Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER 511504
UNCLASSIFIED	

TITLE

Application of Locate Software to United States Navy Surface Combatant-21 - Final Report

System Number:

Patron Number:

Requester:

Notes:

DSIS Use only:

Deliver to:

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAY 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Application of LOCATE Software to United States Navy Surface Combatant-21**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Artificial Intelligence Management and Development Cooperation,206 Keewatin Avenue,Toronto, ON M4P 1Z8 Canada,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report describes Phase II in the application of the LOCATE Workspace Layout Tool to notional designs of the US navy's Integrated Command Environment (ICE). Phase II work involved participation by staff from Artificial Intelligence Management Corporation (AIM) and the Defence and Civil Institute of Environmental Medicine (DCIEM) in a week-long workshop held at the Naval Surface Warfare Center in Dahlgren, Virginia. During the Workshop,' AIM and DCIEM staff worked with Navy personnel to gather data necessary to analyse the design layouts that emerged from the Workshop. Analyses revealed clear differences in the communication efficiency among the designs and the use of LOCATE's new optimiser led to the consideration and analysis of several additional designs with a common theme. Among the observations and lessons learned are that: 1) LOCATE is a mature and useful tool for workspace design and analysis; 2) there a particular features that need to be added to LOCATE to make the design and analysis job easier (a few were added during the current work phase); 3) LOCATE's optimiser, even though currently a simple demonstration optimiser, added value to the analyses of the Navy designs; and, 4) there are particular opportunities for adding intelligent aiding features to LOCATE that will allow it to make explicit some of the complexity inherent in user decisions about the data LOCATE requires.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**43**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Prepared for: Public Works and Government Services
Prepared by: Artificial Intelligence Management and Development Corporation
AIM (AC204, May, 1999)
Contract: W7711-9-7524/001/TOR
"Application of *LOCATE* Software to United States Navy Surface Combatant-21"
Scientific Authority:
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Simulation and Modelling for Acquisition, Rehearsal and Training (SMART)
Defence and Civil Institute of Environmental Medicine

Application of *LOCATE* Software to United States Navy Surface Combatant-21

- Final Report -

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Table of Contents

Abstract

This report describes Phase II in the application of the LOCATE Workspace Layout Tool to notional designs of the US navy's Integrated Command Environment (ICE).

Phase II work involved participation by staff from Artificial Intelligence Management Corporation (AIM) and the Defence and Civil Institute of Environmental Medicine (DCIEM) in a week-long workshop held at the Naval Surface Warfare Center in Dahlgren, Virginia.

During the Workshop, AIM and DCIEM staff worked with Navy personnel to gather data necessary to analyse the design layouts that emerged from the Workshop. Analyses revealed clear differences in the communication efficiency among the designs and the use of LOCATE's new optimiser led to the consideration and analysis of several additional designs with a common theme.

Among the observations and lessons learned are that: 1) LOCATE is a mature and useful tool for workspace design and analysis; 2) there a particular features that need to be added to LOCATE to make the design and analysis job easier (a few were added during the current work phase); 3) LOCATE's optimiser, even though currently a simple demonstration optimiser, added value to the analyses of the Navy designs; and, 4) there are particular opportunities for adding intelligent aiding features to LOCATE that will allow it to make explicit some of the complexity inherent in user decisions about the data LOCATE requires.

Background

The work reported here extends an earlier **proof-of-concept** study that demonstrated the usefulness of the LOCATE Workspace layout tool in analysing certain notional designs developed by the US Navy for its Integrated Command Environment (ICE), which is part of its Surface Combatant-21 (SC-21) project.

The Navy's SC-21 project involves the development of requirements for expeditionary force surface combatants for the 21st century. Part of the SC-21 project is the development of an Integrated Command Environment (ICE). Stated objectives for ICE design include designing for:

- effective mission performance and ship control;
- effective/appropriate application of technologies;
- operational utility;
- assistance in manning reduction goal;
- reconfigurability;
- comfort supporting potentially long watchstanding periods.

These objectives reflect a desire for optimised manning and for improved human interface. At the heart of effective command is a layout that specifies how members might be organized in ways that will optimise their communication.

LOCATE is a tool used to assess the efficiency of 2-D layout designs in any combination of four communication domains: visual, auditory, tactile (reach) and distance (or movement). Traditional techniques have focused only on the distance (or movement) domain and, thus, are limited in the information they can provide about many real-world layouts. LOCATE's analysis allows designers to compare design configurations across a much broader communication spectrum.

As already mentioned, the current work is an extension of earlier efforts to apply LOCATE to the Navy's ICE Designs. As a result of that work and a presentation to Naval and associated personnel at DCIEM in March 1999, an invitation was issued for AIM and DCIEM personnel to attend a week-long workshop at the Naval Surface Warfare Center in Dalhgren, Va.

The purpose of attendance at that workshop was to become more thoroughly familiar with the Navy's SC-21 project and with their efforts to create effective designs for the Navy's 21st century warships. Further, opportunities were to be provided for applying LOCATE to the Navy's efforts to refine and extend its ICE designs.

Proof-of-Concept Study

The earlier, proof-of-concept study was conducted in the context of a contract to add intelligent aiding to the LOCATE Workspace Layout Tool[1]. In that study, LOCATE workspaces were populated using downloaded DXF files for three ICE design configurations: 1) Amphitheatre; 2) Arena; and 3) Table Top.

Cooperative work with a US Navy Subject Matter Expert (SME) provided additional information necessary to performing the LOCATE analyses, the purpose of which was a comparison of the efficiency of the three ICE designs across the four communication domains, mentioned earlier.

The **most important findings** of that study were:

- that LOCATE was able to generate metrics that provide for quantitative comparisons of the communication efficiency of the US Navy's notional ICE designs;
- that clear conclusions can be drawn about the relative efficiency of those designs within the context of assumptions made about the players involved and their communication patterns;
- that features of LOCATE, such as its colour cost displays for quickly identifying, high, medium and low pairwise costs between workstations (players), support effective decision making about how designs might be modified to reduce communication costs.

Given that there were a number of limiting factors on the data in that study and that the important findings emerged from the process of applying the LOCATE tool, results of LOCATE analyses showed the Table Top to be the most efficient configuration, followed by the Amphitheatre and then by the Arena.

The ability to draw such conclusions in a timely manner provides a context in which ideas often quickly emerge as to how to make the "best" configuration even better. In this context, the quick results for the Table Top led to a modification that produced a more efficient design.

Some of the limitations on the data in that study included the following:

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1 The proof-of-concept study report entitled, "Application of the LOCATE Workspace Layout Tool to Notional ICE Designs", was submitted as part of contract W7711-8-7480.

- the designs were notional;
- only three ICE designs were compared;
- the three designs chosen, initially contained different numbers of players. In order to compare configurations, LOCATE assumes a common set of players for all configurations. After consultation with the SME, eight players were identified as common to each design. Standardising the configurations involved adding, moving and combining players;
- variations in workspace size also occurred among configurations. Similar to the number of players in the configurations, LOCATE assumes workspace size to be the same for all designs. Consequently, each ICE design was assigned a workspace size equal to that of the largest configuration;
- measurements within designs, such as positioning and angle of rotation of consoles, were not directly available and had to be extrapolated from object characteristics in the imported DXF files;
- key data were of a preliminary nature and were based on assumptions about communication patterns among the players in the three configurations;
- wall and table displays were not represented in the analysis;
- no object was identified as an obstacle to communication, although some items, such as the table in the Table Top configuration, might qualify.

Notes on some assumptions underlying the choice of link function and priority weight data used in the study appear in the "Assumptions..." sections of the Appendices of the proof-of-concept study report.

It was felt that more detailed knowledge about the characteristics of designs and the patterns of communication among players certainly would lead to more accurate results in the LOCATE analyses. A key purpose of AIM's and DCIEM's participation in the Navy workshop was to acquire that kind of knowledge.

The ICE COLD Workshop

Following a presentation[2] of the results of the above proof-of-concept study to representatives of the US Navy and interested US contractors working with the Navy on the SC-21 project, AIM and DCIEM personnel were invited to attend a week-long workshop at the Naval Surface Warfare Center (NSWC) in Dahlgren, VA.

The name of the workshop was "Integrated Command Environment Collaboration on Organization and Layout Design", or, "ICE COLD" for short, and was held on 19-23 April 1999.

The following description of the workshop was provided by Mr. Dennis White, a systems engineer at Basic Commerce and Industries, Inc. (BCI), the contractor responsible for organizing and conducting the workshop:

> *"...a concept exploration, system definition, and brainstorming workshop whose product will be an ICE mock - up demonstration at NSWC Dahlgren. The ICE concepts are formulated to take future ships beyond the conventional Command and Control environment to the future. Discussions regarding the brainstorming sessions will include scenario development, physical and logical layouts, ICE team composition, and an implementation plan to meet future ship schedules.*
>
> *We will be hosting a number of people from various disciplines throughout the country for this effort – our desire if [sic] for you to think and imagine well beyond today's concept of a CIC. What is a Command Environment? What aspects of command and ship function should reside together? Should anything be co-located? What about a virtual presence of some team members?"*

The first order of business of the workshop was a briefing on LOCATE and a presentation of the results of the LOCATE analysis in the proof-of-concept study, described in the previous section. This was a repetition of the presentation that had been given the previous month at DCIEM to a select group from the Navy and its contractors .

The full agenda for the workshop appears in Appendix A.

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2 That AIM presentation is available as a Powerpoint file entitled, "Applying LOCATE to the US Navy's ICE Designs." It was prepared as part of the project work for the proof-of-concept study.

Applying LOCATE to US Navy ICE Designs
- Phase II –

Day 2 of the workshop began with a briefing by the Navy's Trish Hamburger on ICE concepts and was followed by a brainstorming session, using the Navy Decision Support Center's GroupWare, that produced a list of functions for ICE.

After a subsequent directed discussion that organised the functions presented, participants broke up into four groups to refine those ideas and generate layout concepts.

On Day 3, a further refinement of layout candidates was conducted along with a group discussion that resulted in proposed options for watch team composition. Those options were refined while other work was conducted on possible layout and display options. A demonstration scenario was generated for use in an upcoming ICE presentation later in the summer.

In the afternoon, the LOCATE team met with two members of the group who had operational experience and began the task of identifying the Link Strength Function (LSF) and Priority Weight data necessary to a LOCATE analysis of the proposed layouts.

Day 4 involved further meetings of the LOCATE team and the completion of the data requirements. At the end of the day, four configurations were submitted for analysis. Work continued into the evening to implement the designs in LOCATE, enter the data and run the analyses. The use of a newly incorporated optimiser in LOCATE proved useful in extending and refining the analyses.

On Day 5, the LOCATE team presented the results of its analyses to a select group of participants meeting at BCI, the location of the consulting group who helped organise the workshop for the Navy.

Phase II Study Results

A thorough treatment of the results of the Phase II work was prepared under separate cover and sent to the US Navy at Dahlgren approximately a week after the Workshop. That report appears in Appendix B. Although the complete results are laid out in that report, some of the highlights are worth repeating here.

In addition to the four configurations analysed by the LOCATE team at Dahlgren, a fifth configuration was added after the team returned to Toronto. All of the configurations were developed over the course of the workshop and LOCATE analyses were run for each.

Descriptions of the configurations and the LOCATE results appear in Table 1, below[3]. The cost function results, which are LOCATE measures of communication efficiency, appear in Column 3 of that Table; the lower the cost function value, the more efficient the configuration.

Configuration	Attribute	Cost Function
Configuration A	Outward facing, central executive with displays arranged around the outside.	0.158
Configuration B	Inward facing, boardroom layout with executive at one end and displays at the other.	0.064
Configuration C	Amphitheatre with displays on one wall.	0.093
Configuration D	Inward facing cellular arrangement with distributed overhead displays.	0.050
Configuration E	Inward facing, roundtable with wall displays.	0.035

Table 1. LOCATE Cost Function Values for ICE-Team-Developed Layouts

As can easily be seen from the Table, the most efficient configuration is E, which is a layout with wall displays and in which the players are facing inward toward each other. In fact, all inwardly facing layouts are more efficient by half, at least, than the one outwardly facing layout (Configuration A).

These layouts are graphically depicted in Figures 1-5 in Appendix B.

Recent work on the LOCATE Workspace Layout Tool added a demonstration optimiser, which proved to be of value in analysing the Navy's ICE designs in the Phase II work.

The results of using LOCATE's optimiser was to produce three additional designs with a common theme: All configurations tended to reduce to an inward facing arrangement with executive, warfare and ship's systems cells, with common use displays in a central location.

3 See Table 5 in Appendix B.

Table 2[4] provides extends the summary of results. The first configuration (Configuration F) is the most efficient of all of the eight configurations. Configuration G is more efficient than all five of the original configurations except Configuration E, the inward facing roundtable.

Configuration H is the least efficient of the new optimised configurations and strikes a balance between inward and outward facing configurations. There, the executive is placed in between the other two cells and can rotate to bring them into view as needed. In spite of its showing relative to the other two optimised configurations, it is substantially improved over the one outward facing configuration of the initial set.

Configuration	**Attribute**	**Cost Function**
Configuration F	Inward facing with centralised displays.	0.032
Configuration G	Inward facing with displays ceiling hung or placed around the outer walls.	0.048
Configuration H	Two huddles (warfare and ship's systems) with a central executive.	0.060

Table 2. LOCATE Cost Function Values for Optimised Layouts

In summary, inwardly facing clusters of players with centralised displays tended to produce the best results. Slight improvements on several of these designs can be achieved by moving the consoles closer together and rotating them so as to minimise the angles among them. In general, an advantage can be achieved from rotation by providing consoles with the ability to rotate toward or away from each other as the situation demands.

Other results and conclusions appear in Appendix B along with discussions of related issues such as obstructions (no obstructions were modelled in either of the Phase I or Phase II studies), movement patterns and orientation. Also included in that Appendix are all link function and priority weight data used in the analyses.

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4 See Table 6 in Appendix B.

Observations and Lessons Learned

The proof-of-concept study and efforts at the ICE COLD Workshop have provided solid application contexts in which to test the usefulness of the LOCATE Workspace Layout Tool.

A number of lessons were learned from these experiences. First, during the proof-of-concept study, several aspects related to importing DXF files emerged which necessitated changes to the LOCATE algorithm for handling that feature. As a result, modifications were made to LOCATE that now allow users to see the dimensions of the original DXF file and be able to make better decisions about how such files are to be imported.

Second, it became clear that summaries of both link function and priority weight data are needed for users to review the data they enter more locally. Although there were limited expenditures in this contract available for the modification of LOCATE, it was possible to expand the software to allow for an overview by communication domain of the link function data for all players in a configuration. The newly implemented summary, however, not only permits inspection of the data but also allows users to modify the data directly in the summary window.

It is left to future work to extend data summaries to priority weights and further, to broaden them so that users may inspect and modify each type of data across all domains at once.

There are other changes that should be incorporated into LOCATE that emerged from the work with the US Navy. Some of those changes involve altering LOCATE's tool palette to permit only click and drag options for all palette objects. Default values for sizes of objects, which now permit the user simply to click in the workspace to create an object of a particular size, may mean the creation of very large or very small objects depending on the ratio scale settings for the workspace.

One of the exciting discoveries that emerged from discussions with the Navy personnel at Dahlgren relates to the complexity inherent in decisions about what data are to be entered into LOCATE. There are often more than a few aspects to consider, for example, when making decisions about the value of priority weights.

Likely, it will prove useful to implement intelligent aiding features within LOCATE that would make that complexity explicit, while maintaining for the user a sense of well-organised control over the complexity. Such efforts also may reveal the need for a multi-dimensional weighting scheme for LOCATE.

In recent efforts to extend LOCATE by adding intelligent analysis features, it was decided to include an example optimiser. An optimiser, constructed by AIM as part of an internal development effort, was added and made available for use during the ICE COLD Workshop.

The optimiser proved unexpectedly useful in analysing the Navy data. Had it not been available, it is possible that the last three configurations, described in the previous section, would not have emerged from the work. Conclusions from the optimiser results, therefore, allowed for the identification of a common theme, a somewhat different view on the important aspects of the Navy's layouts than emerged from the Workshop discussions.

As a result of the use of the optimiser, modifications were made to some of the options in the "optimisation settings." Certain optimiser rules need to be able to change the way workstation overlap is handled but those, and other changes to the optimiser, will have to await future development efforts.

In summary, the efforts in both Phase I and Phase II showed just how useful application work can be with LOCATE. They demonstrated that LOCATE is indeed is a mature tool, which can provide direction in the design of workspace layouts. During the ICE COLD Workshop, LOCATE not only provided measures of efficiency for the emergent configurations but also optimised those designs in ways that encouraged "thinking out of the box", a requirement repeated many times for workshop participants.

Further, the process of applying LOCATE pointed up additions and modifications that could extend the tool's basic features and, thus, its usefulness to designers and human factors engineers. Some of those have now been implemented.

Finally, applying the LOCATE tool in a real-world context pointed to ways that its intelligent aiding capabilities might be extended. One example is finding ways of helping users make explicit the complexity inherent in their decisions about the data they must enter, and thus better rationalise the decisions necessary to a LOCATE analysis.

Appendix A

ICE COLD WORKSHOP
- AGENDA -

Artificial Intelligence
Management and Development Corporation

ICE

Integrated Command Environment

COLD

Collaboration on Organization and Layout Design

19-23 April 1999
NSWC DD, Dahlgren VA
Building 180

AGENDA

Monday, 19 APRIL

Location: Control Systems Advanced Concepts and Technologies (CSACT) Laboratory

AM	LOCATE Team Arrive, Setup Equipment	
1400	LOCATE Brief and Demo	

Tuesday, 20 APRIL

Location: Decision Support Center

0830	Welcome, What is ICE?	Trish Hamburger
0900	DSC Mechanics, Admin	Myla
0915	Break	
0930	Goals, Methods for Today and Tomorrow	Dennis White
	----- break as necessary -----	
1200	Working Lunch	
1600	Adjourn Day One	

Wednesday, 21 APRIL (Secretary's Day)

Location: CSACT Lab

0830	Review Yesterday's Results, New Ideas, Layout Ideas	Dennis White
1000	Break into Slinter Groups [1]	
	1. Refine Layout Candidates	Dr. Daniel Wallace
	2. Displays, Comms Details	John Winters
	3. Demo Scenario	Trish Hamburger
1200	Working Lunch	
	LOCATE Team Begin Preliminary Data Prep for Analysis	
1400	Regroup for Review	Dennis, Trish
1600	Adjourn Day Two	
	Brainstorm Team Depart	

Thursday, 22 APRIL

Location: CSACT Lab (LOCATE Team), Decision Support Ctr (ICE Construction Team)

0830	LOCATE Team Continue Analysis	John Winters, Chris Knowlton
	CSACT Team Establish LOE, WBS, POAM	Dennis, Greg Hildebrand
1200	Working Lunch	
1400	LOCATE Team Provide Analysis Results[2]	
1530	Refine LOE, WBS, POAM	Dennis White

Friday, 23 APRIL

Location: CSACT

0830	LOCATE Team Complete Analysis (If not completed day before)	
TBD	FINEX	

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[1] The subject of these groups may change to reflect results of Tuesday's efforts.
[2] Team will provide final results (if analysis complete) or preliminary w/ final results 4/23/99. Location will be in either CSACT or DSC, whichever is most appropriate.

Appendix B

ICE COLD WORKSHOP
Results Of The Locate Analysis

Artificial Intelligence
Management and Development Corporation

ICE COLD WORKSHOP

NSWC Dahlgren

19-23 April 1999

RESULTS OF THE LOCATE ANALYSIS

ELEMENTAL WORKSTATIONS

Eight operators and four displays were modelled in LOCATE. They are

Operators

1. Commanding Officer (CO)
2. CDO
3. Air Warfare (AW)
4. Land Warfare (LW)
5. Surface/Subsurface Warfare (SW)
6. Ship's Systems Management 1 (SSM1)
7. Ship's Systems Management 2 (SSM2)
8. Special Evolutions (SE)

Displays

9. Common Tactical Picture (CTP)
10. Special Tactical Picture (STP)
11. External Picture (EP)
12. Ship's Status (SS)

DOMAINS OF COMMUNICATION/INTERACTION

Human-human and human machine interactions were represented in four domains, namely:

- Vision
- Audition
- Reach
- Distance

Modelling within the domains of audition and reach was straightforward. However, based on discussions during the first days of the workshop, an attempt was made to incorporate the effects of **co-ordination** and **command** into the LOCATE analysis. Co-ordination was introduced through the visual domain for human-human interactions — command through the distance domain.

The LSFs and priority matrices were created and reviewed by the DCIEM team plus two of the ICE evaluation team with operational experience.

LINK STRENGTH FUNCTIONS

Visual Domain. LSFs in the visual domain were used to model the potential for **co-ordination** in human-human interactions, and the strength of information exchange for human-display interactions. Co-ordination was assumed to be facilitated by visual contact with the team. Obviously co-ordination will also depend on communication links such as audition, however voice links are dealt with separately. Because the visual domain is being used to model two effects an *ability to be co-ordinated* property was attributed to the source link of all human operators. It was assumed that the strength of this ability would degrade with distance but would not be sensitive to the orientation of the person being co-ordinated (unlike a potential to be commanded — see the distance domain). Lacking hard data, a linear degradation with distance was chosen.

For the receipt of all visual information (both co-ordination and interaction with displays) an acceptance angle of 60° was assumed (modelled by a Butterworth function). This was a compromise between what was thought to be reasonable for the co-ordination aspect, and the standard HE recommendation that critical displays be placed within the central 30° of the operators field of regard (e.g., see (Van Cott and Kinkade, 1972), p78). Table 1 shows the visual LSFs used in this evaluation of the ICE designs, and the parameters chosen for this analysis. In this and the other domains, distance parameters are in feet, with angles in degrees. All human operators are described in identical terms.

For the display as a source of information a viewing angle of 60° was assumed out to 15 feet. Obviously this will depend on the properties of the displayed information. As link lengths are generally less than 15 feet this assumption is relatively neutral with respect to all configurations except Configuration C. These LSFs could be defined more precisely once the display characteristics are known.

TABLE 1.

Link Strength Functions in the visual domain for the LOCATE analysis of proposed ICE designs (Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS]).

Visual Domain				**Parameter**	
Element	Source or Receiver	Distance or Angular	LSF	1	2
CO	Source	Distance	Linear	57.0	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	5	60

CDO	Source	Distance	Linear	57.0	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	5	60
AW	Source	Distance	Linear	57.0	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	5	60
LW	Source	Distance	Linear	57.0	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	5	60
SW	Source	Distance	Linear	57.0	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	5	60
SSM1	Source	Distance	Linear	57.0	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	5	60
SSM2	Source	Distance	Linear	57.0	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	5	60
SE	Source	Distance	Linear	57.0	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	5	60
CTP	Source	Distance	Comp. Error	15	3
		Angular	Butterworth	10	60
	Receiver	Distance	Constant	1	1
		Angular	Constant	1	1
STP	Source	Distance	Compl. Error	15	3
		Angular	Butterworth	10	60
	Receiver	Distance	Constant	1	1
		Angular	Constant	1	1
EP	Source	Distance	Compl. Error	15	3
		Angular	Butterworth	10	60
	Receiver	Distance	Constant	1	1
		Angular	Constant	1	1
SS	Source	Distance	Compl. Error	15	3
		Angular	Butterworth	10	60
	Receiver	Distance	Constant	1	1
		Angular	Constant	1	1

Auditory Domain. The assumption was made that communication would be aided by a voice communication system, but that important cues were available from facial expressions and *body language*. Hence, no penalty due to distance is applied to the ability to communicate by voice. However, face to face communication is favoured by requiring a source of auditory information to be within the receiver's first and second quadrants in azimuth. A Butterworth function with sharp shoulders (10^{th} power) was chosen to span the central 180° of the receiver's visual field (see Table 2). No auditory displays were modelled although it is recognised that the four displays included in these layouts may be multi-media and hence might have an auditory component. However as voice is aided by a communications system, display audio would most likely be added to this system.

TABLE 2

Link Strength Functions in the auditory domain for the LOCATE analysis of proposed ICE designs (Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS]).

Auditory Domain				**Parameter**	
Element	Source or Receiver	Distance or Angular	LSF	1	2
CO	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
CDO	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
AW	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
LW	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90

SW	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
SSM1	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
SSM2	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
SE	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
CTP	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	
STP	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	
EP	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	
SS	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	

Tactile Domain. LSFs in this domain are straightforward and are derived from standard shirt sleeved reach capabilities of human operators. (e.g., see Van Cott and Kinkade, 1972), Table 11-76). No attempt is made to be exact, but 2.5 feet (30in) is a ball park figure for the reach of a 5th percentile shirt-sleeved male operator, 20 inches above the seat reference point and over the first and second quadrants in azimuth. Reaches behind the operator are heavily penalised (by the use of a Butterworth function with sharp cut-offs at ±90°). A coefficient of variation of 10% is assumed. Although these figures are ostensibly for male operators, a SD of 3in and the ability to move the trunk to extend reach allows for considerable variability.

TABLE 3

Link Strength Functions in the tactile domain for the LOCATE analysis of proposed ICE designs (Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS]).

Tactile Domain				**Parameter**	
Element	Source or Receiver	Distance or Angular	LSF	1	2
CO	Source	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
	Receiver	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
CDO	Source	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
	Receiver	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
AW	Source	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
	Receiver	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
LW	Source	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
	Receiver	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
SW	Source	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
	Receiver	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
SSM1	Source	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
	Receiver	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
SSM2	Source	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
	Receiver	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
SE	Source	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90
	Receiver	Distance	Compl. Error	2.5	0.25
		Angular	Butterworth	10	90

CTP	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	
STP	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	
EP	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	
SS	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	

Distance Domain. Movement within the workspace was not included in these analyses. Rather the distance domain was used to capture the *potential to be commanded.* A source potential to be commanded was attributed to all human elements in the ICE space. This potential was assumed to depend on distance from the commander and on the facial aspect seen by the commander. A Complementary Error function was chosen to represent a diminishing potential to be commanded as distance increased, having a mean distance of 12 feet (corresponding to the 50% point) with a standard deviation of 3 feet. Potential to be commanded was also assumed to depend on facial aspect. This potential was considered to erode quickly as team members were viewed from their 3rd and 4th quadrants (i.e., the back of their heads). A Butterworth function with sharp cut-offs at ±90° was used.

For the commander high command potential exists in the 1st and 2nd quadrants but degrades rapidly in the 3rd and 4th. Again a Butterworth function with sharp cut-offs at ±90° was used. No receiving penalty is incurred with distance as this is already contained in the source properties of all human elements.

TABLE 4

Link Strength Functions in the distance domain for the LOCATE analysis of proposed ICE designs (Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS]).

Distance Domain				**Parameter**	
Element	Source or Receiver	Distance or Angular	LSF	1	2
CO	Source	Distance	Compl. Error	12	3
		Angular	Butterworth	10	90
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
CDO	Source	Distance	Compl. Error	12	3
		Angular	Butterworth	10	90
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
AW	Source	Distance	Compl. Error	12	3
		Angular	Butterworth	10	90
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
LW	Source	Distance	Compl. Error	12	3
		Angular	Butterworth	10	90
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
SW	Source	Distance	Compl. Error	12	3
		Angular	Butterworth	10	90
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
SSM1	Source	Distance	Compl. Error	12	3
		Angular	Butterworth	10	90
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
SSM2	Source	Distance	Compl. Error	12	3
		Angular	Butterworth	10	90
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90
SE	Source	Distance	Compl. Error	12	3
		Angular	Butterworth	10	90
	Receiver	Distance	Constant	1	
		Angular	Butterworth	10	90

CTP	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	
STP	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	
EP	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	
SS	Source	Distance	Constant	1	
		Angular	Constant	1	
	Receiver	Distance	Constant	1	
		Angular	Constant	1	

LINK PRIORITIES

Two subject matter experts with operational experience participated in assigning priority weights (see Appendix A) to the domains of interest. Taking, in turn, each human and display element as the receiver, priorities were assigned down the columns (i.e., for each source) for the domains of audition [A], distance [D], tactile [T] and visual [V].

For ease of assignment, priorities were made from a 10-point scale (0 to 10) and later transformed to the range 0 to 1 for entry into LOCATE. Note that priorities do not have to be symmetrical, although they can be if this is an appropriate description of the flow of information. For example, while co-ordination may be a symmetrical concept, command is not. Generally, audition and reach between humans is likely to be more symmetrical then not.

Only second order links (element to element) were considered. No first order links (due to absolute position within the workspace) were analysed. All priorities exerted an attractive (positive) force during optimisation. No negative priorities were included, although LOCATE will allow repulsive forces to be modelled (e.g., to remove workstations from noise sources or to model the need for privacy).

DOMAIN WEIGHTS

The following cost functions were obtained with all domains (visual/co-ordination, auditory, tactile, and distance/command) active. Domains were weighted equally (all 2nd order domain weights 1).

CONFIGURATIONS

Five configurations were developed by the evaluation team over the course of the week (see Figures 1 to 5). LOCATE analyses were run on each of these with the results shown in Table 5. In each figure a workspace element is shown contained within a 1.5 feet radius enclosing boundary. The Source/Receiver node is located at the centre of the enclosing boundary, and the arrow defines the zero azimuth vector (the straight-ahead position), from which link angles are defined, for each element.

TABLE 5

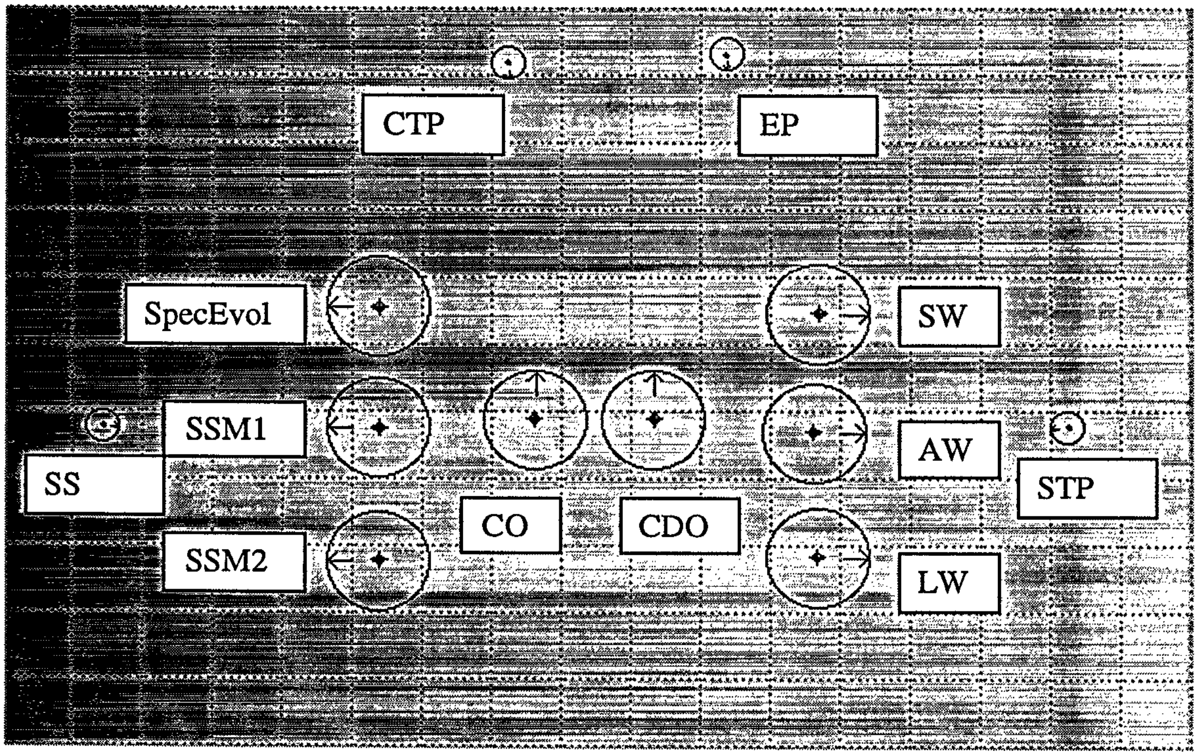
LOCATE cost function values for ICE team developed layouts.

Configuration	Attribute	Cost Function
Configuration A	Outward facing, central executive with displays arranged around the outside.	0.158
Configuration B	Inward facing, boardroom layout with executive at one end and displays at the other.	0.064
Configuration C	Amphitheatre with displays on one wall.	0.093
Configuration D	Inward facing cellular arrangement with distributed overhead displays.	0.050
Configuration E	Inward facing, roundtable with wall displays.	0.035

Common use displays are modelled in all cases as point sources. LOCATE currently does not have an implementation for a distributed source, but is capable of such an extension in the future. For the sake of the ICE evaluations little is lost in assuming point source representations for the displays. The centre to centre separation of the display elements can represent the physical size of the displays.

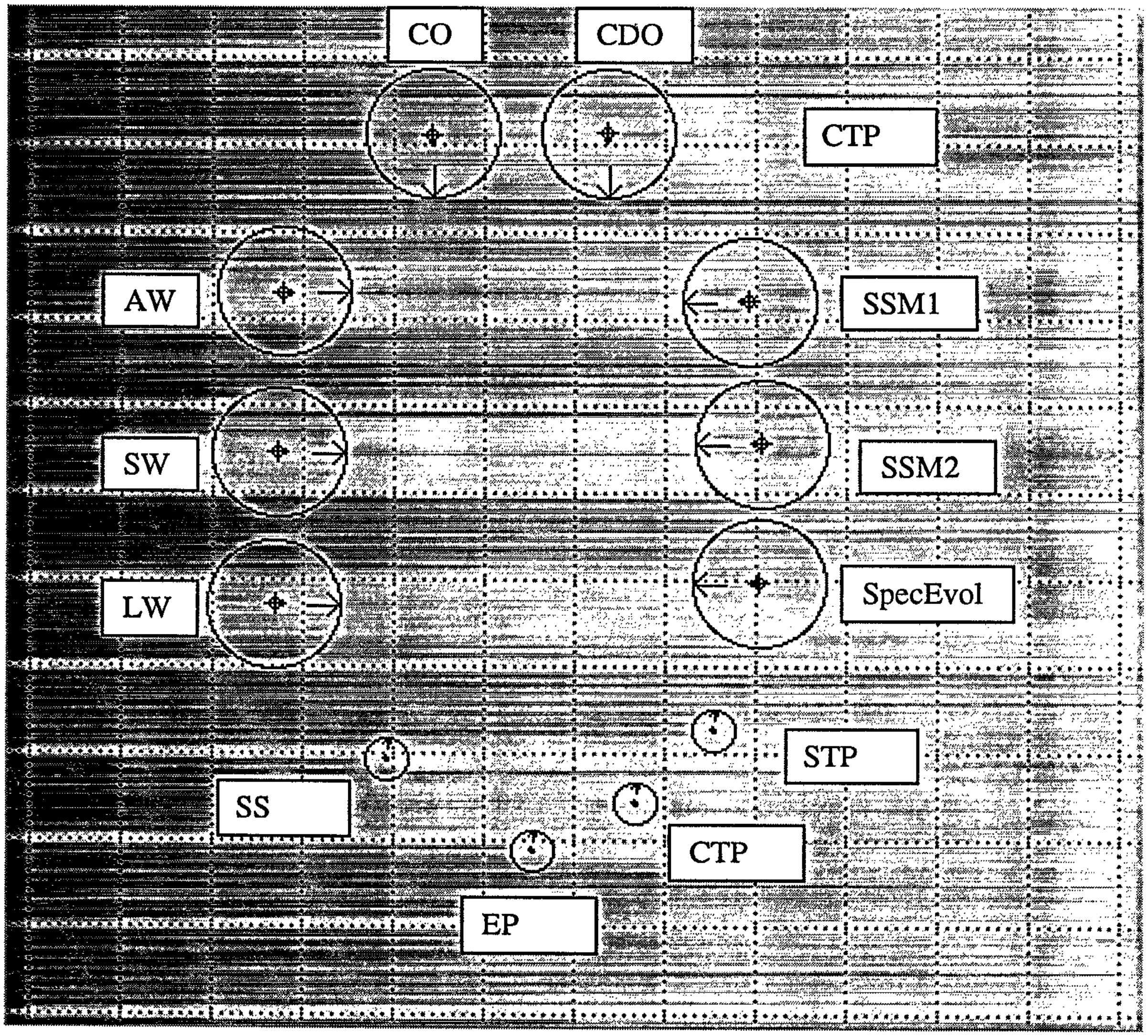
No obstructions were modelled. It is assumed that there are unobstructed sight lines to all displays. On refinement of the layouts the effects of obstructions could be incorporated. Note that as the distance domain was not used to model movement patterns within the space, the elemental workstations are not considered to be obstructions to movement.

Under the assumptions of the analysis, there are considerable differences in cost function values between the layouts. The cost function is bounded by the values 0 (Good) and 1 (Bad). Overall cost function values provide a figure of merit but have no physical meaning. Within a domain, however, the values may or may not be interpretable in terms of some performance parameter such as the probability of detection.



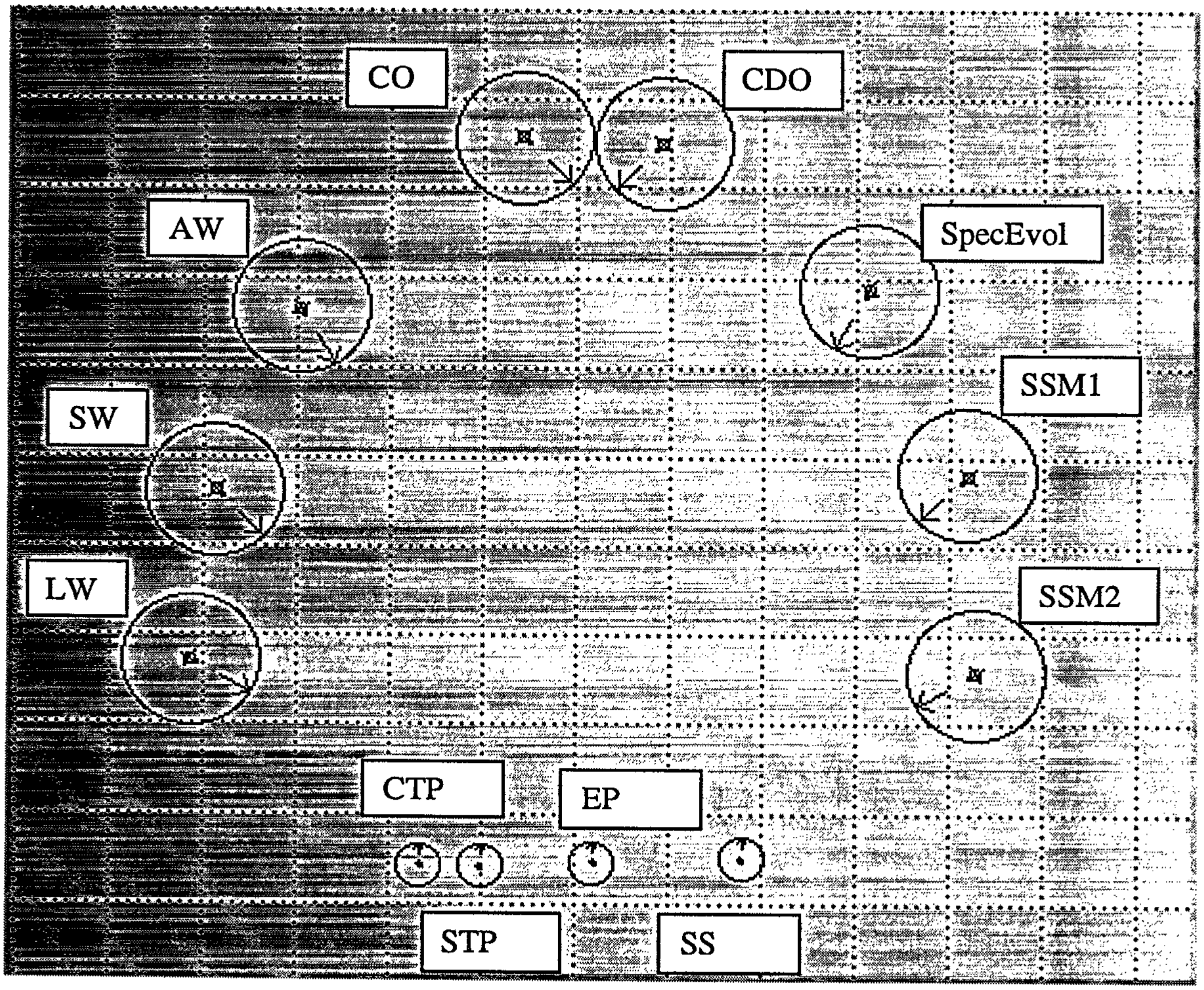
Cost Function value = 0.158. Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS].

Figure 1. *Configuration A for the Integrated Command Environment.*



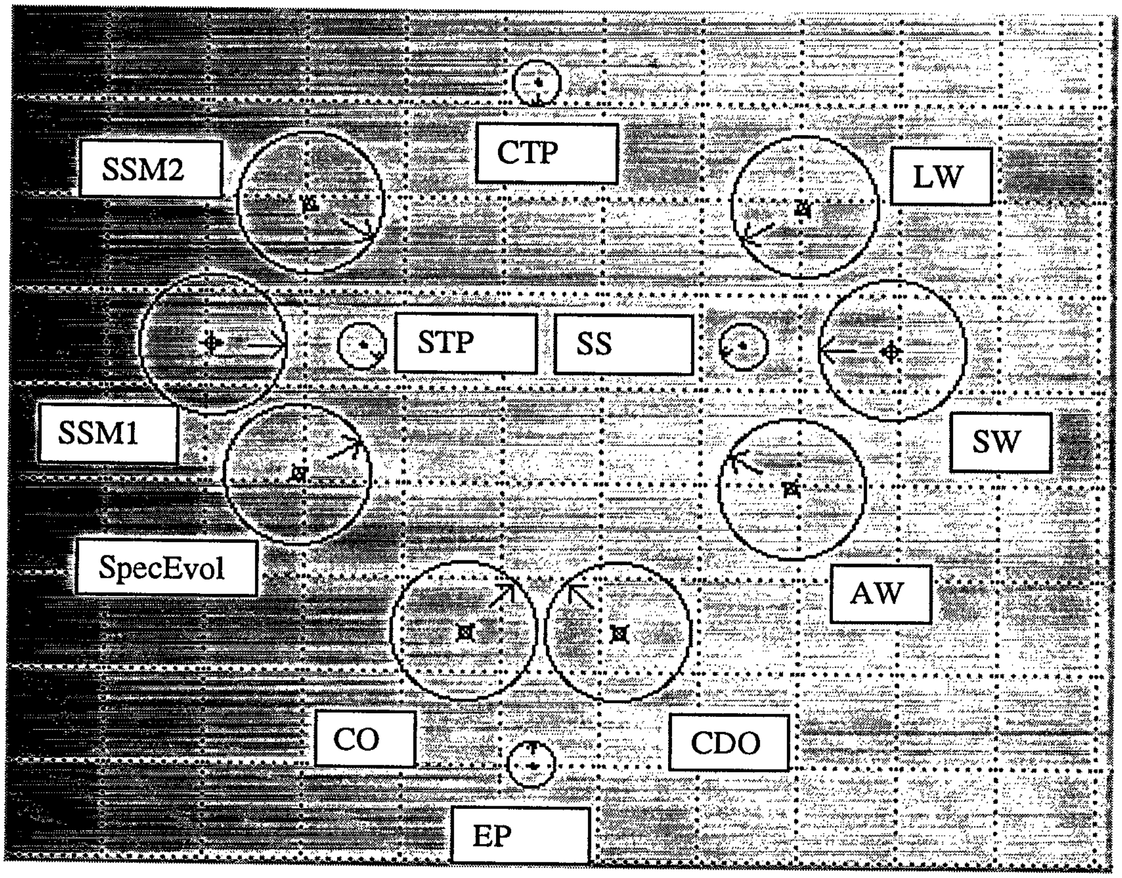
Cost Function value = 0.064. Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS].

Figure 2. *Configuration B for the Integrated Command Environment.*



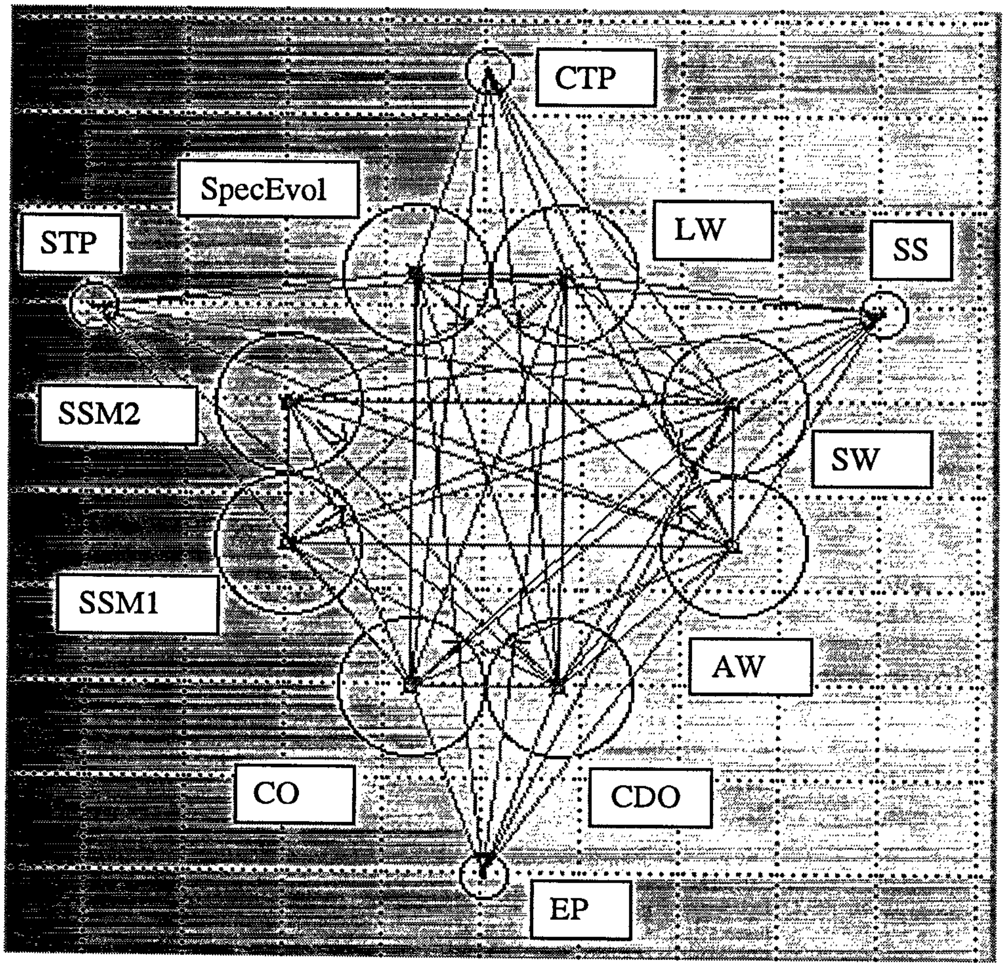
Cost Function value = 0.093. Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS].

Figure 3. *Configuration C for the Integrated Command Environment.*



Cost Function value = 0.050. Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS].

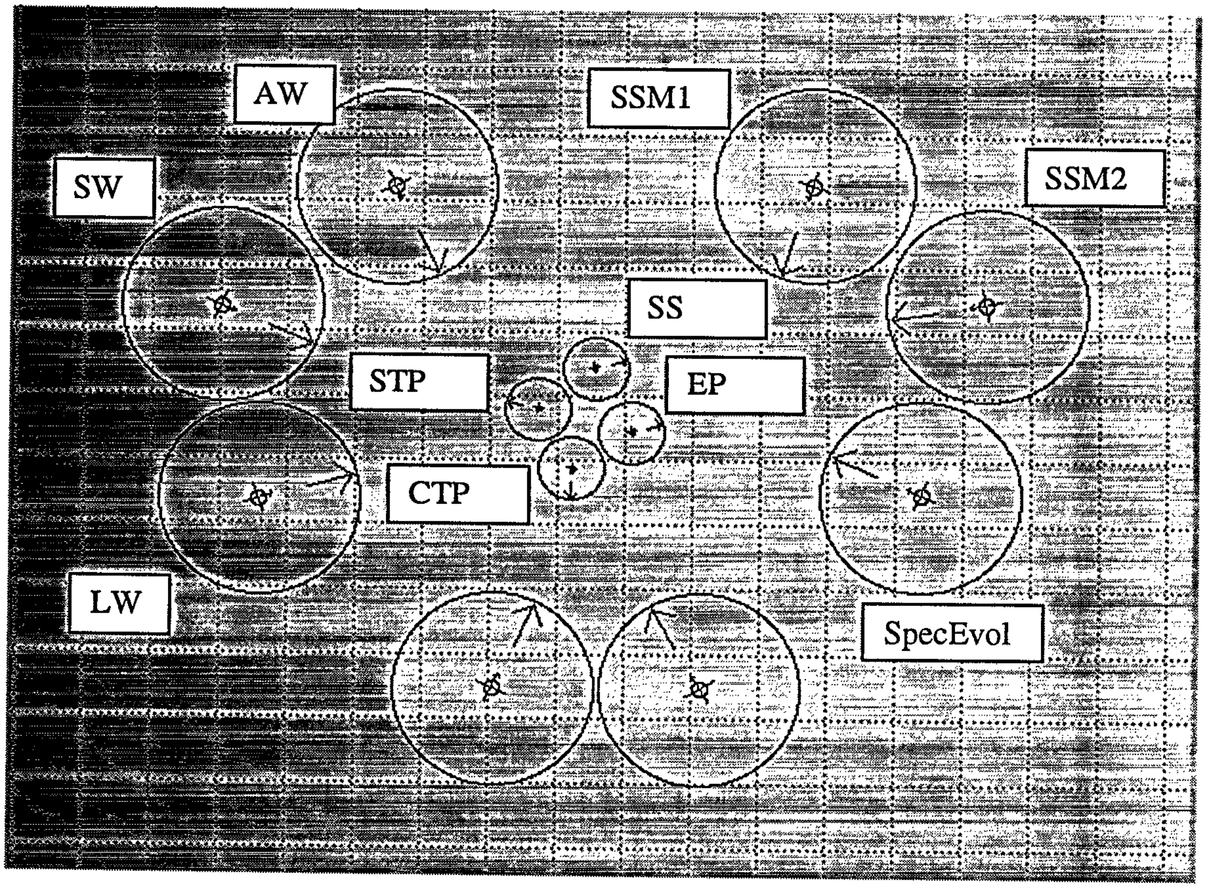
Figure 4. *Configuration D for the Integrated Command Environment.*



Cost Function value = 0.035. Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS].

Figure 5. *Configuration E for the Integrated Command Environment.*

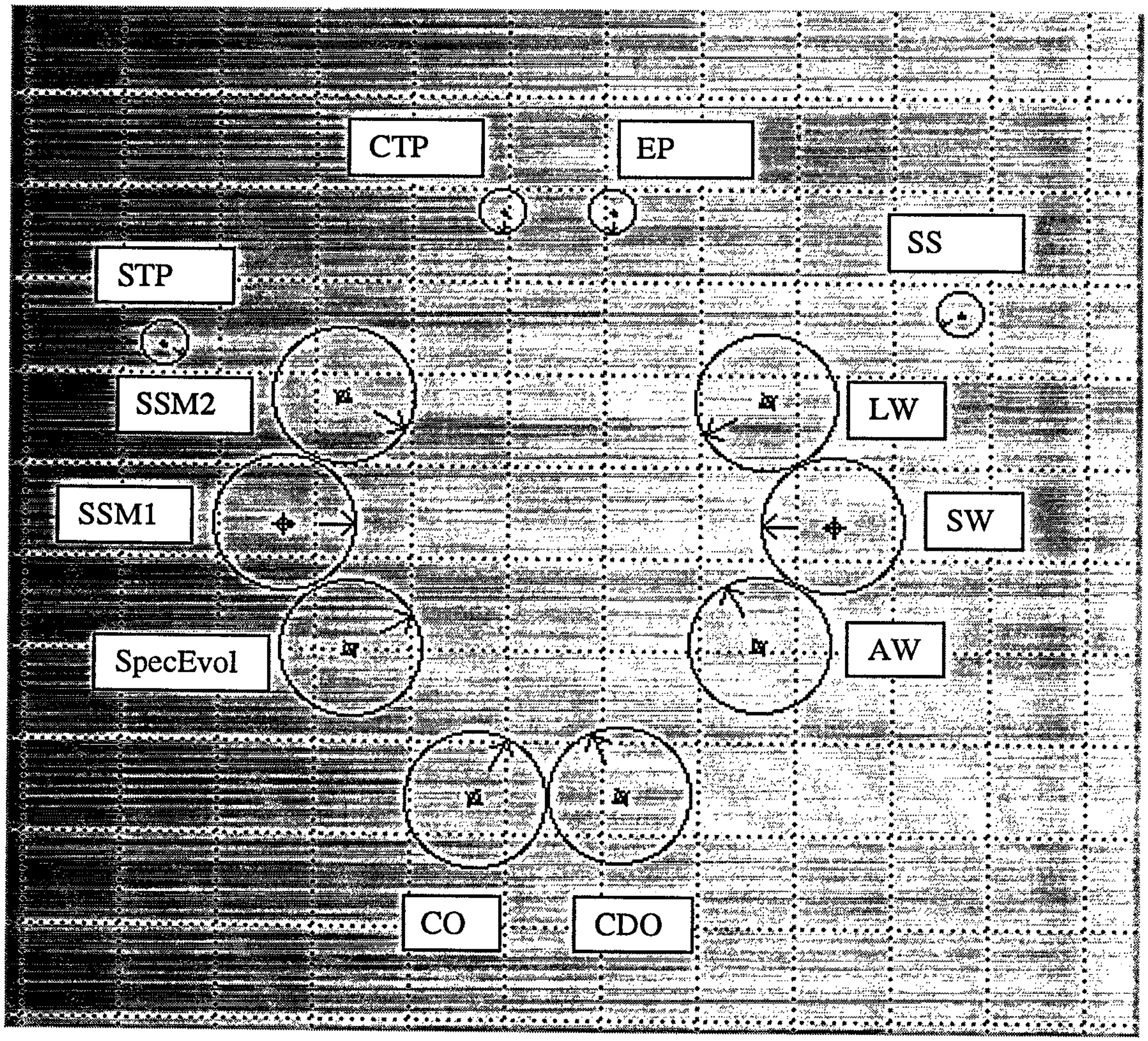
Each of the ICE configurations was used as a starting point for the optimisation algorithm of LOCATE. Generally optimisation produced compact arrangements with cost function values around 0.025 to 0.030. A common theme was evident. All configurations tended to reduce to an inward facing arrangement with executive, warfare and ship's systems cells. A central location of common use displays was suggested. Configuration F came from pulling apart one of the optimised arrangements, to allow space between consoles for access and movement.



Cost Function value = 0.032. Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS].

Figure 6. *Configuration F for the Integrated Command Environment.*

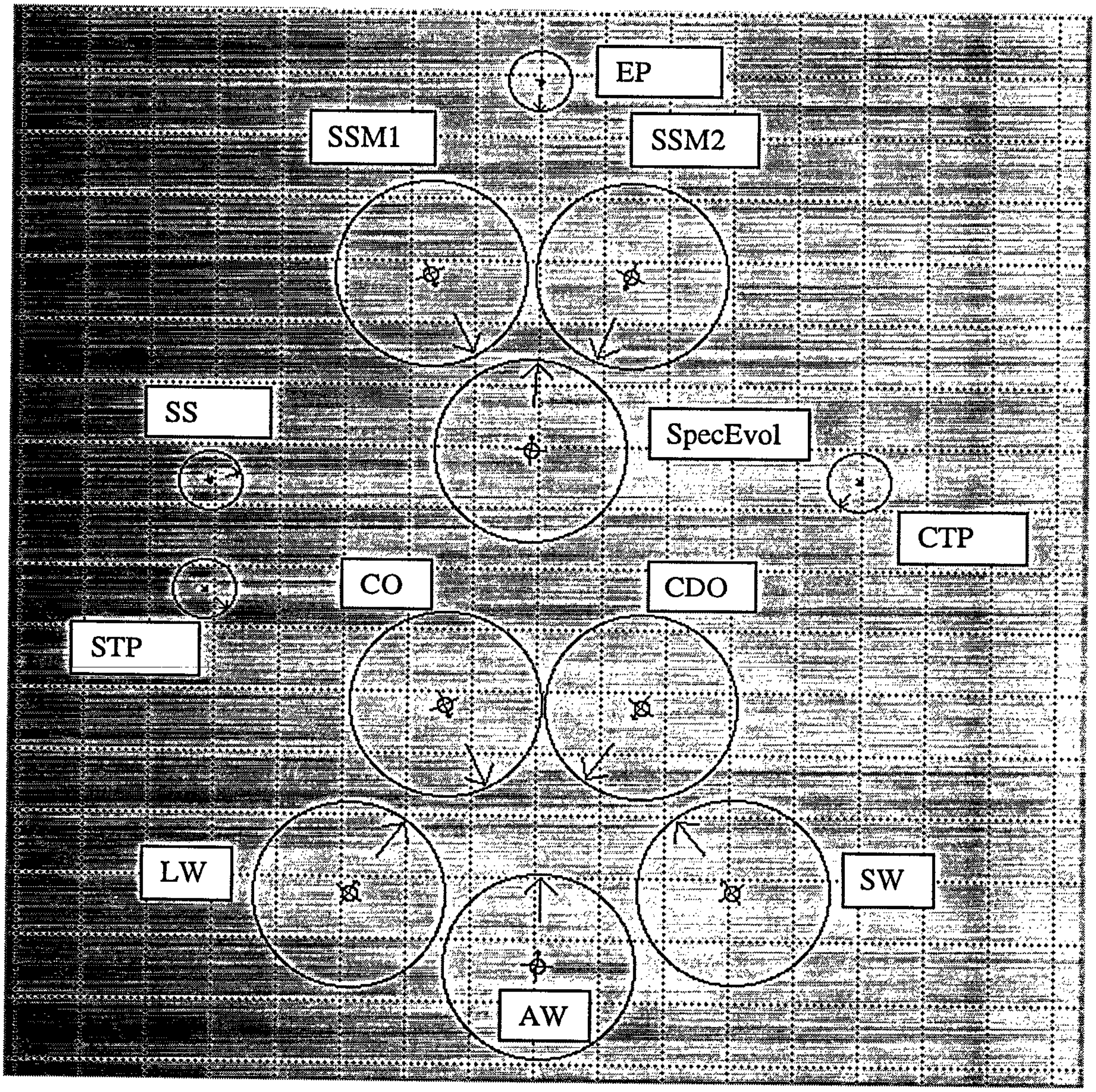
Configuration G is a variation on this theme with all displays moved from the centre of the space to the outside wall. It is assumed that these displays are ceiling mounted to allow unobstructed sight lines.



Cost Function value = 0.048. Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS].

Figure 7. *Configuration G for the Integrated Command Environment.*

Configuration H focuses on two distinct cells, one cell comprising the executive and warfare areas, the other cell organised around ship's systems and special evolutions. The cost function suffers from having the CO/CDO turned away from the ship's system cell.



Cost Function value = 0.060. Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]; Common Tactical Picture [CTP]; Special Tactical Picture [STP]; External Picture [EP]; Ship's Status [SS].

Figure 8. *Configuration H for the Integrated Command Environment.*

The results are summarised in Table 6. To the earlier results of Table 5 are added the cost function values and attributes of 3 derived configurations.

TABLE 6

Summary results of the LOCATE cost function values for notional ICE layouts.

Configuration	Attribute	Cost Function
Configuration A	Outward facing, central executive with displays arranged around the outside.	0.158
Configuration B	Inward facing, boardroom layout with executive at one end and displays at the other.	0.064
Configuration C	Amphitheatre with displays on one wall.	0.093
Configuration D	Inward facing cellular arrangement with distributed overhead displays.	0.050
Configuration E	Inward facing, roundtable with wall displays.	0.035
Configuration F	Inward facing with centralised displays.	0.032
Configuration G	Inward facing with displays ceiling hung or placed around the outer walls.	0.048
Configuration H	Two huddles (warfare and ship's systems) with a central executive.	0.060

DISCUSSION AND CONCLUSIONS

Some configurations (particularly A to C) can all be improved by 5-10% by condensing the layout and moving consoles closer together. In all configurations greater flexibility could be derived from workstations that can rotate to allow different relationships to be formed between the principle cells as the situation demands. For example in configuration H, the executive might rotate their consoles (towards the bow and the ship's system cell) if their primary concern involved ship steerage or damage control. While all this could be modelled in LOCATE, time constraints restricted the analysis to the eight configurations shown.

Some of the human factors issues not modelled in these evaluations, that may be important to the efficacy of the ICE layout, include the following.

1. <u>Obstructions to communication</u>. All consoles were assumed to be 'look-over' and the presence of intervening operators was assumed not to interfere with communication

in any domain. Hence, LOCATE's obstruction functions were not used in this analysis.

2. Movement patterns may become more important to the analysis if additional workstations were introduced into the design. For example, displays that are focal points for planning activities or decision making huddles.
3. Orientation with respect to the ship's axes. For example, some activities may be facilitated if an operator is aligned with a vehicle axis (often this is the axis aligned with the direction of travel). For example, the performance of ship's helm or lookout might be sensitive to absolute orientation, particularly if this involves a direct view of the external world. With the ability to create a virtual world, or with sensor aided perception, the situation clouds — although the movement of the vessel is always feedback that a helm command is being correctly interpreted. Also the orientation of operators with respect to the dominant ship motion may have an effect on feelings of well being and incidents of sickness. Note that the effects of the absolute position of a workspace element within the global workspace is measured by a first order distance link. On the other hand, orientation with respect to a vehicle axis can be handled by creating a link with a dummy workspace element(s) and then measuring angular relationships with respect to this element(s) (e.g., see Hendy, Berger, and Wong, 1989).

Under the assumptions modelled in this analysis, an inward-facing configuration is highly favoured. Various options exist for shared displays for this type of geometry. Displays can be positioned centrally at eye height or overhead. Overhead displays provide greater options in terms of size and location. Head mounted displays provide a whole new dimension to the problem.

REFERENCES

Hendy, K. C., Berger, J., and Wong, C. (1989). Analysis of DDH280 bridge activity using a computer-aided workspace layout program (LOCATE) (DCIEM 89-RR-18). North York, Ontario, Canada: Defence and Civil Institute of Environmental Medicine.

Van Cott, H. P., and Kinkade, R. G. (Eds.). (1972). *Human Engineering Guide to Equipment Design.* New York, NY, USA: John Wiley and Sons.

APPENDIX A: LINK PRIORITY MATRICES

	RECEIVER CO				RECEIVER CDO				RECEIVER AW				RECEIVER LW			
	A	D	T	V	A	D	T	V	A	D	T	V	A	D	T	V
1 CO					10	0	10	10	10	0	0	0	10	0	0	0
2 CDO	10	10	10	10					9	0	0	0	9	0	0	0
3 AW	9	9	0	9	9	9	0	9					8	0	0	7
4 LW	8	8	0	8	8	8	0	8	8	0	0	7				
5 SW	8	8	0	8	8	8	0	8	8	0	0	7	8	0	0	7
6 SSM1	6	6	0	6	6	6	0	6	6	9	0	9	6	9	0	9
7 SSM2	6	6	0	6	6	6	0	6	6	9	0	9	6	9	0	9
8 SpecEvol	5	5	0	5	5	5	0	5	5	10	7	10	5	10	7	10
9 Common Tactical Picture	0	0	0	10	0	0	0	10	0	0	0	9	0	0	0	9
10 External Picture	0	0	0	9	0	0	0	9	0	0	0	7	0	0	0	7
11 Special Tactical Picture	0	0	0	8	0	0	0	8	0	0	0	10	0	0	0	10
12 Ship's Status	0	0	0	7	0	0	0	7	0	0	0	8	0	0	0	8

Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]

Source	RECEIVER SW				RECEIVER SSM1				RECEIVER SSM2				RECEIVER SpecEvol			
	A	D	T	V	A	D	T	V	A	D	T	V	A	D	T	V
1 CO	10	0	0	0	6	0	0	0	6	0	0	0	5	0	0	5
2 CDO	9	0	0	0	6	0	0	0	6	0	0	0	5	0	0	5
3 AW	8	0	0	7	6	0	0	0	6	0	0	0	5	0	0	10
4 LW	8	0	0	7	6	0	0	0	6	0	0	0	5	0	0	10
5 SW					6	0	0	0	6	0	0	0	5	0	0	10
6 SSM1	6	9	0	9					10	0	10	10	0	0	0	0
7 SSM2	6	9	0	9	10	0	10	10					0	0	0	0
8 SpecEvol	5	10	7	10	0	0	0	0	0	0	0	0				
9 Common Tactical Picture	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	8
10 External Picture	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10
11 Special Tactical Picture	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	9
12 Ship's Status	0	0	0	8	0	0	0	10	0	0	0	10	0	0	0	7

Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]

Source	RECEIVER Common Tactical Picture				RECEIVER External Picture				RECEIVER Spec. Tactical Picture				RECEIVER Ship's Status			
	A	D	T	V	A	D	T	V	A	D	T	V	A	D	T	V
1 CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 CDO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 AW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 LW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 SW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 SSM1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 SSM2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 SpecEvol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9 Common Tactical Picture					0	0	0	0	0	0	0	0	0	0	0	0
10 External Picture	0	0	0	0					0	0	0	0	0	0	0	0
11 Special Tactical Picture	0	0	0	0	0	0	0	0					0	0	0	0
12 Ship's Status	0	0	0	0	0	0	0	0	0	0	0	0				

Commanding Officer [CO]; [CDO]; Air Warfare [AW]; Land Warfare [LW]; Surface/Subsurface Warfare [SW]; Ship's Systems Management 1 [SSM1]; Ship's Systems Management 2 [SSM2]; Special Evolutions [SE]

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