USER PERFORMANCE UNDER SEVERAL AUTOMATED APPROACHES TO CHANGING DISPLAYED MAPS[1]

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ABSTRACT

State-of-the-art computer displays seldom have sufficient resolution and size to show usable detail for a large map. One solution is to satisfy user needs by designing map display systems that present sequential map segments. The utility of two types of presentation conditions was evaluated: (a) continuous map scanning, and (b) discrete map segments using three different amounts of border overlap (0%, 25% and 50%). The task was to determine the fastest road routes between cities. A 19 in. color television monitor displayed 6x8 km map segments (1:50,000 scale) within a 60x80 km map region; participants viewed the larger map area by changing the displayed segments. Solution time, number of map segments viewed, and quality of route solutions were recorded by 24 participants on each of 12 problems divided among presentation conditions. Results showed that different presentation conditions did not significantly affect the quality of routes chosen. Problems took the least time when map segments with 50% overlap were used although 25% overlap produced similar data. Overall, the participants who changed map segments more often took less time working problems. Discrete map segments with around 25% overlap would contribute to an efficient design for a sequential map display system.

KEY WORDS AND PHRASES: map/computer interaction, graphic display applications, computer graphics, display design, map displays, military systems

CR CATEGORIES: 3.36, 3.72, 8.2

INTRODUCTION

The computer's capability to display geographical information is a potentially valuable component of information retrieval systems. Such displays allow a user to study and plan resource allocations (e.g., fire department services), analyze geographically related problems (e.g., crime; drug traffic), study route planning (e.g., traffic flow; transportation design), modify cartographic images (e.g., design maps), and so on [1,2,3,5]. An Army application for such displays is the use of map information for determining optimal traffic routes for military units. The present research examined alternative displays for support of the Army application.

Algorithms [3] are available for assistance in this type of route selection problem. However, the focus of the present research was on user performance under exposure to alternative conditions of automated change from one displayed map area to another. Therefore, participants were asked to perform unassisted route selection tasks.

An Army officer choosing a route manually may need from five to fifteen minutes for a single problem, depending on its complexity. The procedure often requires numerous hard-copy maps covering a large geographical area and emphasizing various aspects of terrain and road characteristics. Selecting the optimum route involves close examination of several similar possibilities and detailed consideration of road types, population densities and other obstacles to quick travel. A computer display system could assist in making relevant information more readily available without the need for extensive hard-copy map storage.

A major problem in using displays for map information is the limitation in state-of-the-art screen size and resolution. (The availability of an adequate map data base is not a concern for this paper.) The fineness of detail is illustrated by hard-copy maps which are designed not for accurate display by electronic devices, but for reading by the human eye. For example, one grid box (about 4 square cm) of a standard military map requires all of a 525 line color television screen in order to show the smallest printed details. For many tasks, users require a larger map area in more detail than is electronically possible. The likelihood is that electronic display resolution and size will only slowly catch up with such requirements. Methods are needed for displaying segments of maps without unduly isolating one segment from another.

[1]The views expressed in this paper are those of the authors and do not necessarily reflect the views of the United States Army or the Department of Defense.

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These methods must help users to integrate individual map displays into a cohesive picture of the total interest area.

There are at least three approaches for developing better map displays. One approach is to determine what detail (if any) can be sacrificed to make present maps more compatible with current display technology. A second approach is to provide for changing the scale of a displayed map so that more or less detail can be presented as required. A third approach, considered here, is to sequentially display limited map segments with enough detail to satisfy many of the user's needs.

The problem of using map segments for convenient presentation is not new. Hard-copy maps represent only subdivisions of larger areas. For many tasks, the user often requires several map sheets to satisfy his needs. For example, for long-distance driving in the United States, a traveler may use several state and city highway maps. In military applications, there is a need to have map-to-map continuity of various features, including roads and topography. Several alternatives for maintaining orientation from one map sheet to another are available to the user. One map sheet can be placed next to another, or related points marked on adjacent sheets, or sheets flipped back and forth, and so on. Looking at map sheets one after the other rather than simultaneously is quite challenging because of the burden of remembering related factors on adjacent sheets.

Two research projects [4,6] have investigated some of the issues in remembering map details. Shimron asked participants in a study to learn a simple line-drawing map. The map showed a river, a mountain range, three major roads and ten cities. Cities were located at road intersections and roads were given names. Participants remembered local connections between map elements (e.g., most northern city; city in the mountains) after even a short six-minute learning period. However, overall integration of map units such as naming the order of cities along a particular road or remembering the orientation between cities (e.g., What city is south of city A?) produced only 50% accuracy after 12 minutes learning time. One implication is that integrating information across the boundaries of map sheets presented sequentially requires considerable cognitive processing time. Research by Layman [4] supports the idea that map segments are harder to use than single maps of an entire area. He asked participants to use a map for locating an aerial photograph and the position of a particular photographed object. The time to perform the tasks increased significantly when map segments rather than a single map sheet had to be used. Layman suggests that the primary problem occurs when the area of interest lies along the border of two adjacent map segments which cannot be viewed simultaneously. The user requires more time for map reading when depending on memory of a map segment not in view.

A computer display of map information is the electronic equivalent to using a hard-copy map segment. The ease with which map information can be retrieved and the provision for continuity of one map display with another are important human factors issues. Using discrete sources of maps in the form of slides is a convenient way to store and retrieve such information. However, the user has trouble combining information across boundaries of disparate map segments. One possibility for improving map presentations is to allow some percentage of map area to overlap between adjacent segments. This could provide better user orientation than non-overlapping segments. An alternative is to allow continuous map scanning where the display is a "window" for a large map area. The user could explore the map and stop on any area of interest. In this report, the two basically different map presentation conditions are referred to as "discrete" and "continuous." Intuitively, the continuous condition might seem to be the most flexible and promising for the future. On the other hand, the user might be served more quickly, less expensively and equally well by discrete map displays. The purpose of the research reported in this paper was to test the ease and accuracy of map use with (a) displays of discrete predetermined segments with both overlapping and non-overlapping areas; and (b) displays allowing continuous map scanning.

METHOD

Task. The task was to use 6x8 km map segments (1:50,000 scale) within a 60x80 km region to determine the fastest road routes between cities. Participants were required to solve four sets of three problems where each set was combined with one of four display presentation conditions: continuous map scanning, or viewing of discrete segments (Fig. 1) with 0%, 25%, or 50% overlap. Map scale was kept constant and standard military coordinates (universal transverse mercator) were used as a reference system. Each problem specified a city of origin, a destination city, and the relative map location of each, using the general form: "You are presently at (city name), (map coordinates) and have to go to (city name), (map coordinates). What roads would get you there fastest?" Participants solved problems by using a computer-interfaced trackball to mark roads electronically on a 19 in. raster scan color CRT (Conrac, Inc).[4] Participants were asked to work quickly but to consider the effects of road quality as well as intervening cities and towns on choosing a "best" route.

Design. Participants were 24 Army officers with military map reading experience, divided into four groups of six. Each of the six participants was assigned randomly to one of four unique sequences of problem sets combined with map change conditions. The problem sets were constructed to be similar in length and difficulty by use of an optimal path algorithm [3] designed for Army applications. The apparatus used in the present research caused a delay of about eight seconds between map changes in the discrete presentations; a similar wait after a move request in the continuous condition insured that the eight-second

[4]Trade names are used only for precision in reporting and do not constitute endorsement.

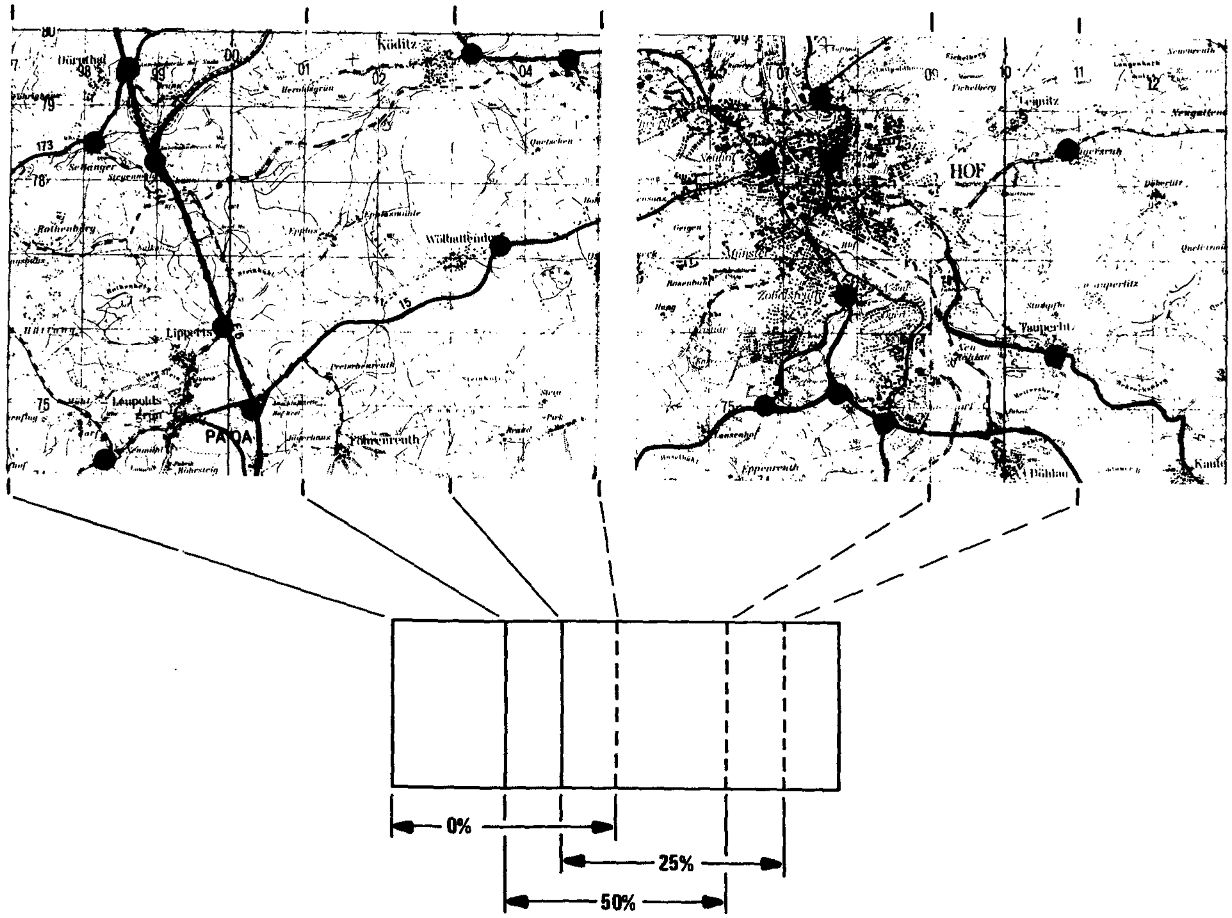

Figure 1. Map photographs (not to scale) and diagrams illustrating the discrete overlap conditions. Only one segment appeared on the CRT at a time.

interval was constant for all presentation conditions. The delay strained immediate memory but was considered reasonable for laboratory evaluation of a map display system. In order to control any other time, practice and presentation effects, the problem sets and map change conditions were counterbalanced in the design.

Apparatus. The principal apparatus is shown in Fig. 2. Participants used the keyboard to control changes in displayed map area and the trackball cursor to mark road routes. The computer system (Anagraph by Amcomp, Inc.) generated displays of all alphanumeric and graphic information except the map. The map image was transmitted to a display by a color television camera (GBC CTC 3XP) and could be combined with computer-generated images. The stationary camera framed a segment of the entire map which was glued against a 4x6 ft movable vertical surface. This surface was equipped with a separate motor, clutch, and drive system for movement along both x and y axes, with digital encoders to read the board's position on each axis, and with a control system interfaced with the computer. The research station also provided the participant with a booklet of instructions, a participant-experimenter intercom, and pencil and paper for notes. The experimenter had CRTs linked to the participant's displays so that problem solutions could be monitored.

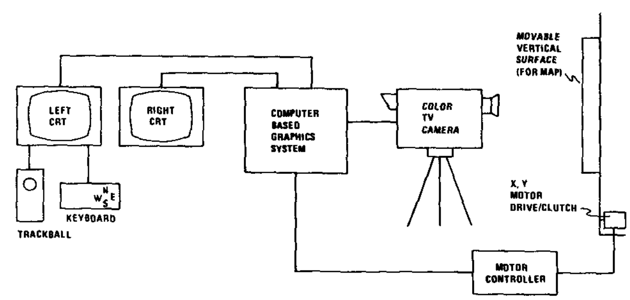

Figure 2. Block diagram of major apparatus components.

Procedure. Each participant sat in front of the CRTs. The left-hand CRT showed map segments with roads marked by black dots at intervals along their length. The right-hand CRT (Fig. 3) had two purposes: (a) the top was reserved for presenting each problem; (b) the rest of the screen showed a grid and coordinate system representing the total map area of interest. When the left screen showed a map segment, the right screen used a red rectangle to show a segment's location on the grid and an arrow to show the direction of

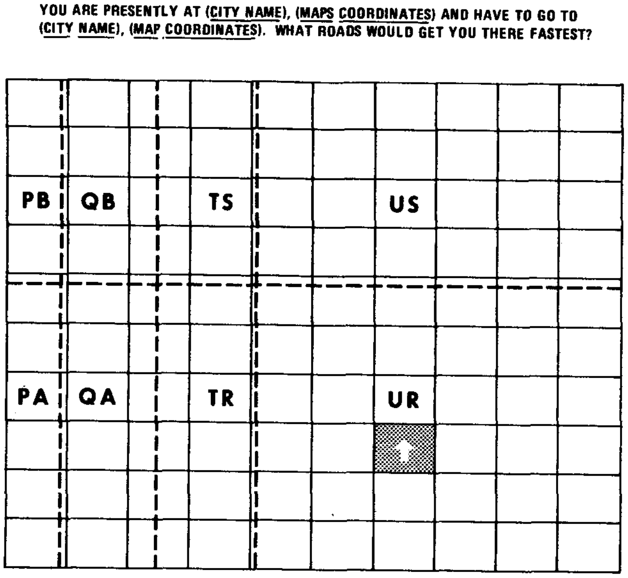

Figure 3. Right-hand CRT display (not to scale) shown here in black and white. The darkened rectangle represents a 0% overlapping condition.

the last map change. Dashed lines and letter codes designated the map coordinate system. Instructions for the task were supplemented by displayed information, by practice problems and by hands-on practice until the participant was comfortable with the hardware necessary for solving problems.

The map board in front of the TV camera moved for both the continuous and discrete conditions for changing map displays. The map was always readable for continuous displays. However, between discrete map presentations, while the map was moving, the display was completely covered by a computer-generated blue mask. Map changes were controlled by four direction keys oriented W N S E on the participant's keyboard.

Entering "N," for example, was a request to look at the map north of the current display. Angular moves were not allowed because, for a controlled research project, the times and distances of such moves would have been difficult to equate with x-y changes. The computer controlled the amount of change during discrete conditions, but the participants controlled starting and stopping the map during the continuous condition. Participants were told what change method would be used for a problem set and how much overlap a particular discrete condition had.

Participants were instructed to mark only the black dots on red (primary) and red-dashed (secondary) roads in the process of determining the best problem solutions. They learned to use the trackball cursor for marking each dot along a chosen route with a green asterisk. An added feature was that green asterisks could be replaced ("erased") by a red asterisk to show that a spot had been abandoned.

The research session lasted between 4 and 7 hours with rest and lunch breaks. Any equipment malfunction could be reported using the participant-experimenter intercom.

Performance Measures. Performance measures were (a) time needed to solve problems, (b) number of map changes necessary per problem, and (c) quality of route selected. The solution time equaled the overall time for a problem solution minus the time waiting for new map information to appear. Since the screen was blacked out during map changes in the discrete conditions, these times were not considered to be part of solution time. In the continuous scan condition, the participant could view the map as it moved. These intervals were part of solution time. The time delay before scanning began, however, was subtracted from overall time. Number of map changes equaled participant requests to move the map in any of the four directions available. Thus, a very limited area could be viewed with many map changes. Quality of solution was determined by finding the percent of corresponding points along road sections between routes selected by participants and "ideal" routes selected by a computer algorithm [3] for each problem. The algorithm calculates the fastest road sections between points on the map network. Calculations include considerations of average travel speeds along different types of roads and the effects on travel speeds of cities and terrain factors. A final source of data was responses to a written questionnaire. These opinions were sought after a session was over and the project's purpose had been discussed.

RESULTS AND DISCUSSION

A user-efficient system for sequentially displaying maps should be accepted easily and should allow quick problem solutions of high quality. In current results, participants expressed a first-place preference for continuous scanning of maps and a second-place preference for 25% overlapping segments. Performance data showed overlapping segments to be most efficient. A compromise weighted toward performance suggests that designers and developers of such systems should use discrete presentations with about 25% overlapping map segments. Data trends indicate that the actual overlap could vary somewhat without any meaningful effect on performance.

Not all performance data differentiated among the four map change conditions. Research measurements of the quality of road route solutions were about equal. However, an analysis of variance showed significant performance differences for solution time ($F = 4.23$; $df = 3.60$; $p < .01$) and for frequency of map changes ($F = 2.78$; $df = 3.60$; $p < .05$). These trends are evident in the summary of results (Table 1). An analysis of the performance differences (Newmann Keuls tests of means) revealed that: (a) the number of map changes with the 25% and 50% overlapping conditions is about .15 times greater than with the zero overlap or the continuous scan conditions; and (b) the shortest solution time, by a factor of about .25, was produced by map segments with 50% overlap, although a 25% overlap produced similar data. Overall, an increase in the frequency of map changes necessary to solve a problem is associated with decreased problem solution times.

	MAP CHANGE CONDITIONS			
	0% DISCRETE	25% DISCRETE	50% DISCRETE	CONTINUOUS
SOLUTION TIME (IN SECS)	607.2	547.1	508.7	672.4
STANDARD DEVIATION	295.2	186.3	165.9	246.1
RANGE	1409.3	802.7	578.3	649.4
NO. OF MOVES	21.7	24.9	27.4	21.8
STANDARD DEVIATION	10.5	13.4	13.4	10.2
RANGE	34.7	45.7	48.3	39.7
SOLUTION QUALITY (PERCENT)	52.1	48.8	48.9	52.0
STANDARD DEVIATION	14.6	11.3	12.7	16.3
RANGE	51.7	42.5	43.5	71.4

Table 1. Data summary for different map changes conditions.

Measures of route quality averaged only about 50% because of the stringent scoring rule used. The routes chosen by participants were judged by how well they corresponded with the algorithm's ideal solution, not by whether they offered a reasonable alternative solution. Parts of routes which were similar or even parallel to the ideal one were scored as incorrect. The nature of problem solutions was visible on road routes where: (a) participants often marked a route compatible with the algorithm's solution and later erased it and (b) the alternate solutions chosen by many participants were identical. The important point was that route quality remained consistent in the research while performance time and frequency of map changes systematically varied.

Performance Strategies. One consideration for optimizing use of a map change system is redundancy between adjacent segments. Built-in overlap aids the user in integrating information from one map segment to the next and may have partly accounted for the lower solution times in the discrete conditions with 25% and 50% overlap. In contrast, the 0% overlap and the continuous scanning conditions allowed the user to see more map area with fewer moves. An increase in solution time in the 0% overlap condition was probably due to the demand on memory for combining new information with information from previously seen displays and from the need to go over routes to check work.

The continuous condition, where users can scan new map areas easily, was not expected to take as much time as discrete conditions. However, the problem-solving stragegy most participants adopted for this condition seemed to increase their solution time. Participants spent much longer exploring possible routes during continuous scanning than during any discrete condition. Large areas were first viewed with a single map change to try to locate the best route. Later, once a route was defined, participants tended to move the map only far enough to keep the last marked point (green asterisk) in view. The outcome was few map changes, long performance times and no improvement in the quality of problem solutions.

The strategies adopted by subjects in the three discrete conditions (0%, 25% and 50% overlap) also may have contributed to the resultant time and map change data. Participants exposed to the 25% and 50% overlap conditions usually proceeded from the origin to the destination without first exploring the whole route. They would continue along a path as long as it proved useful. When it stopped going in the right direction, they tried another route. Having any overlap usually enabled participants to keep at least one previously marked node (green asterisk) in view when they changed map segments. This seemed to provide necessary orientation and allowed participants to make choices without having to search. Thus, in the 50% overlap condition, less overall area was viewed than in the 25% conditions. In both these conditions, less overall area was viewed than for the 0% overlap condition. Zero overlap produced fewer moves than either the 25% or the 50% condition, but a completely new area appeared with each move. This completely new information created a problem of orientation. Most participants dealt with the orientation problem by carefully studying a display of new information, and sometimes reversing to view the previously seen segment. This reversing occurred mainly when a path was not obvious and the participant wished to check his work. Overall, results suggest that using a discrete method with overlap is important for minimizing time for problem solutions.

Participant Opinions. A final source of results was the written questionnaire completed after the research and returned by 24 participants. User opinion should be considered in selecting display system charcteristics, although many biases not related to performance may quickly disappear with use. Responses showed that 19 participants preferred continuous scanning and five preferred discrete changes. Three participants preferred discrete changes with 25% overlap and 12 others made it their second choice. There was only one second choice preference for continuous scanning. Participants' comments indicated that continuous scanning provided quicker understanding of the relevant map area and easier orientation as displays were changed. This opinion contrasts with data which showed that the continuous condition resulted in the highest average problem solution time. The opinion agrees, of course, with the extensive map exploration that participants tended to do under continuous changes. The discrete change condition with 25% overlap was liked almost as well because it provided continuity without too much or too little redundancy. In addition, 25% overlap resulted in a near tie for shortest problem solution time. The implication is that many users could accept a discrete system with some overlap. Preference data suggests that discrete changes with around 25% overlap would be a good choice for displaying map information. Nevertheless, the strong preference expressed for a system where the user can scan the map should not be ignored.

System Design Tradoffs. In general, the results show how designers of military map change systems can give strong consideration to efficient user performance in tradeoffs with equipment characteristics and user satisfaction. One set of tradeoffs revealed by in the present research was between performance times and hardware requirements for changing map segments. The most cost-effective and durable hardware design probably would minimize the percent of overlap and the number of changes needed to encompass a map. By using 25% as a guideline for overlapping segments, the demands on equipment should be reasonable without negative effects on user performance.

Another set of tradeoffs involves user performance data vs. user satisfaction with a map change system. In spite of the efficient performance times with overlapping map segments, the majority of participants made continuous scanning their first choice, with 25% overlapping discrete segments their second choice. The extensive map exploration possible with continuous scanning seemed to improve confidence in problem solutions while lengthening performance time. Users could perhaps be taught to work more rapidly with continuous scanning. However, the effect of such training on user preference, number of map changes, and even solution accuracy is not known. In addition, the training costs and even the system development costs for continuous scanning may be higher than for discrete presentations with overlapping map segments. Based on the current research, a discrete system which uses about 25% overlapping map segments has better overall support than any other tested alternative.

Alternative Tasks. A key question about the research is whether the task was demanding enough to cause differences in performance quality among the four map change conditions. The task was chosen because deciding on a road route requires several different map reading skills, such as locating map positions, discriminating road types, determining travel directions, and understanding terrain and city impacts on ease of traveling a road. However, when a map is segmented, the roads often are the easiest features to line up and follow. They have a natural continuity, unlike, for example, the location of one city relative to another. Such road continuity could minimize the performance effects of different methods for changing displays from one map segment to an adjacent one.

Perhaps the task should not have been limited to finding a quick route "from here to there." One possibility would have been to ask for the best route for traveling to several cities in an optimal sequence. This would require integration of scattered information across boundaries of map segments. Another way to increase problem difficulty would be to place obstacles (e.g., bridge out; flooding) which would make remembering bad routes and choosing good routes more challenging. Changing the map area displayed by use of a zoom capability also could lead to difficult problems for the user to solve. Changes in map magnification would allow emphasis to be placed on interpreting map details. Alternatively, map overviews could be used for conceptualizing difficult road network problems. A task that exploits map detail as well as overview would provide a challenging test of automated map display methods.

CONCLUSION

To optimize user performance time, the designer of a map display system for military use should begin with discrete map segments that overlap by about 25%. The percentage can vary somewhat without affecting performance. The 25% guideline considers user preference but requires fairly frequent map changes which increase demands on hardware. Performance criteria, user satisfaction and equipment design all have a place in determining the most appropriate map display system.

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