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ABSTRACT

Visual mental imagery protocols can provide step-by-step traces of executive decisionmaking. Sequences of drawings that externalize thought processes are often easier to analyze than transcriptions of tape recorded verbal protocols. The technique is of obvious use for investigating spatial problem solving behavior since such tasks are usually solved with sketches, drawings, or graphs; the methodology is also appropriate for abstract, non-spatial decisionmaking for which mental images often function as models that managers mentally construct and manipulate. This paper reports an application to the analysis of decisions by a high level executive: the commander of a naval task force. The study will influence both design and evaluation of the command and control systems that support tactical decision making by such commanders and their staffs, over long periods, in hostile environments under extreme stress.

1. THE IMPORTANCE TO MIS OF COGNITIVE DECISION RESEARCH

The psychological study of managerial decisionmaking is essential in the design and evaluation of many information systems. A growing tradition of psychological research in MIS demonstrates its importance to investigators. According to Keen and Scott Morton (3), it is fundamental to the design of Decision Support Systems (DSS); Schneidewind (1980, personal communication) and others argue for the study of human problem solving processes in other MIS areas. Nonetheless, some of the best known DSS's (1,2,4,5) are not based on extensive formal research on managerial decision making behavior. Their roots are frequently in normative theories developed by microeconomics, finance, or other disciplines; alternatively, systems may gain recognition by exploiting new computer technology in clever, innovative ways. In the development of more conventional information systems, behavioral decision research is even less influential.

This inattention to the managerial decisionmaking process has unfortunate consequences. Although Stabell (6) found that implementations of portfolio management systems provided important benefits including better communication with clients, the designers did not achieve their primary objective: shifting the orientation of security analysts from individual securities to overall portfolio management. Drawing on Stabell's analysis of such experiences, Keen and Scott Morton warn DSS designers not to make commitments for significant cost savings or other objectively measurable achievements. It is much too risky!

Partly because DSS's are chancy, users are middle managers, not executives. Also, in comparison with large traditional data processing systems, DSS's are invariably smaller, less sophisticated, and much less expensive: modest projects minimize the inherent risks in poorly understood processes.

2. TRACING EXECUTIVE DECISIONMAKING PROCESSES WITH VISUAL MENTAL IMAGERY PROTOCOLS

Since computer decision aids are difficult to implement, designers should carefully study the underlying managerial processes. In fact, they do; but their analyses are fraught with methodological dangers. Clearly, such cognitive decision research requires new techniques.

2.1 THE LIMITATIONS OF EXISTING METHODS

Unless the decision tasks are very simple, descriptive efforts by economists and psychologists are rarely successful. Studies in the paradigm of information-processing psychology are the principal exceptions: subjects solve complex problems, while verbally describing their step-by-step solution procedures. Researchers then develop simulations which they compare with transcriptions of the tape recorded verbal protocols. While these computer models are often useful to systems analysts, they present several limitations. For one thing, the theories are sufficient explanations, but cannot preclude alternative hypotheses. The major objection, however, is that simulations take too long to program. As a consequence, information processing theories typically describe a few subjects on two or three variations of a single task.

Ideally, applications to MIS require large samples, because of potentially important individual differences in decisionmaking styles. Also, systems must support many related problems that differ in parameter values, or structure. For example, a system for budget decisions must cover a wide range of allocations, or even application domains with different structures. Executive problem solving makes great demands on decision analysts and DSS designers. It requires support systems for a large set of nearly intractible tasks.

2.2 THE ADVANTAGES OF MENTAL IMAGERY PROTOCOLS

Investigations of complex processes require so much data that appropriate techniques must summarize them to facilitate interpretation. Psychological evidence demonstrates the power of drawings or other graphic forms of information. For example, subjects who briefly examine a thousand photographs can identify them later with few errors. Also, professional mnemonists often use mental imagery to perform their astounding memory feats.

In earlier work with Edward Feigenbaum, Roger Shepard, Patrick Suppes, and David Thompson at Stanford, Weissinger-Baylon (7) developed techniques for externalizing the sequences of mental imagery experienced during the solution of scientific problems. They found enormous variation in imagery reports across subjects and tasks. However, this study demonstrated that mental imagery is not an epiphenomenon as claimed by Pylyshyn and others. It has the function of a model that decisionmakers build and manipulate.

For high imagery tasks, subjects can report thought processes by drawing sequences of mental images that they experience. This protocol technique is especially appropriate for images that do not tax subjects' drawing abilities, for spatial problems whose usual solution methods involve sketching, drawing, or graphing, and finally, for abstract tasks solved by manipulation of mental models. These conditions place clear limits on applications for mental imagery protocols. Under the appropriate circumstances, however, they are enormously useful.

2.3 THE DEVELOPMENT OF PROTOCOL METHODOLOGIES FOR VISUAL MENTAL IMAGERY

Baylor and Moran report simulations of human problem solving or tasks for which:

a) visual mental imagery is essental, and

b) subjects can verbally describe their problem solving operations.

For example, Baylor's subjects give step-by-step protocols of visual images they require to mentally cut a cube into twenty-seven smaller elements. Moran's simulations describe how his subject learns mental paths for which directions are north (N), south (S), east (E), or west (W), and all distances are of unit length. (Thus N,E,N,E,N,E represents a step-like path)

In extending these protocol methodologies, Weissinger-Baylon (7) analyzes less structured tasks. He investigates problem solving where:

a) mental imagery is useful, but not always necessary, and

b) imagery operations are easier to draw than describe verbally.

While the subjects of Baylor and Moran verbally describe their problem solving, Weissinger-Baylon's protocols are step-by-step reports that include both drawings of mental images and verbal descriptions. Although most earlier work in this tradition is based on very small samples, he uses Markov models to analyze thirty-seven subjects on fourteen tasks. Consequently, this is an important step toward a methodology for analyzing executive decisionmaking.

3. ANALYSIS OF DECISIONMAKING BY A HIGH LEVEL EXECUTIVE: THE COMMANDER OF A NAVAL TASK FORCE

Our study applies mental imagery techniques to analyze decisionmaking by a naval task force commander, a top level manager. It will influence the design and evaluation of command and control systems. In order to obtain imagery protocols, we are conducting laboratory investigations with wargaming and simulation facilities of the Advanced Command and Control Test Bed at the Naval Postgraduate School. The experimental task requires subjects to make decisions as commanders of a task force. Its main asset is a carrier with squadrons of attack, interceptor, anti-submarine helicopter and other aircraft. An inner screen of guided missile cruisers and destroyers guards the carrier against air or submarine threats. At greater distances, a cruiser, destroyers, and various carrier and land based aircraft patrols have similar roles.

By any standards, these resources are substantial. The carrier's F-14 interceptor squadrons, for example, cost nearly four hundred million dollars; certain ships are in the one to two billion dollar range. Logistics and other necessary support activities are much larger than the battle group itself. Consequently, a deployed task force rivals in sheer magnitude all non-government organizations except the very largest international corporations.

4. EXPERIMENTAL PROCEDURES

Ten officer students and staff members of the Naval Postgraduate School are subjects. All have tactical training; their relevant skills, however, range from novice to expert. In rank, they vary from lieutenant to lieutenant colonel or commander.

A video tape presentation by Capt. Wayne Hughes describes the mission and tactical situation of the battle group for which subjects assume the commander's role. In the experimental scenario, an antisubmarine patrol bomber monitors a long linear barrier of sonar buoys to the northeast. This aircraft detects and then loses contact with an enemy nuclear submarine heading directly for the naval task force. The subject must prosecute an attack before the submarine is in range to launch its missiles. His suggested options are to use the patrol bomber, launch from the carrier an additional patrol aircraft of the same type, send another antisubmarine aircraft currently on patrol to the south, send helicopters from either the carrier or a destroyer, send a destroyer or submarine.

While solving the problem, subjects report their visual mental imagery by drawing it. Protocols are tape recorded for subsequent transcription and analysis. At the end of the session, they provide written summaries of their solution procedure. The experimenter continuously monitors problem solving, and answers appropriate questions using a modified directed interaction technique. It prescribes for specific situations the questions he should ask and the responses he should make to subjects' queries or behavior. The technique elicits talking, imagery reports, and written summaries. While limiting experimenter bias, the method reduces difficulties in the analysis stage that arise from inaccurate, incomplete, or ambiguous protocols.

5. ANALYSIS

Weissinger-Baylon (7,8) develops protocol elicitation and analysis techniques for visual mental imagery. Application of these methods must first address the anti-imagery arguments of Pylyshyn, who describes mental images as functionless by-products of thinking, or epiphenomena. By operationally defining "epiphenomenon" as stochastic independence between mental imagery report and problem solutions, Weissinger-Baylon (8) demonstrates that his data on abstract mathematical problem solving are inconsistent with Pylyshyn's claims. Errors in imagery and solutions are in fact highly correlated.

If mental images have a function, what is it? This question has stubbornly resisted analysis for half a century. In Weissinger-Baylon (7), a taxonomic study of mental images finally solves much of the long mystery. He describes imagery as a first order, discrete state, discrete transition Markov model. Protocol data provide estimates of the transition probabilities, and permit categorization of images as states. From this classification, the function of images is now clear: they are mental models that subjects build, reconstruct, or retrieve from memory during problem solving. Thinking, when analogue, involves manipulation of these images or their parts (by translation, rotation, flipping, dilation, stretching, bending, twisting, or by other linear and nonlinear transformations).

5.1 MENTAL IMAGERY PROTOCOLS OF TASK FORCE COMMANDERS

Experience in antisubmarine warfare is the major individual difference among our subjects. The imagery of Figure 1 is for a participant without specialized training; Figures 2, 3, 4 and 5 are from a subject with several years of relevant experience. For both subjects, we present imagery reports only. However, we summarize their verbal descriptions below each figure. Because some distance information is confidential, the graphs are not to scale. In at least one important respect, these reports are artificial: our subjects prosecute the attack at all decision levels; in practice, however, the overall commander has the assistance of a large staff and subordinate commanders; he is less involved than our subjects in details of execution.

Protocol One: an Untrained Subject

For one subject without antisubmarine warfare experience, the imagery in Figure 1 summarizes his decisions: a field of sonar buoys, and deployment of a submarine, destroyer, and F14 aircraft. This behavior is representative of participants with similar training.

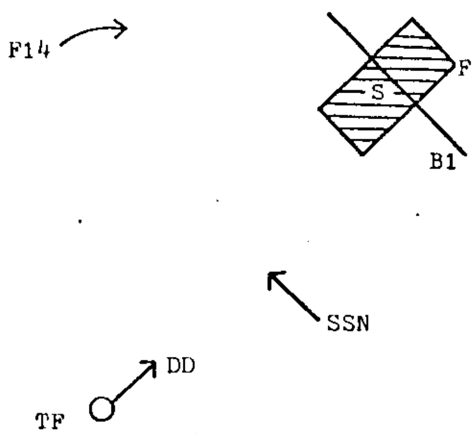

Figure 1. Imagery Protocol for an Untrained Subject.

The circle (TF) is the carrier and its inner screen. A linear sonar buoy barrier (B1) is 100 nautical miles to the northeast. An enemy nuclear submarine (S) penetrates the screen. The subject's responses are to send a destroyer (DD) in the direction of the threat, send a submarine (SSN), and send an interceptor aircraft (F14). He also lays a sonar buoy field (F) in the area of last contact with the enemy submarine. For simplicity, we omit the sequence of S's decisions.

Protocol Two: a Trained Subject

In the figures below, a trained subject presents a sequence of mental images, tracing step-by-step his problem solving procedure. First, (see Figure 2) he places a linear buoy barrier halfway between the task force and submarine threat.

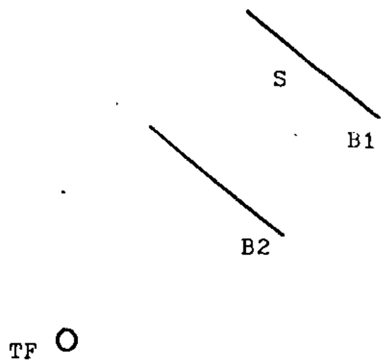

Figure 2. Image 1 for a Trained Subject

A barrier (B1) of sonar buoys protects the task force (TF) against enemy submarines such as S, which B1 detected as it crossed. Our subject initially plans a second linear barrier (B2) about halfway between S and TF. At this point in his decisionmaking, he believes that S is within approximately ten nautical miles of TF.

After discovering a large error in his interpretation of scale, this participant abandons his linear barrier plan. Instead, he proposes a wedge (Figure 3) near the last enemy submarine contact.

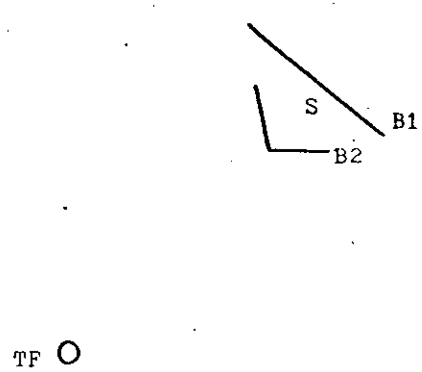

Figure 3. Image 2 for a Trained Subject

After noticing an error in his interpretation of scale, this subject realizes that enemy submarine (S) is approximately 100 nautical miles from the task force (TF). He now plans a wedge-shaped sonar buoy barrier (B2) in S's path.

The submarine will not pass the wedge in much less than an hour. Consequently, the patrol aircraft will "walk back" to it by dropping additional buoys. Figure 4 reports this mental image.

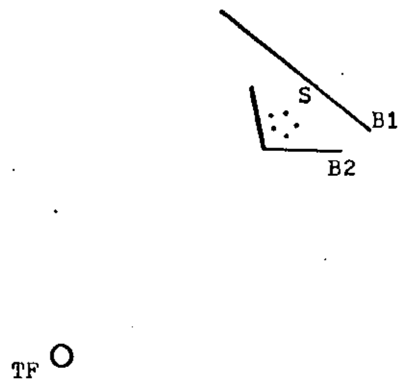

Figure 4. Image 3 for a Trained Subject.

After laying the wedge barrier (B2), the patrol aircraft will "walk back" toward enemy submarine S by dropping additional buoys. Their approximate positions are shown by the five points inside B2.

The final step is a detailed plan for walking back: a smaller wedge inside the first barrier (see Figure 5).

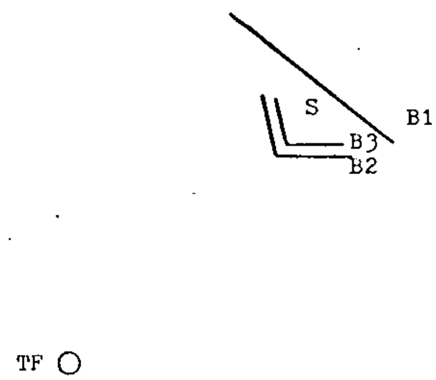

Figure 5. Image 4 for a Trained Subject.

This image represents the subjects final plan. After laying wedge B2, he will walk back toward enemy submarine S by laying a second, smaller wedge (B3).

5.2 ANALYSIS OF INDIVIDUAL DIFFERENCES IN TRAINING

The protocols above are reasonably representative of behavior by subjects with similar training. They suggest that experts may sometimes use techniques unknown to others. An example is a sonar buoy wedge pattern. Also, experienced decisionmakers seem to use resources more conservatively.

From the graphic protocols of ten subjects, Table 1 extracts the key solution elements. It compares these decisions according to participants' training in antisubmarine warfare, generally confirming the observations already suggested by direct exanmination of representative protocols. Thus, the wedge is conservative of sonar buoys relative to very long linear barriers; trained subjects always use it, others never. Similar observations apply to both ships and aircrft: thus, no expert sends a destroyer; only one deploys a submarine. For nonexperts, however, both rates are seventy percent.

6. CONCLUSION: VISUAL MENTAL IMAGERY PROTOCOLS FACILITATE THE ANALYSIS OF EXECUTIVE DECISIONMAKING

Eventually, our work will yield a specification of information requirements, based on an understanding of the cognitive processes, communications, and group interactions of senior managers who participate in high level decisionmaking. With rare exceptions, however, decisionmaking studies have no direct influence on systems design; this work is necessarily exploratory. To achieve our goals, we need a continuing research program.

For the moment, our emphasis must be on developing suitable methods for tracing executives' complex problem solving processes: mental imagery protocols are a good bet. Our initial results, while extremely tentative, illustrate the potential usefulness of that methodology. Later on, much larger samples will permit a more penetrating analysis in terms of many factors that still await discovery. Individual differences in abilities, professional training and orientation, decisionmaking style, and responses to time pressure and other sources of stress are a few of the candidates. Structures of problems may also be important; for specific tasks, we will investigate their influence on information requirements.

Imagery protocols offer a powerful technique for the study of decisionmaking. In his database research, for example, Hoffer (1980, personal communication) is collecting and analyzing managers' images. Obviously, they are most useful for high imagery tasks and subjects. One potential consequence is intriguing: of all executive problem solving and decisionmaking processes, those that depend on visual mental imagery may be the first that we will understand well.

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	Untrained Subjects (N=7)	Trained Subjects (N=3)
Aircraft:		
Patrol bomber (S-3)	15	67
Helicopters (SH-3H, LAMPS)	30	0
Interceptor (F-14)	30	0
Ships:		
Destroyer	70	0
Submarine	70	33
Carrier (withdrawal)	0	100
Sonobuoy Barriers:		
Wedge	0	100
Linear	70	0
Field	30	0

Table 1. Effect of Training on Solutions.

Principal elements of solutions by ten subjects appear in the left column. These involve deploying aircraft or ships and laying sonobuoy patterns. For each solution type, the center column gives the percentage of untrained subjects choosing it. In the right column are corresponding figures for three subjects with some prior exposure to antisubmarine techniques.