MCR OR BRIDGE CONTROL

PROMISE, PROBLEMS, GUIDELINES AND THE WAY AHEAD

BY

LIEUTENANT-COMMANDER K. A. HEEMSKERK, C.D., M.SC.
C.ENG., M.I.MAR.E., M.C.I.MAR.E., C.A.F.
(*Sea Systems Controllerate*)

Abstract

Modern microprocessor systems and display technology make it entirely feasible to place on the Bridge machinery control functions previously found solely in the Machinery Control Room (MCR) or performed manually. The question today is not whether a function can be automated, but whether it should be, due to various operational and human factors issues. Flexibility of operation and total system (ship) safety is not necessarily enhanced by allocating control functions to the bridge rather than to MCR operators. There are few guidelines available to the system designer. This article presents a number of problem areas worthy of debate, and some guidelines. Further work is necessary in order to develop guidelines for deciding the optimum location of future machinery control consoles.

The aim of the article is to identify some of the managerial and technical issues involved if the Royal Navy adopts bridge control of the propulsion machinery. The extent of this control would encompass propulsion machinery start, stop and operating functions, and include any ancillary or auxiliary systems necessary to accomplish this (lubrication and cooling systems are typical examples). Safety auxiliaries such as fire pumps or HP Sea Water systems are also potential candidates. The article identifies the forces driving the R.N. towards change and attempts to highlight potential trade-offs. Many questions are posed and still need to be addressed. A first attempt is made to provide guidelines around which a Bridge Machinery Control Position might be designed.

Introduction

In machinery control and surveillance system design, two fundamental assumptions are usually made concerning the roles of 'the man' and 'the machine'.

(*a*) The man is not as efficient as a machine at the routine monitoring task and is more likely to miss critical signals as well as make occasional 'human' errors. He is less likely to respond immediately to small errors, and is therefore less precise. Nevertheless, he is not 'rule-driven' so there is less likelihood of a false alarm.

(*b*) Automatic devices will provide for the real-time control of ships' machinery thus freeing the human operator to perform the role of decision maker, allowing him to keep watch only for system irregularities and failures and take over when necessary. This recognizes that a man has remarkable flexibility as a supervisor and standby controller in case of unforeseen events. Whilst a computer can reduce the incidence of human error, full elimination is not possible.

Two further assumptions are made: firstly, the bridge console will need to be as simple as possible and thus require automation of many of the functions presently done by the machinery specialists in the MCR; secondly, the 'machinery expert' will not be located on the bridge. This leads to the conclusion that the transfer of machinery controls to the bridge would require far more complex automation to ensure machinery safety. This automation could not only make the bridge reliance on the control system more complete but could also lull the marine engineers (MEs) into complacency, which might lead to serious problems should the automated system fail, thus eliminating many of the (supposed) advantages accrued due to automation.

Having a warship MCR unmanned in State 3 (as it typically is in a commercial ship) is neither unthinkable nor technologically unfeasible. The question is whether it would be 'financially', 'politically' or 'operationally' acceptable. The size, function, selection, training and motivation of a ship's crew (especially the ME department) could be considerably changed should the MCR be unmanned and the bridge take over most of the control functions for the fitted machinery.

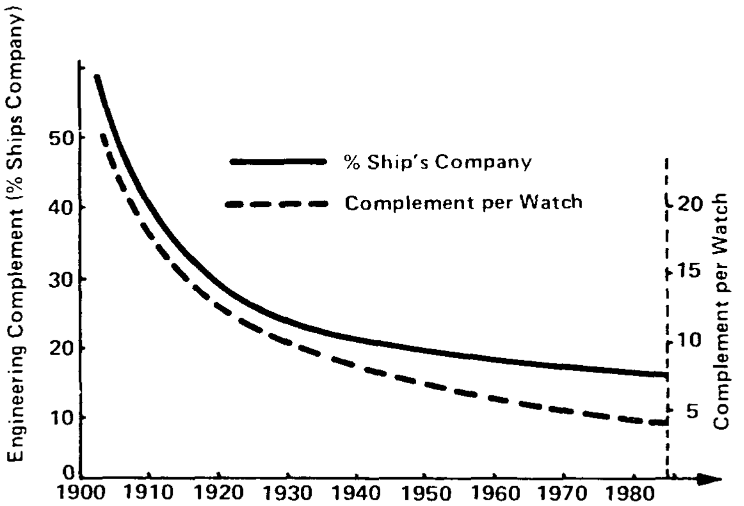

FIG. 1—MARINE ENGINEERING COMPLEMENT OF FRIGATES AND DESTROYERS

The shift towards increased automation is by no means new to the ME Branch. A major change in the late 1950s was the adoption of a Machinery Control Room (MCR). The heated discussions between the two factions—one group advocating the many tangible advantages of having men 'on the plates', the other the value of the MCR in information gathering and decision making, resulted in a significant upheaval in the way marine engineering was accomplished in warships. The concept of changing to full bridge control is no less traumatic, but is not without precedent. Indeed, many ships already have limited control facilities on the bridge. As shown in FIG. 1, the drive to reduce manning continues. Senior ME watchkeepers tend to be expensive. Any area of potential saving should be investigated. Bridge control appears to be one such area.

Scope

This article is concerned with the shifting of the MCR propulsion functions to the bridge. Comparisons have been made with the commerical sector where this shift of control function has largely taken place. While it is recognized that commercial ships are not warships, there is, nevertheless, a significant equivalence in role of the ME department when in State 3. Higher states of readiness of course do not exist in commercial ships.

It is critically important that command has the best information available concerning the propulsion plant. This article could just as easily address the shift of the MCR propulsion control functions to the operations room, rather than the bridge. Unfortunately in the absence of data this could mean that any conclusions reached would be unverifiable—an ideal situation if the Navy intends to maintain the *status quo*, but certainly not ideal if full use of available technology is envisaged.

It was therefore deliberately decided to limit this article to considering only the shift of propulsion control to the bridge, recognizing that there is a wealth of experience in the commercial sector that one can draw upon to reach a sensible conclusion. The details of where the control function should rest, if not in the MCR, should not be an issue here; regardless of where the controls are moved to, one would likely be dealing with issues similar to those raised in the rest of this paper.

Driving Forces

What are the driving forces behind this shift of MCR functions to the bridge? Three factors have been identified: technology, safety, and economics.

Technology

The explosive growth of microprocessor technology, the rapid improvement in its performance, and the decrease in size, cost and power consumption of the various electronic devices make single man bridge control of MCR propulsion functions a cost-effective alternative to the traditional manpower-intensive method of operation. A distributed digital control system with full self-diagnosis, automatic self-reconfiguration, cheap duplication (for reliability/survivability reasons), high speed and accuracy, all at a reasonable cost makes the shift to bridge control entirely feasible. One should note, however, that this technology is not a goal (as the next two factors are) but a facilitating factor.

Safety

A Bridge Watchkeeper (BW) with full control of critical machinery (including 'safety' auxiliaries such as fire pumps) and their various modes of operation may be able to reduce the time lag between say, loss of propulsive power and correcting action. The possibility exists with bridge control to marry two aspects of safety to a single location; namely, ship and machinery safety. Manpower below decks in dangerous waters could be minimized. Thus personnel safety may also be enhanced with bridge control. Indeed, in small coastal minesweepers this is already the case.

Economy

Bridge automation will probably reduce direct labour costs by reducing the watchkeeping requirement (particularly of the MEs). However, due to the (likely) additional complexity of the automation equipment there may be additional maintenance costs. It appears that direct bridge control should be a very good investment considering the possibility of manpower savings. This is of course one reason for bridge control in the commercial sector.

Another important economy could be the utilization of the MEs, once freed from the MCR, in more maintenance tasks at sea. This could result in increased ship availability, up-to-date maintenance and consequently economical operation.

Discussion of Problems

Five general problem areas are now examined. As with any complex issue, the boundaries cannot be well defined. Further, the problem areas do not only deal specifically with placing a machinery operating facility on the bridge, but also at times with the question of remote controls versus manual controls.

Automation

When control tasks are highly automated, as it is assumed they will need to be if the bridge is in direct control of the machinery plant, the BW's role becomes one of machinery monitor and supervisor. The primary issue revolves around his ability to perform this additional major function, noting that the control task is almost always accomplished satisfactorily by the automatic system. Questions which arise are:

(*a*) Under what conditions will the BW acting as monitor be a worse or better failure detector than the ME expert in the MCR?

(*b*) How significant is the 'warm-up' delay when a man changes from passive monitor to active controller? Does automation lull the BWs (and MEs) into a state of low alertness? Will the BWs be easily distracted from the monitoring task by other important events? How will they be trained to sort priorities between ship, personnel or machinery safety in an emergency?

(*c*) What should be the form of the interaction between the operator and the control system? If the control system can change the machinery plant configuration, say, should it make the change automatically and inform the operator, or make the change only after operator acknowledgement? Should the system indicate why it is making the change, or not? With an unmanned MCR, how can the ME department be kept current on the status of the plant?

(*d*) What is the impact of different levels of equipment reliability on the operator's ability to detect, diagnose and treat malfunctions? For example, if the equipment is very unreliable, then the operator will be expecting malfunctions and will be adept at handling them. If the equipment is very reliable, then there is little need for failure detection and diagnosis on the part of the operator. An intermediate level of reliability however, may be insidious since it will induce an impression of high relaibility and the operator might not be able to handle the failure when it occurs.

Training and On-Board Drills

Automation implies reduced routine manual operation of equipment. Without a step increase in training, the use of bridge automation is likely to result in a decrease in the skill level for well-learned manual tasks within the ME department. It is difficult enough now to get time in the programme for drills. How much more difficult will this be if the control position is no longer in ME hands? Of practical importance is the rate at which these operating skills deteriorate and the countermeasures needed to prevent unacceptable skill loss. The major unanswered questions regarding this initial acquisition, re-acquisition and retention of skills include:

(*a*) How quickly do manual skills deteriorate with lack of use? What factors influence the rate of loss? Do these skills need to be retained at all?

(*b*) Can periodic drills prevent the deterioration of skill? If so, how often are they required? What is the optimum?

(*c*) Are there alternatives for practice with the actual system, for example part-task simulators or on-board trainers? How significant is this increased cost? Can the MCR be used as a training centre when in bridge control?

(*d*) What quality control techniques will be necessary to ensure maintenance of operating skills? More FOST input?

(*e*) Is graceful degradation desirable, where the control system very slowly degrades in performance without the operator being aware of the change, or if made aware, is not fully able to understand the increased danger due to the (often imperceptible) loss of system performance? Will the necessity of learning to operate the bridge console(s) (perhaps a complex problem in itself), require increased training costs for the BWs, and hence offset the cost advantages of using a 'less expensive' man to do part of the ME task.

Monitoring of Complex Systems

There are many situations that require interpretation using multiple sources of information. The major issue is assessing the BWs capability to take on the additional load of machinery control given their already heavy responsibilities.

(*a*) Does monitoring performance degrade with time on watch? If so, will the control of machinery suffer?

(*b*) What are the means for maintaining alertness? Will artificial signals and alerts (i.e. false alarms/drills) improve or degrade monitoring effectiveness? Will the additional work-load of drills, in addition to complex monitoring, improve or degrade performance?

(*c*) An automatic bridge machinery control system should be sufficiently interpretable to enable the BW (a non-engineer) to detect and diagnose machinery degradation not severe enough to be considered a malfunction. How can this be done? Will there be a need for computer aids to make diagnosis effective?

Alarms and Warnings

Human behaviour with alarm warning systems is a demanding topic in man-machine design. It is long been recognized that people will ignore an alarm if experience has shown that the alarm may be false.

(*a*) What are the characteristics of an ideal (but attainable) alarm and warning system?

(*b*) What attributes make a false alarm rate unacceptably high? Is there a difference if the operators have varied backgrounds? Can one over-train?

(*c*) Why do alarms apparently go unheeded, especially when there are many of them at once?

(*d*) Under what conditions do operators rely on alerting and warning systems as primary devices rather than as back-up devices? Is this operationally sound? Will it be different for the BW when compared to the MCR operator? Do the 'alarms' needed on the bridge differ from the traditional ones in the MCR? If the MCR is unmanned, will the method of presentation of alarms in the MCR need to be changed?

(*e*) Under what conditions will bridge operators be able to check the validity of an alarm? Will an 'expert system' be needed?

(*f*) Technology exists to develop alerting and warning systems that are intelligent, which can prevent 'obvious' false alarms, and assign priorities to alarms. The logic for these systems can be very complex and thus possibly lead to the BW's total reliance on the automatic system. Will the priorities (which decide whether an operator or the automatic system takes action) always be appropriate? If not, will the operators recognize this? Which operators (BWs or MEs) will be able to change these priorities? Who will be available with the expertise to carry out any corrective actions required?

Social Aspects of Automation

The social aspects of automation may prove to be the most difficult of all because they influence the basic attitudes of the operator towards his task; his motivation, adaptability and responsiveness. The effect bridge automation will have on the role of the (few) remaining highly skilled (and expensive) MEs and for that matter, on the responsibilities of the BWs, is expected to be significant. Questions to be addressed include:

(*a*) How will bridge automation affect job satisfaction, prestige and self esteem?

(*b*) What does increased bridge control imply for traditional MCR operators? Are there clearly defined aptitudes or personality attributes which impart better monitoring (or manual) effectiveness? Should the ME be moved to the bridge? How will the bridge procedures need to be changed to accommodate machinery control?

(*c*) How should training programmes be altered to deal with the possible social effects? Is there an effect on the recruiting of personnel?

TABLE I shows some of the possible advantages of shifting from MCR to bridge control. Much work needs to be done not only to quantify the

TABLE I—*Bridge versus MCR control*

Possible Advantages of Bridge Control	*Possible Disadvantages of Bridge Control*	*Unknowns*	
Increased capacity and productivity of MEs Reduction of manual workload and fatigue Relief from routine MCR operations Relief from small (human) errors (automated out) More precise handling of routine manoeuvring (reduced time lag) Economical utilization of machinery (for example, more on-board maintenance at sea due to change of ME responsibilities)	Seen as dehumanizing; lower ME job satisfaction; naval resistance Lower proficiency of MEs in case of need for manual takeover Over-reliance on control system: complacency; willingness to uncritically accept machinery degradation More false alarms Automation-induced failures	Overall workload: reduced or increased? Total operational cost: increased or decreased? Training requirements: increased or decreased? ME's task: dramatically changed for the better or worse? Crew size: increased or decreased? Implications for liability (for example, software error resulting in an accident; OOW or Engineer?)	Capital acquisition costs: higher or lower? Maintenance costs: higher or lower? Extent of redundancy necessary and required Long-range safety and operational implications Long-range effect on BWs and MEs (including physical and mental health, job satisfaction, self-esteem, attractiveness of job to others entering field)

advantages but also present the findings in a clear concise manner which will allow objective decisions concerning bridge control options to be made by ship design project managers.

Outline Bridge Automation Guidelines

Some guidelines are presented for designing and using (or not using) bridge machinery control systems. They are not specifications, since conditions exist where they may not be appropriate. Nevertheless they are meant to serve as an indication that thought has gone into this problem already, and future work will be aimed not at fundamental research but application work to solve the specific problems experienced in a naval environment.

Control Tasks

The shift of control responsibility to another group of operators should take into account the following:

(*a*) The machinery system operation should be made easily interpretable or understandable by the new operators to facilitate both the detection of improper operation and a high level of diagnosis of malfunctions.

(*b*) The bridge system must be able to perform the task which the Officer of the Watch (OOW) requires (consistent with other constraints, such as safety). This may require user control of certain parameters, such as trip over-rides. Many users of civilian bridge systems find that the control systems do not perform their functions in the manner desired by the OOW. For example, autopilots may have too much rudder action (especially if there is insufficient weather compensation), or the propulsion system controller may allow too much machinery plant surging, which will not please either ME or the OOW. As a result, often these automatic systems are not used. Since the ship is complemented for bridge control, this may result in overloading the MEs.

(*c*) It is important to design the man-machine interface (and degree of automation) to prevent peak levels of task demand from becoming excessive (this may vary from operator to operator). System monitoring is not only a legitimate, but also a necessary activity of the BW; however, it generally takes second priority to other, event-driven tasks. He is more likely to be event-driven by non-machinery incidents than the MCR operator. Keeping task demands at reasonable levels will ensure available time for monitoring. Alternately, automation of monitoring may also provide some relief.

(*d*) The workload of the bridge must be analysed in detail to ensure that the additional task of machinery control is not too high. The BW must be trained and motivated to use automation as an additional resource. The design must not tempt the bridge to revert to MCR control routinely. This implies that the system must be easy to start up, easy to implement and provide distinct operating advantages for both the bridge *and* MCR.

(*e*) The desire and need for automation varies between operators and, with time, for any one operator. Different operator 'styles' (choices of automation options) should be allowed for if feasible. If choice is allowed, the design must ensure that overall system performance will be insensitive to different automation options, or styles of operation. For example, the OOW may choose to have the auto-pilot steer the ship on pre-selected headings, but maintain manual control of the ship's speed. Conversely he may decide to steer the ship manually but use navigation aids to provide ship position information and automatically make changes in propulsion speeds to ensure the ship remains on time and on track. It must be easy to change from one mode to the other, or combine modes when required.

(*f*) There must be a means for the BW to confirm status of the ship's machinery (i.e. confirmation that pre-sailing ME checks are completed prior to allowing bridge control). Many failures have been, and will continue to be, due to set-up error rather than hardware failures. The control and surveillance system itself can check some of the set-up, but independent error-checking equipment should be provided when appropriate. This is particularly valid for ensuring protection of prime movers (e.g. by use of interlocks).

(*g*) Extensive training is required for both the bridge and the MCR operators when working with automated control equipment, not only to ensure proper operation, but to impart a knowledge of correct breakdown drills and diagnostic procedures. To ensure ship safety during these evolutions, it is necessary that the changes between control modes be quick, easy and unambiguous.

Monitoring Tasks

(*a*) Both bridge and MCR operators must be trained, motivated and evaluated to ensure the machinery monitoring task is done effectively.

(*b*) If the control and surveillance system reduces task demands to low levels, meaningful duties must be provided to maintain operator involvement and resistance to distraction. In the case of the BW this may be helmsman duties; for the ME, rounds or on-board maintenance. It is extremely important that any additional duties be meaningful (and not 'make-work') and directed towards the primary task itself, whether it be moving the ship (BWs) or increasing ship availability (MEs).

(*c*) The behavioural impact of excessive false alarms must be recognized.

(*d*) Alarms with more than one mode or more than one triggering condition must clearly indicate which condition is responsible for the alarm display. Thus some group alarms may not provide sufficient information to allow the bridge watchkeeper to take action to correct the condition. For instance, an alarm will not necessarily tell the bridge if the machine can continue to be used or if reconfiguration of the system is necessary. Additionally, the ME must be able to detect immediately the failure condition upon entering the MCR (with minimum delay in fault diagnosis), which may mean a re-design of the below-deck facilities to augment historical data collection. The information needed on the bridge must be of the form 'Do I still have propulsive power; can I reconfigure?', whereas in the MCR it must provide diagnostic data to allow rapid remedial action to be taken.

(*e*) When response time is not critical, most BWs should be able to attempt to check the validity of the alarms. The display system must provide information in the proper format so that this validity check can be made quickly and accurately and not become a source of distraction. This includes providing the operator with information and controls to diagnose the control and surveillance system operation.

(*f*) The format of an alarm should indicate the degree of emergency. Multiple levels of urgency of the same condition may be beneficial (i.e. warning, then alarm, then trip).

(*g*) Training techniques, as well as training hardware, must be devised to ensure that both the bridge and ME crews are exposed to all forms of alerts, covering as many combinations of alerts as possible. All parties must understand both how to deal with them and who deals with them.

Concluding Remarks

There are many potential safety, operational and economic benefits to be realized by automating most MCR functions and placing them on the bridge. The rapid pace of automation is outstripping one's ability to comprehend all the implications for ship's crew performance. It is unrealistic to ignore the civilian trend which has extensively implemented the shift from the MCR to the bridge. One definitely must not wait until the manifestations for the Navy are completely understood. It is important that those who are designing, analysing and installing control systems for bridge control on naval ships do so carefully. They must recognize the behavioural impact of automation, avail themselves of guidelines and remain watchful for any negative symptoms that might appear in training and operational settings. Not just the BWs and the MEs will be facing these problems. Changes in Command and Control and in the role of bridge and operations room watchkeepers are already underway. No one is immune from this technologically (and financially) driven change.

References

1. East, D. W.: Digital control progress in the Royal Navy; *Journal of Naval Engineering*, vol. 29, no. 1, June 1985, pp. 121–123.
2. Neumann, J.: Control of warship machinery; *Journal of Naval Engineering*, vol. 28, no. 3, Dec. 1984, pp. 381–404.