IMPROVED DAMAGE SURVEILLANCE INSTALLATIONS FOR IN-SERVICE WARSHIPS

BY

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ABSTRACT

Royal Naval vessels have a well proven but highly evolved damage control organization which is nevertheless vulnerable to communication bottlenecks and the corruption of important information. A modern data communication system is considered as a means of improving the flow and collation of information under damage conditions. This article investigates the feasibility of installing a suitable network based system in surface ships, using the requirements of frigates to illustrate the main options. The article concentrates on matching the problems experienced by the damage control organization to cost-effective design options which can be installed with minimum disruption between refits.

Introduction

The Damage Control (DC) organization, as applied in current warships, was first set up in the early 1980s. It represented a radical improvement over earlier practice and provided the benefits of a centralized command structure, backed up by more extensive communications. This organization has evolved over the years but has stood the test of time and is unlikely to undergo major change in current warships.

The principles behind the organization are, therefore, well proven. However, communication bottlenecks and the problems of compiling a consistent and accurate shipwide picture of the situation make it difficult to provide an efficient response.

A modern, network based data communication system, which will be referred to as a 'damage surveillance' system in this article, has therefore been proposed as a means of supporting the damage control organization of in-service warships. The underlying requirement is for a ruggedised, PC based system with a distributed architecture. The need for software development is to be minimized and every opportunity taken to use commercially available Commercial Off The Shelf (COTS) equipment.

This article discusses the problems experienced by ships' companies and investigates the feasibility and cost-effectiveness of installing a suitable system in frigates or destroyers.

Limitations of the current DC organization

The process of collating information on the state of the ship under damage conditions can be referred to as 'picture compilation'. The process is made difficult by the:

- Stress under which everyone must operate
- Unpredictable nature of events
- Effect of any damage on the voice communication nets.

These factors are unavoidable. In current ships, however, there are additional issues which can be addressed directly by the provision of a damage surveillance system. The picture compilation task for members of the damage control organization, and in particular for the key decision makers, is often made inherently difficult by the following:

(*a*) Initial damage reports have to be made quickly and can seldom address the wider implications of any damage. Ship's staff may know that they have lost a particular system or one of a system's functions but will not necessarily be able to identify the originating failure.
Inevitably, the initial picture is incomplete. The problem is exacerbated by any inaccurate, hasty or contradictory reports, by the need for all reports to compete for time on the overcrowded voice nets and by the inability of Incident Board Operators (IBOs) to keep up with the myriad of reports being made. These problems can be addressed in part by providing outstations with computer terminals where the more important damage reports can be selected on a menu. The local operator has only to make the correct selection and the report is passed immediately, without corruption, to all stations.

(*b*) Even if the collation of information by the IBOs is progressing well, the key decision makers such as the Command Advisor, the Action Nuclear Biological and Chemical Defence Officer (ANBCDO) and the Damage Control Officer (DCO), have great difficulty in collating a picture on which they can base their decisions. They currently have to receive many verbal reports themselves and the ANBDCO, in particular, has to spend part of his time marking up his own Incident Board. They often have to pass on some of the information to others. This represents a significant communications overhead. They need a common, consistent and up-to-date picture presented to them so that they are free to think ahead. They should be free to make their decisions and pass instructions without having to be intimately involved in the picture compilation process. A damage surveillance system directly addresses this requirement.

(*c*) A ship's damage control organization relies on a number of routines by which it regulates and controls its resources during an incident. Closing up reports, for example, ensure that every position has mustered its people and equipment appropriate to the Damage Control State. This and similar processes take several minutes and represent a considerable load on the voice communications nets. Since the reports themselves are specified in advance, few should require voice communications at all. Check-off lists can be provided at each terminal of a damage surveillance system so that mandatory and predictable reports are made locally and are passed immediately to other stations.

(*d*) The limitations of the voice communications fits continue to reduce efficiency in many surface ships. Although this article does not address voice communications directly, the specifications of a damage surveillance system would allow other reports, in addition to those at (*c*) above to be passed more efficiently. Ship's staff have repeatedly asked for an 'e-mail' priority message passing facility, both to catch the attention of all stations and to allow the Command Advisor and other decision makers to communicate directly with stations of their choice.

Requirements of DC personnel

The following paragraphs give a very brief introduction to the nature of the DC task for the main members of the team. Without discussing their detailed tasking or proposing changes to the current organization, it is possible to identify how a damage surveillance system could make major contributions to the level of teamwork, information flow and decision making.

Commanding Officer

The Commanding Officer retains overall responsibility for DC at all times. In practice, he is only concerned directly with DC to the extent that it affects the ship's ability to fight, move or float. He relies on the Weapons Engineer Officer (WEO), the Command Advisor, to brief him on the effects of damage and to pass on the Command priorities to the rest of the organization.

As far as possible, the Commanding Officer wants to be free to concentrate on fighting the ship and the main facility he needs is a single, graphic briefing page which tells him how the damage affects the ship's operational availability.

Command Advisor

The Command Advisor is the WEO and is stationed in the Operations Room (Ops Room) where he has immediate access to the Captain. He has the formidable task of providing carefully filtered briefs to the Captain, agreeing with DC headquarters on how best to prioritise the shipwide response to damage and reconciling the tactical situation with damage to the weapon systems.

He has an assistant and an IBO to help him but the amount of information to be processed can be vast and he has to make key decisions very quickly.

The particular benefits of a damage surveillance system would be an electronic display of the Command and Weapons Stateboards as well as a fully marked up Incident Board. In common with the ANBCDO, DCO and Weapons Section Base Officer (WSBO), he would have an identical shipwide picture on which to base his instructions to his subordinates.

ANBCDO

The Marine Engineer Officer (MEO) is the ANBCDO and is located within the DC headquarters (HQ1) at Action Stations. In overall charge of HQ1, he has the overview of both the DC effort and the machinery control. He is responsible for advising the Command, via the Command Advisor, of all matters which affect the availability and safety of the ship, including stability calculations and the availability of propulsion.

In common with the Command Advisor, the ANBDCO must be given the information and time to make key decisions. His task is often made more difficult because, in some ships, he has no IBO to assist him. Picture compilation is particularly difficult for him and yet he has to direct the DCO and the other members of the team.

His main requirements from damage surveillance system are the Command Stateboard, Incident Board and Stateboards for weapons and propulsion systems.

DCO

The DCO is stationed in HQ1 at Action Stations. He co-ordinates the DC activities shipwide and directs the Fire and Repair Parties, allocating additional support when more resources are needed locally. With the help of his assistant, he oversees the state of his Incident Board and requires, above all, an accurate and complete picture of the fires, floods and damaged equipments throughout the ship.

Although many of his frustrations are caused by poor flow of information, his single greatest need is for a display of the Incident Board which is common to all members of the team. He can then concentrate on directing the DC effort without having to brief other positions on the state of the ship and without having to spend so much time agreeing priorities with the ANBCDO.

Weapons Section Base Officer (WSBO)

The Deputy Weapons Engineer Officer (DWEO) is normally in charge of the Weapon Section Base at Action Stations. He is responsible for the entire weapon repair organization and his team passes information from the weapon system maintainers to the ANBCDO and Command Advisor. He relies partly on accurate and speedy advice from the electrical supervisor in HQ1 to help identify the cause of equipment failure and select the fastest way of reinstating it.

The Weapons Section Base (WSB) currently uses four stateboards:

- WE Manpower Control
- WSB Command Stateboard
- Weapons and Sensors Stateboard
- Incident Board.

To run these, as well as co-ordinating the management of all weapon systems, the WSBO typically has a team of three to help him. With these facilities displayed and updated electronically, the WSB could operate much more efficiently.

Main facilities

The above comments address the main requirements of the core DC team. Incident Board information is also needed by the:

- Fire and Repair Party Posts
- Mobile Repair Parties
- Containment Party (which co-ordinates measures to prevent the spread of damage at Emergency Stations).

Casualty summaries are produced at the Medical HQ and have to be passed to the Command via the DCO.

Detailed investigations have consistently led to a recommendation for a system which improves teamwork by presenting a complete and consistent picture shipwide and which allows immediate access to all. Possible system architectures are at (FIGS 1, 2 and 3).

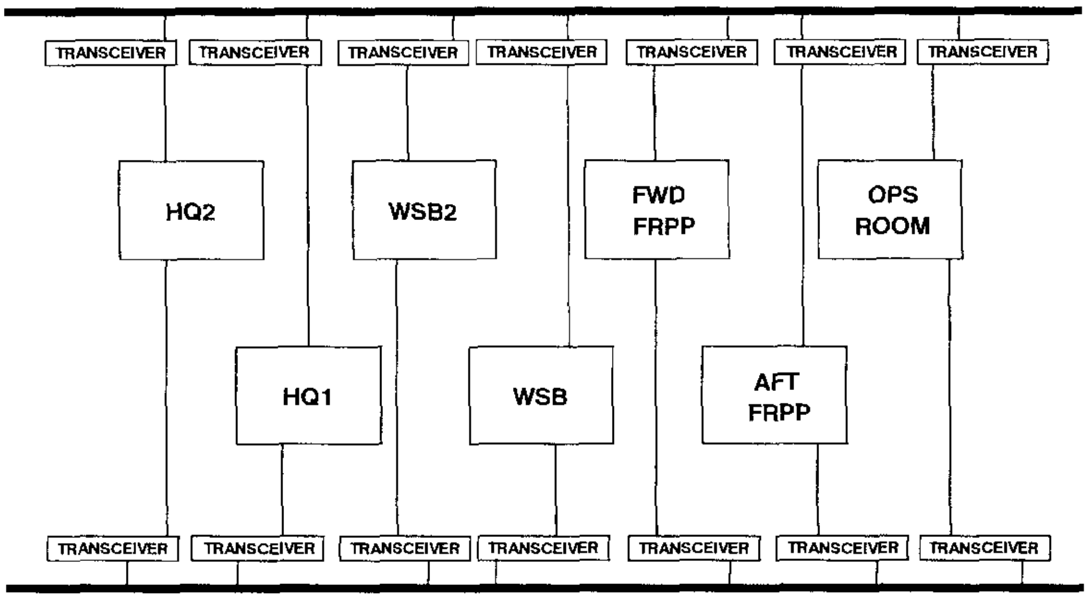


FIG. 1—DUAL REDUNDANT COPPER ETHERNET DATABUS

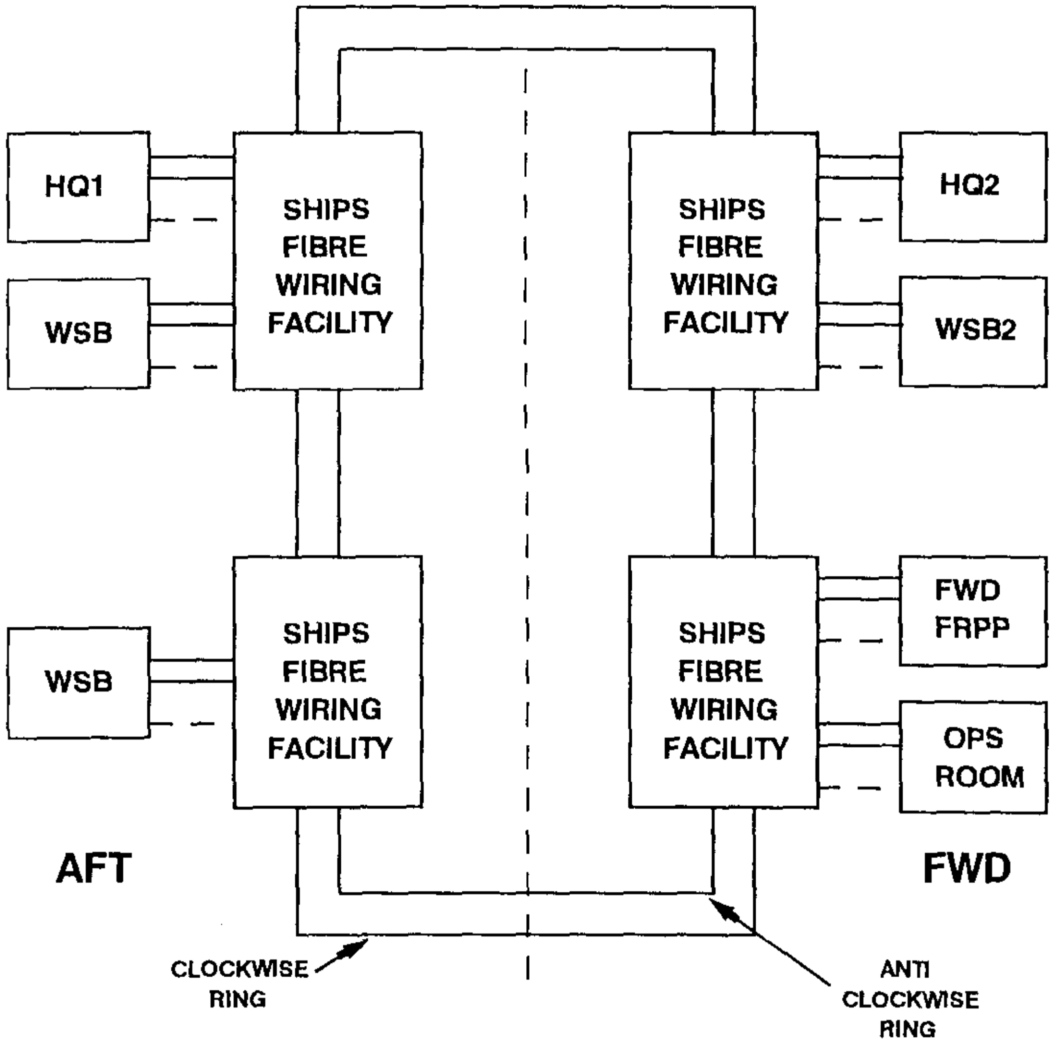


FIG. 2—FDDI COUNTER ROTATING RING

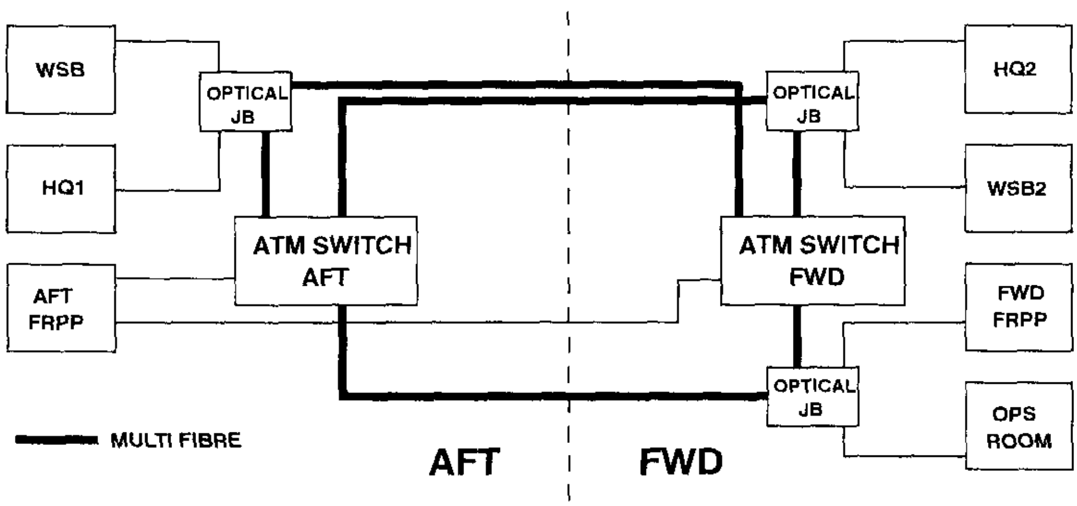


FIG. 3—DUAL REDUNDANT ATM NETWORK

A number of facilities are considered fundamental and are listed below. These are considered the minimum realistic requirement to support the procurement of a suitable damage surveillance system for a frigate or destroyer:

(*a*) *Command Stateboard*

The Command Stateboard includes the command aims, current threats and command priorities, as well as status summaries of weapon and propulsion systems. This stateboard is the most fundamental tool by which the key decision makers have a working summary of the state of the ship and by which they can decide what needs to be done.

(*b*) *Command Briefing Page.*

This page presents the simplest possible summary of the damage control picture to the Captain who, in general, wants to be able to concentrate on fighting the ship. Some Captains prefer to rely on talking directly to their Advisor, the WEO, but this page nevertheless provides the latest summary for him to consider when he sees fit.

(*c*) *Incident Board.*

Based on a plan view of the ship, this is the tool which presents the level of damage in each compartment and helps the DCO, in particular, to assess where to direct the damage control and firefighting teams.

(*d*) *Weapons and Sensors Stateboard.*

A summary of weapon systems used extensively by all key decision makers.

(*e*) *Propulsion Systems Stateboard.*

The summary of the main propulsion and steering systems. The Command is mainly interested in the shaft revs available and the ability to manoeuvre.

(*f*) *Casualty Board.*

The ability to monitor the number and location of casualties is more important than training scenarios often imply. During a real incident in peacetime, casualties are likely to become the Command's top priority.

(*g*) *Check-off Lists.*

Preparations for Action Stations, Emergency Stations and other states of readiness require multiple checks to be carried out and recorded. Electronic check-off lists can avoid queues for verbal reports and reduce the workload on operators who have to collate them.

The foregoing facilities require both static graphics, which have to be configured for individual ships, and active graphics for facilities such as the marking of compartments with damage control symbols. The processing power required for these facilities is not excessive. Several manufacturers provide tools based on rapid prototyping techniques, which can support fast and flexible reconfiguration of these graphics.

A number of additional facilities have been considered which, although not essential for the primary damage control task, would provide significant benefits. They have not been included in the minimum requirement because they imply either technical risk, unjustified cost growth or specialist support for individuals. Examples are:

(*a*) *Stability Curves.*

The MEO, as the ANBCDO, currently relies on curves in the *Class Book* to estimate the effect of flooding and to identify appropriate countermeasures. The process is manual, complex and inaccurate. Several MEOs have asked for an operator aid to assist them.

(*b*) *System Summaries.*

The state and capacity of chilled water, ventilation and high pressure salt water systems are particularly relevant to the damage control effort. Schematic summary pages could be provided so that all positions could monitor them. This would be of particular benefit to the DCO and Fire and Repair Party Posts.

(*c*) *Electrical Failure Diagnosis.*

Initial damage reports often fail to identify the originating failure which may, for example, be the loss of a power supply rather than the equipment itself. Much of this diagnosis is done manually in HQ1 by the Damage Control Officer (Electrical), DCO(L), who has to both collate and analyse a variety of reports from around the ship. At the other extreme, a fully automatic diagnostic aid would require extensive sensors and an 'expert' system to analyse the data. With manual inputs and a limited budget, there is limited scope to ease this particular burden.

Workstation requirements

In the context of this paper, a 'workstation' incorporates one or two VDUs, a QWERTY keyboard, trackerball and a processor unit. The number and location of workstations has been generated by analysing the tasks each member of the team has to perform and allowing for the particular problems or constraints they have to deal with. This approach helps identify a system which supports the current organization and which is consistent with current manning levels. It also makes it easier to preserve the current manual arrangements as a viable fallback mode, should the damage surveillance system be put out of action.

The total number of VDUs required, including five in HQ1 and three in the Ops Room, comes to about 22, depending on the class of ship. About 14 of these are currently assessed as 'essential'. Less expensive solutions are being considered and the absolute minimum number of VDUs which can provide a core contribution to the picture compilation task is assessed as six. This minimum solution covers two VDUs at HQ1 and a single VDU in the Ops Room, the WSB and Fire and Repair Party Posts (FRPPs).

A consistent aim throughout this analysis has been to support the key managers in their decision-making tasks without imposing on them the unwelcome burdens of having to operate a workstation. The system has been configured to allow the managers to read the information they want from their allocated VDU, whilst leaving any data input tasks to a subordinate. This subordinate, typically the IBO or equivalent, is therefore the 'workstation operator'. There is then no danger of the manager becoming too absorbed in driving his workstation and failing to interact with the personnel around him. It is accepted that if the manager wishes to put information into the system, he must direct his workstation operator to do it for him.

Data input

Commonality with the PC office environment has been strongly supported by Flag Officer Sea Training (FOST) staff and other personnel interviewed. Most ship's staff now have a working knowledge of personal computers and feel confident with windows-based environments. For a damage surveillance system which may have to be operated by any member of the ship's company, at short notice and under extreme duress, the benefits of relying on office practice, wherever possible, are considerable. Training requirements should be correspondingly reduced.

QWERTY keyboards are, therefore, preferred to touchscreens. Over recent years, touchscreens have continued to prove unpopular in the naval environment and have a reputation for poor reliability. They do not work well when operators are wearing anti-flash gloves, have dirty hands or when more than one person has to read the same screen.

The authentication of data is a recurring issue but the conclusions drawn by this study are emphatic in their endorsement of an approach which allows immediate access to the system for all personnel. Any constraints on access, such as passwords, may cause unwelcome delays in their own right but may also make it extremely difficult to continue operating the system when the authorised and experienced users become casualties. It is recommended that the system be configured for immediate access by all and that the basic facilities provided be 'user friendly' for anyone with any experience of personal computers.

The danger of allowing immediate access to all is that any incorrect data entry will immediately be communicated to other positions and could lead to the wrong actions being taken. The recommended approach is to rely on the validation checks common in the WINDOWS environment. Specified entries can be made to trigger validation checks:

'You have entered..........

Are you sure you want to..............'.

Given the discipline and level of training of ships' companies it is realistic to assume that the system could be operated without abuse. It is also feasible to have the system log the location and time of each data entry so that operators can contact the originator if they believe further checks or more information are required.

Large panel displays

With emerging display technology, it is now viable to provide large panel electronic or projected displays which can be read by several people at a much greater range than has been possible with standard VDUs. The possibilities of this approach are being explored *inter alia* by the Damage Control Information Displays (DaCoiDS) programme in support of the developing National Equipment Specification (NES) 624.[1]

The purpose of considering a large panel display is to 'support co-operative working between members of the NBCD organization', notably in HQ1. It is clearly attractive to provide every member of the team with a single, central display of the Command Stateboard or Incident Board. The state of the ship and the Command priorities are then immediately apparent to all.

For most frigates, however, the severe space constraints mean that a large panel display could not be fitted in suitable locations without major modifications. The DCO's position in HQ1 usually represents both the most attractive and the most difficult location to fit one. If a damage surveillance system is to be fitted to current vessels in the near future, the cost and installation implications make it difficult to argue that such panels can be justified.

Reliability and survivability

Operators will only learn to value the system if they believe it will be available to assist them as long as they themselves are still capable of acting to save the ship. The system will have failed to achieve this if the operators ever feel the need to keep chinagraph records to back up the data displayed.

Irrespective of the system design chosen, the following issues must be addressed:

(*a*) *Ruggedised Hardware.*

The processors and displays must be robust enough to withstand not only the general shipboard environment, but also the additional abuse in areas such as the FRPPs, where ship's staff have to move heavy equipment around in cramped conditions.

(*b*) *Redundant Data Highway.*

Installation and space constraints in current warships limit the level of survivability which can be achieved, but a level of redundancy is essential. In general, dual redundancy of data highways is considered the most cost effective approach.

(*c*) *Intelligent Workstations.*

Damage to the surveillance system itself must be allowed for. If the data highways fail, it is essential that each workstation maintains its own database for local operation and alerts the operator that data communications have been broken. On restoration of the highway, all databases must be updated.

(*d*) *Uninterruptable Power Supply (UPS).*

It is essential that the system operates throughout prolonged breaks in the power supply. UPS is available to meet a range of requirements, but the specification of a longer back-up time carries a direct size, weight and cost penalty. Individual workstations are expected to operate independently if necessary and, therefore, require their own UPS, but many of the workstations on the market already include sufficient battery power to last several hours.

(*e*) *Displays.*

VDUs must be flat screen to meet the space constraints. Military standard liquid crystal displays are available and are the recommended choice for the 16 to 20 inch range. Plasma panels are preferred for large screens.

(*f*) *Accuracy of Display Layouts.*

If operators are to rely on electronic Stateboards and Incident Boards, they must display the correct information. This may sound obvious, but every ship is different. The ability to upgrade configuration control problems requires close consideration. If the equipment list is wrong, the chinagraphs will appear immediately.

Technical options

At the time of writing, there are a range of technical solutions being assessed for this application. These include:

- Copper and fibre optic based ethernet,
- The Fibre Distributed Data Interface (FDDI)
- Asynchronous Transfer Mode (ATM).

Without identifying individual design solutions, it is possible to make some brief comments on how each approach relates to this particular requirement.

Copper versus fibre optic

The rapid advances in fibre optic technology allow a wide range of highly adaptable and rugged system architectures to be chosen. With higher bandwidths, a variety of high speed message handling protocols and freedom from electromagnetic interference, the fibre optic solution is undoubtedly the most capable and offers a much greater potential for future expansion. One specific limitation of a copper ethernet is that it cannot reconfigure automatically when a data highway is broken. A fibre optic ethernet or a dual redundant FDDI ring effectively provide interconnected highways which can reroute data to allow for a break in one or both highways.

Copper based ethernet nevertheless offers the cheapest solution and is currently backed by greater industrial experience and a much wider range of well proven products to choose from. The performance of ethernet is more than enough for this application, but may not satisfy the upgrade requirements in future years. In particular, fibre optics are preferred if it is a requirement to provide voice and CCTV channels within the system.

Ethernet, FDDI or ATM?

Suitable topologies for ethernet, FDDI and ATM are shown at FIGS 1, 2 and 3. Variations on these topologies are possible but these examples illustrate that, for a system of this size, it can be difficult to exploit the inherent flexibility of multiple data paths associated with ATM in particular. (FIG. 4) shows an ATM solution with a much higher level of redundancy, but at the added cost of two additional ATM switches.

The benefits of FDDI and ATM topologies come into their own when large amounts of data pass between multiple users over large distances. For a relatively small surveillance system in a ship the size of a frigate, the data handling requirements may not justify several routing devices. A single ATM switch, for example, would easily handle all the system data but is unacceptable on survivability grounds. The four switches at FIG. 4 offer an impressive choice of data paths but these switches are cost drivers and such a solution is unlikely to be considered cost-effective.

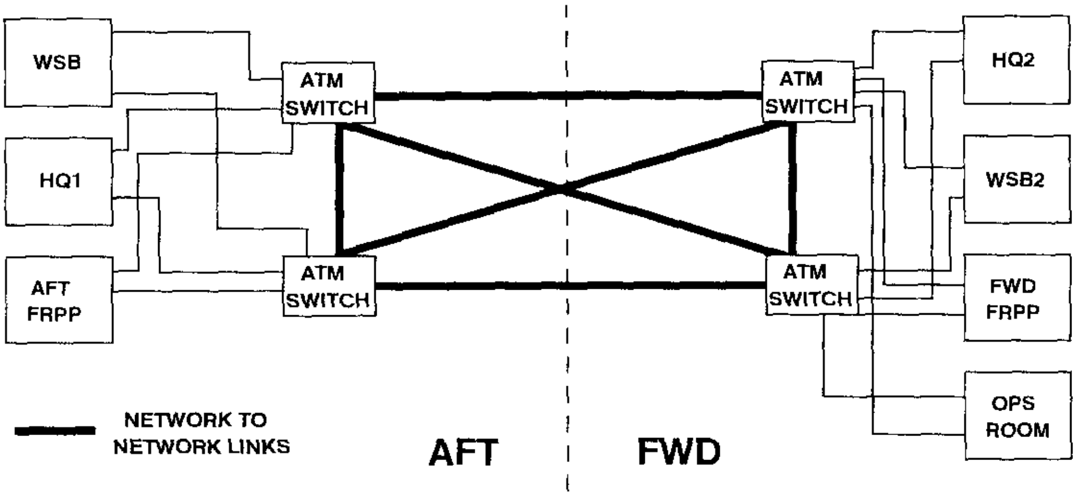


FIG. 4—MULTI REDUNDANT ATM NETWORK

Similar limitations apply to the cabling routes. Dual redundancy is a feature of all the systems proposed, but there is a limit to the separation that can be achieved between each path without the major expense of installing special cable routes.

The choice of system configuration is not, therefore, considered the overriding factor. If the priority is to keep costs to a minimum and get a system to sea in the shortest possible time, copper based ethernet is a realistic choice. Fibre optic ethernet has increased bandwidth and greater survivability, but at additional cost. FDDI is proven technology offering further improvements in performance, but suffers from industry's reluctance to adopt it as the preferred 'backbone' solution. ATM is widely recognized as the approach of the future and offers an unassailable potential for growth. However, it is not yet subject to an international standard and whatever cost penalty may be carried by a particular design solution must be justified against specific requirements.

This work continues to investigate the technical options, but there is no doubt that the data handling and display performance of modern systems offer a wide range of viable solutions with ever increasing value for money.

Installation

Aims

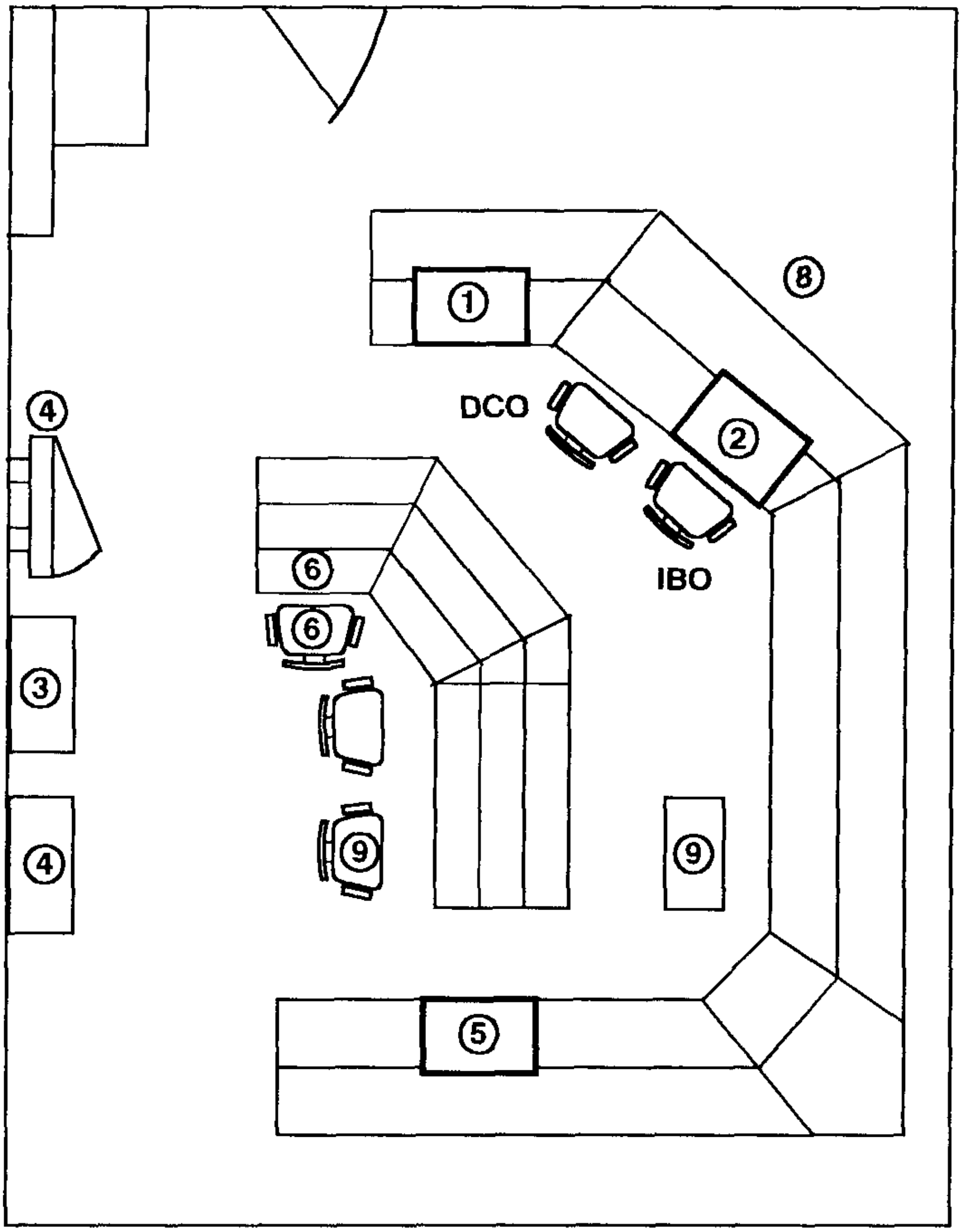
Priority has been given to identifying systems which can be fitted between refits. Workstations should be installed without disruption to existing equipments and without mandating ship's staff to change their operating position at Action or Emergency Stations. Cabling routes are being proposed which use existing cable runs wherever possible, whilst maximizing separation and survivability. Where workstations have to be sited in passageways, a balance has to be struck between ensuring clear access for personnel and avoiding costly resiting of minor equipment.

Constraints

The locations for workstations fall into three categories. The easiest positions to site them are compartments, such as the WSB, which are already fitted out with office space. The second category covers areas such as the FRPPs, which require bulkhead space where two or three personnel can read the screen without having to fight for room amongst other activities. The final category, and the single most challenging location, is where key damage control personnel must operate at a modern, integrated console as represented at (FIG. 5). The ANBCDO, in this example, stands at the back and can use the same bulkhead space as he does at present for his manual stateboards but the DCO and DCO(L) positions are more difficult. They work at the main console and their VDUs and keyboards can only be sited on the console itself. Fortunately, there are usually areas of clear desk space at these positions and it may be feasible to mount them without having to re-engineer the consoles themselves.

This discussion assumes that workstations have to be permanently mounted, but it is possible to provide removable workstations and additional connection ports around the ship. It becomes possible to resite the equipment when the preferred operating position has to be abandoned. Options for this approach are being considered.

In general, the routing of data highways and the siting of network servers or switches have yet to raise any problems of note. Given the number of existing cable runs and the limited scope for separating dual cable runs which connect common workstations, an acceptable balance between survivability and cost can be achieved.



1. DCO's POSITION
2. DCO's POSITION
3. ANBCDO's POSITION
4. ANBCDO's POSITION
5. DCO (L)
6. NBCPOA's POSITION
7. MANUAL INCIDENT BOARD
8. "GINGE KERR" ALARM PANEL
9. WATCHKEEPING POSITIONS

FIG. 5—TYPICAL HQ1

Conclusions

The major problem experienced by the DC organization in frigates and destroyers is compiling a consistent, accurate and rapidly updated picture of the state of the ship. The key members of the organization are spending valuable time collating poor quality information at the expense of their primary, decision making role.

Without having to change the present damage control organization or fit additional voice communication nets, an electronic damage surveillance system can be specified to provide a rapidly updated and accurate picture through the ship. The necessary display pages, which are mainly Stateboards and the Incident Board, can be provided without costly software development.

Many network solutions are feasible. Copper based ethernet remains the cheapest and most widely used protocol and offers the performance to meet the system specification in the short term. Fibre optic ethernet, FDDI and ATM offer much increased bandwidths, superior upgrade capability and improved survivability.

The constraints of fitting a relatively small system in existing ships mean that the greater redundancy offered by multi-path fibre optics cannot be fully exploited.

The main benefit of the work so far is increased confidence that the problems being experienced at sea can be addressed directly by a damage surveillance system. A wide range of suitable equipment is available commercially and there are cost-effective solutions which can be installed outside refit. This work continues to progress towards specific design options for each class of ship.

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Reference

1. 'Requirements for the Design of a User Interface to Electronic Damage Control Information Displays', *NES 624, Issue 1 (January 1995).*

Bibliography

1. 'A task analysis of the NBCD organization on surface ships and submarines', Smith Report, TR-93/219/1.0 (September 1993).
2. 'A report on the implications for NBCD roles and organizational structure resulting from the introduction of a damage control information display system', Smith Report TR-93/385/0.1 (November 1993).
3. 'Recommendations for DaColDS large electronic display', Smith Report, TR-94/253/1.0 (April 1994).
4. 'Requirements definition for an electronic damage control communications link for RN frigates', BMT DSL Report, 34439/R2841 (March 1996).
5. 'Requirements for the Application of Fibre Optics in Ships and Submarines', *NES 1009.*