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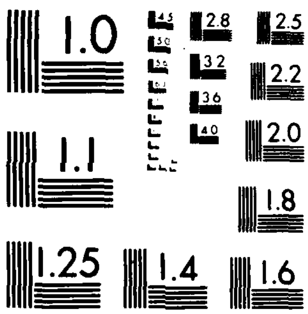
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DEVELOPMENT OF INNOVATIVE GRAPHIC SYMBOLOGY FOR ARMY TACTICAL DECISIONMAKING

FINAL REPORT PFR -1103-83-10
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DEVELOPMENT OF INNOVATIVE GRAPHIC SYMBOLOGY FOR AIDING TACTICAL DECISION MAKING

Prepared For:
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The goals and accomplishments of a program of research and development directed at the systematic design, implementation, and evaluation of graphic concepts for supporting tactical decision making are summarized. These aids focus on new ways to dynamically portray and adaptively manipulate tactical symbols on computer-generated displays so that relevant task-based performance can be enhanced. A new form of automated situation-display system that efficiently and effectively served the information requirements and processing demands of tactical users was demonstrated.

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1. OVERVIEW

This report summarizes the goals and accomplishments of a program of research and development directed at the systematic design, implementation, and evaluation of innovative graphic concepts for supporting tactical decision making. These aids focus on new ways of dynamically portraying and adaptively manipulating tactical symbols on computer-generated displays so that relevant task-based performance can be significantly enhanced. In essence, the goal was to design and demonstrate a new form of automated situation-display system that would efficiently and effectively serve the modern information requirements and processing demands of tactical users.

Subsequent sections of the report briefly describe the research problem and specific objectives of the program, as well as highlight the work that was accomplished. In addition, listings are given of the technical reports prepared and the scientific personnel who contributed to the program accomplishments.

2. PROGRAM OBJECTIVES

2.1 Research Problem

Despite rapid changes in the nature of tactical warfare and in the methods by which the battlefield environment is graphically portrayed, the symbology used to portray tactical situations has remained the same for decades. Conventional symbology (as represented in U.S. Army Field Manual 21-30, Military Symbols) is frequently an integral part of tactical graphic displays which provide command staffs with an overview of the friendly and enemy battlefield situation. The symbology of FM 21-30, and its related NATO version, provides a communicative language for the U.S. military services as well as for the Allied Nations.

However, there is widespread consensus that the mechanics and utility of the current symbol system are being severely strained by the increasing volume and complexity of tactical data. In particular, conventional symbology has been criticized for such reasons as: the level of detail is often inappropriate; the extraction of salient information is difficult; and the adaptation to automated displays is cumbersome and inefficient. Hence, analytical and empirical work is required to carefully identify current problems with symbology use and to suggest promising solutions that incorporate both human factors and technological considerations.

In addition to problems related to the design of individual symbols, the significant problem of display clutter occurs when several symbols are configured into one situation display. Since various symbols can interfere or "compete" with one another, the clutter appearance of battlefield displays makes the rapid extraction and comprehension of tactical information difficult. Furthermore, there is general agreement that the clutter problem is particularly acute when automated tactical graphics systems are used.

Thus, emerging doctrine and advancing technology call for the development of improved tactical symbology and display techniques. For example, there is a need to include the graphic portrayal of such key concepts as the dynamic composition of units and unit capability (strength, reach, mobility, etc.) in tactical situation displays. In particular, more empirical data are required that can be interpreted toward the generation of guidelines for the design and selective manipulation/display of tactical symbols.

Since the same military symbols are typically used across an entire range of display configurations and tactical tasks, the derivation of generalized principles for effective symbology and graphics is necessary. With developers of command and control systems continuously making efforts to design methods of automated graphic representation that can significantly improve tactical performance, a need exists for a structured methodclogy to convert information requirements into new symbol designs and display configurations that are both effective from a human factors point of view and compatible with present computer-based display capabilities.

2.2 Specific Objectives

The specific objectives of the research program were as follows:

(1) Identify and exploit the capability of automated situation displays to serve the performance-based information and processing requirements of tactical users.

(2) Design, demonstrate, and evaluate a user-responsive experimental computer-generated symbology display system for supporting tactical decision making.

(3) Assess and descriptively model the performance of system users in answering key tactical questions by analyzing their individual display protocols for a variety of symbol overlays viewed selectively by users (i.e., study which overlays they look at and in what order they call them up).

(4) Demonstrate a systematic method, based on the analysis of human performance data, for deriving a set of initial procedural guidelines to aid tactical users in selecting the specific displays and symbol features likely to be most appropriate and useful for answering particular tactical questions.

3. SUMMARY OF WORK ACCOMPLISHED

3.1 Research Setting

This research program was conducted with the close cooperation and support of the Marine Corps Tactical Systems Support Activity (MCTSSA), Marine Corps Base, Camp Pendleton, California. MCTSSA provided support in terms of tactical background test scenarios, access to the Marine Tactical Command and Control Systems (MTCACS) General Test Facility (GTF) and required computer software, as well as Marine personnel for use as test subjects. The GTF has been serving as a testbed for advanced concepts being considered for implementation into the Marine Tactical Combat Operations (TCO) System. Since this facility has available to it a sophisticated graphics display package offering many possibilities for innovative tactical symbology, an excellent opportunity existed for immediate transfer and operational application of the techniques developed under this research program.

3.2 System Description

The automated selective overlay system that was developed allows the user to selectively call-up symbol overlays and map backgrounds that are considered to be crucial for answering tactical questions. A user can select any of twenty overlays, individually or in combination, to look at while formulating an answer to a given tactical question. Table 3-1 gives a coding key for the overlays, providing a description of the information content of each overlay as well as the portrayal method and color used by the overlay. As shown, various methods of portrayal and coding are used in the overlays. The rows of the table are organized according to general unit type (maneuver, support, or service support) and affiliation (friendly or enemy). The method of unit identification is taken from the military

TABLE 3-1

CODING KEY TO SYMBOLOGY OVERLAYS

[Overlay code number and color are presented in cells]

UNIT CLASSIFICATION	Unit Information →	Identification	Designators	Capability	Strength	Range	Movement
	Method of Portrayal →	Basic Military Symbol	Alpha-Numerics	Alpha-Numerics	Perimeter Density	Vector Projection	Arrow
Maneuver	Friendly	1 blue	4 blue	6 black	8 black	10 blue	
	Enemy	12 red		14 black	16 black	18 red	20 red
Support	Friendly	2 blue	5 blue	7 black	9 black	11 blue	
	Enemy	13 red		15 black	17 black	19 red	
Service Support	Friendly	3 blue					
	Enemy						

symbology standard (FM 21-30), with red and blue color coding used to distinguish enemy and friendly units. Friendly designators are also portrayed according to convention.

The remaining dimensions of unit informat on--namely, capability, (i.e., current major weapon) strength, range, and movement--are each graphically displayed in a manner that is not represented in FM 21-30. The method used in each case to append the respective supplementary information to the core symbol was guided by a number of concerns including common (but nonstandardized) practices used by military personnel, meaningfulness, avoidance of conflict with conventionally displayed information (e.g., unit designators), legibility, and discriminability. The latter criteria are of particular importance because of the need for simultaneous overlays to be displayed and viewed. For example, since both the capability and strengt of units would likely be desired to appear together, the former is coded one way (by alphanumerics) and the latter is coded another way (by perimeter density, with the number of sides filled in reflecting differen levels of percent strength). The color black was selected to portray capability and strength because of discriminability concerns; in particular perimeter sensity would have been difficult to identify had it been coded the same color (i.e., blue) as the unit symbol. The portrayal of weapon range indicators employs vectors drawn to scale to reflect the actual range of the principal weapon system of each unit and arrows are used to indicate moving units; while not a convention of FM 21-30, vectors and arrows are commonly used by military personnel and were therefore employed in this system.

Each individual overlay contains very specific information on only one dimension; and by virtue of this technique of overlay development, the overlays could be easily combined with, as well as deleted from, each other. For example, overlay #1 shows only the core symbols for friendly maneuver units in their respective positions. Overlay #4 contains only the unit designators for the friendly maneuver units. When overlays #1 and #4 are combined, the result is the portrayal of each friendly maneuver unit together with its associated designators. As another example, the combined display of overlays #7, #9, #11, and #15, #17, #19 shows the capability, strength, and range of the friendly support units in comparison to their enemy counterparts.

The system also allows for a digital map background to be displayed. The map backgrounds studied included a standard topographic map and a blank white background. The map was a computer-generated digitized gray and white map with a scale of approximately 1:88,000, with grid lines, and of medium detail (including roadways, waterways, built-up areas, vegetation, but no contour lines). All overlayed symbol information was observable on the map background and on the blank white background.

3.3 Experimental Studies

A total of 28 Marine Corps personnel served as participants in the experimental studies, in the preliminary investigation and 22 in the main experiment. The participants came from a variety of backgrounds including infantry, artillery, and air defense, and they had various military ranks (Lieutenant, Captain, Major, and Lieutenant Colonel). The experimental procedure was the same for all subjects.

For use in the experiments, an initial tactical scenario and an updated situation associated with it (a second scenario) were prepared with considerable military realism. The first scenario provided an account of a friendly-unit offensive action. The second scenario or update, which was given to the participants mid-way through the experimental session, advanced the tactical situation and described an enemy counter-attack which placed the friendly forces in a defensive posture.

Each test session began with an extensive briefing that explained the general purpose of the study and presented an overview of the experimental scenarios and procedures. Then, the overall test procedure and the nature of the overlays and map background that would be used in the test were described. The subjects were thoroughly instructed on how to use the various features to call up and delete the various overlays and backgrounds. The instructional procedure also included on-line comprehensive demonstration by the experimenter on how each overlay was to be selected/deleted and exactly what the resultant configuration of overlays would look like on the graphics screen. Finally, the experimenter demonstrated the use of the system to solve a practice problem, and each subject then completed a different practice problem himself.

In each experimental session, a sequence of four tactical questions was prepared in a different random order for each subject. The questions represented both different echelons of command and different tactical functions (e.g., operations, logistics). All questions were designed so that they could be answered adequately on the basis of the tactical information displayed on the various overlays. Each subject worked at his own pace and received a new question from the experimenter after completing and submitting the previous one. In answering each question, the subject was free to request any sequence and configuration of overlays and backgrounds and to maintain these in view for as long as desired.

All subjects responded to the four questions in the context of the initial tactical scenario. The updated scenario was presented after all four questions were answered with respect to the initial scenario. The subjects were then presented with the same questions a second time and asked to now respond in light of the new scenario. In this manner, participants proceeded to answer the questions and receive new ones until the conclusion of the experiment.

3.4 Research Results

The experimental methodology and data collection procedures, particularly the overlay selection protocols, provided a rich source of performance data for analysis. The analyses focused on patterns of overlay use and associated overlay selection sequences, and how they impact upon the quality of tactical performance. In general, all officers were able to quickly, easily, and comfortably operate the system to solve tactical problems. User acceptance was very high and all officers were impressed with the capability and potential of the system. A summary of the key findings follows.

While solving the tactical problems, the participants tended to add overlays incrementally to build-up their situation displays. On average only 18% of all overlays selected were turned off (erased). Apparently, the participants preferred to examine the newly-added graphic information in the context of the previously selected information. Significantly different overlay configurations were called-up to solve the different tactical problems.

As the display of tactical symbol overlays was built up, the blank background was typically used instead of the map. The digitized topographical map was turned on for an average of only 30% of the total viewing time, and the percent time varied across tactical questions. In only 32% of the instances where the map was selected, it was called near the very beginning of the problem-solving protocol (within the first three overlay selections). Thus, the option to view at least some of the overlay material without the perceptual complexities of a topographical map appears to have been a popular one.

During the first phase of the experiment, the friendly forces were portrayed in an offensive posture; whereas in the second phase, the updated situation found the enemy forces in a counter-attack maneuver with the friendly forces in a defensive posture. However, even though the configuration of available tactical information on the overlays changed from Phase 1 to Phase 2, there was little difference in the build-up of situation displays between phases. In contrast to the relative absence of general performance differences in overlay use between the two phases (scenarios), significantly different overlay configurations were called up to solve the different tactical problems. Therefore, it is necessary to characterize the overlay-selection protocols on a problem-by-problem basis, as the symbology information was clearly used selectively in response to tactical task demands.

The quality of each answer to each tactical problem in each phase of the experiment was evaluated by a combination of (a) the essentiality of the component parts of the answer, and (b) the completeness of the answer. Based on this analysis, the participant-supplied answers were divided into two different quality groups: the best answers, called the "good" answers, and the remaining answers, called the "poor" answers.

To determine whether the better answers resulted from different overlay selection behavior, performance was contrasted with respect to the two different levels of answer quality. Problem solution time was generally greater for the good answers than for the poor answers. Similarly, the good answers were preceded by the selection of more overlays than were the poor answers. In general then, the selective call-up protocols tended to be somewhat longer and more complete prior to the generation of good answers, but there were sizeable individual differences on these measures across participants.

A suitable methodology for examining the participants' overlay selection protocols was provided by an application of schema theory. Schema theory holds that the comprehension of any information is affected by past knowledge, which is organized as a mental template for interpreting and understanding new information. Since a set of schemata should exist in the minds of skilled officers for understanding graphic tactical data, our participants were a resource for investigating which overlays are perceived as most important and in which order they are most appropriately viewed.

The schemata analyses were particularly useful to describe the performance of the participants whose answers to the problems were judged to be "good." Thus, a schema analysis was conducted for each tactical question studied using the overlay selections of those participants who prepared the good answers to that question; and for one problem, the selection schema of the poor answers was derived for the purposes of comparison. For example, Problem A required the participants to recommend whether or not, as well as where, any of the friendly artillery batteries should be moved. To answer this tactical question, the majority of participants were concerned primarily with the following tactical information and corresponding overlays.

(1) Current location of the friendly artillery batteries.
(2) Tactical reach of the friendly artillery batteries.
(3) Identification and major weapons of the friendly artillery batteries.
(4) Current location of the friendly units that the artillery is supporting.
(5) Location of enemy targets.
(6) Threats to friendly artillery batteries.

Thus, the schema analysis of the protocols leading to the good answers to Problem A indicated that participants who did well first built a picture of their own forces, and then they added information dimensions about the enemy. That is, friendly unit locations, their ranges, weapons, and identity were selected first, and enemy information was subsequently added to this configuration. In contrast, the schema analysis for the protocols leading to the poor answers on Problem A revealed a different information processing style. The participants who provided poor answers vacillated between the selection of friendly and enemy information, although the same overlays were ultimately called up during the problem solution.

The empirical schematic results were reformatted to represent a set of task-based procedural guidelines to enable the overlay system to be used more efficiently and effectively. In particular, the guidelines are intended to aid tactical users in selecting the specific overlays that are likely to be most appropriate and useful for solving certain tactical problems. The guidelines for approaching each tactical problem were described in tabular form as an ordered sequence of suggested overlays with annotations concerning their relative importance for being viewed (vis a vis the given tactical problem).

A significant by-product of the results of the experimental studies is the successful demonstration of a performance-based approach to system design. This approach, which is applicable to many different task domains, involves two steps. The first step is to perform an experiment in which all system capabilities are made available to all test subjects on a self-selection basis. In this case, appropriate subjects were briefed about the selective overlay call-up system and <u>all</u> it can do. As they then proceeded to solve tactical problems using the system, they were given the opportunity to select at will among the different overlay configurations provided by the system. As the subject performed, the system kept an automatic record of his selection protocol with regard to the use of all system capabilities.

Based on the subjects' tactical performance only (not the overlay selection protocols), the subjects were divided into two groups: the better performers and the poorer tactical problem solvers. The overlay selection protocols of the "good" performers were then carefully analyzed and contrasted with those of the "poor" performers. The assumption was made that the "good" performers are better than the others not only as problem solvers but also as selectors and utilizers of the variety of symbology information made available by the system. Thus, by studying and modeling the strategies actually used by the better performers, we were able to derive procedural guidelines that can be applied in similar problem solving situations. By incorporating these empirically-derived guidelines into future system capability (either via system software or off-line guidelines given to users), the effectiveness of the system can be greatly improved.

3.5 Research Conclusions

The research described here centered on the development, implementation, and experimental demonstration of an automated selective overlay system for tactical symbology. The rational for using this type of system is based on the need to adaptively reduce clutter on computer-generated situation displays and make them more responsive in meeting user information requirements. The results of the experiments that were performed clearly demonstrated the system's capability, versatility, and potential effectiveness for facilitating tactical decision making. It is anticipated that the selective call-up system can be incorporated into an integrated set of computer-based decision aids for supporting real-time management of tactical data. With the present empirical work as a foundation, further studies can be carried out to assess the impact of such person-computer systems on the quality of information-processing and decision-making performance.

Traditionally, situation displays have been information intensive, combining many types of information into a single display. For example, convention would dictate that friendly and enemy units, and their unit designators, would typically be presented together on one acetate overlay. In the present approach, however, this information is divided and presented on separate automated overlays. The overlay selection protocols that were elicited in this study indicated that, given the option, users do not always follow convention; in some instances in fact, designator overlays were viewed without the unit symbols they identified. In general, users took full advantaoe of the flexibility of the selective call-up system to reduce display clutter by matching symbol parameters with task demands.

The results illustrate that the selective overlay call-up system is useful both as a tactical problem solving aid and as a research tool. Although the graphic displays were usually built up with few overlay deletions, the build-up was carried out systematically such that the information on each overlay could be comprehended and integrated toward addressing the tactical problem at hand. The integrity of each individual overlay was supported in that no two overlays were selected so often together to warrant their merging into a single combined overlay. Furthermore, much of the processing of displayed information was done without the use of the background topographic map, indicating the importance of the option allowing the user to separate unit information from terrain information. User opinion emphasized the beneficial effects of this type of task-adaptive graphic capability for improving information-processing and decision-making performance in a tactical environment; and, overall, the potential utility of such an automated system has been evaluated positively.

As a research tool, the call-up system was demonstrated to be useful in modeling the ongoing congnitive processes of users who must comprehend a tactical environment accurately and rapidly. It was shown that a simple form one such model could take is a list reflecting the selective call-up of a sequence of various overlays pertinent to a given tactical problem, and these prescribed sequences can be translated into corresponding sets of guidelines for overlay use. It should be emphasized that such guidelines are developed and applied in a task-based manner. That is, a different normative overlay schemata and corresponding sets of guidelines would be necessary for different tactical situations. At first, this requirement may sound impractical; however, based on the findings of the present work and other related research (e.g., similar information requirements and information processing strategies for offensive and defensive scenarios), it is our belief that it will be feasible to develop a manageable set of schemata which correspond to a variety of basic tactical situations (border attack, withdrawal maneuver, etc.) and - lated tactical information and decision support requirements (deployment of reserve units, movement of artillery units, etc.).

3.6 Future Research

The cumulative results of the present experimental findings suggest the importance of follow-up research to further validate the tactical use of the selective overlay system. In particular, the effect of aiding system users with procedural guidelines for overlay use in solving tactical problems should be investigated. Methodologically, encouraging a user to follow a prescribed set of procedural guidelines for solving a problem while working with an interactive system can be accomplished in alternative ways. One possibility is to automatically "spoon feed" the user with a prescribed sequence of overlays. That is, the user would not have a choice in selecting and deleting overlays but would be forced to view them in the prescribed order (configuration). However, previous research and the accumulated wisdom of good practice in the design of interactive computer-based information systems suggest that a preprogrammed fixed-sequence mode of information presentation is not a good alternative.

Instead, a more prudent approach for aiding system users is to guide them through the desired information sequence by employing the appropriate prompts; that is, rather than force a sequence upon a user, the idea is to apply good human factors techniques to encourage the user to follow the prescribed sequence. At the same time, the user must always have the option to override the suggested sequence when he or she believes there was a good reason for doing so. This latter approach is recommended for an initial follow-up experiment designed to validate the guidelines developed from the present data.

4. TECHNICAL REPORTS

The final technical report describes the research and development work performed under the contract; the citation for that report is as follows:

> Samet, M.G., Geiselman, R.E., and Landee, B.M. An Automated Selective Overlay System for Tactical Symbology (Technical Report PFTR-1103-83-11). Woodland Hills, CA: Perceptronics, November 1983.

In addition, a number of conference presentations were made by Dr. Michael Samet (Principal Investigator) describing this work including at the First Conference on Human Factors in Computer Systems (Gaithersburg, MD, March 1982) and at the Third Israel Symposium on Man-machine Systems (Tel Aviv, Israel, June 1982).

5. SCIENTIFIC PERSONNEL

The key scientific personnel who contributed to this contract were: Dr. Michael G. Samet (Principal Investigator), Dr. Edward Geiselman (Senior Experimental Psychologist) and Betty M. Landee (Research Psychologist). A brief description of each individual's role in the project and resume follows.

Dr. Michael G. Samet was responsible for the direction and accomplishments of the research program, including all technical reports. He developed the concept of the selective symbology overlay system, guided its design and implementation, and planned the methodology for its demonstration and evaluation. Dr. Samet, who holds an Ph.D. in General Experimental Psychology from TUFTS University (1971), has extensive experience in the application of human factors to military command and control systems. His work at Perceptronics, and previously at ARI, has focused on computer-based support systems for information management and decision making. Recently, he has created several widely-marketed software packages for personal computers. Dr. Samet has taught several university courses in human factors and computer systems, and he has published many scientific articles in such journals as Human Factors, Military Intelligence, and IEEE Transactions on Systems, Man, and Cybernetics. Dr. Samet is a member of the Human Factors Society and the American Psychological Association and is listed in American Men and Women of Science and Who's Who in the West.

Dr. R. Edward Geiselman supported the project by participating in the design and conduct of the experimental studies, the analysis and interpretation of the data collected, and the drafting of the technical reports. Dr. Geiselman, who has a Ph.D. in Experimental

Psychology from Ohio University (1976), has been a regular consultant to Perceptronics for several years. His research accomplishments have been primarily in the area of cognitive psychology. He is highly experienced in experimental and research techniques, human factors methodology, as well as in the analysis of behavioral data. His broad background includes involvement in several government-supported projects relating to tactical symbology and computer displays, information summarization, and message format. Together with Dr. Samet, he has published articles on these topics in Human Factors, Military Intelligence, Perceptual and Motor skills, and IEEE Transactions on Systems, Man, and Cybernetics. In addition, he has many other publications on human memory in various psychological journals. Dr. Geiselman is a member of the Midwestern Psychological Association, Psychonomoic Society, Sigma XI, and the Westerm Psychological Association.

Betty M. Landee performed the following contract-related tasks: contributed to the design of the symbology overlay system; prepared the tactical scenarios and experimental materials used in the pilot study and experimental evaluation; collected, reduced, and analyzed the empirical data; and helped in the drafting of the technical reports. Ms. Landee has an academic background in experimental psychology and has acquired extensive military science background during the performancee of many research projects, including experimentation on computer-generated movie maps, tactical symbology, and tank gunnery systems. In addition, she has conducted interviews, surveys, and workshops with military personnel concerning the elicitation and organization of information requirements for tactical decision making (especially as related to symbology and maps). This work has required familiarity with a broad range of military literature as well as direct liaison work with military consultants and experts at the U.S. Army Command and General Staff College, U.S. Army Intelligence Center and School, National War College, etc.

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