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Quarterly Technical Report PTR-1033-78-7
Contract MDA903-76-C-0241
ARPA Order No. 3200
for the period April 1, 1978
to June 30, 1978
Report Date July, 1978

AD-A134 980

COMPUTER-BASED SUPERVISORY SYSTEM FOR MANAGING INFORMATION FLOW IN C3 SYSTEMS: AUTOMATED INFORMATION SELECTION AND PACING

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Michael G. Samet

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Prepared for:

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER PTR-1033-78-7	2. GOVT ACCESSION NO. A134 980	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Computer-Based Supervisory System for Managing Information Flow in C3 Systems: Automated Information Selection and Pacing		5. TYPE OF REPORT & PERIOD COVERED Quarterly Technical 4-1-78 to 6-30-78
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Michael G. Samet		8. CONTRACT OR GRANT NUMBER(s) MDA903-76-C-0241
9. PERFORMING ORGANIZATION NAME AND ADDRESS Perceptronics, Inc. 6271 Variel Avenue Woodland Hills, California 91367		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ARPA Order No. 3200
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency Office of Human Resources 1400 Wilson Blvd., Arlington, VA 22209		12. REPORT DATE July 1978
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Adaptive Models
Command and Control
Decision Aids
Decision Making
Information Exchange
Information Pacing
Information Processing
Information Routing
Information Selection
Man-Computer Interaction
Multi-Attribute Utility

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

>This report begins with a ~~brief~~ summary of progress on work centered on the demonstration and implementation of a system of integrated on-line adaptive user models designed to automatically select information for multiple users in a simulated command, control, and communication (C3) system. The report then goes on ~~to~~ provide a formal description of a portion of the system designed to automatically select and pace information messages. The algorithms which control information presentation are based on a multi-attribute

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20. ABSTRACT (Continued)

decomposition of message content. The information-selection model employs adaptive training logic to prioritize available messages for an individual operator according to his observed information preferences. The information-pacing model calculates the display duration of each selected message on the basis of certain characteristics of the message (e.g., length) and of the operator (e.g., cognitive load - as assessed on-line through the implementation of a competing secondary task). Experimental demonstrations of the system were conducted within the context of a politico-military simulation. The results demonstrated the system's capability to adapt to varied individualized information processing strategies, and to automate the presentation of verbal messages as appropriate to different operator styles. Furthermore, When information flow was automatically controlled by the computer, users were able to process information effectively. The techniques are discussed in terms of the advantages and potential of the adaptive approach toward improving information management in computer-based systems.

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0. SUMMARY

0.1 Report Period

This period of contract activity primarily involved software development and system implementation of the newly developed configuration of information selection and pacing models in the multi-man situation. In addition, the configuration of models previously developed for the single-man system was refined, demonstrated, and documented. The specific tasks accomplished during the report period included:

Multi-Man System

(1) The program supervisor and subject processes were coded, tested, and implemented on the PDP 11/45 computer system.

(2) The display software for monitoring and controlling operator stations was designed and coded.

(3) The interprocess communication software was debugged with respect to the UNIX operating system.

(4) The message base for the Tactical and Negotiations Game (TNG) scenario was extended and adapted for interactive play on the computer system.

Single-Man System

(1) The pacing component of the supervisory system for managing information flow was further refined and subjected to an experimental demonstration within the context of the TNG simulation.

(2) A description of the integrated configuration of the information selection and pacing models - including design, implementation, operation, and demonstration - was prepared and appears as the text of Sections 1 through 5 of this report.

0.2 Next Period

The next period of contract activity will concentrate on the refinement and completion of the software for the multi-man system and the experimental demonstration of system operation. The specific items of work include the following:

(1) Test and refine model components and their configuration.

(2) Improve operator display format according to human factors guidelines.

(3) Implement full message complement within TNG data base.

(4) Code, implement, and debug software for on-line monitoring and storage of operator performance measures.

(5) Conduct simulations and manual run-throughs in order to specify initial parameters and procedures related to the C3 task.

(6) Demonstrate and evaluate system performance.

0.3 Program Milestones

The milestone chart for the contract is shown in Table 0-1, with periods of performance completed to date illustrated as the shaded portion.

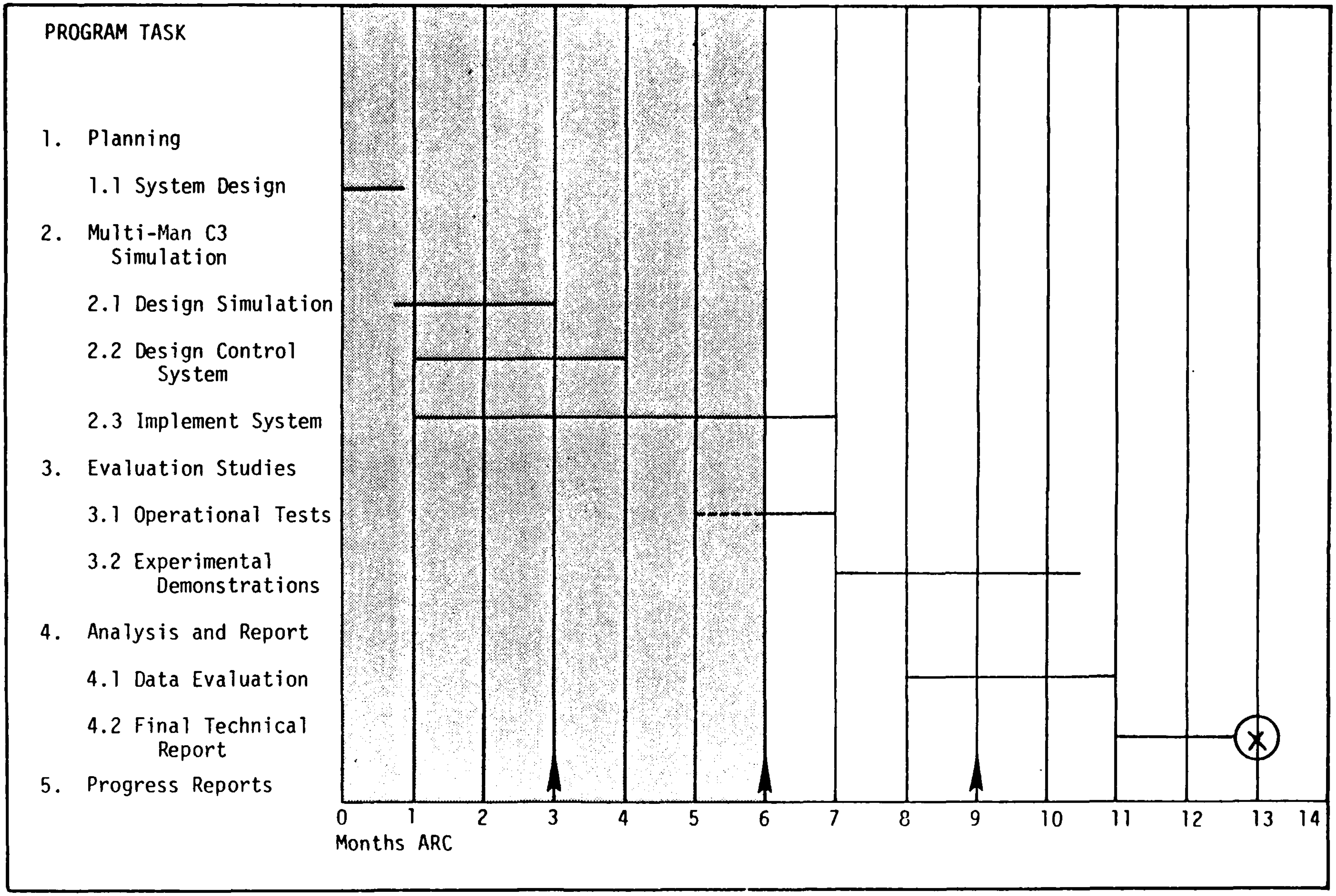

TABLE 0-1. PROGRAM MILESTONES

1. INTRODUCTION

Technical advances have enhanced the capability of military operations to the extent that the amount of relevant information, and the rate at which it is acquired, have greatly increased. For commanders to make tactical decisions responsive to the rapidly changing succession of events requires information to be processed more efficiently and more effectively than ever before. To meet this need, new computer-based command, control, and communication (C3) systems are being developed and implemented. These systems will aid in the collection, processing (e.g., storage and communication, analysis, and interpretation), and utilization of different types and amounts of military data. The overall process is cyclic -- as information is being used, other information is being processed, and new information is being sought and collected. The dynamics of information flow are, therefore, of critical importance and must be constantly monitored and directed.

The consensus concerning current computer-based military systems for C3 operations is that they have increased the density of information flow to such an extent as to overwhelm a commander and his staff. Research is therefore necessary to determine how to control information flow so as to best match the machine capability with the human function in the man-computer interaction. In particular, the programmable features of computer systems should be exploited so that the behavioral dimensions of information flow, such as message selection, routing, sequencing, pacing, etc., can be monitored and maintained in a mix optimal for command decision making.

Future C3 systems will be characterized by an increasing emphasis on the man/computer interaction. Experience and experiment have shown that the most cost-effective computer-based information systems are those which most closely match the requirements of their users. Accordingly, a major goal of C3 system design will be to provide individualized organization and management of dynamic information flow.

The purpose of the research undertaken here is to develop and demonstrate means by which computer-based models of the individual user can be employed to provide the critical function of information control. The goal is to allow each user consistently to obtain information that is both relevant and timely with regard to his individual processing characteristics and immediate decision making needs. Such an aid could improve system effectiveness by increasing the efficiency of information selection and presentation.

The specific objective of the research program was to develop, implement, and demonstrate a prototype adaptive system for automatically selecting and pacing information messages for an individual user performing a complex information processing task. The design of the system is based on the logical integration of separate models for information selection and information pacing. Subsequent sections of this paper present the components and dynamics of the system, describe an experimental demonstration of its operation, and discuss extended developments and applications of the system concept.

2. SYSTEM DESCRIPTION

The domain of application for the information selection and pacing models developed here is a dynamic local environment, where new information of the same general type must be processed repeatedly. Such environments are common in modern computer-based C3 operations. If the human operator and the computer can be considered as representing a single man-machine system, then the goal of the technique is to provide the operator with information which will improve the overall decision output of the system. The two models composing the system are described separately below.

2.1 Information Selection Model

The basic concept of the information selection model is illustrated in Figure 2-1. The message universe includes all information currently available to the operator or system user. In the manual mode, the recipient continuously selects messages in accord with a selection strategy. A strategy represents individual preference for information in response to situational needs. In the automatic mode, an adaptive program automatically selects messages for the user on the basis of the individual's selection strategy which the program has learned.

The factors which characterize an individual's strategy are incorporated in an adaptive multi-attribute utility model. In this model, messages are decomposed into measurable attributes such as content area, level of specificity (summary or detailed), and whether or not the operator has previously seen the message. The subjective weight, or utility, that the user places on each attribute is estimated on-line, by an adaptive technique, as the user manually selects information. The utilities, in combination with the measured attribute levels, permit

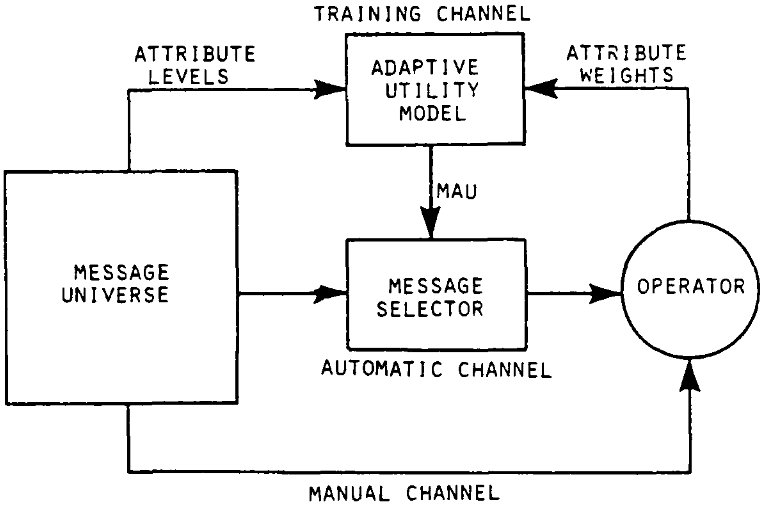

FIGURE 2-1. INFORMATION SELECTION MODEL

calculation of a multi-attribute utility (MAU) value for each available message. The selector mechanism then passes to the operator the message(s) in the queue with the highest MAU. In situations where several messages are sent to an operator simultaneously, the model-based selector can reduce the size of the transmitted message set by retaining only those messages which contribute more than some criterion value of utility. For example, a pruning rule has been demonstrated which first ranked messages in order of decreasing MAU; then, beginning with the message with the highest MAU, each successive message was added to the set only if its individual MAU value exceeded 15% of the total MAU of all messages already in the set (Samet, Weltman, and Davis, 1976).

The MAU for a given message (i) is computed on the basis of its level on each attribute (A_{ij}) and the current importance or utility weight for that attribute (U_j). Thus

$$MAU_i = \sum_{j=1} A_{ij} U_j$$

The A_{ij} are derived directly from characteristics of the message, and these levels are stored in the data base together with the text of the message. The U_j are continuously updated in accordance with a weight training algorithm applied to repeated paired-comparison preference choices made by the operator. He is presented with the headers (i.e., vector of attribute levels) for each of two potentially available messages and is asked to state a preference for actually receiving one message or the other. As the operator performs his task, the on-line weight estimator observes his choices between each pair of message headers, and views his decision-making as a process of classifying patterns of information attributes. The estimator predicts each choice by classifying the attribute patterns by means of a linear evaluation (discriminant) function. These predictions are compared with the operator's actual choices. Whenever they are incorrect, the adaptive error-correction training algorithm shown in Table 2-1 is used to adjust each entry (U_j) in the utility vector. More details concerning this technique can be found in Freedy, Davis, Steeb, Samet and Gardiner (1976) and Samet, et. al. (1976).

2.2 Information Pacing Model

The pacing model, designed to present one message at a time, is based on the implementation of a secondary task (involving choice reaction time) to dynamically assess the operator's load on the primary C3 information processing task (i.e., the reading and analysis of messages). An adaptive algorithm continually adjusts the pacing rate in accordance with fluctuations in assessed operator load. In addition, the display time for each specific message is adjusted as a function of a set of predetermined pacing attributes. The parameter values required by the model are determined in an operator calibration session. A more detailed description of the model follows.

A single pacing algorithm is used to compute the display time for each message before it is presented on the screen. The algorithm has two basic components. The first component involves a baseline display time which is adaptively adjusted in accordance with gradual changes in operator response to task demands as measured by secondary task performance. The adjustment process is accomplished reiteratively across a moving window of task performance lasting about 30 seconds. The second component is a linear function of specific features of the particular message to be displayed.

TABLE 2-1

WEIGHT-TRAINING RULE

						CORRECTION DIFFERENCE		
Adjusted Weight		Previous Weight		Adjustment Factor		Attribute Level in Chosen Message (i)		Attribute Level in Predicted Message (k)
U_j	=	U_j'	+	λ	$\cdot$	$[A_{ij}$	-	$A_{kj}]$

The two components are combined multiplicatively to determine the display time ($M_{i,e}$) for message i during interval (i.e., window) e:

$$M_{i,e} = (1 + D_i)\, T_e ,$$

where

$$D_i = b_1 p_{i1} + b_2 p_{i2} + \ldots + c$$

and

$$T_e = \text{baseline display time during interval } e.$$

D_i is the estimated relative signed-deviation in display time for message i as a function of pacing-attribute levels (p_{i1}, p_{i2}, ...), regression coefficients (b_1, b_2, ...), and a constant (c). The parameters of the equation are determined from an analysis of operator performance during a calibration session in which messages are self-paced. By considering a large number of these self-paced messages, a step-wise linear regression analysis can be performed with the levels of all attributes of message i as the independent (predictor) variables, and the relative signed deviation of the observed message display time (M_i) from some overall mean display time ($\overline{M}$), namely $D_i = (M_i - \overline{M})/\overline{M}$, as the dependent (criterion) variable. In this manner, a subset of message attributes can be identified to serve as the pacing attributes (p_{i1}, p_{i2}, ...). Thus, the role of the $1 + D_i$ term is to proportionately increase or decrease the current baseline display time in terms of the expected processing time requirements for the particular message to be presented.

The baseline display time (T_e) for interval e is based on an adjustment to the operator's baseline display time during the previous interval (T_{e-1}) in accordance with his level of primary task load as inferred from his observed level of secondary task performance during that interval. Performance on the secondary task is a function of the operator's reaction time on a decision choice task. At the start of a system paced session, the baseline display time is initialized at the previously calibrated average message processing time for the operator (T_0). Thereafter, the baseline display time is adjusted on an interval-by-interval basis by the following equation:

$$T_e = T_{e-1} + (S_{L,\ e-1} - S_{X,\ e-1}) \cdot \Delta,$$

where

$S_{L,\ e-1}$ = observed level of secondary task performance during interval e-1;

$S_{X,\ e-1}$ = Expected level of secondary task performance during interval e-1, determined in accordance with previously calibrated operator task performance;

Δ = Adaptive increment (i.e., sensitivity coefficient determining the amount of change in T per unit difference between $S_{L,\ e-1}$ and $S_{X,\ e-1}$).

The expected level of secondary task performance is computed as a function of S_0, T_0, and T_{e-1}, where S_0 is the standard or average level of secondary task performance achieved by the operator during the calibration session for which his average message processing time was T_0. The equation describing this computation is:

$$S_{X,\ e-1} = \frac{S_0}{T_0} T_{e-1}.$$

Thus, during a given interval the expected level of secondary task performance is proportional to the actual level of primary task performance.

2.3 System Process Description

The functional block diagram in Figure 2-2 shows the major components of the information selection and pacing system. These components can perhaps be most easily described in terms of their impact upon each other.

The scenario-generated "Message Universe" leaks messages into an "Available Ranked Messages" store in accordance with a preselected time-dependent distribution (e.g., Poisson). This process depicts the situation in the real world where messages generated from the external environment are not available for display until they have been stored in a computer data base. In addition, the time-tagged message inflow could allow for message age (from time of availability) to be computed and used as a message attibute likely to affect operator information preferences.

The messages in the available store are continually maintained in rank order according to their aggregate MAU value. The computation of MAU is determined by the "MAU Model" whose input includes the respective attribute levels determined for each message, and the attribute importance weights currently assessed for the operator. Thus, the available information store represents a queue of messages whose MAU ranks are updated continuously, i.e., whenever a new message enters the stack, whenever any message attribute level changes, or whenever the operator's attribute importance weights change.

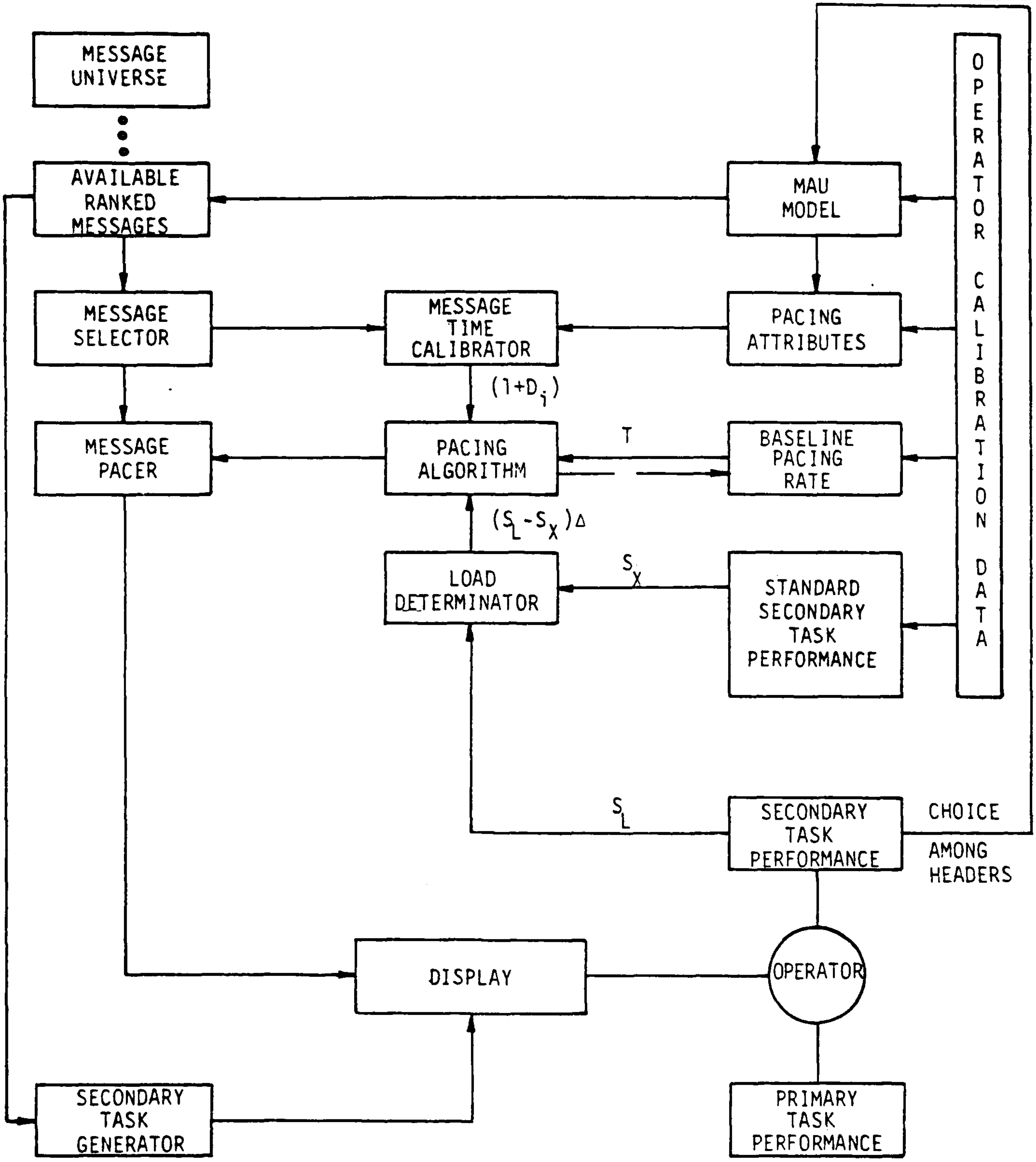

FIGURE 2-2. INFORMATION SELECTION AND PACING MODELS

Messages are extracted from the available message store and displayed to the operator by the "Message Selector" and "Message Pacer". The selector simply chooses the available message with the highest current MAU value. The pacer takes advantage of the "Pacing Algorithm" which is directly dependent upon multiple components. Initially, a "Baseline Pacing Rate" for the operator is determined from previously collected calibration data. This baseline rate is then adjusted by the algorithm in two separate ways: first, a message-by-message adjustment is made by the "Message Time Calibrator" unit. This calibration utilizes the level of specific "Pacing Attributes" of each particular message to predict how much its display time should be increased or decreased with respect to some average message display time. Second, the "Pacing Algorithm" adjusts the baseline display time within a given time interval as a function of operator load during the previous interval. The adjustment is carried out by the "Load Determinator", which measures load on the primary task by comparing, across the previous interval, the operator's observed level of "Secondary Task Performance" (S_L) with an expected level (S_X) derived from a "Standard Secondary Task Performance" score. The expected score is determined from parameters observed to be appropriate to the given operator in a calibration session. Thus, "Operator Calibration Data" provide an important contributory component to the pacing procedure.

The "Operator" performs the primary task and secondary task concurrently; his major goal is to process information contained in the messages in order to provide effective "Primary Task Performance". The successive messages (i.e., input for primary task) and message headers (i.e., input for secondary task) presented to the operator on his "Display" both originate from the "Available Ranked Messages" store. The message headers are produced by the "Secondary Task Generator", which displays the headers corresponding to two messages randomly picked from the store. Finally, the operator's decisions or choices among headers which result during "Secondary Task Performance" play a role in updating the "MAU Model".

2.4 Summary

The integrated configuration of the information selection and pacing models determine what new information should be supplied to the operator and when it should be supplied. In fact, the two models are logically interconnected through the secondary task, which involves the paired-comparison choices between headers of available information messages. The rate of decision performance on this task is pivotal to the pacing model, while at the same time, the actual choices serve the important additional function of training the adaptive information-selection model and keeping it tuned to momentary changes in information preferences.

3. EXPERIMENTAL DEMONSTRATION

3.1 Task Scenario and Procedure

The information selection and pacing models were implemented[1] into a C3 scenario based on the Tactical and Negotiations Game (TNG) (Streufert, Castore, and Kilger, 1967). This scenario was selected because it possesses considerable task complexity and provides results with applications to real-world decision making. The scenario required the operator to process information messages and make situation assessments concerning the military, intelligence, negotiation, and economic activity of a small, underdeveloped, fictitious nation called Shamba, which is plagued by an internal revolution and foreign intervention. The four activity areas were matched in scope and complexity, and each was presented to the operator in a separate experimental session. The object of the task was to learn the message content and to correctly diagnose the strategy apparently being followed by an organized rebel movement.

Corresponding to each of the four areas of activity, 30 information messages were available in the data base. This set was composed of 15 pairs of messages, with each pair consisting of a detailed and a summary version of the content. An example of the text of a detailed message within the intelligence area is provided in Figure 3-1. The summary version of the message pair is as follows: "Agent J.S. heard that the enemy may be planning large attacks on a major transportation route in central Shamba."

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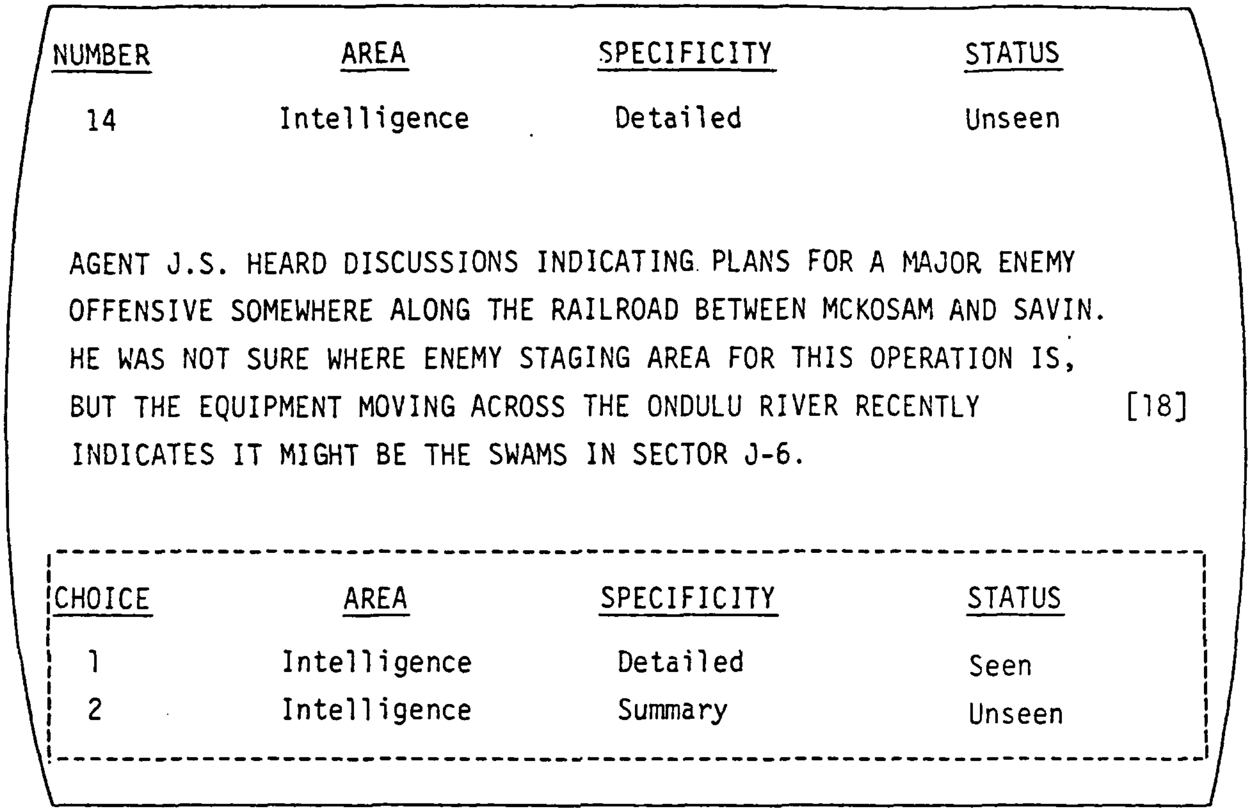
[1] The experimental hardware consisted of a 20-row x 80-column Beehive-100 cathode ray tube (CRT) display, on-line to a PDP-11/45 computer with a Unix operating system.



NUMBER	AREA	SPECIFICITY	STATUS
14	Intelligence	Detailed	Unseen

AGENT J.S. HEARD DISCUSSIONS INDICATING PLANS FOR A MAJOR ENEMY OFFENSIVE SOMEWHERE ALONG THE RAILROAD BETWEEN MCKOSAM AND SAVIN. HE WAS NOT SURE WHERE ENEMY STAGING AREA FOR THIS OPERATION IS, BUT THE EQUIPMENT MOVING ACROSS THE ONDULU RIVER RECENTLY INDICATES IT MIGHT BE THE SWAMS IN SECTOR J-6.

[18]

CHOICE	AREA	SPECIFICITY	STATUS
1	Intelligence	Detailed	Seen
2	Intelligence	Summary	Unseen

FIGURE 3-1. TASK FORMAT ON OPERATOR CRT
[NUMBER IN BRACKETS INDICATES REMAINING MESSAGE LIFE
IN SECONDS; DOTTED, BOXED AREA CONTAINS SECONDARY TASK DISPLAY]

The messages were displayed as shown in Figure 3-1; one message was shown at a time, yet any message could be presented more than once. When messages were automatically paced, remaining display time in seconds was shown along side the message; this number was decremented every 10 seconds, but when less than 10 seconds were left, the countdown was every second. Above the message text, header information appeared which included message identification number, content area, specificity, and status. Only the latter two items were employed as message attributes within the experimental demonstration described here.[2] The specificity attribute took on levels of 0 (summary message) and 1 (detailed message). Status referred to the number of times that the message was previously seen by the operator. For simplicity, when status = 0, "unseen" appeared on the display; when status = 1, "seen" appeared; when status = 2, "seen 2" appeared; etc. For a given message, specificity determined a fixed attribute level, whereas the level for status was dynamically updated as a function of operator viewing.

The secondary task involved a preference choice between two potentially available messages randomly selected from the data base (i.e., "Available Ranked Messages" store). For example, Figure 3-1 presents a choice between a detailed intelligence message that the operator has already seen (choice 1) and a summary intelligence message that he has not seen (choice 2). A new secondary task display came on and off the screen simultaneously as the operator proceeded to read messages; the on time was 6 seconds, and the off time varied at random within an interval from 5 to 11 seconds. The operator indicated his message preference by typing either a 1 or 2 into the keyboard, and his

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[2] In other demonstrations of the system, message content area has been successfully manipulated as an attribute in a modified version of the MAU model.

choice reaction time was used as a measure of secondary task performance. If he failed to respond during the period when the choice was displayed, his reaction time was recorded as 6 seconds. The operator was instructed on the importance of the secondary task, and that he would not immediately receive the particular messages he chose but that the system would keep track of his preferences and would soon select messages for him accordingly. In fact, each time the operator responded, his choice was predicted by the MAU model, and his utility weights for the message attributes were adjusted given an incorrect prediction.

The experimental demonstration was conducted with six college students serving as operators. Each operator was run individually and performed the same basic tasks. After reading a manual providing background on the TNG scenario, and receiving comprehensive instructions concerning the primary and secondary tasks and on how to interact with the experimental console, operators completed a set of problem sessions. The initial session was a practice session in which the pacing of messages was under the control of the operator, i.e., self-pacing. The remaining three sessions were experimental sessions in which message pacing was controlled by either the operator or the computer; the specific pacing manipulations applied in each of the three sessions are described in paragraphs below.

The problem-solving procedure was identical throughout all sessions. Prior to receiving messages about the one activity area presented in the session (military, intelligence, economic, or negotiations), the operator was given four alternative hypotheses concerning the rebel movement's strategy, only one of which was actually correct. A session lasted exactly six minutes, during which time the operator read messages and performed the secondary task simultaneously. At the conclusion of this period, the operator was required to provide a probability vector over the four strategy alternatives, with each probability reflecting his confidence that the respective alternative was correct. In addition, a true-false and a multiple-choice quiz were administered to assess the operator's knowledge/memory of message content. These tests each contained 15 different questions, with one question corresponding to each message pair available within the data base. Thus, for a given operator and session, two measures of information processing performance were available, namely, probability on the correct strategy (y) and number of correct answers (z) for the 30 objective questions. These measures were used in conjunction with an index of secondary task performance [number of missed selections (w)] to compute a bonus payoff[3] for each operator which, when added to his flat-rate pay ($10 for 2½ hours), resulted in an average overall earnings of about $20.

For all operators, the military activity area was presented in the practice session. At the conclusion of this session, each operator received feedback concerning his performance. He then proceeded to complete sessions 1, 2, and 3. The activity areas (intelligence, economics, negotiations) were assigned to sessions according to a Latin Square design so that each group of two operators received a different assignment (ordering). Feedback on performance during the three experimental sessions was not given until the last session was completed. A description of the pacing manipulations during each session, and the type of corresponding calibration data provided, are described below; these manipulations refer to message pacing only, since the secondary task was automatically paced in all cases.

---

[3] The bonus payoff in dollars (BP) for performance on a given session was determined by the following algorithm: $BP=[2 + \log (y + .01)] + [.10z] - [.10w]$.

Session 1: Self-Pacing (SP). In this mode of system operation, the operator reviewed each message for as long as he wanted. When ready to proceed, he pressed a button on the CRT keyboard, and the next message was immediately displayed. Results from this session provided an average self-pacing message rate ($\overline{M}$) for the operator as well as input which could be used to determine the operator-suited regression coefficients for the D_i component of the pacing algorithm.

Session 2: Message-Based Pacing (MP). During this session, messages were automatically paced by the computer. The baseline pacing rate was set for the operator at a fixed value, namely, $T_0 = \overline{M}$, and the display time (M_i) for a given message (i) was computed by $M_i = (1+D_i)T_0$. Thus, in this session, message display time fluctuated around the operator's self-paced message processing rate ($\overline{M}$) as a function of D_i, i.e., in accordance with the levels of the pacing attributes (p) for message i. As it turned out, the same regression equation[4] was employed to compute D_i for all operators, namely:

$$D_i = .6P_1 + .7P_2 - .7,$$

where

P_1 = number of lines of message text appearing on CRT;

P_2 = 1 for an unseen message,
0 for a message scene more than once.

---

[4] This equation accounted for about 50% of the variance in the prediction of D_i.

Thus, for example, if T = 20 seconds, then a two-line, already-seen message was displayed for 10 seconds, and a four-line, not-yet-seen message was shown for 28 seconds.

In the MP session, to summarize, pacing was a function of message parameters and a pre-calibrated operator parameter ($\overline{M}$); however, a dynamic measure of operator load as assessed on-line was not incorporated into the pacing procedure. From operator performance in this session, the calibration parameter S_0 (i.e., standard level of secondary task performance) was determined, and its ratio to T_0 was used to adjust pacing according to assessed operator load in the subsequent session.

<u>Session 3: Load-Based and Message-Based Pacing (LMP)</u>. In this final session, messages were again automatically paced by the computer; however, this time the full capability of the pacing system was applied. In addition to the adjustment of display time as a function of message pacing attributes as done in the previous session (MP), the current pacing manipulation also took advantage of the on-line assessment of operator load. In this session, therefore, the baseline display time (T_e) was initialized at a value of T_0, and was then successively adjusted by the adaptive equation according to the difference between the observed (S_L) and expected (S_X) levels of secondary task performance during each 30 second interval. Then, to obtain the display time ($M_{i,e}$) for message i during interval e, the current value of T_e was multiplied by the message adjustment factor ($1 + D_i$).

3.2 Demonstration Results

The experimental demonstration described in the preceding section was not intended to assess the relative effectiveness of computer-controlled information selection and pacing. Instead, the goal was to demonstrate that these functions, normally controlled by the human operator, could be automated via a user-based model so that the information integration achieved by the operator can be maintained at an acceptable level. Because of the requirement of operator calibration, therefore, no attempt was made to control for the effect of session order (1=SP, 2-MP, 3-LMP) on operator performance. Since the effects of these session manipulations were confounded with any possible effects due to learning or task familiarity, data obtained in these experimental runs were not subjected to tests of statistical significance.

Performance data were averaged across the six operators, and the means for selected dependent measures are presented in Table 3-1. Without making statistical inferences concerning the results, the following observations can be noted. The small differences among sessions with respect to "number of message presentations" and "message display time" do not signify any important performance differences; rather, they reflect slight variations in the types of messages displayed (i.e., pacing attribute vectors and their impact on D_i) and rounding errors within the pacing algorithm. "Secondary-task reaction time" was faster in the MP and LMP sessions than in the SP session, possibly suggesting that when operators are relieved of deciding when to proceed to the next message, their residual task capacity can increase. Had the level of secondary task performance been much slower or faster in the LMP session than in the MP session, then the pacing rates in the two sessions would have differed respectively; but this phenomenon did not occur. As for information processing performance, the results for "percentage of operators with highest probability on the correct strategy" and "percent correct answers" to test questions indicated that operators did a little better in the MP and LMP sessions than in the SP session.

TABLE 3-1. SUMMARY OF AVERAGE RESULTS

PERFORMANCE INDEX	SELF-PACED (SP) SESSION	COMPUTER-PACED SESSIONS	
		MESSAGE-PACED (MP)	LOAD-AND MESSAGE-PACED (LMP)
No. of Message Presentations	25.3	27.0	29.3
Message Display Time (sec.)	14.3	13.9	14.0
Secondary Task Reaction Time (sec.)	3.3	2.7	2.7
No. of Operators with Highest Probability on Correct Strategy	4	5	5
% Correct Answers	60.0	71.0	64.3

In general, the results do not indicate any very large differences in information processing performance as a function of whether messages are paced manually by the operator or paced automatically by the computer. This finding agrees with empirical results obtained by Levine, Samet, and Brahlek (1974) that it made little difference whether information was presented automatically or upon request, as long as the rate of information presentation was approximately equivalent. Furthermore, the data suggest that accurate model-based prediction of required display time on a message-by-message basis may be a reasonable approach to the control of pacing, without the necessity of assessing operator load on-line (by an obtrusive secondary task or other method) and including this measure as an additional adjustment within the pacing mechanism. However, when interpreting this suggestion, it should be kept in mind that the message-based pacing attributes used here (number of textual lines and whether the message was previously viewed) did, in fact, reflect upon immediate operator load.

4. DISCUSSION

Two aspects of this research have been selected for discussion. First, a few advantages of the multi-attribute modeling approach are mentioned. Second, an ongoing research program is outlined which is intended to extend the applications of these models to the computer control of information flow among a cooperative group of operators.

4.1 Advantages of the Multi-Attribute Approach

The adaptive models for information selection and pacing developed in this research are characterized by several attractive features. These features, briefly described below, can be seen as advantages which endorse the application potential of the approach. Although the advantages arise out of the theoretical structure of the models, especially the decomposition property, they have all been empirically illustrated to some degree in the experimental demonstration.

The models are considerably general. They can be applied in a variety of situations where information messages can be decomposed into a small set of manageable, quantifiable attributes. These attributes must be logically taken into account by the operator in judging the utility of potentially available information. That is, they must directly impact upon his choices among competing information messages. Several decision making environments have already been demonstrated to fit this paradigm (e.g., Hayes, 1964; McKendry, Enderwick, and Harrison, 1971; Samet, 1975).

The models are inherently flexible. If accuracy of prediction of information selection or pacing behavior is not sufficient (i.e., if selection or pacing attribute-weights cannot be appropriately adjusted), additional features or attributes can iteratively be added and irrelevant ones deleted. The response to dynamic changes in conditions is similarly flexible; in instances where conditions change rapidly and radically, new sets of weights trained for the conditions can be substituted.

The models are parsimonious. They need only assess an operator's selection or pacing weights for a limited number of information dimensions or attributes. Besides significantly minimizing the models' computational needs and software complexity, this feature is in consort with the result of psychological experiments (e.g., Hayes, 1964; Wright, 1974) and contemporary decision theory (e.g., Hogarth, 1975; Tversky and Kahneman, 1974); namely, that a decision maker can perform an intuitive conscious weighting and aggregation of only a relatively small number of what he considers to be the important dimensions common to the decision evaluation.

The models are robust. Like other linear composition models, their performance (i.e., capability to mimic the information processing behavior of an operator) is not significantly degraded by proportionately small perturbations in the model's parameters (Dawes and Corrigan, 1974).

4.2 Further System Development

Research and development efforts are continuing to provide a far-reaching extension of the adaptive modeling technique for information selection from the domain of the individual to that of a group. The fundamental idea is to route information to individual operators in accordance with a group-based model of information preferences and needs. This multi-man supervisory system takes into account each operator's preferences both for receiving and for sending information messages, as well as his position (i.e., relative power) or communicative role within the group. Basically, the pattern of information distribution is expressed as a compound set of multi-attribute information utility models which comprise each operator's information preferences for himself and for each of the other group measures.

These individual-based models are continuously integrated by the system so that the combined roles of the individual group members (i.e., pattern of information exchange), commonly referred to as the group "structure" or "communication network", can be dynamically altered in real-time. Essentially, the idea is to adaptively distribute "power" or control over information flow among group members in accordance with measures of each operator's relative expertise. The goal of these manipulations is to create the most effective policy of information exchange in response to situational needs.

In the system under development, a computer program continuously monitors the "goodness" or relevance of messages received by each group member, and accordingly, it automatically adjusts group structure in real time in the direction which offers more effective message communication among group members. Furthermore, the allocation of power over information flow can take on a different distribution (i.e., group structure) vis a vis each individual in the network. Structure is manipulated by means of the relevant knowledge-base and information-distribution power demonstrated by each group member, and power is considered to be proportional to an operator's expertise to both evaluate and route information. This approach fits the theoretical framework of Wood (1973), which conceptualizes the group decision process as "a multi-phased process, in which participation, multiple bases of power, and interaction dynamics affect power relationships". In this view, the distribution of power is sensitive to both situational and individual differences, and it serves as an intervening variable which determines group structure.

The notion of having a computer, rather than people, manipulate group structure is particularly appealing in light of a recent hypothesis stated and confirmed by Bourgeois, McAllister, and Mitchell (1977), namely: "...environment-organization contingency theories are not only counter-intuitive but in fact require organizational participants to respond in a manner quite opposite to their natural inclinations". Thus, for example, a member of a decision making team might be intuitively inclined to decrease information communication at a time when he should in fact increase it. In such cases of consistently poor human performance, the normative rule-based procedures of computer control could serve as a potentially valuable information processing aid.

An interesting and important characteristic of this computer-controlled model for information exchange is that an operator (i.e., receiver of information) need not be informed of the current status of the communication network, i.e., how much relative information-control power he or anyone else has. The implication of anonymity is that non-constructive bias, resulting from the social psychology of role relationships in a people-controlled communication network, can be removed from the information-distribution system. Such bias is represented, for example, in the common and sometimes tragic problem brought on by status differential when a subordinate fails to tell his commander something that the commander would ordinarily need or would want to know in a particular situation. In the system under development, such information would automatically be passed to the commander by a consistent, intelligent model which incorporates his stable preferences for receiving specific information, and which is not affected by the psychological "noise" in the communication channels.

4.3 Conclusion

The work described here allowed the development and demonstration of a computer-based adaptive system which automatically selects and paces information messages for a human operator. It is anticipated that these kinds of user-based models can be incorporated into an integrated complex of intelligent aids for supporting real-time management of information flow. Considerable empirical work, however, will be required to assess the impact of such man-computer systems on the quality of information processing and decision making.

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