between human and computer. An optimal interface for a given human-computer system can be specified in terms of a specific combination of the four interface subfactors. The development of guidelines for the design of efficient task allocation dialogues can thus be pursued through the identification of appropriate combinations of medium, mode, style and strategy for a given human-computer system and task environment.

The dialogue-based communication study reported here investigated the effects of two input media and four task allocation strategies on the performance of a human-computer system within a simplified air traffic control task environment. Dedicated function keys proved to be a more effective medium than the standard QWERTY keyboard in terms of both objective performance and subjective preference measures. Of the task allocation strategies considered, spatial assignment, contingency-based assignment, and assignment by designation achieved the highest levels of overall system performance, while temporal assignment achieved a significantly lower level of performance. Subjective ratings indicated an overall preference for assignment by designation, followed by spatial assignment and contingency-based assignment. Spatial assignment was the most powerful strategy; it could be used to allocate many tasks with one command invocation. But spatial assignment was also the least specific strategy; it could seldom be used to pinpoint particular tasks for assignment to the computer. Assignment by designation was the least powerful strategy, but the most specific and the most flexible; it could be used to assign virtually any subset of the current tasks to the computer.

This work may serve as a basis for further investigation of the effect of interface medium, mode, style and strategy on dynamic task allocation and overall system performance. First, additional input media, including, for example, the touch sensitive display and voice-recognizer might be considered. Second, different dialogue modes, including human-initiated, computer-initiated and mixed-initiative modes might be investigated. The study reported here utilized a small set of subject-invoked task allocation commands and thus involved only human-initiated task allocation dialogue. Examples of computer-initiated dialogues include form-filling and menu selection. Under a mixed-initiative dialogue, the computer is programmed with a representation of the task environment. Typically the human initiates the interaction, but the computer takes initiative when the human overlooks some aspect of a task or requests assistance. A comparison of these dialogue modes may indicate their relative appropriateness for task environments involving different levels of stress and workload. Through conduct of a sequential program of research, it will be possible to determine a comprehensive set of guidelines for the design of efficient task allocation dialogues.

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