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ANALYSIS OF DDH280 BRIDGE ACTIVITY
USING A COMPUTER-AIDED WORKSPACE
LAYOUT PROGRAM (LOCATE)

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ABSTRACT

This report describes the application of a computer-aided workspace layout program, called *LOCATE*, to a complex real world environment involving the evaluation of five ship's bridge configurations. The purpose of the study was to test the performance of the *LOCATE* procedure against the results of a previous evaluation from the same data base. The results of the *LOCATE* analysis are compared with the previous analysis, which used a variety of quantitative and qualitative techniques but lacked a structured method for integrating the results. *LOCATE* provided an assessment of the bridge designs which incorporated most aspects of the original analysis into a single quantitative process. The results of the *LOCATE* analysis agreed with the outcome of the original analysis so far as the overall recommendation is concerned. The *LOCATE* procedure can, however, be improved in a number of areas, including: the incorporation of a distributed representation of a source of information; the modelling of free standing personnel in the workspace as obstructions to communication; dynamic representations of the layout problem; and the incorporation of absolute angular relations into the cost function evaluation.

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1. INTRODUCTION

This report describes an analysis of five ship's bridge configurations using a computer-aided workspace layout program called *LOCATE*. The primary purpose of *LOCATE* is to assist with the solution of 2-dimensional layout problems of a geometric scale characterised as "...within the intermediate to far range of human sensory performance" (Hendy 1984), for example, an office, factory floor plan or operations room. Central to *LOCATE* is a model of human-machine and human-human communication which computes the quality of a given interaction from link ***length***, link ***direction***, various link ***strength*** functions (representing human and machine capabilities in the visual, auditory and spatial domains) and various ***transmission*** functions (representing the effects of obstructions in the workspace). The analysis of the ship's bridge layouts was conducted in order to assess *LOCATE* in an environment which is of sufficient complexity to provide a reasonable test of the program's capability.

The criteria for assessment of a model like *LOCATE*, include: its ability to correctly rate the performance of human-machine and human-human communication in typical real world environments such as operations rooms, air traffic control centers, office layouts etc; and how it compares in this ability, and at what cost, with other methods of solving the problem. For the purposes of demonstration, *LOCATE* has been applied to a number of relatively small problems (Hendy 1984), which were useful in establishing the basic operation of the process, but which did not represent the scale of complexity of most real world problems. Obtaining data from an environment of sufficient complexity to provide an adequate test of a model like *LOCATE*, requires considerable resources and represents a formidable challenge for experiment. An alternative to validation by experiment, is to compare the results obtained with the new process with those from a previous evaluation, based on the analysis of a common set of data. This report describes such a procedure, conducted with a view to assessing the performance of the underlying model of human-machine and human-human interaction in *LOCATE*.

For this application, the *LOCATE* model is embedded in a development program, written in DEC VAX FORTRAN.77, and implemented on a DEC VAX 11/785 computer running the VMS operating system. The need to make *LOCATE* compatible with mathematical optimisation procedures, in order to provide a capability for machine generated solutions, was a central issue in the development of the model (Hendy 1984). In this particular implementation the optimisation features were not available due to the lack of certain software (from the Numerical Algorithms Group Fortran library) in the current computing environment, therefore *LOCATE* was used in the role of an assessment tool rather than a solution generator.

2. THE LOCATE MODEL

The *LOCATE* model is described in detail elsewhere (Hendy 1984), therefore only the main features will be covered here. A fundamental feature in the *LOCATE* model, and that which distinguishes it from other procedures, is the concept of link ***strength***. It is through link strength functions that *LOCATE* transforms link properties (i.e., length and orientation) into measures of an elemental pair's capability to source and receive information. Link strength functions are chosen to represent human and machine properties which can be characterised by distance and angular dependent relationships, for example: the preferred region for locating visual displays with respect to the normal direction of view, reach envelopes, the angular subtense of a display as a function of viewing distance, or the sound pressure pattern of an audio source.

In *LOCATE* the quality of a given communication link is calculated as follows

$$q(i,j) = r(i,j)\, s(i,j) \prod_h \alpha(i,j,h) \prod_k \beta(i,j,k),$$

where:

[1] $q(i,j)$ is the *quality* of the (i,j)th link;

[2] $s(i,j)$ represents the ***strength*** of the information originating at the jth source;

[3] $r(i,j)$ represents the ***strength*** of the information which, if unattenuated by obstructions, would be received by the ith receiver; and

[4] $\alpha(.)$ and $\beta(.)$ represent the ***attenuation*** to the (i,j)th link by elemental and fixed obstructions in the workspace (it is convenient, for computational reasons, to treat attenuation due to fixed and elemental obstructions separately).

The functions $r(i,j)$ and $s(i,j)$ are further split into distance dependent and angle dependent components (denoted by R and Ω subscripts respectively) which are combined as follows

$$r(i,j) = r_R(i,j)\, r_\Omega(i,j),$$

and

$$s(i,j) = s_R(i,j)\, s_\Omega(i,j).$$

The overall system cost function has the following general form

$$J = \sum_i \sum_j \kappa \left[1 - q(i;j)\right] p(i,j),$$

where:

[a] J is a measure of the system *cost;*

[b] $p(i,j)$ is the *priority* associated with the (i,j)th link; and

[c] κ is a ***weight*** for each domain of communication (vision, audition, tactile or movement).

A composite cost value is obtained by performing this weighted sum over all domains of interest.

3. DDH280 BRIDGE DESIGNS

Activity on the bridge of HMCS ATHABASKAN, a Tribal class (DDH280) destroyer of the Canadian Forces Department of National Defence, was studied during three harbour entrances and exits (Evans, Beevis and Beach 1984). This study was conducted as the first stage of a comprehensive human engineering input to the Tribal Class Update and Maintenance Program (TRUMP). Data from the study included frequency of movement between various locations on the bridge, time spent at each location, communication patterns between key bridge personnel, and comments/ratings from operators.

A number of features of the existing bridge design were identified for improvement and four alternate bridge layouts were proposed and evaluated (Evans, Walker and Beevis 1984). Criteria used in this evaluation included: a quantitative assessment of the total straight line distance travelled by bridge personnel; a largely qualitative assessment of auditory communication quality; an assessment of external vision (partly quantitative); consideration of the need for visual monitoring of bridge personnel; subjective ratings of the degree of obstruction to movement; and the absolute orientation of the chart table and ship's radar display. Each part of the original evaluation used a separate method with the overall assessment, which integrated all information gathered during the evaluation, essentially qualitative.

The existing bridge (see Figure 1) involves 19 items of equipment (some manned) or locations of interest, and 7 key personnel. In addition to the workstation elements, various fixtures and structures within the bridge provide obstructions to one or more of the movement links, visual links or auditory links considered in this study (tactile links, were ignored). With two exceptions, equivalent items of equipment and locations exist for each proposed configuration. The exceptions are: a tactical display (CC280) on the existing bridge is replaced by new equipment for Proposals 1 to 4, and an additional Pelorus (an aid for visual fixing) is added, on the bridge

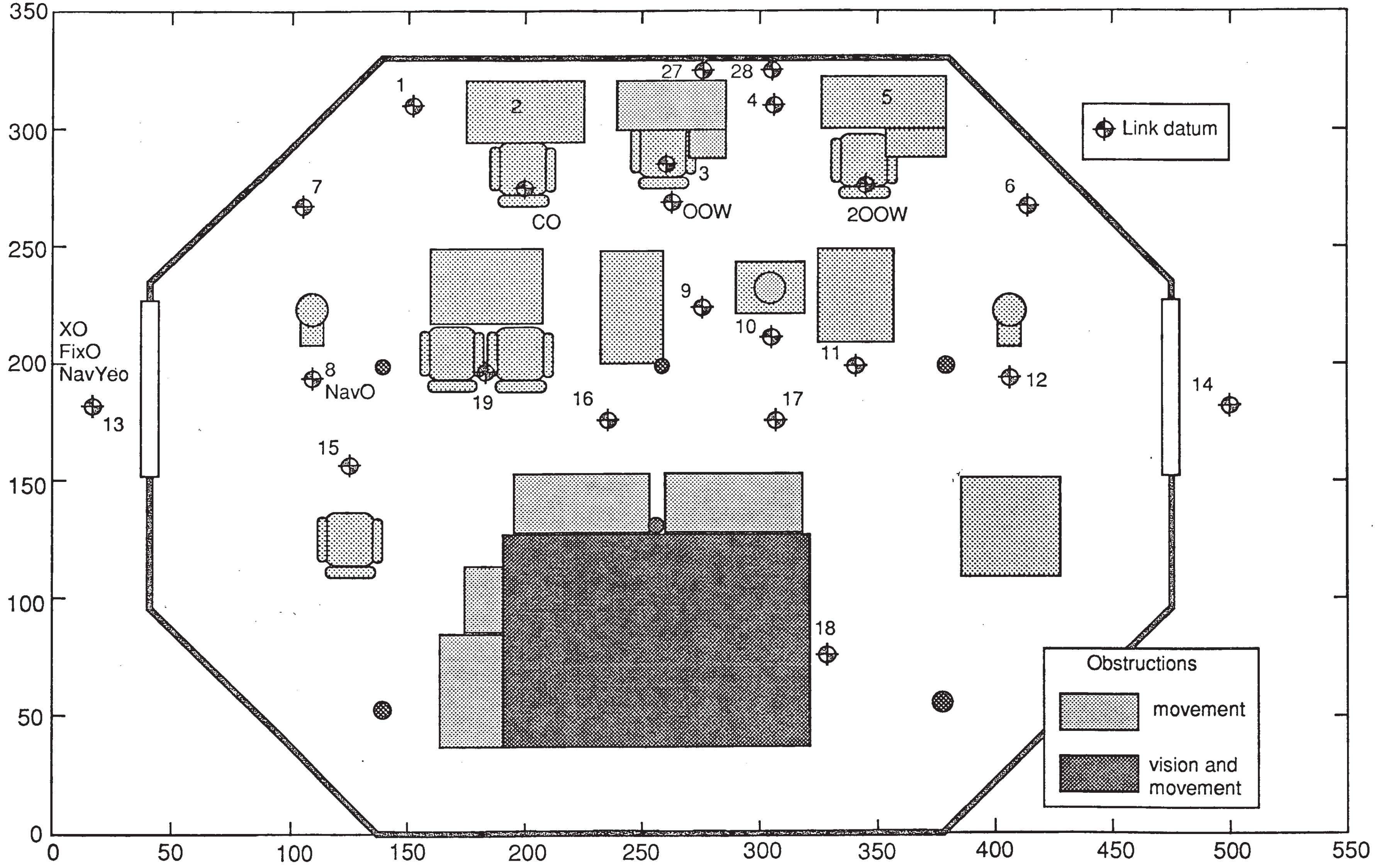

Figure 1: Layout of the existing DDH280 bridge.

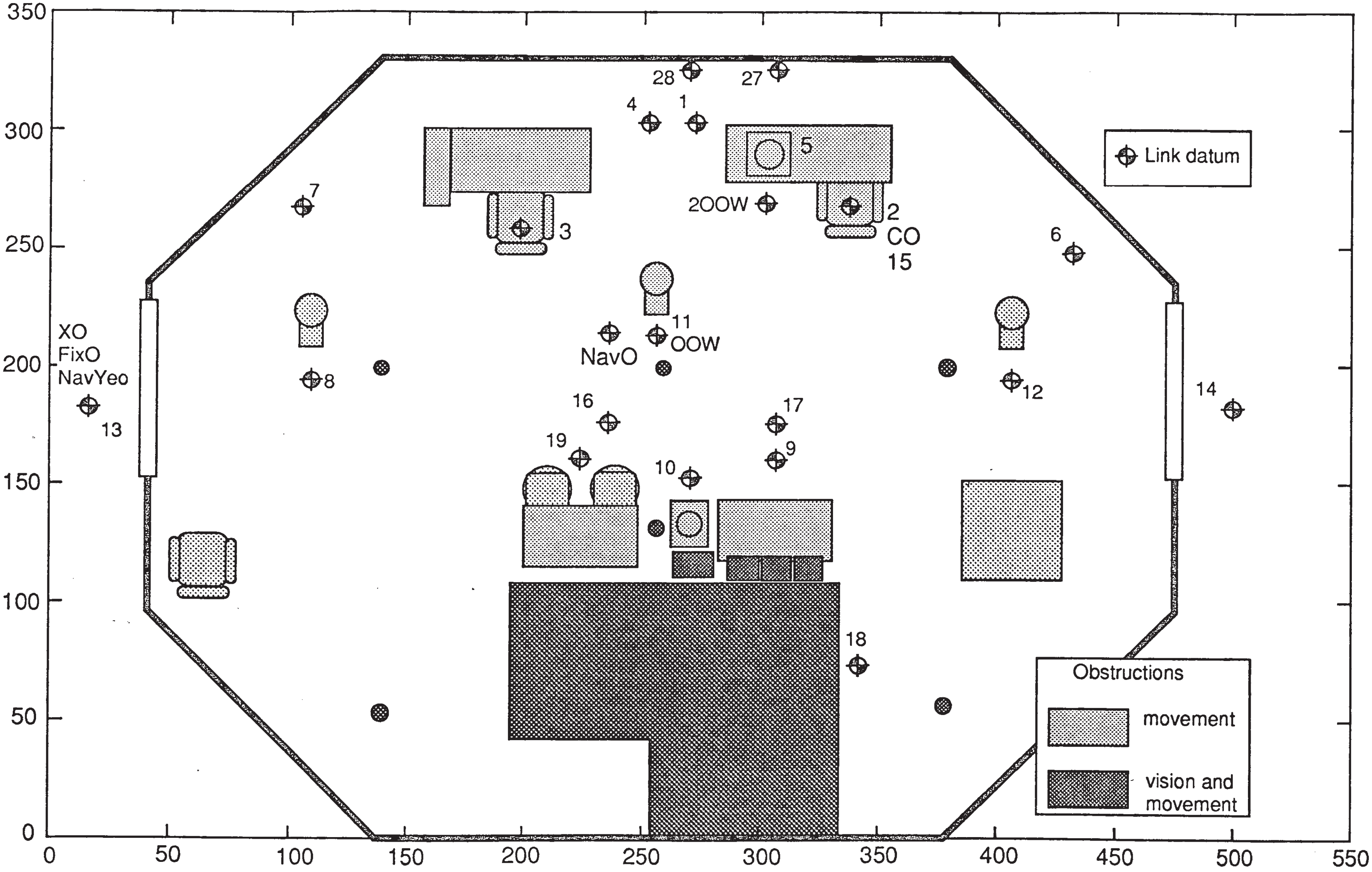

Figure 2: Revised layout of DDH280 bridge- Proposal 1.

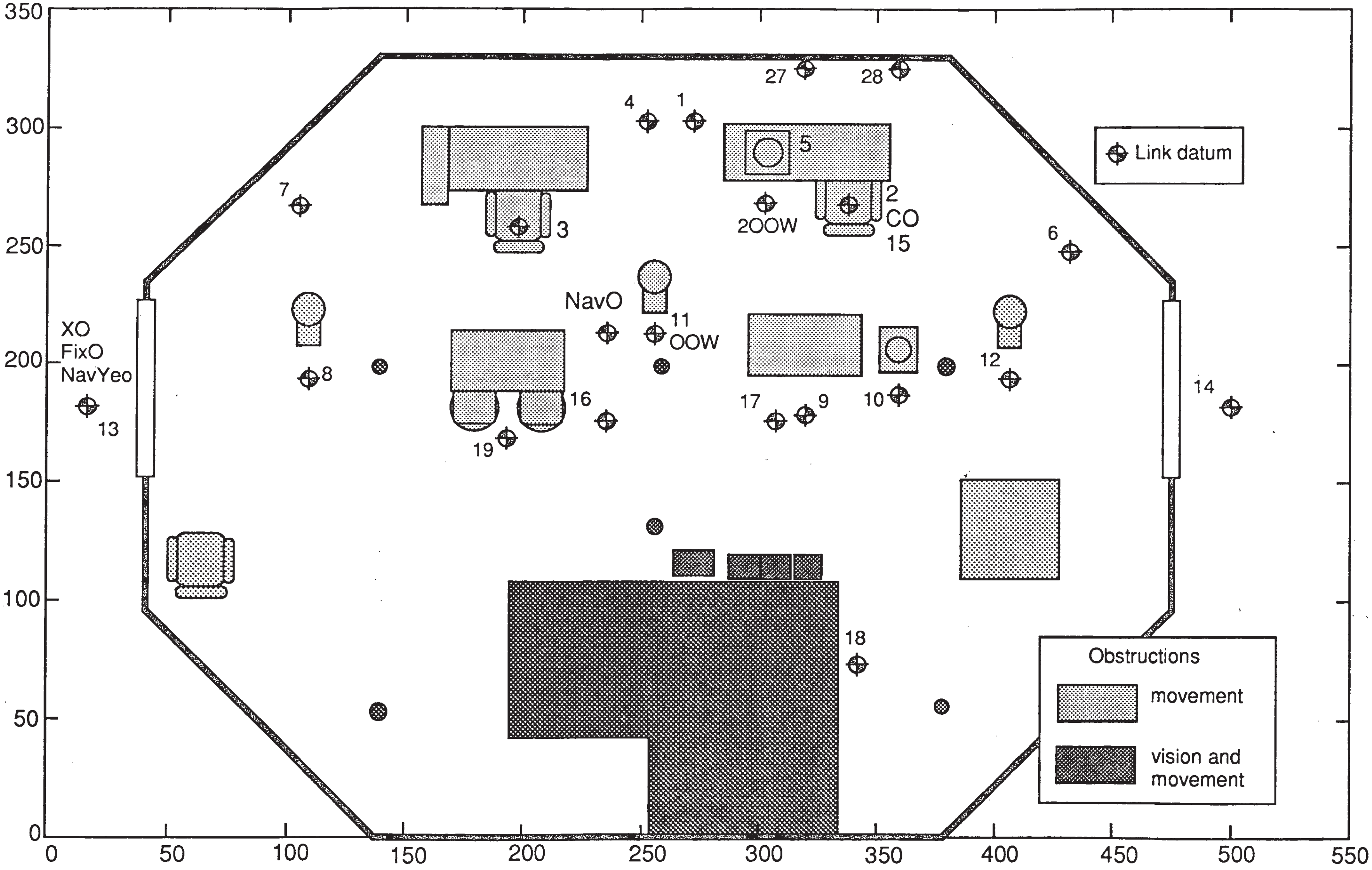

Figure 3: Revised layout of DDH280 bridge- Proposal 2.

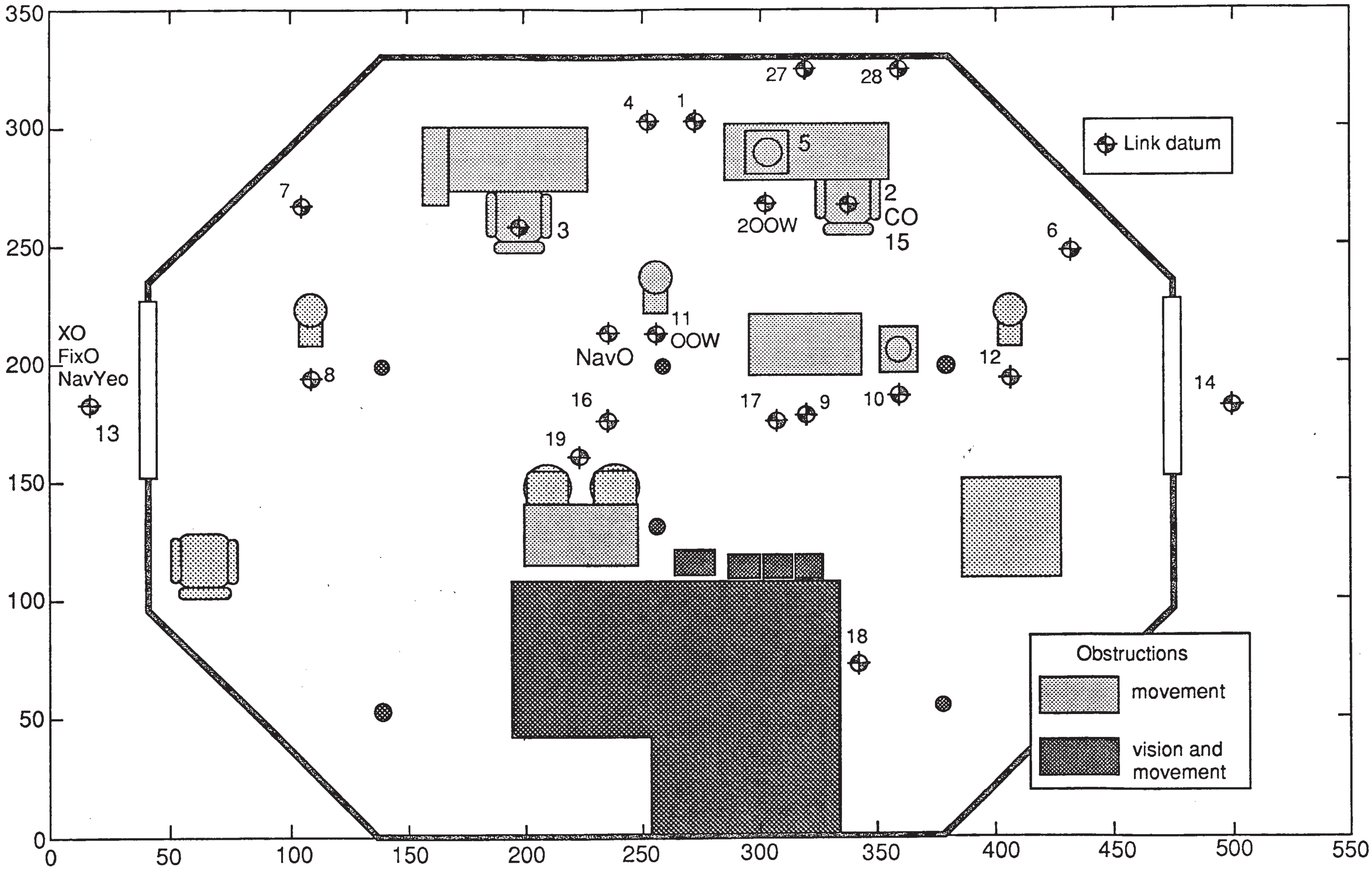

Figure 4: Revised layout of DDH280 bridge- Proposal 3.

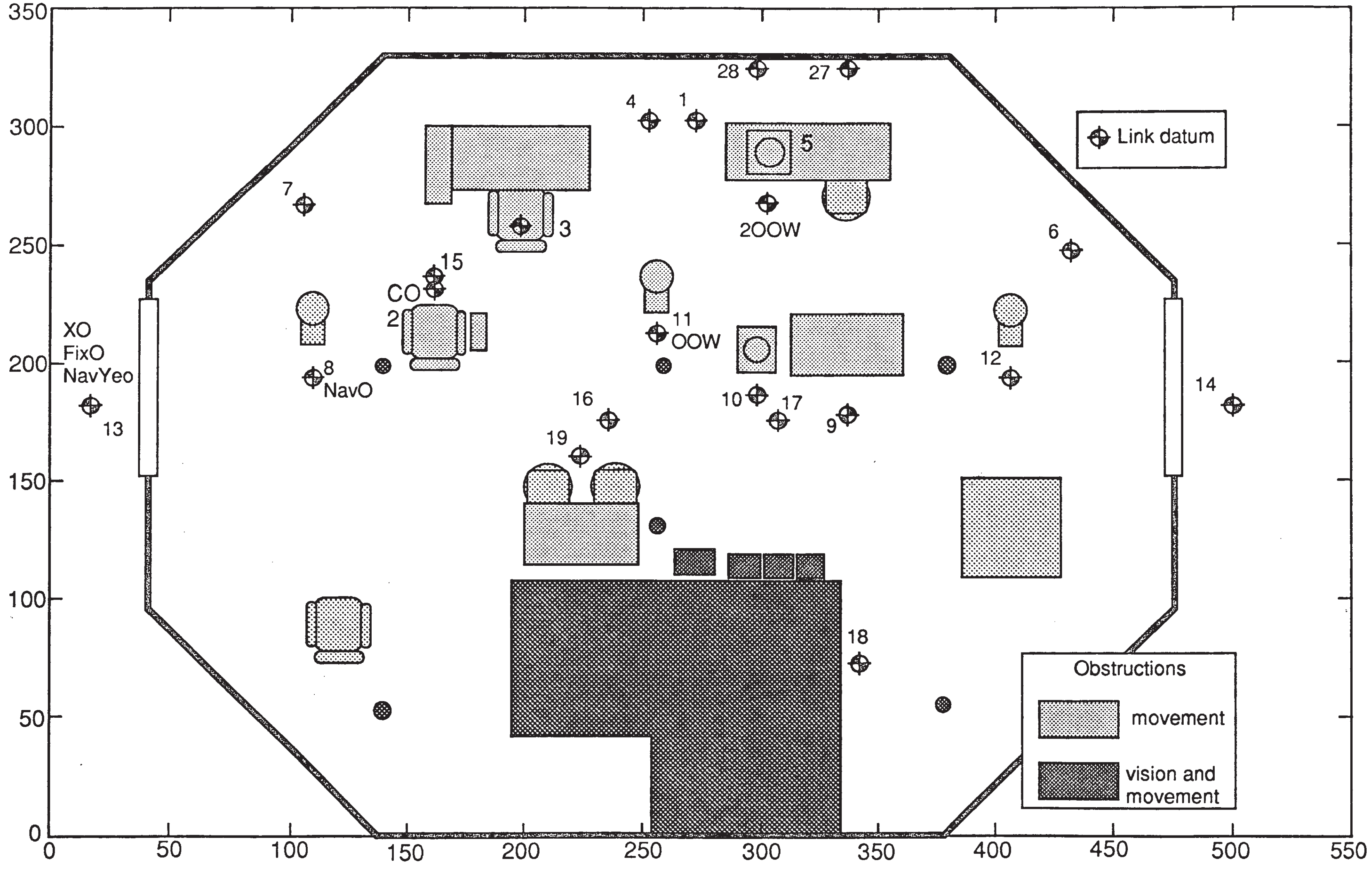

Figure 5: Revised layout of DDH280 bridge- Proposal 4.

centerline, in all updated configurations.

The principal features of Proposals 1 to 4 are:

Proposal 1 (Figure 2): The Commanding Officer's (CO) and Officer of the Watch's (OOW) consoles are combined and located to starboard, the Helmsman's (HM) console is located to port. The external communications console, chart table and radar display are positioned, facing aft, against the chart room bulkhead.

Proposal 2 (Figure 3): The external communications console, chart table and radar display are positioned, facing forward, in the forward mid-bridge area. Otherwise layout is the same as for Proposal 1.

Proposal 3 (Figure 4): The layout is the same as Proposal 1, except the chart table and radar display are positioned, facing forward, in the starboard hand forward mid-bridge area.

Proposal 4 (Figure 5): Same as Proposal 1, but with the chart table and radar display located, forward facing, in the starboard hand forward mid-bridge area; and a new workstation for the CO near the port Pelorus.

Because of the potential for left-right confusion and errors in localisation, the absolute orientation of the chart table and bridge radar display is considered to be an important factor in bridge operation. In the existing bridge the chart table faces athwartships, and in Proposal 1 both the chart table and the radar face aft. In order to represent this arrangement in the *LOCATE* assessment, 2 dummy elements (making 28 in all) were created to form links with these critical elements. These dummy elements have one role only, and that is to provide a directional reference for the orientation of the chart table and the radar.

The 28 elements (items of equipment, locations on the bridge and personnel) consist of the following:

1. CO's forward window area (distance links);
2. CO's console (distance links);
3. HM's console (visual and auditory links);
4. OOW's forward window area (distance links);
5. OOW's console (distance links);
6. starboard forward window area (distance links);
7. port forward window area (distance links);
8. port Pelorus (distance links);
9. chart table (distance links);
10. radar display (visual and distance links);
11. CC280 display or centerline Pelorus (distance links);
12. starboard Pelorus (distance links);
13. port bridge wing (distance links);
14. starboard bridge wing (distance links);
15. CO's chair area (distance links);
16. port mid-bridge (distance links);
17. starboard mid-bridge (distance links);
18. chart room entrance (distance links);
19. communications desk (visual, auditory and distance links);
20. OOW (visual and auditory links);

21. Navigating Officer (NavO- visual and auditory links);
22. CO (visual and auditory links);
23. Executive Officer (XO- visual and auditory links);
24. Second Officer of the Watch (2OOW- visual and auditory links);
25. Fixing Officer (FixO- visual and auditory links);
26. Navigator's Yeoman (NavYeo- visual and auditory links);
27. dummy element for chart table orientation (visual links); and
28. dummy element for radar display orientation (visual links).

The locations of these elements, together with their link datums, are shown in Figs. 1 to 5.

Link Strength Functions

For the sake of commonality, the *LOCATE* analysis focuses on the same types of interactions and evaluation criteria which were considered in the original analysis, viz.:

[1] the distance travelled by all key personnel during the course of harbour entrances and exits;
[2] visual communication within the confines of the bridge related to the need to recognise the identity of individuals and to monitor their activity;
[3] the quality of speech communication between key bridge personnel; and
[4] the absolute orientation of the chart table and bridge radar.

In applying *LOCATE* to the bridge assessment it should be recognised that the original data gathering exercise was not performed with this technique in mind. Hence there are gaps in the data which necessitate a number of assumptions in the choice of link strength functions and priority matrices. Generally these assumptions do not represent limitations in the technique, but rather reflect a problem with the available data. Specifically, in choosing link strength functions to represent the characteristics listed above, the following assumptions were made:

[a] bridge lighting levels are sufficient for 100% recognition at the maximum distance which can occur between viewer and subject;
[b] visual recognition does not depend on the orientation of the subject;
[c] visual displays will not be read remotely, that is, personnel will move to the source of information (it is accepted that some displays, e.g., heading and rudder angle, are read remotely and could be modelled under *LOCATE*, however, in common with the original study they will not be considered here);
[d] visual monitoring is unimpeded if the subject to be monitored is located within the range of the observer's normal head movement (assumed to be ± 90°);
[e] the absolute orientation of the chart table and radar display is treated by forming links, in the visual domain, with the dummy elements 27 and 28 respectively;
[f] a severe penalty should result if the chart table is more than 45° (0.785 radian) from the reference axis, similarly if the radar deviates by more than 15° (0.262 radian); and
[g] no penalty will be applied if a person has to turn before moving to a new location.

The parameters for the link strength functions in the visual, auditory and distance domains are shown in Table 1. These values are intended to reflect the characteristics to be modelled under the assumptions listed above. Because the current version of *LOCATE* treats communication as a point to point process, an assessment of external vision from the bridge was beyond the scope of this evaluation. External vision from the bridge could be evaluated by treating the horizon as a distributed source. The need for a distributed representation of a source of information, and the mechanism by which this might be achieved in *LOCATE*, has been described by Hendy (1984).

Table 1: Parameters of link strength functions for the DDH280 bridge study.

Link Type & Element	Dist. Ang.	Receive Function †			Source Function †		
		Type	Arg1	Arg2	Type	Arg1	Arg2
Visual							
Element 3	R	Constant	1.0	n.a.	Constant	1.0	n.a.
(Helmsman)	Ω	Butterworth	4.0	1.571	Constant	1.0	n.a.
Element 9	R	Constant	1.0	n.a.	Constant	1.0	n.a.
(Chart table)	Ω	Gaussian	0.0	0.785	Constant	1.0	n.a.
Element 10	R	Constant	1.0	n.a.	Constant	1.0	n.a.
(Radar)	Ω	Gaussian	0.0	0.262	Constant	1.0	n.a.
Elements 19 to 26	R	Constant	1.0	n.a.	Constant	1.0	n.a.
(Personnel)	Ω	Butterworth	4.0	1.571	Constant	1.0	n.a.
All Other Elements	R	Constant	1.0	n.a.	Constant	1.0	n.a.
	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.
Auditory							
Element 3	R	Constant	1.0	n.a.	Butterworth	5.0	78.0
(Helmsman)	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.
Elements 19 to 26	R	Constant	1.0	n.a.	Butterworth	5.0	78.0
(Personnel)	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.
All Other Elements	R	Constant	1.0	n.a.	Constant	1.0	n.a.
	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.
Distance							
Elements 1 to 26	R	Constant	1.0	n.a.	Linear	630.0	n.a.
(all active elements)	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.
Elements 27 & 28	R	Constant	1.0	n.a.	Constant	1.0	n.a.
(Dummy elements)	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.

† Note: Parameters, with the exception of non-dimensional numbers, are in ***radians*** for angular (Ω) functions, and in ***inches*** for distance (R) functions.

Constant

$$F(u) = Arg\ 1$$

Linear

$$F(u) = \left[\frac{Arg\ 1 - u}{Arg\ 1} \right] , \quad u \geq 0$$

Butterworth

$$F(u) = \left[\frac{1}{1 + 3\left(\frac{u}{Arg\ 2} \right)^{2Arg\ 1}} \right]^{1/2}$$

Gaussian

$$F(u) = \exp - \left[\frac{(u - Arg\ 1)^2}{2Arg\ 2^2} \right]$$

Butterworth functions with sharp cutoffs at 90° (1.571 radian) were chosen to model the range of acceptable head movement for visual monitoring. Van Cott and Kinkade (1972) gives ±79° as the mean range of neck rotation for male civilian subjects. Some additional torso rotation was arbitrarily allowed in choosing the cut-off value of ±90°. The Butterworth function approaches a 'brick wall' characteristic (i.e., either 1 or 0) as the value of *Arg* 1 in Table 1 approaches ∞. For the values of *Arg* 1 shown in Table 1, link strengths degrade rapidly from ≈ 1 to ≈ 0 as the subject of the visual monitoring behaviour is located further to the side of the observer. Specifically this transition from good visual monitoring to bad visual monitoring, takes place rapidly as the link orientation changes from $0.85 Arg\,2$ to $1.05 Arg\,2$. No penalty was applied with increasing length of visual link, therefore the R-function for both receiver and source is a constant function, value 1. Monitoring was assumed not to be effected by the orientation of the subject, therefore the source Ω-function also has the constant value 1.

Gaussian functions were chosen for the orientation of the chart table and radar displays because of their strong lobe-like shape when plotted in polar coordinates, for example, link strength is down to 61% of the maximum value at the angular deviations shown, as *Arg* 2, in Table 1. The values of *Arg* 2 were chosen arbitrarily as there were no data available to indicate the probability of reversal errors as a function of orientation. It was considered that of the 2 elements, the radar was more critical in this aspect, hence, a more narrow lobe (smaller *Arg* 2) was chosen for its link strength function. As the visual links associated with these elements are intended for orientation only, the R-functions were chosen to be constant functions of value 1.

The ambient noise level on the bridge of a DDH280 has been measured at 64dBA (Crabtree 1975). Between 60 and 65 dBA, normal voice communication is possible up to about 2 meters (Salvendy 1987, page 633). It was assumed that intelligibility would decay rapidly with distance in the presence of noise due to a compounding of the attenuation of speech according to a R^2 law, with the rapid loss of intelligibility as peak amplitude reduces (Van Cott and Kinkade 1972, p203). The validity of these assumptions could be questioned in light of the relatively small size of the bridge enclosure and the presence of reflective surfaces which will generate diffuse fields, however, more appropriate relationships could be established by experiment if one wished to pursue this matter. Therefore under the assumptions stated previously, a Butterworth function was selected with a sharp cut-off at 78 inches (1.98 meters) for the distance dependent component of all auditory communications. This choice of cut-off value is consistent with the assumptions of the original evaluation (Evans *et al.* 1984). In selecting omni-directional properties for all receivers and sources of auditory information, it was assumed that speakers would turn towards their intended receiver and so compensate for the variation in sound pressure levels around the head (Van Cott and Kinkade 1972, p167), and that intelligibility would not be effected by the orientation of the receiver.

A simple linear penalty function was chosen for distance relationships between all active elements. The function reduces from 1 at 0 inches distance, to 0 at 630 inches distance. This limiting value was chosen to be greater than the maximum distance between any 2 points on the bridge. Under this type of function, true distance on the bridge is linearly transformed to a cost value in the range 0 to 1. No advantage was ascribed to movement in any particular direction, for example, the requirement to turn before moving to a new location was ignored. Other types of distance dependent functions could be used, for example, to provide a greater incremental penalty for the first few steps than for the remaining distance travelled.

Location of Personnel

Personnel on the bridge are mobile, moving from one location to another to observe, gather data and monitor the activities of others. However, an analysis of the time spent by key personnel at each location indicated that certain locations dominated each individual's behaviour (see Table 2). For the purposes of this analysis, the key personnel were assumed to be located at the positions which they occupied for the greatest proportion of time, viz.: the OOW in a central position behind the HM; the NavO at the port Pelorus; the CO at his console; the XO, FixO and Nav Yeo

Table 2: Proportion of time spent at each item of equipment or location.

	Item of equipment or location																		
Key Personnel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
OOW	4.1	5.1	56.9	2.1	1.5	0.0	1.5	6.7	0.0	0.0	0.0	2.1	10.8	7.2	0.5	0.5	0.5	0.0	0.5
NavO	1.0	5.6	6.2	0.5	1.0	1.5	1.5	26.2	9.7	0.5	1.0	19.5	9.7	7.7	0.0	3.6	0.0	0.0	1.5
CO	2.6	38.5	21.0	0.0	1.5	5.6	1.5	1.5	3.1	0.0	1.0	1.0	12.8	7.2	0.5	0.0	1.0	0.0	1.0
XO	9.7	8.7	7.7	0.5	0.0	2.1	4.6	3.1	1.0	0.0	2.1	1.0	34.4	15.4	4.1	0.5	0.5	0.0	3.6
2OOW	0.0	0.0	12.3	0.0	84.1	0.0	0.0	0.0	1.5	0.0	0.0	0.5	1.0	0.5	0.0	0.0	0.0	0.0	0.0
FixO	0.0	0.0	0.0	1.0	0.0	1.5	1.5	4.6	24.1	1.5	2.6	6.2	27.2	23.1	0.5	1.5	0.0	0.5	0.5
NavYeo	0.5	0.0	0.0	0.0	0.0	1.5	1.0	2.1	26.2	2.1	4.6	5.6	27.2	21.0	0.5	1.0	1.5	3.6	0.0

Table 3: Number of movements to and from items of equipment and locations.

Origin of movement	Destination of movement																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. CO's forward window area		2	7	0	0	0	2	4	1	0	0	1	1	1	0	1	0	0	1
2. CO's console	8		13	0	2	1	3	5	1	0	0	3	1	1	0	0	1	0	0
3. HM's console	3	14		3	8	1	2	9	4	0	0	3	5	3	0	1	1	0	3
4. OOW's forward window area	1	1	3		0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
5. OOW's console	0	3	9	0		0	0	0	1	0	0	2	2	1	0	0	0	0	0
6. Starb. forward window area	1	0	3	0	0		1	1	1	0	0	4	1	2	0	0	0	0	0
7. Port forward window area	1	2	5	0	0	0		3	1	0	0	0	5	0	1	0	0	0	0
8. Port Pelorus	3	5	5	0	0	1	5		3	0	0	1	11	1	0	0	2	0	2
9. Chart table	1	3	3	2	2	5	1	4		3	4	8	14	18	1	1	1	1	0
10. Radar display	0	0	0	0	0	0	0	0	3		1	1	1	2	0	0	0	0	0
11. CC280 or centerline Pelorus	0	0	0	0	0	0	0	1	2	0		1	2	2	0	0	0	0	0
12. Starboard Pelorus	0	3	3	0	2	0	0	2	12	2	1		2	5	0	2	0	0	1
13. Port bridge wing	0	3	3	0	0	1	3	8	23	1	0	1		20	2	4	1	2	1
14. Starboard bridge wing	1	2	6	0	1	1	1	0	24	1	2	2	20		0	2	1	0	2
15. CO's chair	1	0	2	0	0	0	0	1	0	0	0	0	1	0		0	0	0	0
16. Port mid-bridge	0	0	0	0	0	1	0	1	1	0	0	2	2	2	1		0	0	0
17. Starboard mid-bridge	0	0	1	0	0	2	0	1	0	0	2	0	1	0	0	0		0	0
18. Chart room entrance	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0		0
19. Communications desk	1	1	2	0	0	1	0	0	1	0	0	2	2	0	0	0	0	0	

on the port bridge wing; and the 2OOW at the OOW console.

For this analysis, as in the original analysis, it was assumed that the time the OOW spent standing behind the HM on the existing bridge would transfer to a position behind the centerline Pelorus for Proposals 1 to 4. Also it was assumed that the NavO would use the Pelorus which was closest to the CO, viz. the port hand instrument for the existing bridge and Proposal 4, and the centerline instrument in Proposals 1, 2 and 3.

The assumption that key personnel are located at fixed positions is a simplification made necessary by the essentially static representation of this type of analysis. If key personnel spend approximately equal proportions of their time at a number of widely separated positions, this assumption could lead to an incorrect interpretation of the analysis. In this case a dynamic representation would be needed.

Link Priorities

The presence of Movement (Distance) and Auditory links was determined from the activity analysis of the existing bridge configuration. Distance link priorities were computed from the relative frequency of movement from one point on the bridge to another. Table 3 shows the number of movements on the bridge during three harbour entrances and exits.

For the *LOCATE* analysis, some minor corrections were made to the original data (Evans, Beevis and Beach 1984), and some of the original locations were combined into single points. Locations on the bridge wings, considered as separate in the original analysis, were combined into single points at the port and starboard bridge exits for the present analysis. As the configurations differ only in layout within the bridge area itself, this does not effect the accuracy of the simulation and it avoids problems due to links passing through the bridge structure, as occurred in the original analysis. Two areas (positions 19 and 24 in the original study) apparently associated with the CO were amalgamated, and 2 positions at the starboard forward window area were also combined. Link data associated with the positions 22, 25 and 31 of the original study were ignored for lack of information as to the purpose of these movements.

Because of changes in workstations, some movement links were reassigned for Proposals 1 to 4 (see also the discussion on location of personnel). Specifically the following reassignments were made: all movement links associated with the region behind the HM's position were reassigned to the centerline Pelorus; all movement links associated with the CC280 tactical display were reassigned to the OOW console; all OOW movement links associated with the port and starboard Pelori were reassigned to the centerline Pelorus; all CO movement links associated with the port Pelorus were reassigned to the centerline Pelorus; and, for Proposals 1, 2 and 3 only, all NavO movement links associated with the port Pelorus were reassigned to the centerline Pelorus.

Table 4: Total duration of various verbal communications between key bridge personnel.

	Speaker							
Addressee	HM	Comm	OOW	NavO	CO	XO	2OOW	FixO
HM		0	27	0	6	0	0	0
Comm	0		2	6	3	1	0	1
OOW	0	0		8	38	0	10	4
NavO	0	0	17		36	6	3	33
CO	0	0	28	52		19	1	6
XO	0	0	1	2	6		0	5
2OOW	0	0	10	6	0	0		1
FixO	0	0	2	26	3	9	3	

Auditory link priorities were obtained from a record of the total duration of verbal communication between key personnel on the bridge (see Table 4). The total duration of verbal communication was obtained from individual cell values, and link priorities calculated on the basis of relative duration.

The analysis of the various bridge configurations made by Evans, Walker and Beevis (1984), treated visual monitoring behaviour in a qualitative fashion. Therefore in order to provide data for *LOCATE*, a simple scaling procedure was used to assign values of 0.0, 0.5, 1.0 or 2.0 to each link (see Table 5) on the basis of an established requirement for visual monitoring, and an assessment of the degree of importance attached to each relationship. The sum of the cell values was obtained and link priorities were calculated from the relative ratings.

In using the activity data from the existing bridge to establish priority matrices for the modified bridge configurations, the possible effect of bridge design on movement and communication patterns was ignored, as in the original study, with the exceptions already noted for movement links.

Table 5: Rating of the requirement for visual monitoring of bridge personnel (rating is based on, 0.0 = no, 0.5 = likely, 1.0 = yes, 2.0 = most important).

					Observed				
Observer	HM	OOW	NavO	CO	XO	2OOW	FixO	EI27†	EI28†
Chart Table†	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Radar†	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Comm	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0
OOW	1.0		0.5	0.5	0.0	0.5	0.0	0.0	0.0
NavO	0.0	0.5		0.0	0.0	0.0	1.0	0.0	0.0
CO	1.0	1.0	1.0		0.5	0.0	0.0	0.0	0.0
XO	0.0	0.0	0.0	0.5		0.0	0.0	0.0	0.0
2OOW	1.0	1.0	0.0	0.0	0.0		0.0	0.0	0.0
FixO	0.0	0.0	1.0	0.0	0.0	0.0		0.0	0.0

† Note: for the purposes of orientation only.

Obstructions

All workstations were considered disruptive to movement on the bridge, as were obstructions such as the chart room, the CO's chair, a hatchway and a number of stanchions supporting the deckhead. The chart room and stanchions were considered to obstruct visual links as well. Obstructions were represented by either rectangular or circular approximations to the physical profiles of the objects. Auditory communication was assumed to be unaffected by bridge furniture and structures.

4. METHOD OF EVALUATION

Separate *LOCATE* analyses were performed for each domain of communication and for all domains combined, with and without obstructions. From the cost function values a *Clutter Factor* was calculated as follows,

$$C_i = \frac{Obstructed\ cost\ function\ value}{Unobstructed\ cost\ function\ value} - 1,$$

where: i = E,1,2,3,4. The subscripts denote *Existing* and *Proposals 1* to *4* respectively. Each configuration was ranked according to the values of its cost function and Clutter Factor. To aid in the interpretation of the results, the cost function values for Proposals 1 to 4 were normalised through division by the cost of the existing bridge configuration.

The *LOCATE* analysis provided a quantitative assessment of overall system cost and degree of obstruction, separately in each domain of interest, and in all domains combined. The original analysis of the 5 bridge configurations used a variety of qualitative and quantitative methods of assessment. Because of this fundamental difference in approach, an absolute basis for comparison between the studies does not exist. However, wherever possible, the major conclusions of the original study were compared with the results of the *LOCATE* analysis.

The sensitivity of the *LOCATE* analysis, to the choice of domain weights and link strength function parameters, was examined. Three sets of domain weights were considered which provided greater emphasis, than the reference set ($w_v : w_a : w_d$ = 0.333:0.500:0.167), to each domain in turn. The critical distance and angle dependent parameters of all visual and auditory link strength functions were varied by ±20% to test the sensitivity of the ranking to changes in the choice of these values. As distance link functions linearly transform distance travelled, the choice of limiting value (*Arg* 1 in Table 1) can be made arbitrarily without loss of generality and therefore sensitivity to this choice is not really an issue. The choice of limiting value for distance links will manifest itself in the magnitude of the distance component of cost, hence its effect is similar to varying the value of w_d.

In order to demonstrate the significance of the link strength functions in *LOCATE*, analyses were performed with linear distance dependent, and constant angle dependent, functions in all domains. In this form, *LOCATE* reduces to the material flow analogy (Hendy 1984) and therefore these analyses provide points of comparison with techniques such as SPACE (Siegel, Wolf and Pilitis 1982), CORRELAP and CRAFT (Francis and White 1974).

5. RESULTS

The results of the *LOCATE* analyses are shown, together with the rankings from the original analyses, in Tables 6 and 7. On the basis of overall cost function, when all communication domains are considered, Proposal 4 emerges from the *LOCATE* analysis in the top rank position with the existing bridge second. The positions are reversed when clutter is considered. These results are to be compared with the original analysis which contained the recommendation that Proposal 4 be adopted over the other configurations. Justification offered in support of the original decision included the orientation of the chart table and a preferred arrangement of items (not considered in the present analysis because of lack of data on the extent of human-machine and human-human interaction) in the aft bridge area. Although certain features of the existing bridge design, such as the raised platform in the foreward area, present major limitations, it seemed to be assumed that the layout of elements on the existing bridge was inferior to the all of the updated configurations.

The original analysis of movement patterns ranked the configurations in the order {1,2,4,3,E}, although the difference in cost (total distance travelled) between the highest and lowest ranked design was only 2% of straight line distance. The *LOCATE* analysis of unobstructed distance relationships yielded the ranking {3,2,4,1,E} with a similar difference in system cost separating the best from the worst. The differences between these analyses are due to the minor reorganisation of movement pattern data for the current analysis. Given identical input data and linear strength functions, the 2 methods will give equivalent results for unobstructed distance links.

The introduction of obstructions to movement has only a minor effect on the overall ranking of designs (Proposals 2 and 4 change positions), however, the cost differences are accentuated with a 4% margin now separating the highest from the lowest. In the original analysis 5 evaluators

Table 6: Results of the analysis of DDH280 bridge proposals.

Condition	Cost Fn.	Norm. Cost Fn.	Rank	Clutter Factor	Rank
1. ORIGINAL ANALYSIS (Distance links, no obstr.)				n.a.	n.a.
Existing	8002	1.000	5		
Proposal 1	7875	0.984	1		
Proposal 2	7910	0.989	2		
Proposal 3	7970	0.996	4		
Proposal 4	7940	0.992	3		
			{1,2,4,3,E}		
2. *LOCATE* (Distance links, no obstructions)				n.a	n.a
Existing	3.888	1.00	5		
Proposal 1	3.827	0.98	4		
Proposal 2	3.791	0.98	2		
Proposal 3	3.779	0.97	1		
Proposal 4	3.804	0.98	3		
			{3,2,4,1,E}		
3. *LOCATE* (Distance links, obstructions)					
Existing	3.960	1.00	5	0.019	5
Proposal 1	3.863	0.98	4	0.009	2
Proposal 2	3.837	0.97	3	0.012	4
Proposal 3	3.817	0.96	1	0.010	3
Proposal 4	3.827	0.97	2	0.006	1
			{3,4,2,1,E}		{4,1,3,2,E}
4. *LOCATE* (Visual links, no obstructions				n.a.	n.a.
Existing	7.045	1.00	3		
Proposal 1	10.03	1.42	5		
Proposal 2	6.329	0.90	1		
Proposal 3	7.198	1.02	4		
Proposal 4	6.371	0.91	2		
			{2,4,E,3,1}		
5. *LOCATE* (Visual links, obstructions)					
Existing	7.056	1.00	2	0.002	1
Proposal 1	11.00	1.56	5	0.097	3
Proposal 2	7.299	1.03	3	0.153	5
Proposal 3	8.174	1.16	4	0.136	4
Proposal 4	6.861	0.97	1	0.077	2
			{4,E,2,3,1}		{E,4,1,3,2}

Table 6 cont.

Condition	Cost Fn.	Norm. Cost Fn.	Rank	Clutter Factor	Rank
6. *LOCATE* (Auditory links, no obstructions)					
Existing	8.469	1.00	2	n.a.	n.a.
Proposal 1	9.785	1.16	3		
Proposal 2	9.832	1.16	5		
Proposal 3	9.785	1.16	3		
Proposal 4	7.422	0.88	1		
			{4,E,1,3,2}		
7. *LOCATE* (Visual, auditory, distance link, no obstructions)					
Existing	7.230	1.00	2	n.a.	n.a.
Proposal 1	8.871	1.23	5		
Proposal 2	7.655	1.06	3		
Proposal 3	7.920	1.10	4		
Proposal 4	6.468	0.90	1		
			{4,E,2,3,1}		
8. *LOCATE* (Visual, auditory, distance, obstructions)					
Existing	7.245	1.00	2	0.002	1
Proposal 1	9.202	1.27	5	0.037	3
Proposal 2	7.987	1.10	3	0.043	5
Proposal 3	8.252	1.14	4	0.042	4
Proposal 4	6.635	0.92	1	0.026	2
			{4,E,2,3,1}		{E,4,1,3,2}

rated the configurations for ease of movement between various critical areas. A high degree of inter-rater agreement (Kendall's coefficient of concordance $W = 0.94$, $p < 0.01$) was obtained with a pooled ranking, obtained from the sum of ranks values (Siegel 1956, p 238), of {1,3,4,2,E}. For comparison the *LOCATE* analysis produced the ranking, on the basis of Clutter Factor in the distance domain, of {4,1,3,2,E}. Both analyses indicate that the existing bridge design provides the most obstruction to movement. Kendall's rank correlation coefficient, between the results of the original analysis and the present results, is not significant ($\tau = 0.60$, $p = 0.12$).

Proposal 1 fares badly in the *LOCATE* analysis of visual links, both with and without obstructions, because of the orientation of the radar and chart table combined with the high priority given to this aspect of the layout. The existing bridge design and Proposal 4 rank best in terms of visual link quality and visual clutter. The existing bridge and Proposal 4 also perform best with respect to auditory communication links. The original analysis, although listing the requirement for both visual monitoring of personnel and auditory communication, does not consider these aspects at a level of detail which can be used to establish a ranking for the configurations.

The range of domain weights considered in this analysis had no effect on the ranking of the 5 configurations (see Table 8). Changes in visual link strength function parameters resulted in minor changes to ranked position when overall system cost and Clutter Factor was considered (see Table 9). When rank changes did occur, only one pair was affected (Kendall's $\tau = 0.8$, $p = 0.04$) in each case.

Table 7: Rankings of DDH280 bridge configurations (E = Existing bridge, 1 = Proposal 1, 2 = Proposal 2, 3 = Proposal 3, 4 = Proposal 4)

Type of Analysis	Rank 1	2	3	4	5
Original Analysis					
Operator ratings	1	3	4	2	E
Original Analysis					
Distance links, no obstructions	1	2	4	3	E
LOCATE Analysis					
Distance links, no obstructions	3	2	4	1	E
Distance links, obstructions	3	4	2	1	E
Visual links, no obstructions	2	4	E	3	1
Visual links, obstructions	4	E	2	3	1
Auditory links, no obstructions	4	E	1	3	2
All links, no obstructions	4	E	2	3	1
All links, obstructions	4	E	2	3	1
Movement Clutter Factor	4	1	3	2	E
Visual Clutter Factor	E	4	1	3	2
Overall Clutter Factor	E	4	1	3	2

Table 8: Sensitivity of *LOCATE* analysis to choice of domain weights.

Condition	Cost Function (J)			
	Weights (i)	Weights (ii)	Weights (iii)	Weights (iv)
LOCATE (Visual, auditory, distance links, obstructions)				
Existing	7.245	6.497	7.009	6.861
Proposal 1	9.202	8.219	9.405	9.210
Proposal 2	7.987	6.992	7.564	7.367
Proposal 3	8.252	7.261	7.983	7.786
Proposal 4	6.635	6.038	6.541	6.422
Ranking	{4,E,2,3,1}	{4,E,2,3,1}	{4,E,2,3,1}	{4,E,2,3,1}

Notes: (i) $w_v : w_a : w_d$ = 0.333:0.500:0.167

(ii) $w_v : w_a : w_d$ = 0.333:0.334:0.333

(iii) $w_v : w_a : w_d$ = 0.500:0.333:0.167

(iv) $w_v : w_a : w_d$ = 0.500:0.300:0.200

Table 9: Sensitivity of *LOCATE* analysis to choice of link strength function parameters.

	Cost Function			Clutter Factor		
Condition	-20%	Ref.	+20%	-20%	Ref.	+20%
1. *LOCATE* (Visual links, no obstructions)				n.a.	n.a.	n.a.
Existing	9,900	7.045	4.223			
Proposal 1	12.40	10.03	7.583			
Proposal 2	8.718	6.329	3.937			
Proposal 3	9.572	7.198	4.756			
Proposal 4	8.885	6.371	3.815			
Ranking	{2,4,3,E,1}	{2,4,E,3,1}	{4,2,E,3,1}			
2. *LOCATE* (Visual links, obstructions)						
Existing	9.905	7.056	4.240	0.001	0.002	0.004
Proposal 1	12.87	11.00	9.031	0.038	0.097	0.191
Proposal 2	9.187	7.299	5.386	0.054	0.153	0.368
Proposal 3	10.04	8.174	6.205	0.049	0.136	0.305
Proposal 4	9.118	6.861	4.545	0.026	0.077	0.191
Ranking	{4,2,E,3,1}	{4,E,2,3,1}	{E,4,2,3,1}	{E,4,1,3,2}	{E,4,1,3,2}	{E,1,4,3,2}
3. *LOCATE* (Auditory links, no obstructions)				n.a.	n.a.	n.a.
Existing	10.20	8.469	6.888			
Proposal 1	10.95	9.785	8.325			
Proposal 2	11.05	9.832	8.339			
Proposal 3	10.95	9.785	8.325			
Proposal 4	9.533	7.422	5.478			
Ranking	{4,E,1,3,2}	{4,E,1,3,2}	{4,E,1,3,2}			

Under linear distance dependent link strength functions in all domains, ranking is {4,E,1,3,2} in both the visual and auditory domains (see Table 10). The *LOCATE* analysis, using both distance and angle dependent functions, resulted in the rankings {2,4,E,3,1} and {4,E,1,3,2} in the visual (no obstructions) and auditory domains respectively. Although the results match in the auditory domain, the ranking in the visual domain is quite different (Kendall's $\tau = 0.21$, $p = 0.41$).

Table 10: Results of the *LOCATE* analysis with linear distance dependent link strength functions in the visual and auditory domains.

Condition	Cost Fn. J	Norm. Cost Fn. J^*	Rank
1. LOCATE (Visual links, no obstr., linear R fns.)			
Existing	1.717	1.00	2
Proposal 1	2.315	1.35	3
Proposal 2	2.339	1.36	5
Proposal 3	2.315	1.35	3
Proposal 4	1.674	0.97	1
			{4,E,1,3,2}
2. LOCATE (Auditory links no obstr., linear R fns.)			
Existing	2.289	1.00	2
Proposal 1	2.902	1.27	3
Proposal 2	2.908	1.27	5
Proposal 3	2.902	1.27	3
Proposal 4	2.003	0.88	1
			{4,E,1,3,2}

6. DISCUSSION

The bench mark for this assessment of the *LOCATE* model was considered to be the original evaluation. The original evaluation represented a comprehensive human engineering analysis of the 5 bridge layouts, and the final recommendation was achieved by consensus between operators and the evaluation team. Short of absolute performance data, which would involve high grade manned simulation of all configurations, the original study represents the best overall evaluation of the 5 configurations within the limitations of the techniques used in the assessment. At least for the top rank configuration, *LOCATE* and the original analysis agree.

As the method of evaluation of *LOCATE* depends on a comparison with the original analysis, it is necessary to ensure that a consistent set of assumptions are used in both cases. This has limited the scope of the *LOCATE* analysis in a number of areas, for example, not considered in the *LOCATE* analysis was the need to remotely monitor displays, a penalty factor due to the requirement to change direction during movement between locations on the bridge, and the advantage of face to face auditory communication. It should be kept in mind that the purpose of this investigation is to compare *LOCATE* with alternative methods of assessment under similar conditions.

The analysis of unobstructed distance links provided little evidence for the superiority of any one configuration. If direction changes are ignored, differences of 2% in total straight line distance are unlikely to be important in bridge operation. Even when obstructions are included the differences in total cost, although larger (approximately 4%), are still not particularly noteworthy. The values of Clutter Factor ($0.006 < C < 0.019$) reflect these generally small differences and should not be regarded as significant indicators of performance differences either.

Nevertheless, the ranking of Clutter Factor in the distance domain was consistent with evaluator ratings from the original analysis for Proposals 1, 2, 3 and the existing bridge. However, Proposal 4 was elevated in the *LOCATE* analysis to the first ranked position. Proposals 1 and 3 have a lesser potential for obstruction to movement in the port mid-bridge area, but this potential is not realised for the data observed during harbour entrances and exits as few links pass through this region. In contrast, for Proposal 4, the CO's movement to the forward window area is less restricted.

While the distance domain provides little basis for choice, the visual and auditory domains are potentially more interesting. Differences in visual cost function values range from 3% to 59% in the *LOCATE* analysis while visual Clutter Factors range from 0.002 to 0.153. Generally, ranking remains stable under substantial (20%) changes in visual strength function parameters, and those configurations which do change rank are separated by small (approximately 3%) differences. For visual monitoring of behaviour, Proposals 4, 2, and the existing bridge would be expected to achieve similar overall performance, although Proposal 2 might be rejected on the grounds of visual clutter. The *LOCATE* analysis of auditory performance leads to relatively clear cut differences in cost function values, and the rankings remain stable under the manipulation of link strength function parameters. Proposal 4 is the preferred option in this domain.

The difference between *LOCATE* and those procedures which reduce the problem to a material flow analogy, is illustrated by the results obtained when the analysis is conducted on the basis of link length only, i.e., both independent of link direction and linearly dependent on link length. The effect is most marked for visual communication as this reflects a complete change from the Ω-domain to the R-domain for the evaluation of link quality. If the two approaches give quite different results the question remains as to which, if either, is correct. As visual monitoring behaviour clearly involves angle dependent components, it can be argued that the simple link length model, which has no such representation, is an inadequate description of this type of behaviour. Therefore the issue hinges on whether the *LOCATE* link strength functions capture the essence of visual monitoring behaviour. It is asserted that this has been achieved to the extent that arcs of good visual monitoring, associated with the normal range of head movement, are separated from arcs of bad visual monitoring, associated with the region which requires whole body movement. The difference for auditory links is less dramatic, representing a modification in the shape of the link strength functions rather than a change of domain. The results reflect the more subtle manipulation, as ranking remains unchanged. If an angle dependent component was introduced, say to favour face-to-face communication, it would be expected that this difference would be accentuated.

Perhaps the main point of departure of the present and the original analyses is the favourable showing of the existing bridge configuration under *LOCATE*. Reasons for this might include:

[1] the greater objectivity of the present analysis;

[2] the existing bridge configuration is well known and its limitations (such as the number of personnel - up to 12 people in addition to the key personnel - which can be present during operations, and the resultant overcrowding) are understood from first-hand operational experience, whereas the updated configurations are largely unknowns and their deficiences may not have been fully demonstrated even if mockups have been built and manned;

[3] the data and/or the model do not adequately represent the nature of the interactions on the bridge or the criteria necessary for judging the options;

[4] harbour entrances and exits are not representative of the range of operational requirements the bridge layout must fulfil (Beach, Walker and Beevis 1985for example,) ; and

[5] judgements on layout have been confounded with attitudes, possibly negative, about the equipment and furniture on the existing bridge.

Possibly all of these factors were acting to some extent and in the absence of absolute performance data the matter is impossible to resolve. However, the objectivity of the process might be expected to play a major role in the outcome, as demonstrated by: link values which showed that an advantage expected for Proposal 1 (i.e., less obstruction to movement in the port mid-bridge area) was not realised for these data; and the existing bridge rates well in the objective analysis of visual and auditory domains.

The original analysis relied on evaluator ratings to estimate the effects of obstructions and did not directly address the issue of crowding and restriction to movement due to the presence of people on the bridge. It is possible that the evaluators considered this issue in making their judgements and, if so, it is likely that first-hand experience would provide a more accurate (and probably critical) assessment of the existing bridge configuration than the alternatives. For the bridge analysis, *LOCATE* modelled obstructions due to hardware and seated operators in the workspace, but did not consider free standing personnel as obstructions to movement. In principal *LOCATE* could consider people as obstructions to any type of link, however, modifications would have to be made to the existing program so that the person(s) engaged in a particular interaction did not become an obstruction(s) to their own communication, that is, only personnel *not* taking part in a particular interaction should be considered as potential obstructions for that particular communication.

Whereas the original analysis considered external vision from the bridge, the *LOCATE* analysis was restricted to visual monitoring behaviour within the confines of the bridge as, in its present implementation, all communications are considered to be point to point. The need to assess arcs of view from positions within the bridge is central to the proper assessment of these configurations, and highlights the necessity for a distributed representation of an information source in any layout evaluation tool intended for this type of problem. For the bridge analysis the distributed source would be the horizon, and obstructions to vision would include elements within the bridge, mullions framing the bridge windows and other ship's structures if necessary. Particular arcs of importance could be treated as separate distributed elements.

Both the original link analysis and *LOCATE* are static representations, hence key personnel were assumed to be located in certain fixed positions. The quality of auditory and visual communication is therefore computed with respect to these positions. This causes little loss of generality if personnel spend large proportions of time at certain fixed positions, but does become a problem if personnel are located at widely separated positions for approximately equal amounts of time (e.g., compare the patterns of the FixO and the 2OOW in Table 2). Conceptually a dynamic analysis would be possible, generated from a series of snap shots such as the present analysis, with the system cost integrated (a weighted sum could be used to cope with varying criticality) over time to produce a final figure of merit. The possible gains of an analysis at this level of detail would have to be weighed against the effort required to produce it. For the present study, gaps in the data base suggest that this amount of effort would be misplaced. For example, a detailed record of position against time would be required for all key personnel as well as the activities they were engaged in, and the information they required, at each of these times. The original analysis contained some, but not all of this information.

LOCATE normally treats misalignment from an absolute orientation as a constraint violation during optimisation. This may not be appropriate when the procedure is used as an assessment tool for established layouts, rather than as a solution generator. The need to consider the absolute orientation of the chart table and radar emphasised the need for a first order (i.e., absolute with respect to an arbitrary datum rather than relative) angular relationship to complement the first order distance relationship already incorporated in *LOCATE*. Although it was possible to simulate such a relationship through the use of dummy elements in the bridge analysis, this would have introduced complications if the optimising features of the process were in operation, as the dummy elements would have to be manipulated in concert with the elements they are attached to.

The amount of information required for a *LOCATE* analysis is determined largely by the level of detail required of the evaluation rather than by the *LOCATE* process itself. If one is concerned with the ability to read a display at a certain distance, hear an auditory warning, see around an obstruction etc., the quantitative information required to support such an evaluation, by any method, is generally the type of information required by *LOCATE*. If the characteristics of interest can be reduced to a distant dependent component and an angle dependent component, at whatever level of detail considered appropriate, then the essential features of link strength functions are available. Although the bridge data were not gathered with this technique in mind, it was possible to obtain sufficient information from the original report to perform an evaluation which captured most of the features of the original analysis and arguably provided a more comprehensive assessment of issues such as visual monitoring and auditory communication.

With additional information the *LOCATE* analysis could be extended to take account of factors, not considered quantitatively by the original analysis, such as the measured variation in speech intelligibility with distance on the bridge, the time to locate and visually identify personnel as a function of observer-subject distance and orientation of observer and subject, time to traverse various distances on the bridge including the effects of acceleration time and the need to turn before setting out. Obviously this will be time consuming, but the very action of gathering information at this level of detail can greatly assist in the understanding of the problem as well as establishing a variety of measures of effectiveness against which the layout can be assessed. Once these data are gathered, the use of a procedure such as *LOCATE* poses little extra overhead.

7. CONCLUSION

The use of *LOCATE* to re-analyse data from the DDH280 bridge study, illustrated the type of information which is necessary to support this process. It was argued that the data required to support a conventional type of analysis, such as the original bridge evaluation, and *LOCATE* are similar. Therefore the possible advantages of using an integrated evaluation process need not be rejected simply on the basis of effort and complexity. Indeed the objectivity of the process, and the integration of several aspects of the evaluation into a single cost function value, may reduce the effort required to conduct such an exercise particularly if a number of potential solutions are to be compared. Once the *LOCATE* data base has been built, evaluation of any workspace geometry is done simply and speedily.

The results of the *LOCATE* process itself appear reasonable in light of the final recommendation from the first study, although a possible point of divergence is to be found in the relative rankings of the existing bridge configuration. It was found that the *LOCATE* analysis of the 5 bridge configurations was reasonably robust with respect to the choice of critical parameters, therefore the results are not highly dependent on a capricious choice of these values. The conclusions drawn from a *LOCATE* analysis are fundamentally different from those which might be drawn from techniques which are based on link length alone as demonstrated by the reduction of the bridge problem to a material flow analogy, through the use of linear link strength functions in all domains. To the extent that link length alone is a poor representation of the ability to communicate, particularly in the visual, auditory, and tactile domains, this is considered to be a reason for rejecting those simple models in favour of *LOCATE*.

Overall *LOCATE* appears to be a useful tool for workspace layout problems although the bridge study pointed to a number of areas where the process could be improved. These include: the modelling of free standing personnel as obstructions to communication; the incorporation of a distributed representation of a source of information; dynamic representations of the workspace; and first order angular relationships to accommodate the absolute orientation of elements into the cost function evaluation.

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// This report describes the application of a computer-aided workspace layout program, called LOCATE, to a complex real world environment involving the evaluation of five ship's bridge configurations. The purpose of the study was to test the performance of the LOCATE procedure against the results of a previous evaluation from the same data base. The results of the LOCATE analysis are compared with the previous analysis, which used a variety of quantitative and qualitative techniques but lacked a structured method for integrating the results. LOCATE provided an assessment of the bridge designs which incorporated most aspects of the original analysis into a single quantitative process. The results of the LOCATE analysis agreed with the outcome of the original analysis so far as the overall recommendation is concerned. The LOCATE procedure can, however, be improved in a number of areas, including: the incorporation of a distributed representation of a source of information; the modelling of free-standing personnel in the workspace as obstructions to communication; dynamic representations of the layout problem; and the incorporation of absolute angular relations into the cost function evaluation. //

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computer-aided design (CAD)
workspace layout
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