AAMRL-TR-86-035

AD-A255 777

LARGE GROUP DISPLAYS AND TEAM PERFORMANCE: An Evaluation and Projection of Guidelines, Research, and Technologies

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SEPTEMBER 1986

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AAMRL-TR-86-035

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR., Director
Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AAMRL-TR-86-035	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Armstrong Aerospace Medical Rsch Laboratory, AFSC, AMD 6b. OFFICE SYMBOL (If applicable) HEC	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Wright-Patterson AFB OH 45433-6573	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: 62202F PROJECT NO.: 7184 TASK NO.: 27 WORK UNIT ACCESSION NO.: 03

11. TITLE (Include Security Classification)
LARGE GROUP DISPLAYS AND TEAM PERFORMANCE: AN EVALUATION AND PROJECTION OF GUIDELINES, RESEARCH, AND TECHNOLOGIES (U)

12. PERSONAL AUTHOR(S)
McNeese, Michael D. and Brown, Clifford E.*

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical	FROM ______ TO ______	1986 September	71

16. SUPPLEMENTARY NOTATION
*Wittenberg University, Springfield OH

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Large screen displays; group displays; team performance; command and control; information display; human-computer interaction; man-machine interface; social psychology
05	05		
05	08		

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

Within team-technology interaction the use of large group displays has been proposed for certain types of command and control activities. This report describes a broad continuum of issues, concerns, variables, problems, and factors that must be considered by both research/design and operational communities, when an integration of team performance and group display usage is desired. Guidelines, research, and technology focusses are reviewed, evaluated, and suggested to begin this integration. A theoretical perspective, a research plan for conducting pertinent studies, and a description of current in-house research is also provided. Necessarily, the topics of group information design, team performance, and cognitive operations are covered.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Michael D. McNeese	22b. TELEPHONE (Include Area Code) (513) 255-8805 22c. OFFICE SYMBOL AAMRL/HEC

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

SUMMARY

An investigation of the uses (past, present, and future) of large group displays is provided in the context of team performance. The report provides a comprehensive examination, evaluation, and projection of guidelines, research, and technology revolving around various aspects of large group displays. The purpose is to integrate much of the team problem solving work with human factors considerations for large group displays. Thus, both theoretical and practical issues are addressed in research and design. A research plan is presented to systematically structure the research studies whereby answers may be distilled for use in practical design situations. This plan encompasses three major research categories: group information design, team performance, and cognitive operations. Within these categories various combinations of factors and variables will be possible, thereby providing a wealthy source of experimental designs that can help to derive specific guidelines. The report also provides thorough descriptions of a baseline study in team performance and two legibility studies that evaluate the light valve technology used for large group displays.

PREFACE

This report describes a human engineering analysis and review of large group display use for team performance considerations. The studies conducted for this analysis were in accordance with Work Unit 71842703, Large Display Evaluation of Experimentation for C^3 Applications, July 1983. This report was prepared by Mr. Michael D. McNeese, Harry G. Armstrong Aerospace Medical Research Laboratory, Human Engineering Division, Technology Development Branch (AAMRL/HEC) with the assistance of Clifford E. Brown, Wittenberg University.

Significant contributions for review, experimentation, and analysis for this report were provided by Ms. Luan Katz, Systems Research Laboratories, Inc. In addition, Mr. Don Monk, Lt Suzanne Kelly, and Dr. John Forester, AAMRL/HEC, provided useful review and inputs for this report.

TABLE OF CONTENTS

SECTION		PAGE
1	**INTRODUCTION**	7
2	**OBJECTIVES**	9
3	**FOCUS 1: GUIDELINE EVALUATIONS**	10
	Viewability/Legibility	10
	Display Design	11
	Team Psychology--Cognitive Operations	12
4	**FOCUS 2: GUIDELINE PROJECTIONS**	13
5	**FOCUS 3: RESEARCH EVALUATIONS**	16
	Orientation	16
	Research Objectives and Orientation	16
	Research Foundations: Issues and Review	17
	The Team Task	26
	Baseline Study	26
6	**FOCUS 4: RESEARCH PROJECTIONS**	29
	Theoretical Perspective and Framework for AAMRL/HEC Research	29
	LEVEL 1 - Planned GRID Experimental Design	35
	LEVEL 2 - GRID Research Extensions	37
	LEVEL 3 - Other GRID Research Domains	40
7	**FOCUS 5: TECHNOLOGY EVALUATIONS**	41
	LGD Configuration: Selection Criteria and Requirements	41
	Future Potential Technology	44
	Large Screen Display System Evaluations	46
8	**FOCUS 6: TECHNOLOGY PROJECTIONS**	51
	Target Technology	51
	Laser Projection LGDs	51
	APPENDIX 1: SUPPLEMENTARY GUIDELINES	53
	LGD Optical Projection Guidelines (Via Light Valve Technology)	53
	LGD Optical Projection Guidelines (Not Specific to Light Valve Technology)	53
	Display Viewability/Legibility Guidelines (References)	53
	Display Design Guidelines (References)	54
	APPENDIX 2: SUPPLEMENTARY RESEARCH	55
	Visual Display Research Source	55
	Team Performance/Group Decision Making/Cognitive Operations Review Sources	55
	Non-Review Source/Bibliography	56

TABLE OF CONTENTS (CONT'D)

SECTION	PAGE
APPENDIX 3: SUPPLEMENTARY TECHNOLOGY	57
General Electric PJ15150 Oil Film Light Valve (Taken from Carbone (1982))	57
Lucitron Gas-Electron-Phosphor Display	61
LGD Technology Comparisons (Laser Projection Included)	61

LIST OF ILLUSTRATIONS

Figure		Page
1	GRID Structure	8
2	Distribution of Resources Within a Group	22
3	Roby (1968) Information Transduction	24
4	Hackman and Morris (1975) Paradigm	25

LIST OF TABLES

Table		Page
1	Premise-Experiment Set Matrix	34
2	Research Possibilities, Variables of Concern	38
3	Legibility Test Criteria	48
4	Comparative Large Group Display Parameters	63
5	Share-Based Navy Command and Control Requirements Rating	64
6	Summary Comparisons of Large Screen Displays	65
7	Current Large Group Display Products and Characteristics	66
8	Laser Projection Compared to Other Systems	67

SECTION 1

INTRODUCTION

The basis for investigating the use of Large Group Display (LGD) technology has many facets but this report will take a broad, interdisciplinary approach to understanding human and team performance as related to various aspects of the display design. For the sake of clarity, the use of the term, Group Information Display (GRID) will designate and capture the broad array of variables that would be of concern for command, control, and communication (C^3) facilities. More specifically, GRID represents the union of three particular research categories: visual information design, social-team psychology, and cognitive operations. Throughout the report, reference will be made to these research categories which categorize past, present, and future orientations for understanding appropriate usage of LGDs for C^3 centers.

This report will consist of a GRID structure which consists of three objectives crossed with three major areas of concern. The objectives are:

(1) Present pertinent GRID knowledge,

(2) Evaluate pertinent GRID knowledge, and

(3) Project pertinent GRID knowledge.

The areas of concern within pertinent GRID knowledge are:

(1) Guidelines,

(2) Research, and

(3) Technology.

When these objectives are crossed with the areas of concern, the resultant repository structures are formed as shown in Figure 1.

FOCUS 1	FOCUS 3	FOCUS 5
GUIDELINE EVALUATIONS	RESEARCH EVALUATIONS	TECHNOLOGY EVALUATIONS
FOCUS 2	FOCUS 4	FOCUS 6
GUIDELINE PROJECTIONS	RESEARCH PROJECTIONS	TECHNOLOGY PROJECTIONS
APPENDIX 1-2	APPENDIX 3-4	APPENDIX 5-6
SUPPLEMENTARY GUIDELINES	SUPPLEMENTARY RESEARCH	SUPPLEMENTARY TECHNOLOGY

FIGURE 1. Grid Structure

SECTION 2

OBJECTIVES

The objectives of the report in general have already been presented. They are to present, evaluate, and project GRID knowledge that will be of use for C^3 centers in general. The emphasis will revolve around human engineering an LGD environment that is sound and functional as a first step, but will go beyond this and look at the variables, characteristics, and attributes inherent in team problem solving and group resources that begin to add dynamics to LGD environments. Thereby the specific purpose is to see how various aspects of the LGD environment can be manipulated to yield optimum group performance within the confines of C^3 environments.

SECTION 3

FOCUS 1: GUIDELINE EVALUATIONS

VIEWABILITY/LEGIBILITY

The application of guidelines will proceed from looking at guidelines specific to large screen optical projection using light valve technology, to guidelines specific to large screen optical projection, and finally to general viewability/legibility requirements for displays. Although there certainly will be overlapping areas of concern among these guidelines, it is imperative to look for guidelines that can be applied to a human using the state of the art light valve technology and then progress to more generic levels. As has been discovered, the more general areas provide many guidelines that can be used. However, as design configurations start to combine particular technologies with various group performance factors, then the need for more specific guidance is required. This report tries to take a look at what is available at various levels of specificity and then how it could apply to the C^3 environment. Because guidelines at the most specific level were unavailable, a large screen display evaluation (utilizing the light valve technology) was undertaken to derive answers in the event that this type of technology would prove useful for C^3 operations. Refer to McNeese and Katz (1985) for a full description of this evaluation. One of the intents of this evaluation was to determine whether large screens that use light valve technology have different guideline values from some of the progressively more generic guidelines.

For C^3 environments, the guidelines that are most relevant are those at the most specific levels. The design of GRID should use these guidelines first, then review other levels to either: 1) obtain answers to questions that the more specific guidelines could not answer, or 2) generate additional questions and concerns that should be attended to by designers. One must realize that there is a tradeoff between utility and reliability as one progresses from the specific to the general. The specific guidelines are peculiar to the new technology and thus more utilizable, but less reliable since they are based on relatively little research; whereas, the general guidelines are less applicable, but are highly reliable given their extensive data base.

An important factor in using the guidelines is to first decide what large group display technology is most appropriate for a particular C^3 context. Thus, the designer should refer to the "Evaluate Technology" focus. The current breakout for <u>specificity</u> x <u>guideline resource</u> is as follows:

<u>Guideline Specificity</u>	<u>Resources Cited</u>
LGD optical projections utilizing light valve technology	McNeese and Katz Evaluation Study (1985)

LGD optical projections	MS1472C (1981) Grether & Baker (1972) Woodson (1981) Shurtleff (1981) Williams (1981) Benel & Benel (1984)
Display Viewability/Legibility	Grether and Baker (1972) Benel & Benel (1984) Nelson (1983) Shurtleff (1979) Buckler (1979)

These resources are cited in APPENDIX 2.

DISPLAY DESIGN

Most of the guidelines in the area of display design have been propagated from human computer interface areas. The Smith and Mosier (1984) guidelines are probably used the most and have undergone extensive review. As in the viewability/legibility area, many of the guidelines are of a general nature and not directed to human computer interfaces that involve LGDs being utilized by teams of humans. Therein, the number of guidelines concerning display design for design configurations consisting of LGDs in combination with other visual display technologies (VDTs) is sparse. Necessarily, for recommending particular display designs for LGDs, one is faced with applying the generic. This can be done by actually using the general guidelines: 1) as a checklist to evaluate designs already created or 2) as an information source that the designer can refer to during the course of design. However, for specific applications there will be questions that generic guidelines cannot answer. Nelson (1983) has produced a report that addresses C^3 operations specifically, but it simply incorporates many of the generic guidelines already presented. Thus, the current evaluation of display design guidelines for teams using LGDs and CRTs reveals a need for more specific guidelines.

There are two solutions in reach that would help alleviate the apparent lack of specific display design guidelines. The first involves the supplication of the designer with rapid prototyping and expert systems for dialogue design. Currently, the Rapid Intelligent Prototyping Laboratory (RIPL) being developed for AAMRL/HEC fits this requirement. With such a system a designer would have a tool to rapidly create command post designs. Furthermore, the RIPL expert system component could help the designer in two distinct ways. First, it could look over the designer's shoulder and provide display design guidance as a design ensues. Necessarily, the developed design would be in accordance with current guidelines. Note that the RIPL system is being developed in accordance with the Smith and Mosier (1984) guidelines. Second, once completed, this tool could provide the capability to create-evaluate-recreate-test in real time, such that those areas where information is sparse can be overcome by design itself. Obviously the power of RIPL is directly contingent upon the degree of specificity of the rules inherent in its knowledge base. As new, more specific guidelines are obtained, the usefulness of RIPL for specific applications becomes more prominent.

The second solution actually involves obtaining new guidelines for specific C^3 applications. This is planned for execution at AAMRL/HEC and is the subject of FOCUS 4: RESEARCH PROJECTIONS. Currently, the research plan prescribes looking at information display design parameters in conjunction with either team performance variables and/or cognitive operations variables. Therein, as each study is completed more data can be added to the knowledge base to improve display design confidence. This also would be transferred to RIPL to update the expert system rules.

TEAM PSYCHOLOGY-COGNITIVE OPERATIONS

To date there is very little information or research available which combines team psychology and cognitive operations with LGDs. Therefore, no reliable guidelines exist in this area. It is premature to list guidelines before they have been derived from research or operational exercises. However, to combat this scarcity one should refer to FOCUS 2: GUIDELINE PROJECTIONS, to sample guidelines that have been brainstormed to relate to these areas. Also FOCUS 3 & 4 will review some current thinking in team psychology--cognitive operations (as it relates to use of LGDs) and then project some research studies that will yield answers for future designs.

At this point, a distinction must be made between guidelines and research results. Guidelines embody a much greater degree of confidence when applied to situations of design that approximate the content value of the guideline. This differs from research results mainly in the degree of generalizability and confidence associated with a result being translated into guidance for situations of design. It is felt to date that the LGD research results have not truly demonstrated a high degree of confidence for transfer into LGD design and evaluation situations. Therein, one must wait for a maturity in the research in order to establish specific and reliable guidelines. In many cases the research results will form the trends toward creating the guidelines. These trends will be discussed under FOCUS 3: RESEARCH EVALUATIONS.

SECTION 4

FOCUS 2: GUIDELINE PROJECTIONS

The following guidelines are very projective in nature and thereby somewhat tentative. However, they may be of use for suggesting how LGDs may be used to facilitate efficient team performance. The projective guidelines were distilled from a COPE brainstorm session which produced many useful comments, perspectives, and innovations. The COPE personnel who participated in this session were:

Mr. Don Monk, AAMRL/HEC
Mr. Mike McNeese, AAMRL/HEC
Dr. John Forester, AAMRL/HEC
Lt Suzanne Kelly, AAMRL/HEC
Dr. Lew Hann, AAMRL/HEC and
Dr. Clifford Brown, Wittenberg University

PROJECTIVE GUIDELINES

1. The LGD should be used to clearly establish and, if possible, facilitate group identity, cohesiveness, and motivation whereby the common goal(s) of tasks are made salient.

2. The LGD should focus a team's attention on summary and overview information regarding procedures and tasks such that group and corporate memory is optimally updated to establish an overall global picture which can guide performance of individual team members.

3. When comparison processes are active for individual operators, the use of an LGD may be an appropriate display to indicate where an operator is within the big picture, to supply the overall context, and/or help prioritize an individual's operations.

4. Because the LGD can be seen from many locations, it will be useful for supervisory control in conditions where the supervisor may be mobile and also keep track of primary tasks.

5. If individual operators must perform dual tasks, their primary task can be placed on the LGD (to be viewed or shared by many) whereas their secondary task (specific only to them) could be performed at their own individual CRTs.

6. Because shared information is given more weight, the posting of critical information may be useful to update knowledge states of individual staff members and also enhance group memory.

7. High level summary/overview information-integration is best presented on the LGD whereas low level, detailed, local, raw data, information is best presented by a CRT.

8. The small group display may be used as a boardroom blackboard interactive decision aid such that it serves as a focal point for high level decision making.

9. When an integrated overview (e.g., resource status) is necessary to interpret system states in a dynamic group context, the LGD may be the most efficient means of display.

10. The LGD may be used as a device to direct a team member's attention to global alarm states such that an operator's attention becomes focused on a centralized area along with all other operators, or a subset thereof, while still allowing operators to return to their individual tasks as necessary.

11. The LGD can be used to capture "evolutionary growth" and a system's perspective for recognition of changes within dynamic time dependent environments.

12. For boardroom layouts in command posts, the use of a small group display is recommended to help focus analyses, other state assessments, resource availabilities/allocations, and action alternatives for particular subsets of the staff.

13. For detailed process information, assessment, detailed status information, input sensor fusion, and information necessary for individualized functions (the command post staff in the lower level of the command post), usually a small screen display (CRT) would be most appropriate, however, the LGD can still function as an effective context comparison, guide, or global assessor for instances that require group actions.

14. For proceduralized group performance, the LGD can provide highlighting and checklisting functions, or timeline analysis and checklists, to tell operators where they have been, where they currently are, and where they might go next.

15. The LGD may surface as a focal point for group decision aiding such as a priority organizer.

16. If LGDs are designated to support blackboard, multipurpose, and/or dedicated functions, then if possible a separate LGD should be provided for each functional requirement. However, it may be possible to have just one LGD with a separate window for each functional requirement.

17. With an LGD there is a temptation to display too much information, but care must be taken to avoid clutter, density, and information overload. As a general guideline, one should not put any more information on an LGD than a small screen display, perhaps even less.

18. Operators must be acclimated to LGD use, having integrated it into their roles and functions as opposed to occasional, infrequent use. Usage should be on a day-to-day basis rather than reserved for unusual stress related activities so that if adaptation is required (as it most

likely will be) operators will be prepared to perform effectively.

19. The placement of LGDs should be integrated with command post positions and roles, and functionally consistent with physical room layout.

20. The design and use of an LGD configuration should be predicated upon analyses of current command post functions, tasks, and procedures in accordance with specified timelines, not on tradition, status quo, or old tasks.

21. Some command centers may have a "show and tell" function which may be a very valid activity of a command center, but the center design should not be specifically driven by such a function in terms of practical configuration design. Such activities should not override the primary mission activities for determining the center's configuration design.

22. The degree and control over what information is displayed on the LGD must be based on front end analysis to prevent a chaotic information management problem.

23. The determination of whether the LGD should emphasize a proactive (preplanning) vs. reactive (planning) work status should be determined as a result of front end analysis.

24. The LGD may be useful for solving socio-organizational issues (such as envoking a top level battle staff position or decision once it is made) wherein it becomes a tool used to produce conformity of actions throughout the command post areas that incoporate LGDs.

SECTION 5

FOCUS 3: RESEARCH EVALUATIONS

ORIENTATION

The nature of the research to be investigated will focus on the intersections among group information design, team performance, and cognitive operations. Unfortunat^ly the past has yielded a dearth of research for the three research category intersections. Note that this does not obviate a lot of research when the union of these categories is considered. In fact, much of the research in team performance necessarily bleeds into the other two research categories even though these other categories were not explicitly identified. Some of the reviews in the team performance area will be considered in this focus. Therefore, this discussion will try to relate elements of research in each of these categories to one another. In particular this focus will describe an orientation for: 1) how a research framework can be established and 2) what some of the premises of such a framework should be. In this section of the report, the emphasis changes somewhat from what has been done to what research should be done to improve group performance with respect to LGD configurations.

RESEARCH OBJECTIVES AND ORIENTATION

The AAMRL/HEC research plan will systematically examine the combination of three major research categories:

(1) Group information design variables,

(2) Cognitive operation variables, and

(3) Team performance variables.

Thus, the crossing of these categories results in a wide degree of variance for possible experimentation. The goal therein is to manipulate a subset of these variables while controlling the rest. The overall objective is to look at variables that provide enhancement or increase efficiency in a C^3 environment and then appropriately synthesize teams and technologies to produce optimal arrangements. However, one cannot just randomly look at these variables; instead one must propose realistic hypotheses to predict performance in the C^3 environment. Underlying the hypotheses formulation is the real world of C^3 in which various technologies are proposed for the human's use. Initially, the research plan specifies group and/or individual displays as target technologies that may synthesize team performance in C^3 situations. A determination of these situations should provide insight into the usage of group information displays for improved team performance.

In C^3 systems performance, a team is frequently required to assess presented information and make decisions about the best course of action to take in a dynamic, time-stressed setting. Although each individual in the team may have functions which can be performed alone, additional tasks may require the joint effort of several team members. In such a multi-person, multi-task environment, the successful integration of team members' time and effort is crucial for optimal team performance.

One of the target technologies proposed for integration of team performance is the use of an LGD as opposed to Small Screen (SS) individual displays. Thus the thrust of this research will focus on the use of shared vs. owned displays as facilitators of performance. One must be aware that the intent is not to evaluate the different legibility aspects of display types, but rather to investigate ways information can be displayed with different configurations in the context of active social psychological dynamics. The way a team interacts with the information display may be a function of how well the system facilitates group interaction factors such as cohesiveness, coordination, and leadership.

Inherent in C^3 team performance are a multitude of tasks that can vary in any of a number of different ways. Attention to these tasks may involve individual or team resources, or variants thereof, whereby in many cases coordination and cooperation are crucial for success. The efficient use of C^3 target technologies, such as group vs. individual displays, will either enhance, detract, or have no effect upon team performance. To the extent that these effects can be evaluated, insightful answers for C^3 design can begin to unfold. The paradigm for studying the complexities involved in team-technology interaction will initially incorporate the Team Resource Allocation Problem (TRAP) as a means of studying team performance. This task provides a dynamic setting whereby some tasks can be completed by an individual team member while other tasks require coordinated processing by two or more team members. Additionally, the priority or importance of the tasks to be processed can be predefined by various rules. Thus, this task provides a baseline for certain types of cognitive operations (e.g., communication, integration, and coordination) associated with team performance in C^3 domains. Because of its inherent flexibility, the TRAP task is relevant for pursuing many of the projected experiments. However, to the extent that this task does not emulate all cognitive operations, other dynamic tasks may be utilized for conducting some of the projected experiments. Within the TEAM TASK section of this focus, the TRAP task will be more fully explained.

RESEARCH FOUNDATIONS: ISSUES AND REVIEW

This subfocus examines the issues, research concerns, and past data to circumscribe the foundations of research for AAMRL/HEC. Literature search and review has revealed that there are many directions, issues, and eclectic viewpoints that need integration before comprehensive research studies can be formulated.

Recent reviews of group problem solving and team performance (Dyer, 1984; Goldin and Thorndike, 1980; Hackman and Morris, 1975; Hill, 1982) reveal a need for experimental paradigms which permit systematic exploration of dynamic group decision making. Thus, the utilization of the TRAP task in the baseline study as well as the overall framework provides a means for a logical progression of the research.

But before discussion of the tasks can be addressed, a more basic issue needs attention. The issue is that of what exactly is a team and/or a group. Because one of the major research categories that the framework must address is team performance, it is important to define what is meant by a team. It is the authors' belief that the team performance category is really the cornerstone upon which this entire framework is dependent. Thereby, some effort should be expended to dwell on the nature of team performance. If one could remove the top of a command post and observe the interactions among various individuals, there would be focal points that would tend to integrate individuals' resources to perform the work that is required to be done. In some instances, the work is performed by individual resources, whereas in other instances it is performed by aggregated resources (one human resource + n other resources). The work is such that the modulation of individual vs. aggregated resources changes dynamically as a function of time and resource availability. It is not as if a given person will be either a team or individual operator exclusively. There are certainly times when a given person will be engaged in both roles successively or simultaneously. Thus, the nature of the team formulation may be very volatile and change as a function of task requirements. It is, therefore, crucial to specify what a team is. With this objective in mind, the first step will be to take a look at how others have defined teams and groups. Dyer (1984) provides useful information in this respect and defines a team to consist of:

(a) at least two people

(b) who are working toward a common goal/objective/mission

(c) where each person has been assigned specific roles or functions to perform

(d) where completion of the mission requires some form of dependency among the group members (explicit or implicit).

The Dyer (1984) definition goes on and discriminates teams from small groups by indicating that small groups are less likely to possess given roles or functions, and that dependencies among members are not necessary to facilitate small group processes. Thereby, a small group comprises 50% of the criteria suggested for teams. One other formulation might also be considered. The network would consist of two or more members that have certain forms of dependencies among members but do not have specified objectives/goal nor specific functions as an integrated team. One might think of the example of electronic mail as indicative of the network. As telecommunications through the use of computer systems become more prominent more of these virtual groups will be formed. This is why it is necessary to specify the definitions. For the C^3 context, the team, the small group, and the network all exist on certain overlapping areas on timelines of activity.

To round out the Dyer (1984) definition of teams, Goldin and Thorndike (1980) report that teams:

(1) Perform particular tasks and have particular goals

(2) Have a particular structure with certain relationships and dependencies

(3) Rely on communication and coordination.

Once again, this reinforces the aforementioned definition and specifically implicates communication and coordination actions. These actions obviously are prevalent in the C^3 command post.

To correlate teams more highly with a military context, Gill (1977) specifies the following characteristics:

(1) There are at least two types of military teams. Some military teams have a history; they are not constructed on an ad hoc basis. Although individual team members may belong to a specific team for different periods of time, this history means that members develop expectations about each other and establish procedures for working together. Other teams are task organized; team members are selected because they possess the requisite skills for solving a problem (maintenance crews are an example). These indivduals may or may not have worked together previously.

(2) The size of military teams can vary greatly. The hierarchical nature of military organizations makes it difficult to determine team size limits; for example, a rifle team is part of a rifle squad, which in turn is part of a rifle platoon, and so on. Military judgments must be used in defining team boundaries. This review focuses on teams at and below the platoon level (Army nomenclature).

(3) The "formal" team, as defined in military documents, will not always correspond to the "active" team, in that the number of individuals who interact with each other at a given point in time varies with the task. Thus, even though the rifle squad may be formally identified as a team, for a particular task or mission only three members may be actively involved in "teamwork".

(4) Although the previous definition has specified that team members work toward a common goal, the definition of goal is relative (e.g., for a rifle squad "prepare a defensive position" is a larger goal than "dig your foxhole"). In addition, military teams often are assigned different tasks (e.g., rifle squad: movement to contact

mission versus defensive mission versus reconnaissance patrol) which may require different degrees of involvement from team members and different forms of "teamwork".

(5) Members of military teams not only are assigned specific positions, they also work within a formal structure where leaders and subleaders are determined on the basis of rank and experience. This formal structure influences the nature of member interaction and the way jobs are performed.

(6) Prior to joining an active military unit members usually receive extensive individual training for their respective positions. The amount and type of team trainning received within an active military unit can vary greatly from unit to unit.

(7) When lay persons think of teams, they may visualize football or basketball teams where the degree of teamwork or coordination among members is fairly high, as compared with a track team in a mile relay, where team interaction is limited to the baton hand-off (critical as it may be). With military teams the frequency and criticality of such interactions and dependencies vary greatly with the task and with the nature of the team. The type of interactions (e.g., verbal versus nonverbal) among members will also vary.

(8) Almost all military teams work with some type of equipment. In some instances, the equipment itself strongly determines the size of the team and the nature of team-member interactions.

(9) Military teams must constantly face turnover in team membership.

(10) Some military teams (e.g., tank crews, rifle squads) must always train for a situation that they hope never to face--combat. On-the-job training for such situations is impossible. For other military teams, primarily those involved in the support of combat (e.g., maintenance teams), on-the-job duties do not differ greatly from those faced in combat itself.

(11) During the conduct of military missions, military teams constantly receive some form of feedback on the appropriateness of their actions. The immediacy, visibility, and completeness of this feedback, however, depend upon the task being performed and the structure of the team.

Many of these characteristics transfer to various teams that are formed in the command centers. Thus, those definitions taken together formulate the nature of what is meant by team, small group, and network concepts. The research conducted in the lab must be formulated in ways that are truly meaningful to these definitions, otherwise the validity and generalizability to the operational world will be suspect.

For the C^3 application, it is desirable to demonstrate how various uses of large screen technologies can facilitate group performance enhancement. But before looking into the technologies themselves, hypotheses about team performance must unfold. Once the definition of a team has been explicitly stated and theories postulated regarding team performance, it becomes time to start looking at representative tasks inherent to teams. First, it is necessary to track some major theories proposed to explain team/group behavior.

The first class of theories is that of systems input-process-output whereby components of the group or team supply various resources to obtain certain objectives and then these resources undergo various types of processing with the results being certain types of outputs. Dyer (1984) refers to Berger, Knerr, and Popelka, 1979; Hackman and Morris, 1975; Knerr, Berger, and Popelka, 1980; Roby, 1968; and Shiflett, 1979 as being representative of the system input-process-output classification. The Shiflett and Roby theories are worth discussing in more depth. The Shiflett (1979) general model of small group productivity is especially interesting in that it has a mathematical foundation to it. The TRAP task used by AAMRL/HEC also has associated with it a mathematical model used to predict optimal performance under certain restrictive assumptions. Thus, it may be that there is some inherent mathematical transcendency between the Shiflett theory and the TRAP task model that would heuristically act to further integrate team performance enhancement and/or prediction. Within the small group productivity model there are three major variables.

RESOURCES (knowledge, abilities, skills, and tools possessed by an individual)

TRANSFORMERS (situational and task constraints, role systems, and personal characteristics that impact resources in a way that they become transformed and related to outputs)

OUTPUTS (objective and subjective performance measures of group interaction)

Note that inputs are necessarily identified within the resource or transformer variables. The relationship among these variable is given in the formula, OUTPUT = TRANSFORMERS X RESOURCES. The mathematics is such that particular values of each of these variables can be specified in matrix format. Resources are multiplied by various matrix algebra transformations and congregated to obtain an overall group output. Figure 2, taken from Shiflett (1979), shows various options that might occur when there is congregation of resources.

Item a. shows the additive option: $A \cup B \cup C = A + B + C$

Item b. shows the disjunction option with redundancy: $A \cup B = A$

Item c. shows the conjunction option: $A \cup B = B$

Item d. shows the nonshared resources as opposed to items b. and c. which shows shared resources

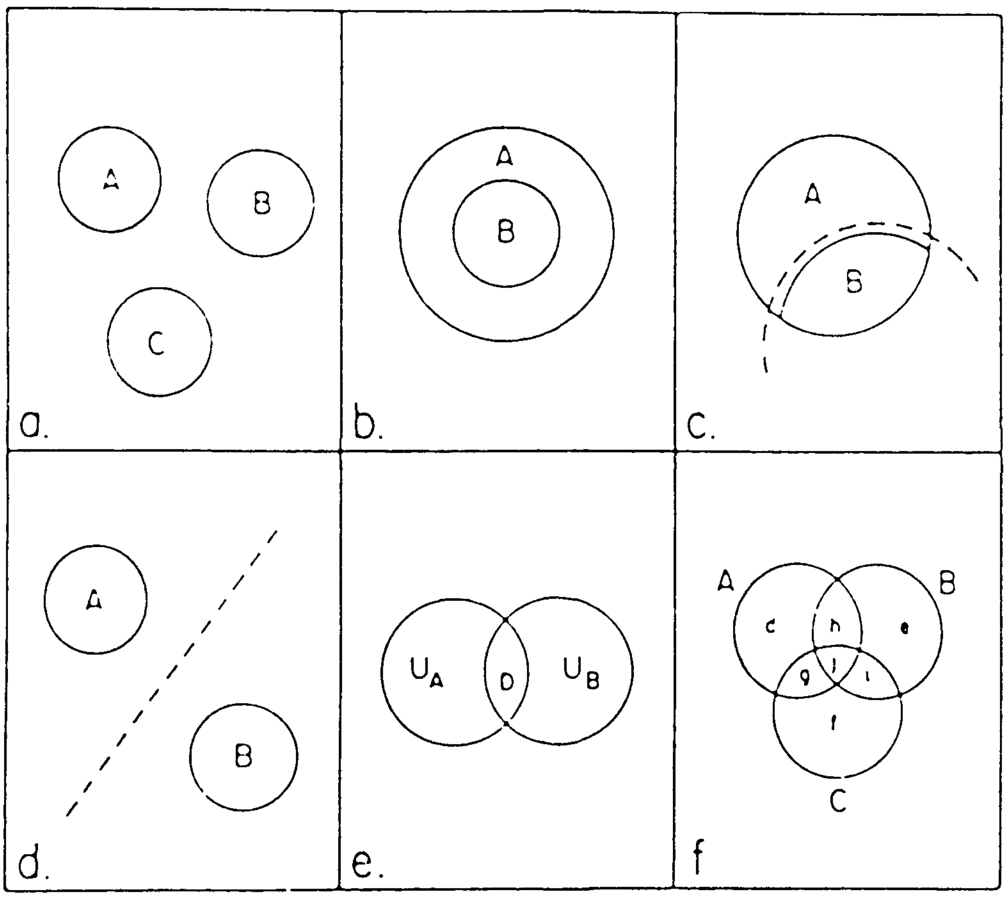

FIGURE 2. Distribution of Resources Within a Group

Item e. shows each members total, unique, and redundant resources

Item f. shows how increase in group size equals an increase in overlapping resources.

As resources are inserted into a matrix, some rules for manipulating these resources must be specified. These rules are placed in a transformation matrix as vectors that mathematically encode the above options. In summary, Shiflett (1979) states that most of the models in the literature are only special cases of a single, unified conceptual framework wherein a specific pattern of transformation weights is postulated to have an effect on group resources. At this point one of the shortcomings of these types of models is that they still have limited capability to generate precise predictions because of the difficulty of specifying all the variables and their values for the matrices.

Roby's (1968) mathematical model of small group performance is a complex, input-process-output model. Figure 3, taken from Roby (1968), shows a schematic of information transduction in a single cycle of group activity. This cycle is initialized by cues that emanate from the task environment and completes itself when actions from the group change the task environment and initiate a new performance cycle. More importantly, the following ancillary processes are identified by Roby (1968) to be necessary to look at empirically meaningful questions:

(a) Primary input subfunctions, including observation, information routing, storage, forecasting, and patterning;

(b) Primary output subfunctions, including executive function and action potential; and

(c) Secondary control processes, including mapping, planning, addressing, and phasing.

The Roby theory is one that would allow a broad based focus for investigation into team performance due to its comprehensive nature. However, given its complexity, the theory can become unwieldy.

Another theory that seems especially useful for integrating many of the concerns, factors, and issues within C^3 group performance applications is presented by Hackman and Morris (1975). Figure 4 presents their paradigm. They present a paradigm consisting of input-process-output for time unit t_1 to t_2, but the basic element of this theory is that input factors affect performance through the <u>group performance process.</u> The individual level, group level, and environment level factors all represent inputs that frequently occur in C^3 situations. In essence, the use of LGD configurations represents an environmental level factor. The question that must be derived by continued research is how these factors are integrated to affect performance as a function of the group interaction process. Mediation of group effectiveness via the interaction process has not been elucidated. However, Hackman and Morris (1975) identify the following factors that are related to the process:

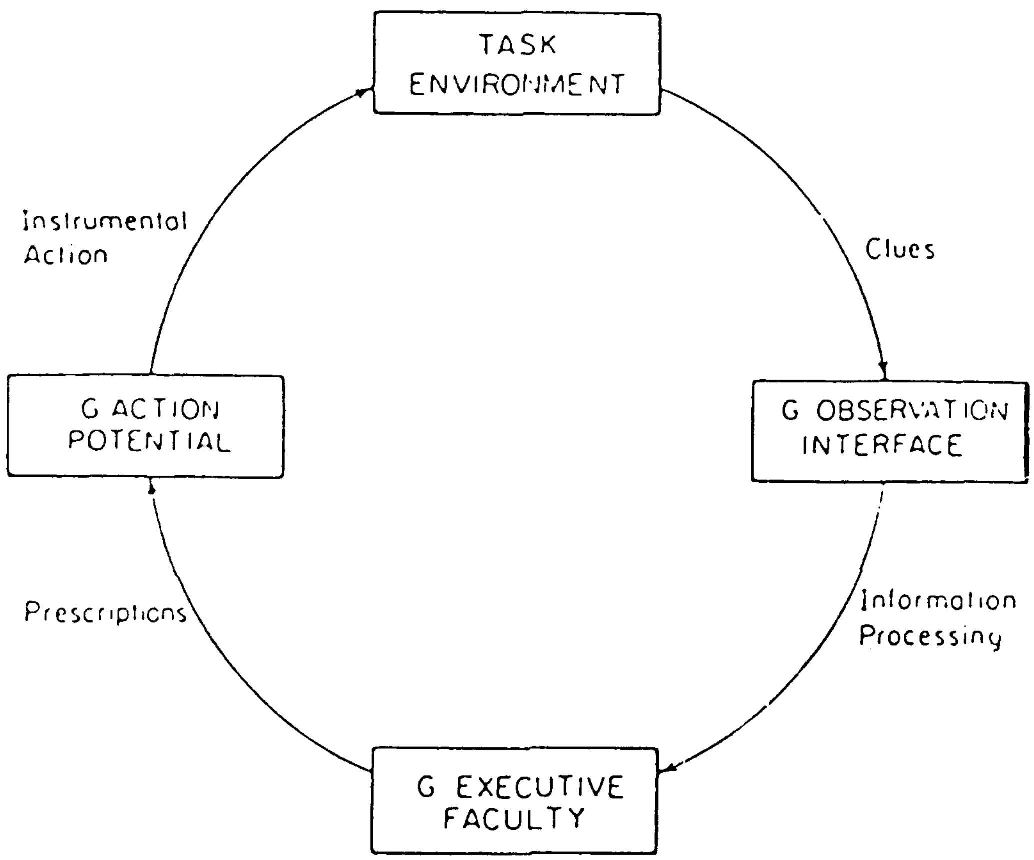

FIGURE 3. Roby (1968) Information Transduction

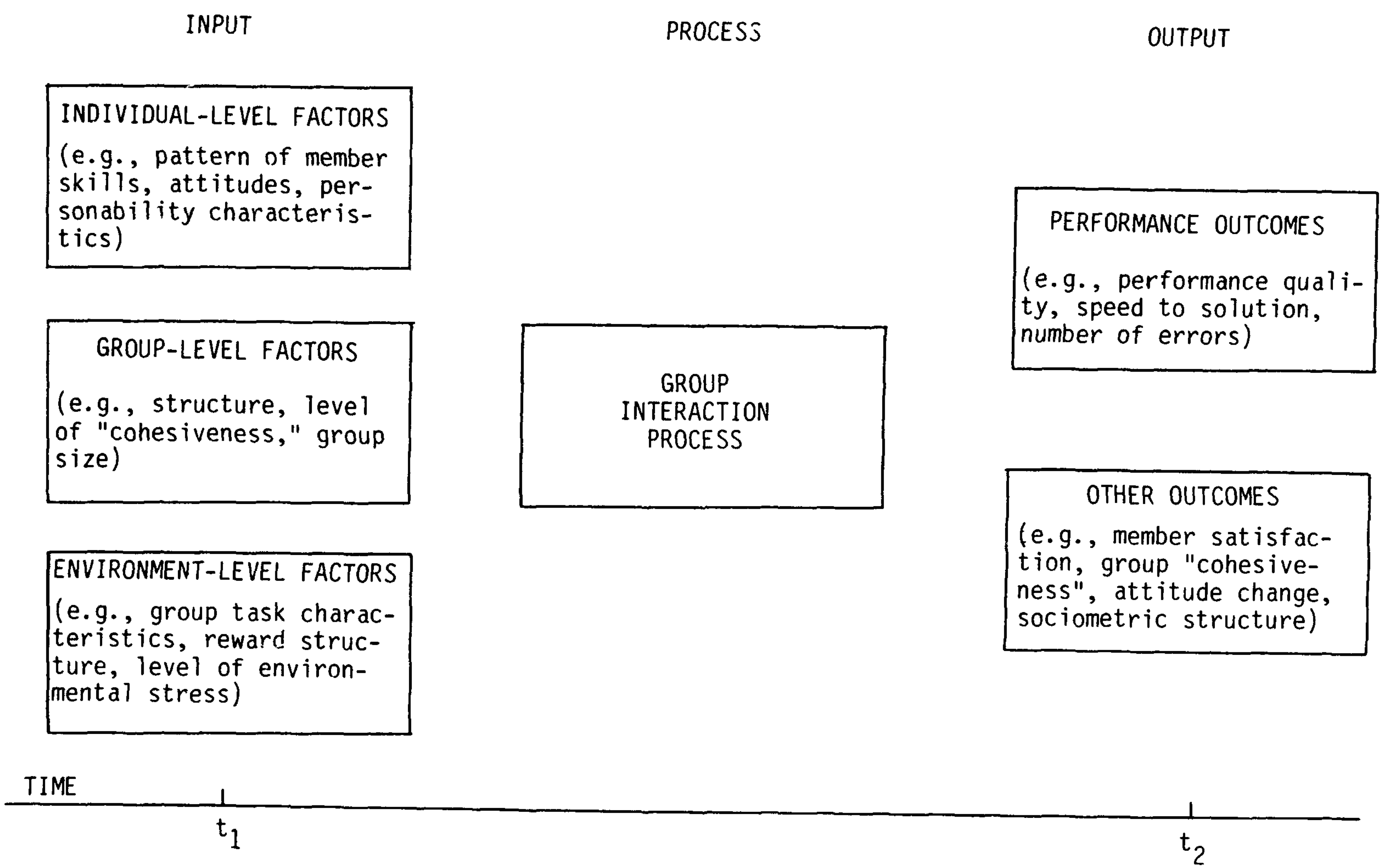

FIGURE 4. The Hackman and Morris (1975) Paradigm

(a) coordination group effort

(b) task performance strategies

(c) knowledge and skill of task members

Thus, if experimental control would capture the nature of these variables, a greater degree of understanding of the process would occur.

In conclusion, the theories presented are representative of the major kinds of theories in team performance. One should refer to Dyer's review (1984) to obtain other examples of models used to account for group behavior. The assessment that Dyer makes is that the theoretical base for team behavior is meager. It seems especially true when discussing the ability to predict and explain team behavior. When one combines the use of LGDs with team performance, theoretical foundations are even more sparse.

THE TEAM TASK

One problem to be overcome is the degree of generalizability from results using a particular group task to the corpus of team performance research, and more importantly to the operational context that often drives the research. The problem for LGD research was to create a task that would capture important parameters from the three specified research categories of group information design, team performance, and cognitive operations. In taking a look at tasks that have been used in team research, there seems to be a dearth of tasks that utilize dynamic group decision making. Thorndike and Weiner (1980) state that "the greatest leverage in team performance research can be attained by focusing research on teams that receive and evaluate dynamic information and perform time stressed decision making." Recent reviews of group problem solving and team performance (Goldin and Thorndike, 1980; Hackman and Morris, 1975; Hill, 1982) reveal a need for experimental paradigms which permit systematic exploration of dynamic group decision making. The issue of finding a task that fits the C^3 environment as well as lending itself to experimental flexibility is very important. The task that has been selected to carry out many experiments in the framework is one that possesses these qualities. Within team research, there have been many issues posited toward use of proper tasks. Refer to the Dyer (1984) review as it does justice in comprehensively describing these issues.

BASELINE STUDY

AAMRL/HEC conducted a baseline study in team performance with large and small screen displays. This study was the culmination of an evaluative review of the research, theoretical perspectives, issues, and tasks necessary to understand requirements for this type of research. Refer to Brown and Leupp (1985) for a complete description of this study. At this point a summary of their baseline study will proceed. Brown and Leupp (1985) created the TRAP task and conducted the first AAMRL/HEC experiment within the overall framework. Prior to this study, a review of the literature revealed that the Smith and Dugger (1964, 1965) research was the only major study to investigate team performance using shared vs. owned displays. They compared team performance with large and small screen, static, monochrome displays using a simple search and counting task.

The baseline study differs from Smith and Duggar's study in many respects. First, problem information and feedback are presented together on the same screen, whether large or small. Second, full color displays are used. Third, the task developed for the study is cognitively complex, dynamic, and requires team coordination and integration for optimal performance: characteristics typical of the operational C^3 context. The experiment investigated team coordination by the use of a team resource allocation problem task whereby the coordination of three team members is required for optimal performance. Thus, by working together in a coordinated fashion, the team receives a higher score on the task.

The task appeared to team members on either a large screen display or a small CRT display. Each display type presented identical information. Because the task requires dynamic decision making of team members, another variable, high versus low time stress, was also included in this study. Time stress was manipulated by changing the frequency with which new tasks appear on the screens.

The major purpose of the investigation was to compare team performance on large and small screen, full-color, dynamic, computer-generated displays, using a time-stressed and cognitively complex group problem solving task which required integration and coordination of team members' behavior for optimal team performance. Overall, screen size did not strongly affect team performance. While teams did respond in a meaningful manner to the properties of the TRAP (responsive to color, shape, 3 person tasks, and the interactive rules thereof), their responses were not greatly affected by whether a large shared display or individual CRTs were used. Since the information presented was identical for the two display formats, it may not be surprising that strong differences were not found. While subjects noted many differences between the two display formats (described below), team performance effectiveness was primarily a function of the TRAP parameters used rather than the display format.

Some subtle effects for screen size were found, however, which should be discussed. When using individual CRTs teams may have been more sensitive to the color of tasks, since they were then better able to process the more valuable red tasks. This effect could be related to subjects' belief that the individual CRTs afforded greater clarity of presentation than the large screen display. Perhaps the strongest indication of potential decrements in performance due to display format occurred during the first test session with the large screen and under high time stress. Note that team performance using individual CRTs was not decremented under high time stress. The relatively low level of team performance found here suggests that teams may need additional training time to adjust to large screen displays before they can be expected to perform optimally in stressful settings.

Subjects were given the opportunity to describe the advantages and disadvantages of the two display formats following the completion of their final test session. Subjects frequently suggested that the large screen display facilitated team communication, but that it was dimmer than the individual displays. Similarly, the individual displays were frequently described as having a sharper picture, but that they tended to isolate the team members and limit interaction. These comments suggest that the different display formats have their own particular advantages and disadvantages which could have canceled each other out in the baseline study; since the TRAP required both accurate and timely recognition of task characteristics presented on the display, as well as team communication, coordination, and integration.

The TRAP used in the baseline research is but a particular instance of a more general research paradigm which can address a host of issues related to team performance in C^3 settings. For example, alternative TRAPs can be formulated which emphasize variables such as multiple resources, uncertainty, risk, expertise, and individual values, through modification of various TRAP parameters. In addition, the TRAP paradigm can be used to investigate the importance of different types of feedback information, presentation format, channels of communication, and alternative team member configurations and roles. The fact that subjects in the baseline study understood and enjoyed the TRAP and responded in a meaningful way to its various manipulated parameters (e.g., time stress, color, and shape), supports the use of the TRAP paradigm for further research efforts.

Thus, the TRAP task is an experimental paradigm that is both useful and meaningful for the overall framework. The results of the first study utilizing the TRAP task have been briefly presented to give the reader a flavor of the anticipated research framework.

SECTION 6

FOCUS 4: RESEARCH PROJECTIONS

THEORETICAL PERSPECTIVE AND FRAMEWORK FOR AAMRL/HEC RESEARCH

Reviews and progress of the past history of team performance and LGD research have been described in the report. At this juncture a transition is proposed that takes feedback from the past and plans for the future. It is necessary to orient the reader to the present train of thought of where AAMRL/HEC should direct resources in the investigative areas. Brown and Leupp (1985) report is useful in this regard. Their baseline study served as an "opening of the door" into the framework. That baseline serves now as a major input into hypothesis formulation for subsequent studies.

The objective of the framework is to provide a logical systematic progression into the research to develop a comprehensive understanding of factors involving LGDs usage in team performance. The approach here is to state some basic assumptions, premises, hypotheses, and directions, then choose the critical combination of variables to be included for projected experimentation.

The first assumption is that the demands of a task, and the information display that portrays a given task, can be either homogeneous or heterogeneous. This homogeneity or heterogeneity can be applied differentially to various display types (large screen, small screen displays). Homogeneous information display/task demands implies that each member of a team is provided with the same information displays, content, and/or task demands regardless of display types. This is in contrast to heterogeneous display/task demands which implies that different information displays, content, and/or task demands can occur for each individual team member.

The second assumption is that there is something unique about team performance that would tend to implicate different combinations of information demands by display typology. The intent here is not to say that a large screen display is better than a small screen display in C^3 environments, but rather to understand the demands on the use of information presented to the team and how that would justify different types or uses of displays. As experimentation has again and again shown, many display characteristics are highly specific to the type of task performed. To show a gain or loss in performance with a particular display using a particular task type may be deceiving in that its applicability to other task types is not externally valid.

Reviewing these premises helps to better define experimentation. The baseline study was an example of homogeneous information and task demands in that the same information and/or task was presented on either the LGD or the SS display to teams composed of three members. Note however, that display size and shareability were varied together (confounded) rather than crossed. The expectation underlying homogeneous presentation is that there are very few reasons to assume that individual or team performance would differ significantly (assuming viewability equivalence) just as a function of increasing or decreasing the size and number of displays. However, one of the few reasons might involve differential fatigue effects that could be associated with large vs. small screen displays, but once again this seems to be inextricably tied to viewability parameters. Another less obvious reason might be termed "perspective realism." This may be explained as the ratio of the ambient size of a human's perspective view of the world to the size of the perspective view seen on a given display size. This assumes that adjusting the distances between relative heights on displays of different sizes cannot account for this sensation of realism. It also assumes that such realism would cause differential performance in teams and individuals. Unless the perspective realism view is adopted, homogeneous presentation on LGD and SS displays would not be expected to yield differential team performance. However, when one parcels out the effect of display size per se and looks at shareability (display user ratios, display information ratios, team composition) there may be some active social-organization psychological dynamics (group cohesion, social facilitation) whereby a team might perform better using a shared display rather than individual displays. There may even be interactions with display size based on the perspective realism just discussed. At any rate, homogeneous information demands presented via varying degrees of shareability represents a situation wherein there would be a greater sensitivity to detecting levels of significance than the previous situations. Shareability is a relevant variable if it is related back to the C^3 environment, as current configurations necessarily dictate that team members share information on very large displays. At this level in the experimental plan it should be possible to localize the effects of display size vs. the effects of display shareability. As discussed, the first stage of experimentation, homogeneous information demands, takes a very conservative approach to assessing technology to be integrated into team performance in that the probability of obtaining significant differences is not likely.

The second stage of experimentation, heterogeneous information demands, sets up a different experimental environment in that the probability of obtaining significant differences should be much more likely than in Stage 1. Stage 2 incorporates experimentation wherein a priori reasons and hypotheses exist that suggest increased likelihood of obtaining significant differences. Heterogeneous information and task demands specify situations whereby different information is presented to the indicated display typology and/or to different team members. This can be conceptualized by breaking tasks or information down into various units which are logically related by some overriding variable (i.e., short term memory, sequence of events, hierarchical structure). The allocation of a set(s) of these units would be present in one condition and the remaining set(s) would appear in the other condition, such that information demands are differentially present across conditions. For instance, three team members under one condition might be presented UNIT A on a large screen display which is shared and UNIT B on a small screen display which is also shared. The diversity of experimentation using heterogeneous demands is vast. Results should produce circumstances which discern how the target technology can be used to facilitate team performance. Many of the research category variables can be crossed with heterogeneous demands to formulate a series of pertinent studies.

The third stage of experimentation will investigate the use of knowledge systems for C^3 team performance. This stage will pick up the research from the succeeding stages and perturb these results by the use of knowledge systems in different capacities. The first projected capacity is the use of a knowledge system as an additional "team member". This combination of team composition and knowledge system variables form what could be termed "the degree of cooperative intelligence". Display typology might be affected by varying the effective intelligence of the team such that different display configurations result in changes in overall team performance. The second projected capability is to utilize the knowledge system in a way that will efficiently adapt salient variables identified under the three basic research categories in a way that results in the best possible configuration per specific time segment. For example, the system could be programmed to switch between homogeneous and heterogeneous display of information as a function of the display/user ratio and display/information ratio to create an adaptive shareability configuration. The use of a knowledge system at this point requires an understanding of the rules that evolve by various combinations of the experimental variables. Once these rules are captured, they can be simulated in a way that adapts the configuration to result in optimized C^3 team performance. The experimentation at this point would try to assess the use of adaptability as well as various combinations of rules to produce that adaptability. Refer to the projected research focus level 3, Other GRID Research Domains for more details.

The key to fulfilling this research framework rests with the effort associated with Heterogeneous Information Display. Thus the remainder of this section will dwell on assumptions and hypotheses related to this stage. In reviewing the Smith and Duggar (1964) study there seem to be some underlying principles and premises that can be re-examined in light of the current experimental paradigm. An attempt will be made to generate a first level hypothesis that can act as a foundation for TIER 1 & 2 research. The different variables which will be manipulated in TIER 1 & 2 will emanate from this foundational hypothesis. An elaboration of this hypothesis will be given as a succession of premises with associated points.

Baseline Premise #1: A shared display configuration yields better team reaction time performance than a separate display configuration; whereas a separate display configuration yields equal or better team accuracy performance compared to a shared display configuration.

Premise #2: The nature of the baseline premise changes as a function of the type and demand of cognitive demands associated with the group task.

Corollary 2A: Tasks that demand concensus among individual comparison processes will actively make the baseline premise more robust. Group tasks that require individual subjects to interpret dynamic perceptual data and then come to a group concensus about the interpretation will bring out the baseline premise more so than innocuously simple group tasks.

Corollary 2B: The group interpretation of perceptual information is contingent on the allotted time of processing, the complexity of the information, the degradation of the information, the density of the information, and the structure of information; any one of these characteristics may interact with the baseline premise.

Corollary 2C: If the nature of the TRAP task was changed to require more perceptual group comparison processes, and if reaction time as well as accuracy measures were collected, then Premise #1 would be most active.

Premise #3: If one can look at display size as well as shareability, then performance can be evaluated in terms of the display size and the shareability as well as any interactions present.

Corollary 3A: For homogeneous information presentation, the shareability result will stand regardless of display size.

Premise #4: The simultaneous utilization of a shared and separate display configuration may tradeoff speed with accuracy to achieve the best overall performance.

Premise #5: The addition of heterogeneous information will better utilize the shareability aspects of group display as across the board increases for accuracy and reaction time performance are expected.

Corollary 5A: The degree of relation between information shown in the shared display and the separate display will affect the relative performance quotient.

Corollary 5B: Information that varies across a continuum (global to local, past to present, top to bottom hierarchy, verbal to spatial) should coax out performance efficiencies.

Corollary 5C: Information presented in the shared configuration that specifies guidance, cooperation, or leadership will be better processed by the group than if it is presented on separate configurations, and should perturb the results inherent in Premise #1, and overall increase the performance quotient in comparison to those conditions where it is not present at all.

Premise #6: Restrictiveness of communication will change Premise #1.

Corollary 6A: All the team performance variables will make significant changes to the baseline performance.

Premise #7: The effect of continuing exposure among teams tends to lessen the relationship of Premise #1.

Premise #8: The robustness of Premise #1 is operative for certain ranges of group size.

Corollary 8A: As team size increases, the Premise #1 robustness also increases up to a plateau point which differs for the reaction time and accuracy measures.

This succession of premises thus forms the backbone for creating the series of experiments necessary to answer questions in the framework. The suggested line of experiments under each research tier are related to these original premises in Table 1. As each experiment is conducted, the premises can be refuted or accepted or expanded such that a comprehensive understanding of team technology interaction can be achieved. Other directions that also seem promising to further bolster the perspective and the basic premise list are available. Guzzo (1982) discusses the study of information flow and intragroup communications as being crucial to the understanding of group decision making. Especially relevant would be the work of Roby (1968) as it inherently sets up empirical relationships in a very comprehensive spectrum of variables. Additionally, Stasser and Titus (1985) recently have begun investigation of biased information sampling, whereby shared information is weighted more heavily than unique information. This might be beneficial for looking at the LGDs as a mechanism for channeling unique information into shared information to enhance group performance. However, at this point there certainly is enough perspective to guide quite a few experimental designs and collect data that would be useful from both theoretical and operational viewpoints.

The framework that underlies the research plan consists of levels of planning. They are:

LEVEL 1: PLANNED GRID EXPERIMENTAL DESIGN

LEVEL 2: GRID RESEARCH EXTENSIONS

LEVEL 3: OTHER GRID RESEARCH DOMAINS

The first level reveals a series of possible experiments necessary to answer questions associated with the basic premises. These experiments are dichotomized into two separate, yet related research tiers. TIER I will consist of approximately five studies and will cross the group information design research category with the cognitive operation research category. TIER II will consist of approximately six studies and will cross the group information design research category with the team performance research category. A systematic progression through each tier should generate relevant information for subsequent experiments and may act to re-orient experiments proposed for a given tier.

After Level 1 is addressed, Levels 2 and 3 take some liberty in looking at other possibilities not addressed in Level 1. Levels 2 and 3 will be more abstract.

TABLE 1. Research Premises and Associated Experimental Sets

Experimental Sets		Premises							
		1	2	3	4	5	6	7	8
		Shared Versus Separate	Cognitive Demand	Sharability	Both Shared and Separate	Heterogeneous	Restr. Comm.	Cont. Expos.	Group Size
Tier 1	ES0	X	X					X	
	ES1		X	X	X	X			
	ES2		X	X	X		X		
	ES3		X		X				
	ES4		X			X			
	ES5		X		X	X			
Tier 2	ES6							X	X
	ES7		X						X
	ES8	X			X		X	X	
	ES9	X	X		X		X	X	
	ES10		X			X	X		X
	ES11		X			X	X		X

LEVEL 1: PLANNED GRID EXPERIMENTAL DESIGN

TIER I EXPERIMENTATION OUTLINE

GROUP INFORMATION DESIGN VARIABLES X COGNITIVE OPERATIONS VARIABLES

ES0: Original baseline experiment: Display size x time stress x session

ES1: Display Configuration x Information Typology

ES2: Display Configuration x Degree of Allowable Communication

ES3: Display Configuration x Secondary Task Restraint

ES4: Display Surface Size x Display Structure x Information Content

ES5: Display Configuration x Control of Clutter

Each set represents an entire region for experimentation, but the experimental designs listed above represent the respective baselines for each region.

ES = Experimental Set

TIER II EXPERIMENTATION OUTLINE

GROUP INFORMATION DESIGN VARIABLES X TEAM PERFORMANCE VARIABLES

ES6: Display Configuration x Team Performance Rules x Social Facilitation

ES7: Display Configuration x Comprehensive Social Facilitation

ES8: Team Performance Rules x Seating to Display Configuration (LGD Only)

ES9: Team Performance Rules x Seating Configuration x Information Typology x Visual Field of Presentation:

ES10: Team Leader Proficiency x Co-worker Function Overlap x Blackboard LGD Usage

ES11: Team Leader Proficiency x Co-worker Function Overlap x Blackboard LGD Usage x Degree of Cooperative Intelligence Available

LEVEL 2: GRID RESEARCH EXTENSIONS

In addition to the planned experimental design there are a myriad of other variables that could be strategically investigated to elucidate an even greater understanding of the use of LGDs in the C^3 arena and also provide more depth to theoretical insights. Table 2 illustrates some of the independent variable possibilities that AAMRL/HEC could insert in appropriate planned designs or they could be considered useful for new experimental designs. Many of these variables can be implemented by just changing various parameters of the TRAP task. Thereby, the insertion process will be relatively easy if the TRAP task is used. Some variables may be an extension of other variables in Level 1.

TABLE 2. RESEARCH POSSIBILITIES: VARIABLES OF CONCERN

Group Information Design

- display format
- information density
- perspective realism
- color utilization strategies
- display to information ratio (# of display windows with unique information)
- user selectivity
- feedback information
- information representation

Cognitive Operations Required

- perceptual processing and complexity
- time sharing/allocation
- short term memory/long term memory task overloading
- motor task demands
- mental fatigue effects
- differential task rules
- multiple resources
- uncertainty
- risk
- expertise
- individual values
- time stress
- fatigue effects
- secondary tasking

Team Performance

display-user ratios (sharability/cohesiveness)

team composition
- number of team members (degree of cooperative intelligence)
- team member roles
- duty cycles
- expertise available

communication structure
- coordination specification
- allowable channels
- alternative configurations

team orientation
- angular perspective to display
- positioning relationships between team member and presentation media
- seating arrangements

learning levels
- session performance
- differential user proficiency
- differential training procedures

team stability

- all vs part of team present during tasks
- disruptability

use of incentives

LEVEL 3: OTHER GRID RESEARCH DOMAINS

At this point, the research projected for Levels 1 and 2 could be overwhelming to conduct let alone analyze. However, with a systematic plan to progress through the right mix of experiments, substantial advancement can be made. The far-term research is conjecture at this point but it provides evidence that AAMRL/HEC is planning long range contingencies. Research for the long term must span the vista of experimental social psychology and team technology insertion. This might be termed group capacitators. In essence research would extend beyond the use of LGDs to a look at other team technologies that could facilitate group performance. This would be looked at in terms of the concept of group capacity or multiple group resources such that various team technologies might properly utilize the right resources of the group. Note that in this context the group necessarily includes the use of cooperative intelligence assistants as members. As currently envisioned, far term research would focus on metateam structures. These would be structures that integrate group capacity, environmental psychology, and human information technology to provide the most adaptable, enhanceable C^3 environment for performance. Within a C^3 environment many metateam structures would be interconnected by a group sensory conduit. Within each metateam structure various expert vision, audition, and handling capabilities would be exploited. Some of the areas necessary to study team technology are as follows:

- optical videodisc technology
- optical computing
- expert systems
- video teleconferencing
- advanced computer graphics
- virtual audio coupling (temporal sound, spatial sound, audio-voice typing)
- virtual visual coupling (dimensionality, exploratory environment, mutual imagery)
- virtual knowledge (verbal information enhancement, logical reconstruction, knowledge search)
- adaptive structure (group dynamic efficiency, spatial reconfiguration, manageable information capture and release)
- holographics
- dialogue structuring
- recombinant group architecture

Truly the direction of long term research will spawn as a function of: 1) preceding planned experimentation, and 2) the advancement in team technologies. The possibility to expand the performance within C^3 environments will dictate the likelihood to pursue the research in this level.

SECTION 7

FOCUS 5: TECHNOLOGY EVALUATIONS

This section comprises much of the actual evaluation that AAMRL/HEC has conducted. First, a short discussion will be provided regarding the reasoning as to why the COPE laboratory was equipped with a certain type of technology mix. After the reader has been provided with an understanding of the technology used and why, a brief account of the evaluation of that technology will proceed. Although this section evaluates and provides rationale for the specific system employed in the COPE laboratory, the requirements used for specifying an LGD system are entirely extensible as general guidelines for specifying LGD technology and will be treated as such.

The COPE-Large Screen Display Systems (LSDS) includes a Silicon Graphics 2400 RGB high-resolution computer graphics work station, a General Electric PJ5150 color light valve projector, and a Phoenix Communications, Inc. Optixx Mark XX high-gain rear-projection screen. Note that the actual display surface denoted by the LSDS is approximately 4 ft x 3 ft but the actual available display surface could be up to 5 ft x 7 ft.

LGD CONFIGURATION: SELECTION CRITERIA AND REQUIREMENTS

There are a number of different types of LGD technologies which could be considered for use in a C^3 center. However, the intent was to choose and then evaluate a technology that provided the most advantage based on predetermined requirements criteria. This section of the report will describe the following points in detail to demonstrate some of the decisions necessary for selecting LGD configurations:

1. Description of technical criteria or requirements which the LSDS must meet.

2. A listing of technology options for LGDs.

3. Evaluation of the technology options.

4. The LSDS chosen.

In order to provide a robust testbed for studying GRID and selecting LGD technology for C^3 operations under various conditions, the following requirements were specified:

Ambient Illuminated Environments/Brightness. The LGD should be capable of being viewed in the ambient illumination of office environments. This eliminates the possibility of reducing illumination to darken the room to obtain sufficient contrast. Thus, ambient illumination refers to the lighting conditions in the environment or surroundings. The AFSC Design Handbook 1-3, Human Factors Engineering, states that for tasks requiring normal detail work for prolonged periods the illumination level should be 215-538 lx or 20-50 ft-C. Thus, the LGD must be bright enough to be seen in these ambient environments. Carbone (1982) suggests that brightness requirements for displays should be at least as bright as the ambient illumination and in general should be twice as great as the ambient illumination. As the projection source for the LGD configuration increases in luminance output (lumens) and as the gain of the projection screen increases, for a given screen area, the brightness at the screen surface will increase. Screen gain is defined as the ratio of the brightness to incident illumination. Thereby in order to ensure adequate brightness in the ambient environment the luminous output of the LGD projection source is an important factor, as is the gain of the projection screen. Carbone (1982) uses the following chart to designate brightness in terms of lumens:

Brightness	Lumens
Low	0 to 300
Moderate	300 to 1000
High	1000 to 3000
Very High	$>$ 3000

Also related is the luminance contrast ratio (defined as the ratio of display brightness to the viewing screen background ambient). The recommended contrast ratio varies as to the degree of ambient light present. In general, higher contrast results in improved legibility especially in high ambient environments.

Full Color Capability. This requirement simply indicates that the LGD system must be capable of generating a full color spectrum rather than just monochrome or partial color capability.

Sufficient Viewing Angle. Viewing angle may be defined as how much angle the observer's line of sight differs from the perpendicular to the display surface. MIL-STD-1472C suggests that an acceptable limit of up to 30^{o} off center is acceptable. However, any system that would provide more viewing angle (up to 60^{o}) without a deficit in performance would be desirable. Viewing angle is considered a necessary requirement as teams viewing a central LGD are necessarily positioned at different viewing angles offset from center. To the extent that a greater allowable viewing angle can be provided, more people can acceptably view the display at the periphery. The determination of viewing angle is highly related to the construction and type of materials used in the projection screen.

High Resolution. This refers to amount of raster scan TV lines the system is capable of generating. As the amount of lines increase, the degree of resolution gets better. Thus high resolution systems are ones that have a sufficient number of raster scan lines available. Carbone (1982) defines the levels of resolution as:

Resolution	
Low	0-625
Moderate	625-1000

High	1000-3000
Very High	> 3000

The degree of resolution of an image is important as this helps determine the extent to which an observer can interpret various degrees of detail of projected images. Many guidelines suggest that there be 10-12 TV lines per character height. An LGD system that can generate high resolution imagery is considered very useful. Resolution should be equivalent to that of CRT imagery.

Short Distance to Viewers. This refers to the actual distance between the users and the screen. The system to be recommended will be one that improves user interaction in that the display is within close proximity of the user, as opposed to very large screen displays where there is a great distance between the user and the display. As the distance from the user to display increases, a number of factors or inadequacies in the system are activated such as improper brightness, poorer image quality, and legibility in general. Thus, one important requirement is that the system be legible as close as six feet from the user. In general, some of the guidelines suggest that the minimum viewing distance be at least two times the width of the projected image and the maximum viewing distance be no further than six times the width of the projected images. LGD systems unable to ascertain these distances should not be considered for use.

Limited Obstructions to Display Surface. The LGD system should not contain obstructions that would interfere with an observer's line of sight to the display surface. Necessarily this delimits the use of front projected display screens as the possibility would exist that the projection equipment could hinder observers' line of sight to the display surface. However, if a front projection is necessary, the use of a ceiling mounted projector or a projection system that is built into a desk can significantly reduce obstructions to the display surface. Also, the rear projected screen reduces the probability of noise obstructions to the user.

Adaptable Display Size. The system that allows only one display projection size is inflexible. Within the C^3 environment, the capability to adaptively change the display size in response to other factors and conditions provides the designer with an extra degree of control whereby relative equivalence among factors can be calculated. A one size only takes away this advantage. The target range of sizes would optimally be as small as you need to as large as you need. The point is that size needs to be considered along a continuum that may range from the very small group display to the ultra-large group display. Flexibility is a very important consideration in determining screen size.

Uniform Light Distribution on the Screen. This refers to the relative variation of luminance across a screen and is given as the ratio of maximum to minimum luminance. MIL-STD-1472C recommends that this ratio be between 1 (optimum) and 3 (acceptable). The degree to which brightness rolls off at the end of the screen is important. In the C^3 environment, the light distribution should be as uniform as possible in order that information on the display extremities can be seen as well as information at the center. In many situations it may be necessary to trade off absolute brightness with uniform light distribution.

Display Registration Drift. When generating color, the LGD type may have considerable problems in registering various colors. The color generation technique may mix or overlay images from different projectors to obtain desired colors. Thus, this makes the probability of misregistration likely. Misregistration can equate to misperception on the part of the observer, thus it must be alleviated as much as possible.

Real-Time Video with Natural Gray Scales. This means that the LGD system must be compatible with real time video rates and have the necessary shades of gray to provide natural transition of imagery. Eike, et al (1980) suggest that at least 10 shades of gray should be used.

CRT Compatibility. The LGD system must have a capability to be compatible with CRTs. This means that the system can be connected to a CRT with minimum problems whereby information present on the CRT can be seen on the LGD also. This allows for a high resolution source for text and graphic capability if so desired.

Cost. Although cost was not a technical factor in evaluating systems, it certainly is a practical limitation. For AAMRL/HEC, research systems which cost more than $100,000 were considered too expensive to acquire.

FUTURE POTENTIAL TECHNOLOGY

This refers to technology that is not "off-the-shelf" but is currently under development. All the criteria already mentioned apply as well as the following additional criterion.

Small Blackboard Display Characteristics. Future technology requirements should focus on creating a display that emulates a "small blackboard". This means that the display should be a smaller volume and lower cost than that of the "off-the-shelf" technology. Specifically, the small blackboard display should be about 1 meter diagonal in size, relatively flat in depth (6"), and have some degree of mobility for repositioning activities. In essence this display would be able to be hung from the wall like a picture and most likely be used for small group interaction.

The technology options that currently exist (or are in development stages) and may satisfy the criteria for selecting LSDS can be classified in three basic groups:

1. CRT based

2. Plasma based

3. Liquid Crystal/Oil Film based (external light sources).

Each of these technologies have inherent limitations and capabilities. The key for selection is to determine not only which of the three basic groups satisfy the most criteria listed in the most desirable way but to also specify a particular manufacturer within that basic group.

An evaluation of the CRT based group reveals that the largest drawbacks are in the areas of resolution and registration. Constant adjustments to registration controls makes the CRT based projector unsuitable in an exacting environment. Note too that they are limited in their brightness output capability to approximately 250-350 lumens. Also because each CRT projection phosphor is often run at high brightness levels, the green phosphor tends to overwhelm the others as the eye is most sensitive to the green phosphor.

Most of the plasma based displays could not meet the necessary criteria of real-time video with natural grey scale range. However, the one plasma based display that is developing this capability turned out to be the designated, "FUTURE POTENTIAL" technology. At this time, the full color requirement seems unobtainable for plasma displays.

The liquid crystal light valves satisfy part of the criteria (high resolution, brightness, possible color requirements) but fall short of providing real time video with natural grey scales. Also the light valve may end up producing "unique colors" that can be undesirable.

Finally, the evaluation of the oil film light valve indicated that it is the only projector to satisfy a majority of the requirements. Most importantly it fulfills requirements of brightness, high resolution, full color, and real time video with natural grey scales. Another major advantage is that there are no registration problems in color oil film projectors. Within the oil film light valve grouping the GE PJ5150 professional large screen projection was chosen as it fulfilled about all of the requirements in the best ways possible. This system also was affordable in terms of the limitations given. The only possible drawback, as experienced so far, is the different coloration of the horizontal and vertical edges which can be a noticeable characteristic on characters of small size.

In combination with the projector a rear screen approach was necessarily chosen to satisfy part of the requirements criteria. The rear screen projection allows the front of the image to be free from obstructions, is quieter for the operators, provides viewability under a wide range of ambient environments, provides a wide viewing angle with little brightness rolloff, and enhances contrast. The rear screen projection's greatest advantage is that it provides high gain with no loss of viewing angle which also equates into allowing higher ambient lighting for users. Contrast enhancement is active as the materials used to form the screen have very low light reflection and appear dark in reflected light. Therein, when ambient light falls on the viewing side of the screen, the contrast is not washed out. Note however that in darkened low ambient lighted rooms this would not be advantageous. The use of the rear projection screen has some factors that will need attention. First, an area behind the screen will be required to house the projection system and achieve proper throw distances of the projector. Second, all the light reflectance and scattering behind the screen must be controlled to ensure contrast enhancement. It is suggested by Benel and Benel (1984) that the application of matte black point to the walls and other surfaces and the use of light baffles should be considered.

The rear projection screen chosen for the LSDS was an OPTIXX Mark 2Ø. The Mark 2Ø is an assemblage of biconvex lenticular lens to which is attached a clear acrylic substrate and a layer of diffusion material. Black matrix striping at defined intervals appears on the front of the lensing material. A photometric evaluation of the screen against another smaller screen revealed that the Mark 2Ø was clearly superior over the screen in terms of hot spots (brightest screen loci) consistency and gain consistency across the screen.

Thus, the marriage of the Mark 2Ø screen with GE PJ515Ø oil film light valve yields an LSDS that maximally satisfied the requirements criteria. There was only one system that met the additional criterion for "future potential" technology as well as other criteria. The Lucitron flatpanel display very much emulated the requirements of the small blackboard screen. It has a depth of less than 6", it is a hangable/mobile display, it will be approximately a meter diagonal in size (although larger screen sizes are certainly possible), it is less expensive than the chosen off-the-shelf technology, and its biggest advantage is that it has the capability for real time video with natural gray scales. This technology should be available in a 6-9 month timeframe for the monochrome prototype version. The color version is still in development with the availability date being indeterminate at this time. Refer to APPENDIX 5-6 for additional specifications on the selected equipment for the COPE LSDS.

LARGE SCREEN DISPLAY SYSTEM EVALUATIONS

Using the LSDS configuration just described, AAMRL/HEC pursued an evaluation of legibility/viewability to determine the correct parameterization necessary using light valve technology. This is an extremely useful evaluation as the results indicate that one cannot just use generic visual display (CRT) legibility guidelines to configure the parameters of an LGD. Thus, this study reveals new suggestions for human factors display criteria when using light valve technology.

The COPE-LSDS is intended for group viewing of critical information under medium (normal) ambient illumination, at various viewing distances ranging from 6 to 15 feet, and at various viewing angles.

The system evaluation, based on human performance measures, assessed the main and interaction effects on display legibility of the following factors:

Character Dot-Matrix Format	Viewing Distance
Character/Background Contrast	Viewing Angle
Character Visual Angle	Position on the Screen

An adaptation of the legibility evaluation methodology and performance measures recommended by Shurtleff (198Ø) for critical information processing of alphanumeric characters, based on a character-identification task, was used. Shurtleff (1981) suggests that legibility criteria cover three important aspects of symbol identification performance: accuracy, speed, and error distribution. The legibility criteria for military applications are shown in Table 3.

The evaluation was conducted in a series of two experiments, resulting in guidelines/recommendations for acceptable data configuration and display viewing limitations. The first addressed the following questions:

1. What is the optimal character size (in dot-matrix dimensions and visual angle) for viewing this display at a range of 6-15 feet? Is there more than one acceptable character size?

2. Is performance equivalent for stimuli of equal visual angle, or is there a size x viewing distance interaction?

3. Does character/background contrast direction (black/white vs. white/black) influence performance, or the choice of acceptable character sizes/format?

The experiment examined a 3x2x4 factorial combination of independent variables to test the legibility/viewability of the LSDS. These variables were operationally defined as follows:

*Character Dot Matrix Format (5x7, 7x9, 10x14)
*Figure/Ground Contrast Direction (black on white, white on black)
*Viewing Distance (6ft, 9ft, 12ft, 15ft)

Subjects identified characters within a constructed set of 3x3 letter matrices in accordance with the specified conditions of the aforementioned variables. The proportion of correct identification and number of correct characters per minute were compared for each variable. An analysis of the results of first experiment provided evidence for the forthcoming recommendations.

The use of single-stroke characters is not recommended because of edge-coloration characteristics inherent within the light valve technology. Instead, double-stroke characters should be used. Based on Shurtleff's (1980) legibility criteria for critical information displays, the 10x14 double-stroke dot matrix format (both black/white and white/black) was acceptable for the entire range of viewing distances (6-15 feet). The 7x9 black/white characters met the accuracy criterion (98% correct) for distances up to nine feet, but fell short of the speed criterion. Therefore, for on-axis viewing, a double-stroke dot-matrix format between 7x9 and 10x14 may be suitable for the entire range of distances, and should be more legible in a black/white display. Using the smallest (threshold) character format which meets the legibility criteria allows for the most information to be displayed simultaneously, or a less-dense display of a given amount of information. In order to find the threshold dot-matrix resolution for the range of viewing distances, this experiment should be repeated using several dot-matrix formats between 7x9 and 10x14. Data

TABLE 3. LEGIBILITY TEST CRITERIA

Accuracy of Response

1. 98 percent or more of the total identifications must be correct.

Distribution of Response

1. Confusions involving a single pair of symbols (e.g., B and 8) cannot exceed 2Ø percent of the permissible error.

2. Confusions for a single symbol cannot exceed 15 percent of the permissible error.

Speed of Response

1. Alphanumerics must be identified with a speed of 12Ø correct identifications per minute or better.

2. Special symbols must be identified with a speed of 5Ø correct identifications per minute or better.

reviewed by Shurtleff (1980) suggest that 7x11 or 9x11 is more appropriate for raster displays.

If a 10x14 dot-matrix character is used, character/background contrast will not affect legibility. However, for formats between 7x9 and 10x14, contrast may influence legibility, and should be tested in the threshold experiment mentioned above.

The legibility threshold cannot be stated in terms of a minimum character visual angle, since performance was dependent on both dot-matrix format and distance. The two- and three-way interactions of the three independent variables indicate the necessity to consider all three parameters together when specifying acceptable character configurations for this display system.

The second experiment addressed the following questions:

1. Are the character sizes which met the legibility criteria in Experiment 1 also legibile from off-axis viewing angles?

2. Are these character sizes legible at the edge and corners of the screen, which are the lowest luminance display loci?

3. Are these character sizes equally legible under all of the degraded viewing conditions mentioned above or is one size better than the other under any of these circumstances?

In order to collect data to answer all of these questions in a timely fashion, a "worst case" situation was devised to represent the most extreme (degraded) display loci and viewing angle.

The second experiment examined a worst case scenario wherein subjects viewed stimuli presented at the extreme opposite edge of the screen at 45 degrees off-axis, which equated to a viewing angle of 60 degrees off-axis to the stimuli. The experimental variables used for the second experiment were:

*Dot Matrix Format (7x9, 10x14)
*Stimulus Loci on the Screen (top, middle, bottm on left screen edge).

The task using the 3x3 character matrices and the dependent variables was similar to that used in the first experiment. An analysis of the results of the second experimment provides the basis of the forthcoming recommendations. The results of the experiment reveal that the 7x9 and 10x14 dot matrix sizes meet the accuracy criterion. Because a worst case situation with respect to viewing angle (60°) and screen position was considered, these results suggest that the COPE LSDS is viewable up to 60° off axis with the extreme screen positions present, for tasks that just require accuracy performance. However, because the 7x9 size did not meet the speed criterion at 60° off-axis with extreme screen positions, it is recommended that a 10x14 dot matrix size be used in situations demanding worst case positions which require speed in performance. Although further empirical testing would be required, it appears that a dot matrix size somewhere in between the 7x9 and 10x14 size would be able to meet the speed criterion. The results also suggest that the screen position does not contribute to improve legibility, given worst case situations. For a more detailed description of these studies, refer to McNeese and Katz (1985).

One other point in the evaluation of the technology needs to be reported. In the baseline COPE-LGD experiment, Brown and Leupp (1985) asked the 24 subjects who participated in the experiment to complete a questionnaire to compare large and small screen displays for: a) clarity of presentation, b) ease of use, and c) coordination of team effort. The results of the questionnaire provide a subjective evalution of the technology under consideration and gives complimentary insight to the objective experimentation.

Results of the questionnaire found that the individual CRTs were rated more highly than the large screen for clarity of presentation. However, the individual CRTs and large screen were not rated significantly different in ease of use or for coordination of team effort. Finally, no significant difference existed in overall preference: eight subjects preferred the large screen, 10 preferred the individual CRTs, and six expressed no preference.

These subjective evaluations suggest that the LGD frequently facilitated team communications but was not as clear as the CRTs; and the CRTs provided a much sharper picture, but they tended to isolate team members and limit interaction. Overall then the subjective evaluation reinforces the point that the use of a LGD with CRTs must be predetermined in the conceptual analysis stage (via an Integrated Analysis Techniques-like front end analysis) before actual designs are in concrete.

SECTION 8

FOCUS 6: TECHNOLOGY PROJECTIONS

TARGET TECHNOLOGY

One of the requirements listed in section 7 was put forth under the heading of "future potential technologies". The requirement suggested a technology that would have small-blackboard display characteristics for use in small group interactions (e.g., boardroom decision making). The technology that is projected for this requirement is termed gas-electron-phosphor (GEP) and is produced by Lucitron, Inc., based in Northbrook IL. The Lucitron display features a one meter diagonal monochrome display with 12.5 pixels per inch resolution. Additionally, the display is flat (less than six inches thick) and features high brightness, fast refresh rate, and CRT compatibility. The major problems at this point seem to focus on thin vertical striations that tend to appear within the display. These striations are created because of the manufacturing process of grids and appear to be a technical obstacle that can be overcome. Also, the appearance of color is probably at least a year or two away.

The use of a GEP display would be advantageous in C^3 settings in the role of a blackboard display. If 2-3 users could refer to a display that could be hung on a wall while still having capabilities for high ambient illumination and high resolution for TV video, then group displays could be implemented much more easily.

GEP displays have much greater potential for C^3 applications than plasma displays because they provide adequate grey scale, faster update rate, and accept standard interface capabilities (e.g., TV). Evaluations of other relevant LGD technologies have been previously compared and specified. However, at this time, the GEP display is the only one that truly appears promising for the near term.

LASER PROJECTION LGDS

Recently, a new laser LGD projection technology has been introduced that may significantly advance the state of the art for LGD systems. The Defense Communications Agency Center for Command, Control, and Communications Systems (C^4S) has published a factsheet that describes a technology survey of large screen display systems (1985). The factsheet states that, "laser projection techniques have demonstrated brilliant images, excellent display resolution (potential to 2000 lines), contrast ratios of better than 500:1, and constant focus." They continue to say that, "the color fidelity is outstanding and precise video registration is achieved (1/3 pixel)." However, they also point out that the system has some disadvantages that include use of a water cooling system and currently limited product availability. Additional qualities of this system are reported in the DCA Command Center Improvement Program (CCIP) newsletter, Vol II, No. 1, March 1985, which include the ability to project an image size of 95' x 45', to project on flat, curved, or domed viewing surfaces, and to allow windowing and mixing video displays with the use of additional optics and beam splitters. The use of the laser projection system will be determined in part by additional experimentation and analysis, operational utility, and availability. However, it certainly must be considered as a high payoff technology that currently seems to be gaining support for use.

As new team display technologies develop, they will definitely have applications in the C^3 arena. However, many of these seem down the road in terms of their development cycles. The team technology areas that seem most probable for study and development for team performance are:

video teleconferencing and
optical videodisc technology.

In order to truly advance the team performance enhancement concept these technologies need to be investigated for C^3 applications.

APPENDIX 1

SUPPLEMENTARY GUIDELINES

LGD OPTICAL PROJECTION GUIDELINES (VIA LIGHT VALVE TECHNOLOGY)

Source 1: McNeese, M.D. and Katz, L., Legibility Evaluation of the COPE Large Screen Display System Under Medium Ambien[illegible]ination. AAMRL Technical Report, 1985 (to be printed).

LGD OPTICAL PROJECTION GUIDELINES (NOT SPECIFIC TO LIGHT VALVE TECHNOLOGY)

1. Benel, D.C.R. and Benel, R.A., "Use of Group Viewing Displays for SHORAD Command and Control" (Technical Note 8-84). Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory, May 1984.

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4. MIL-STD-1472C. Military Standard: Human Engineering Design Criteria for Military Systems, Equipment, and Facilities. Redstone Aresental, Alabama: U.S. Army Missile Command, 1981.

Paragraph 5.2.5 Large Screen Displays
Paragraph 5.2.6.6 Large Screen Optical Project Displays Criteria

5. Shurtleff, D.A., Wuersch, W.F., and Rogers, J.G., "How to Make Large Screen Displays Ledgible," Proceedings of the Human Factors Society 25th Annual Meeting. Rochester, New York: 1981.

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DISPLAY VIEWABILITY/LEGIBILITY GUIDELINES (REFERENCES)

1. Benel, D.C.R. and Benel, R.A., "Use of Group Viewing Displays for SHORAD Command and Control" (Technical Note 8-84). Aberdeen Proving Ground, MD: U.S. army Human Engineering Laboratory, May 1984.

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6. Shurtleff, D.A. "How to Make Displays Legible" Human Interface Design. Whiltier, CA, 1980.

DISPLAY DESIGN GUIDELINES (REFERENCES)

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2. Nelson, M. "Design Considerations for NORAD C^3 Displays," Technical Report No. SRL-HF-83-100, Systems Research Laboratories, Inc., Dayton, OH, September 1983.

3. Pew, R.W. and Rollins, A.M., "Dialogue Specification Procedures" (red. ed.) (Report No. 3129), Cambridge, MA: Bolt, Beranek, and Newman.

4. Smith, S. L. and Mosier, J.N., "Design Guidelines for User-System Interface Software", Section 2: Data Display (Technical Report ESD-TR-84-190) Hanscom Air Force Base, MA: USAF Electronic Systems Division.

5. Willeges, B.H. and Willeges, R.C. "User Considerations in Computer-Based Information Systems" VPI/Industrial Engineering/Operation, Blacksburg, VA (Rev. Ed.), January 1982.

6. Willeges, B.H. and Willeges, R.C. "Dialogue Design Considerations for Interactive Computer Systems." In F. Muckler (Ed.), Human Factors Review, 1984.

APPENDIX 2

SUPPLEMENTARY RESEARCH

VISUAL DISPLAY RESEARCH SOURCE

In order to get a thorough review on human factors research on visual display terminals refer to:

Helander, M.G., Billingsley, P.A., and Schurisk, J.M., "An Evaluation of Human Factors Research on Visual Display Terminals," In F. Muckler (Ed.) Human Factors Review, 1984.

This will review many legibility/viewability parameters and other human factors considerations for visual display terminals. This is not, however, specific to LCDs. Research in the area of light valve LCD technology is non-existent.

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3. Gill, D.L. "Cohesiveness and Performance in Sport Groups" In R.S. Yeston (Ed.), Exercise and Sports Science Review (Vol. 5), Santa Barbara, CA: Journal Publishing Affiliates.

4. Knerr, C.M., Berger, D.C., and Popelka, B.A., "Sustaining Team Performance: A Systems Model" (ARPA Contract No. MDA 903-79-C-0209), Springfield, VA: Mellonoics Systems Development Division.

APPENDIX 3

SUPPLEMENTARY TECHNOLOGY

This appendix will present data, specifications, and comparisons that give more details on the LGD technology that is available. The presentation of technology will be twofold. First, specifications will be given for the COPE LGD technology and then data/comparisons will be referenced for other available LGD technologies.

GENERAL ELECTRIC PJ15150 OIL FILM LIGHT VALVE (Taken from Carbone (1982))

The General Electric Company manufactures a line of moderate cost monochrome and color large screen television video projectors. These devices are commercial product line items and are presently available off-the-shelf. Both the PJ5000 and PJ7000 series provide moderate resolution and moderate brightness display presentations. The PJ5155 is a high intensity, color projector.

The color projectors employ a single electron gun light valve in which the three color images (green, blue, and red) are written simultaneously upon the same fluid control layer (an oil film) in the form of diffraction gratings. The resultant optical spectra are selectively filtered at the output plane by vertical and horizontal slots to produce the desired colors. The image is then projected by a refractive optics projection lens to the display screen. Thus, three simultaneous and superimposed primary color images are projected to the screen as a completely registered full color picture.

The principle of operation for the monochrome projector is basically the same as for the color projector except that the color generating medium has been eliminated.

A summary of these large screen projectors characteristics is as follows:

Screen Size: Up to 400 square feet

Projection Technique: Front or Rear

Color: Full color plus monochrome

Luminance Output: PJ7000 - 750 lumens
PJ5050 - 560 lumens
PJ5155 - 1275 lumens

Contrast Ratio:

Contrast Ratio = B_D/B_A

Contrast Ratio = 75:1 Screen Center

Contrast Ratio = 50:1 Screen Edge

Image Mechanism: Sealed oil medium light valve

Display Technique: Raster scan

Update Time: One TV frame time

Resolution: PJ7000 Series - 1000 lines
PJ5000 Series - 800 lines
PJHI Series - 1000 lines

Scan Mode: 525/625 and 1000 line rasters

Drift: Less than 2.0%

Color Registration: Single color gun - none

Brightness Uniformity: 2:1 from center to edge

Aspect Ratio: 4:3

X-Radiation: Meets requirements of HEW standard 21CFR

Initial Cost: PJ7000 Series (Monochrome): $55K - $67K
PJ5000 Series (Color): $62K - $81K
PJHI Series (Color): $85.5K

Number of Units in Field: Monochrome Projectors, 80
Color Projectors, 800
High Intensity Color Projectors, None

Consumable: Two components requiring replacement are the xenon lamp and sealed light valve. Replacement costs are as follows:

Sealed Light Valve:	Color	$16K
	Monochrome	$15K
Xenon Lamp:		$750

Operating cost per hour is calculated to be less than $5 for both the PJ5000 and PJ7000 series projectors.

Warranty: The GE projectors are warranted to be free of defective materials and workmanship for one year. The light valve is warranted for 4500 hours on a prorated basis. The Xenon lamp is warranted for 1000 hours or one year.

Additional Information: The General Electric Company has developed a High Intensity Color Projector, the PJ5155. This unit has a reported luminance output of 1300 lumens.

The higher brightness has been obtained by a re-design of the xenon reflector assembly, plus a new high intensity xenon lamp and a modification of the light valves internals.

The PJHI light valve for the high intensity projector series is the same physical size as the old light valve and can be used as a direct replacement. The estimated cost of the new light valve is $17,800 and replacement is recommended at 3000 hours. The higher intensity xenon lamp for the unit is estimated at $1000 with replacement at 1250 hours.

Operating cost per hour for the PJ5155 is estimated to be approximately $7.00.

Note that the replacement hours are theoretical. Sufficient data for both the new light valve and high intensity xenon lamp have not been obtained to give an exact operating cost per hour.

Manufacturer:	General Electric Company
Model:	PJ-5155
Projection Technique:	Oil Film Light Valve
Color Capability:	Full
Luminous Flux (Lumens):	1000
Contrast Ratio:	75:1
Resolution:	1000 lines
Display Technique:	Raster Scan
Time from Standby:	One Minute
Update Time:	30 mseconds
Maximum Display Size:	15' by 20'
Throw Distance:	3 by width
Display Aspect Ratio:	3:4
Brightness Uniformity:	2:1 Center to Edge
Projection Direction:	Front, Rear
Power Requirements:	120VAC, 1KVA
TV Standards::	525 - 1029 Scan Lines
Video Amplifier Bandwidth:	20 MHz
Consumables:	Light Valve Assembly, Xenon Lamp
Operating Cost/Hour:	$7
Initial Cost (April 1982):	$82,000

LUCITRON GAS-ELECTRON-PHOSPHOR DISPLAY

1. Lucitron Product Sheet: Lucitron, Inc., 1985

2. DeJule, M., Sobel, A., and Marken, J. A New Gas-Electron-Phosphor (GEP) Flat Panel Display—The Flatscreen Panel. Proceedings of the International Society for Optical Engineering, Los Angeles, CA, 1984.

3. DeJule, M., Whelchel, D.J., Stone, C.S., Sobel, A., and Markin, J. Construction and Circuitry of the Flatscreen* Gas-Electron-Phospher (GEP) Display. Proceedings of the International Society of Optical Engineering, Los Angeles, CA, 1984.

LGD TECHNOLOGY COMPARISONS

There have been other documented efforts to make comparisons among different LGD technologies that do not need to be repeated. It is suggested that the following references be utilized to look at other available technologies that could be used.

Source 1: Carbone, R.M. Large Screen Display Technology Survey. MITRE Corp., Bedford, MA, WP-24321, Project No. 4450/4460, Contract No. F19628-82-C-0001, October 1982.

Source 2: Harder, D.B. Evaluation of Large Group Display Technologies for Command and Control Applications. Naval Air Test Center, Patuxent River, MD, AT-13R-75, 1975.

Although Source 2 is somewhat dated it still provides useful comparative information about different LGD systems. Furthermore, it provides a historical point of interest to determine the progression of technology in the last 10 years. Note too that an earlier version of the GE light valve was one of the technologies evaluated. Refer to Tables 4 and 5 taken from the report to see their summary comparisons.

Source 3: Willey, F.V. A Review of High Resolution Color Large Screen Graphic Equipment. Applied Physics Laboratory, Johns Hopkins University, FS-81-108.

Source 3 provides an additional evaluation and comparison data and also recommends use of a GE 5150 light valve. Table 6 shows the summary comparisons for the equipment reviewed in the evaluation.

Source 4: FACTSHEET: Large Screen Display Systems--A Technology Survey. The Defense Communications Agency Center for Command, Control, and Communications System, Washington DC, 1985.

Source 4 provides the most recent and up-to-date technology comparisons for LGDs and is also useful in describing techniques of this technology. Table 7 shows current LGD products along with their respective characteristics. Table 8 provides a useful comparison between the laser projection system and other LGD configurations. Note that the values in this table indicate qualitative value assessments on a scale of 1 to 10, with 10 best, or either provides a yes/no response where appropriate.

TABLE 4. Comparative Large Group Display Parameters

System	Philco-Ford 3-Pack	General Electric PJ5000	Hughes LCLV
Parameters			
Projection Head			
Technique	CRT, Refractive lens	Light valve	Liquid optical light valve
Writing Surface	Phosphor	Oil film	Phosphor
Color	Multiple Projection Heads	Full Color	Obtained through new LCLV cell
Spot Size/Lines of Resolution	60 mils/1,000 lines	100 mils/600 lines	60 mils/1,000 lines
Brightness	16 foot lamberts - white	11.2 foot lamberts - white	32 foot lamberts - white
Contrast Ratio	12:1	50:1	30:1
Throw Distance	17 feet	15 feet	12 feet
Plot Points	1,024 x 1,024 addressable		1,024 x 1,024 addressable
Interfacing/System Adaptability			
Digital CPU	Yes, additional equipment	Yes, additional equipment	Yes, additional equipment
Random Scan Video	No	No	Yes
Raster Scan Video	Yes	Yes	Yes
General			
Flexibility			
Reliability	517 hours	1,000 hours	1,000 hours
Maintainability			
Overall Sizing	56" x 18" x 56"	22" x 17" x 30"	15" x 18" x 24"
Weight	8,000 lbs	125 lbs	150 lbs
Power	1,200 watts	1,250 watts	1,200 watts

TABLE 4 (Cont'd). Comparative Large Group Display Parameters

System	IBM DSDT	Aydin Controls Model 8082	General Dynamics Model 303A	Singer Librascope LPS
Parameters				
Projection Head				
Technique	Light Valve	CRT, Refractive Lens	CRT, Catadioptric Lens	Laser
Writing Surface	Deformable Polymer, Storage	Phosphor	Phosphor	Metallic Film
Color	Multiple Projection Heads	Multiple Projection Heads	Multiple Projection Heads	Multiple Projection Heads
Spot Size/Lines of Resolution	80-80 mils/760-1,000 lines	90-125 mils/400-667 lines	90 mils/700 lines	90 mils/1,000 lines
Brightness	2.5-4.17 foot lamberts - white	1.0-2.5 foot lamberts - green	10.5 foot lamberts - green	1.5 foot lambers - white
Contrast Ratio	40:1	33:1	36:1	15:1
Throw Distance	15 feet	10 feet	10 feet	12 feet
Plot Points	1,024 x 1,024 addressable	1,024 x 1,024 addressable	1,024 x 1,024 addressable	1,024 x 1,024 addressable
Interfacing/System Adaptibility				
Digital CPU	Yes	Yes, additional equipment	Yes, additional equipment	Yes
Random Scan Video	Yes, constant writing rate	Yes	Yes	No
Raster Scan Video	No	Yes	Yes	No
General				
Flexibility				
Reliability	Arc Lamb 1,000 hours	1,000 hours	1,344 hours	900 hours
Maintainability				
Overall Sizing	40" x 14" x 11" projector	8" x 11" x 30"	17 3/8" d x 28"	84" x 36" x 61"
Weight	150 lb projector	150 lbs	150 lbs	1,000 lbs
Power	300 watts plus arc lamp	300 watts	300 watts	2,000 watts

TABLE 5. Shore-Based Navy Command and Control Requirements Rating

Minimum Requirements	IBM DSDT	Aydin Controls Model 8082	General Dynamics Model 303A	Sinner LPS	Philco-Ford 3-Pack	General Electric Light Valve	Hughes Aircraft LCLV
1. Fully Dynamic	1	5	5	1	5	3	3
2. 1,000 lines of resolution	3	1	3	5	3	1	5
3. 5 foot lamberts at screen	3	1	3	5	3	1	5
4. 10:1 contrast ratio	5	5	5	3	3	5	5
5. Random scan and/or raster scan inputs	1	5	5	1	3	3	5
6. Small size and weight	3	3	3	1	3	5	5
7. 4 color projector	3	3	3	3	3	5	5
8. Reliability	3	3	3	3	3	3	3
9. Maintainability	3	5	5	3	3	3	5
TOTAL	26	31	37	25	29	31	41

Highly Acceptable = 5
Acceptable = 3
Minimally Acceptable = 1

TABLE 6. Summary Comparisons of Large Screen Displays

	Color	Color Fill In	Resolution*	Raster Scan Compatible	Mis-Convergence	Cost	Remarks
General Dynamics	FULL	YES	750	YES	-1/2 line	Mid	Good quality, raster scan compelx and large
Cubic Corporation	MANY	NO	-850**	NO	-1/2 line	Mid	Good quality projection, complex and large, stroker
Aydin Controls	FOUR	NO	-800**	NO	-1 line	Lo	Compact and partially ruggedized
Ford Aerospace	MANY	YES	1023	YES	NIL	Mid	Very big and heavy
CONRAC/ENDOPHORE	FULL	YES	1000	YES	NIL	Hi	Not interested in this requirement
General Electric	FULL	YES	-800	YES	N/A	Lo	Already at sea - needs development and display militarized
Hughes Aircraft	FOUR	YES	1024	NO	NIL	Hi	High resolution, must be militarized, needs new display generator
Singer Librascope	THREE	YES	2000	?	N/A	Mid	High resolution - needs development and display generator
Litton	THREE	YES	22/inch	?	N/A	Unknown	Best choice for the late 1980's

N/A = Not Applicable, Convergence is inherent by design

Cost: *Hi = over a $500 thousand*
Mid = between a $100 thousand and $500 thousand
Lo = *less than $100 thousand*

*Resolution in pixels on a horizontal scan line
**Estimated *from* video band width
? - Compability dependent of type of video generator to be developed

TABLE 7. Current LGD Products and Characteristics

Manufacturer and Model	Color Capability	Projection Technique	Display Technique	Maximum Projection Size	Throw Distance	Projection Direction	Power Input	Lumens	Scan Standards (Lines)	Video Amplifier Bandwidth	Resolution (Lines)	Contrast Ratio	Display Aspect Ratio	Brightness Uniformity	Warm-up Time from Standby	Major Consumables	Basic Cost
CRT Based																	
Aydin 8063-C Series	Full-Color	Direct CRT Projection	Raster Scan or Vector Scan	6' by 6' to 13' by 13'	14'	Front or Rear	115 VAC ± 10%, 60 Hz	300	525-1029	20 MHz	1000	50:1	3:4	2:1 Center to Edge	50 useconds	CRTs	$100,000-$110,000
Aydin 8063-A Series	Monochrome	Direct CRT Projection	Raster Scan or Vector Scan	6' by 6' to 13' by 13'	14'	Front or Rear	115 VAC ± 10%, 60 Hz	300	525-1029	20 MHz	1000	50:1	3:4	2:1 Center to Edge	50 useconds	CRTs	$50,000
Electrohome Ltd EDP 58	Monochrome	Direct CRT Projection	Raster Scan	10' diag		Front or Rear	120-240 VAC ± 10%, 50/60 Hz	500	n.p.	20 MHz	1300	n.p.	3:4	n.p.	Instant	CRTs	$3,950
ESP, Inc Aquastar IIIC	RGB	Direct CRT Projection	Raster Scan	4' to 12'	1.5 x width	Front or Rear	115 VAC, 60 Hz	500	525	30 MHz	1350	15:1	3:4	2:1 Center to Edge	Immediate	CRTs	$9,995
ESP, Inc Aquastar 400/600	RGB	Direct CRT Projection	Raster Scan	4' to 12'	1.5 x width	Front or Rear	115 VAC, 60 Hz	400-500	525	16-30 MHz	1000-1350	15:1	3:4	2:1 Center to Edge	Immediate	CRTs	$6,000-$12,995
Aeronutronic Ford	Monochrome	Direct Single CRT Projection	Raster Scan	5' by 5'	10'	Front or Rear	115 VAC, 400 Hz, 7A	280	525-1225	40 MHz	1000	8:1	1:1 and 4:3	2:1 Center to Edge	Immediate (after 1 hr warm-up)	CRTs	$150,000
Aeronutronic Ford	Full-Color	Direct 3-6 CRT Projection	Raster Scan	15' diag	2 x width	Front or Rear	115 VAC, 60 Hz, 5.7 kW	300	525-1029	40 MHz	1000	15:1	1:1 and 4:3	50% Variation Across Screen	Immediate (after 1 hr warm-up)	CRTs	$500,000-$1,000,000
Kalart-Victor Corp Telebeam II	Monochrome	Direct CRT Projection Schmidt Optics	Raster Scan	15' by 20'	40'	Front or Rear	115 V, 60 Hz	350	525, 625	12 MHz	525 or 1029 Switchable	50:1	4:3	2:1 Center to Edge	Immediate	CRTs	$6,000
Electrohome Ltd. ECP 2000	Full-Color	Laser Aligned Dichroics	Raster Scan	14' diag	87½''	Front or Rear	90-132 VAC, 50/60 Hz	400	n.p.	30 MHz	1024	n.p.	3:4	n.p.	Instant	CRTs	$14,000
Light Valve																	
General Electric PJ 7000	Monochrome	Oil Film Light Valve	Raster Scan	24' by 18'	3 x width	Front or Rear	117V/60 Hz or 220V/50/60 Hz	750-2400	525, 625-1023	20 MHz	800	75:1	4:3	2:1 Center to Edge	1 minute	Xenon Lamp	$55,000-$72,000
General Electric PJ 5000	Full-Color	Oil Film Light Valve	Raster Scan	9' by 12'-24' by 18'	3 x width	Front or Rear	120V or 240V ± 10%, 60 Hz	250-1000	525-1023	20 MHz	750	75:1 to 100:1	4:3	2:1 Center to Edge	1 minute	Xenon Lamp	$39,500-$105,000
Gretag/Eidophor 5170 Series	Full-Color	Oil Film Light Valve	Raster Scan	40' by 50'	150'	Front or Rear	3.0 KVA and 5.6 KVA	3600-7000	525, 625, 1029	20-30 MHz	800	100:1	3:4	2:1 Center to Edge	1 minute	Xenon Lamp	$353,000-$398,000
Gretag/Eidophor 5180	Monochrome	Oil Film Light Valve	Raster Scan	30' by 40'	150'	Front or Rear	3.0 KVA and 5.6 KVA	4000	525, 625, 1029	20 MHz	800	100:1	3:4	2:1 Center to edge	1 minute	Xenon Lamp	$133,000
Hughes Aircraft HDP-4000	Full-Color	Liquid Crystal Light Valve	Raster Scan	15' by 15'-16' by 16'	1.3-2.0 x width	Front or Rear	220 VAC, 47-63 Hz at 4 kW-7 kW	500-1500	525, 625, 1075	20-30 MHz	1024 1075	5:1-20:1	1:1	2:1 Center to Edge	up to 15-30 minutes	CRT Xenon Lamp	$400,000-$500,000
Singer Company Librascope LLCP (built to specification)	Three-Color or Monochrome	Liquid Crystal Light Valve	Raster Scan or Vector Scan	var.	var	Front or Rear	var	2000	var	var	2000-8000	var	var	var	var	CRT Xenon Lamp	Unavail
Sodern SVS	Full-Color	Solid State Light Valve	Raster Scan	var	n.a.	Front or Rear	220V, 50/60 Hz	2500 (max)	525, 625, 1024, 1225	n.p.	1000 x 1000 Pixels	100:1	1:1, 3:4	1.5:1 Center to Edge	2 minutes	Xenon Lamp	$300,000
LED																	
Litton Data Systems Tactical Display Map	Three-Colors or Diode Modules	Light Emitting Diode Modules	Matrix Addressed	6' by 6'	n.a.	Front	V_{LED}, 7 VDC 110VAC, 77 Amps	225	n.a.	n.a.	22 Pixels/Inch	3.5:1	2:1	Within 25% Entire Area	10 seconds	LEDs	$250,000
LCD																	
Mitsubishi Crystal Color 180	RGB	Twisted Nematic (TN) Liquid Crystal Display (LCD)	Electrically Illuminated LCD	9'1'' x 12'1''	n.a.	Rear	120 VAC/60 Hz single phase	n.a.	384 x 512	n.p.	4 Picture Dots/Inch	n.p.	4:3	2:1	Several minutes	Fluorescent Lamps	$1,000,000
Laser Projection																	
Dwight Cavendish Displays Ltd SD-270	Full-Color	Laser	Interlaced Scanning	40'-20' sq.	var	Front	28 kW	n.p.	525	n.p.	1000	n.p.	3:4	Within 10% of center over screen area	n.p.	Laser Rods	$130,000-$160,000
Visulux	Full-Color	Laser	Raster	n.a.	var	Front or Rear	208 VAC 3 phase 60 Hz	2000	525, 1025	n.p.	1500	600:1	var	Within 4% of center over screen area	1 minute	Laser generator	$250,000

KEY

diag.: diagonal
var.: variable
n.p.: not published
n.a.: not applicable

TABLE 8. Laser Projection Compared to Other Systems

	CRT-based Refractive Optics	CRT-based Schmidt Optics	Light Valves Single	Light Valves Multiple	LED	LCD	Laser
Light Output	1–3	2–5	5	6–9	1–2	1–2	10
Resolution							
Color	2–4	2–4.5	5	7	(note 3)	(note 3)	10
Monochrome	4	5	7	6			10
Power Consumption	5	5	5	1	8	8	2
Weight	5	5	3	2	8	8	1
Operating Cost/Hour	4	4	4	8	2	2	7
Purchase Cost	7–9	6–8	4	1–4	(note 4)	(note 4)	5
Color Registration	3–7	3–7	9–10	4–8	(note 9)	(note 9)	10
Ease of Maintenace	4–6	4–6	7–8	2–3	10	10	(note 6)
Deterioration with time	6	6	4	4	10	10	9
Full Color Capability	Y	Y	Y	Y	(note 7)	(note 7)	Y
Scan							
Raster	Y	Y	Y	Y	Y	Y	Y
Vector	Y	Y	Y	Y	Y	Y	Y
(note 8)							
Floor Space Occupancy (note 1)	4	4	4	3	10	10	10
Maximum Screen Size (note 2)	2–3	3–4	5	6–7	(note 5)	(note 5)	10

NOTES:

1. Area required for approximately similar sizes.
2. Assumed similar ambient lighting conditions.
3. Resolution is proportional to number of pixels horizontally and vertically, and thus to the number of LED or LCD elements.
4. Larger picture size requires more elements, and therefore results in higher cost.
5. Theoretically very large, but cost, power and weight prohibit this.
6. Minimal field experience to date.
7. Experimental.
8. Some implementations.
9. Because the position of each LED or LCD is mechanically fixed, the registration is nearly perfect.

Reference terms for LSDS systems are listed below:

Physical Dimensions

Display Aspect Ratio: ratio of display width to height

Projection Size: size of the projected image, expressed typically in length x width, or diagonal, measure

Throw Distance: projection distance for viewable image quality

Performance

Display Brightness Uniformity: ratio of brightness at center to brightness at edge of display

Display Contrast Ratio: ratio of darkfield to whitefield

Display Resolution: measure of picture detail

Warmup Time From Standby: time taken by system to produce an initial image after reaching operational status

Methods

CRT Projection: direct or reflected projection of a cathode ray tube image

Display Technique: method by which an image is formed. Three types:

- Raster scan: a predetermined pattern of scanning lines that provides uniform coverage of a screen
- Vector scan: random direction of light energy to a specific point on a screen
- Matrix addressing: method for directing electrical energy to a specific element in an active display. Typically used in LED arrays.

Electroluminescent Display: flat plate display which excites phosphorescent pixels as a light source

Laser Aligned Dichroics: convergence of light

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