THE PLIGHT OF THE OPERATOR

BY

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Introduction

Ships and their propulsion machinery are complex systems which require control, surveillance, maintainance, repair and replenishment. These are the roles of the operator. The tasks to be implemented are directly parallel to those practised in management with one major difference—the timescale of response.

An interesting observation in response times was made by Herbert W. Ziebolz (1974 Oldenberger Medalist) when he quoted Albert Sperry's table of time constants in decision making:

Control Devices — Nanoseconds to Seconds
Operators — Seconds to Minutes
Foremen — Minutes to Hours
Plant Managers — Hours to Days
Engineers — Days to Weeks
Presidents — Weeks to Months
Governments — Months to Years
United Nations — Years to Decades

Although this is a simplification, it illustrates the operators' place in the response scale. Compare his decision time with that of the designer (Eng.).

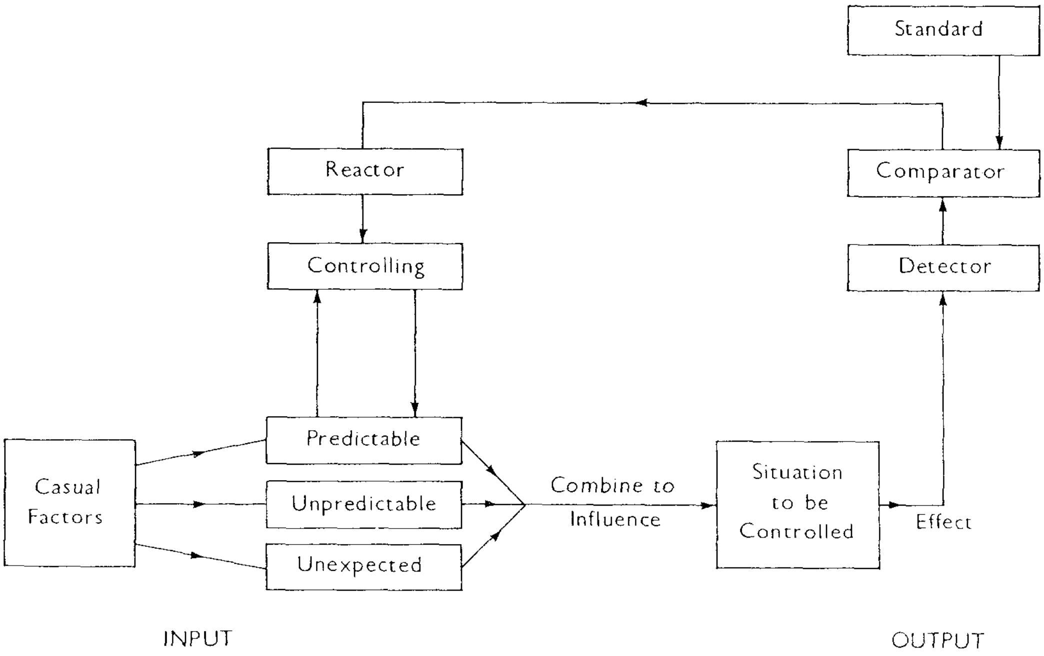

FIG. 1

The analysis of the operators' tasks must be largely subjective, as indeed this article is an expression of opinion based on several years' involvement on both sides of the fence (and bulkhead).

The most common science in operation and management is that of control. Control theory has now developed to the level of a distinctly identifiable science by the work of a number of researchers. The term 'Cybernetics' is frequently used to define the science of communication and control. This was coined by an American mathematician (Norbert Weiner in 1947) and is derived from the Greek Kybernetes, meaning a Steersman. This 'Science' is basic to the study of the behaviour of all systems, be they physical, human, or a combination of both. The operational situation to be studied by 'Cybernetics' is illustrated in FIG. 1.

The definition of terms used in FIG. 1 is as follows:

Causal Factor: A factor which in any way influences the situation and contributes positively, or negatively, towards the effect. Causal factors are sub-classified thus:

Predictable — A factor which is consistent and whose effect can be accurately predicted.

Unpredictable — A factor which is known to have some influence on the situation but whose particular effect cannot be predicted.

Unexpected — A factor which was not allowed for and whose influence was not expected until the ouput effects have been experienced and analysed.

Controlling: This is a special type of predictable factor which has been designated 'Controlling'. It is the one which most easily influences the situation and to which the situation is most sensitive.

Detector: Any agency used to measure, quantitively or qualitatively, the output effect from the situation under control.

Comparator: Any agency used to compare the measured effect with a preset standard.

Reactor: Any agency used to act on the controlling factor so as to influence the situation.

The working of feedback is that the output effect from the situation is compared with the desired effect and any difference initiates change on the situation through the controlling factor. Thus it is possible to compensate for the cumulative effect of all the causal factors, no matter how ill defined any of the factors may be. This type of 'feedback' control is designated 'Negative Feedback' since its general purpose is to reduce progressively the difference between 'actual' and 'desired'.

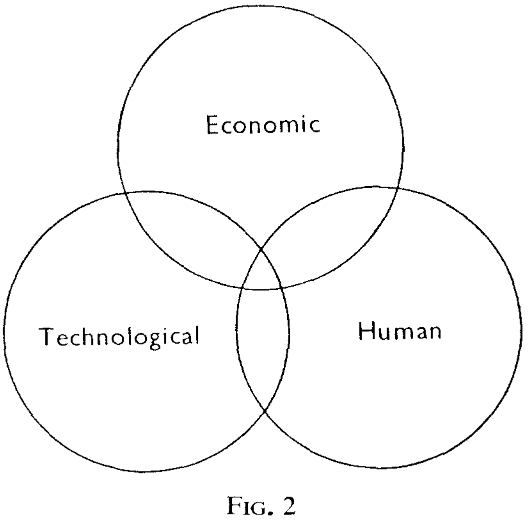

FIG. 2

Management is a process involving the control of three main systems—Economic, Technological and Human. These three are interdependent and the interrelation is illustrated in FIG. 2. The term 'Technological' includes all professional methods, commercial, social, and technical.

A specialist's abilities are primarily used within one of the systems, but he is forced by circumstances to become marginally involved in the others. As he gains promotion in an operational situation, he increasingly leaves behind his 'specialized' activities and has to organize and control others who have varied training and backgrounds. So his work now brings him into the area of overlap of the three systems.

It is reasonable in modern technology to expect machines and materials to be predictable in behaviour, but man as an individual and as a member of a group is rarely predictable. So within the area of direct operational control there can be a considerable degree of unpredictability.

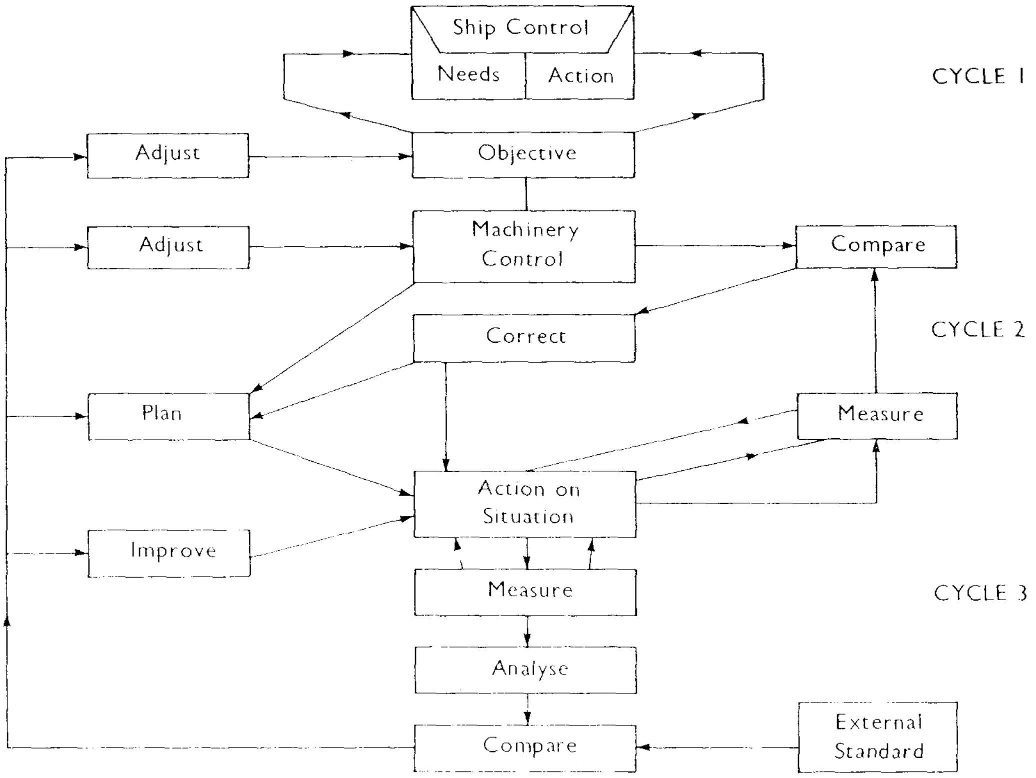

FIG. 3

The operator is frequently required to operate efficiently a complex system where he never thoroughly understands the 'design functions' and where he is exposed to an environment over which he has practically no control.

This is the situation which is within the orbit of the cybernetic theory of control and, in applying this theory, a series of control cycles as shown in FIG. 3 can be developed:

Cycle 1 — The operator meets the demands of ship control.
Cycle 2 — The detailed operation of the individual parts of the machinery.
Cycle 3 — The pattern of the operation is derived, improved and updated.

These aspects daily face the operators of complex marine propulsion plants and the purpose of this article is to draw attention to the fact that, in general, the depth and extent of the liability imposed on the operator is too great in relation to his participation in design aspects.

At present it is assessed that at least 30 per cent of the 'incidents' in the operation of propulsion machinery are operator-aided. Some figures quoted are as high as 80 per cent. Surely the investigation of the root causes of such cases is a highly desirable exercise! The availability, safety and efficiency of the entire ship is significantly affected.

Background

State of the Art

The operation of propulsion machinery has traditionally required a wide spectrum of engineering skills and experience. The developments of the last few years in machinery systems, controls and surveillance, (revised) manning policies and the advent of bridge control, have introduced a number of aspects which have had serious implications on the roles of operating personnel. For example, control of the main propulsion machinery from the bridge has taken the operation in terms of power regulation outside the domain of engineering skills into the hands of the bridge officers who rightly drive the machinery to requirements determined by the vessel's navigation. This practice is perfectly satisfactory provided that all systems continue to function correctly. However, in the event of a failure state arising, the resulting situation can be extremely hazardous because, at the onset of failure neither the bridge officer nor the engineer responsible for machinery safety, may be aware that a malfunction is present. An increasing number of incidents stemming from this type of situation bears witness to this concern and it is the authors' opinion that the operator becomes the unsuspecting scapegoat for poor design.

At present, machinery design principles are favouring restricted machinery space manning, replacement or augmentation of 'human' senses by automatic surveillance systems and addition of remote/auto control elements. The propulsion machinery operators both in the local positions and in the typical machinery control centre have different roles to play in maintaining satisfactory plant operation in normal and emergency situations. In the event of a failure condition arising, the remedial action to be taken differs significantly in the unmanned machinery space concept from previous practice. It is by no means clear that the system design task adequately identifies the operational problems, let alone provides reasonable solutions (to the operator).

The full impact of the introduction of electronics to propulsion plant control and surveillance has not yet been assessed. There are many black boxes to be dealt with and such items have become common place in a comparitively short time, which in turn results in limited and superficial experience. Experience is at the very foundation of an operator's capability.

Typical Design Process

Although ship design methods have improved in recent years, there is still much to be achieved. For various reasons, the propulsion machinery installation (space, weight, economy) may dominate the design. The machinery may involve innovation of considerable significance but new control and instrumentation needs are not necessarily recognized. Decisions are made at plant level which may jeopardize the overall system design. It is rare to find the operator and perhaps the control engineer having a voice at the requisite embryo design stage.

Of course, the design process is complex, particularly with innovative designs where, by definition, the relevant operational experience is not available. The involvement of several engineering disciplines compounds the difficulties. In such cases, the designers must ensure that operational aspects are given adequate consideration. Does this happen, except where some statutory requirement exists? (e.g. nuclear or aircraft safety which demands extensive failure-effect analysis).

The design process usually culminates in drawings and specifications of various levels of detail. In the authors' experience, traditional marine engineering specifications are unbalanced. Many features are carefully (perhaps too rigidly) defined, whereas others remain vague to the point of being meaningless as constraining influences. For example, pressures and temperatures of fluid systems frequently have clear numerical values assigned to them, whereas man-machine interface requirements are rarely defined at all. The reason may well be that it is extremely difficult to specify a factual man-machine interface requirement for which one can define a test to demonstrate acceptance or rejection. A common solution to this difficulty is to use the Lord Nelson blind-eye method; perhaps a harsh comment—there are considerable difficulties in specifying such requirements, nevertheless it needs doing.

The long-term nature of many marine projects creates additional problems. The specification and its basis are keystones; balanced design must be maintained in the face of changing personnel, especially those with extremist views and opinions. Where an operator does participate in the design process, one must beware of the 'prima donna' who endeavours to make the operating task an unnecessary challenge.

Operational Categories and their Problems

Propulsion machinery operations can be divided into two principal categories:

Category 1 — Control of propulsion power from the bridge.
Category 2 — Control co-ordination of all main and auxiliary machinery operations and functions which contribute to propulsion capability.

Category 1 introduces a number of important considerations (not the least of which is the demarcation between disciplines) which illustrate the necessity for basic changes in system design approach. The tasks to be performed in Category 2 differ considerably from those of Category 1; however there remains a need for a well-established link between different disciplines.

One is tempted to make comparisons with the operation of other vehicles and the effect of mission time must be borne in mind when making such comparisons. The typical ship is designed with the assumption that failures will occur and provision is made for repair. The extended mission time (days or weeks) compared with aircraft (hours) has a considerable bearing upon the attitude adopted towards ship machinery breakdown. Back-up facilities are provided, sometimes copiously, normally requiring operator action for proper deployment.

Bridge Operation

The policies presently adopted for operation of propulsion machinery from the bridge represent a partial step towards an aircraft flight-deck control arrangement. However, present marine practice severely limits the display of engineering performance parameters on the bridge. In many cases even basic automatic control action which could be initiated on the bridge, such as engine shut down or changeover, is either prohibited or unwelcome.

In general, bridge control has been accepted with some reluctance in the military marine sphere of operations and the degree of involvement in the design process of operational personnel who understand propulsion machinery, has in many cases been minimal. However, now that bridge operation of propulsion is in service successfully, the reluctance is changing to enthusiasm. Assuming that bridge control becomes the normal mode as distinct from a novelty, are the respective roles of bridge and engineering operators tenable in all circumstances? The authors have doubts, but the *overall* situation should be no worse than with telegraph systems, as hitherto. It is clear that the operators' roles are different and should be studied with respect to their responsibilities. The conflict between machinery protection (e.g. turbine trip on apparent loss of oil) and ship safety (about to collide) is apparent. The lack of comprehensive machinery-state information on the bridge could contribute to incidents which experienced engineering operators avoid by 'nursing' methods. Should the bridge override the engineering operator or vice versa?

By way of example, consider the situation which can arise where a ship is being piloted through a narrow seaway, the propulsion machinery being under bridge control, voice command being given from the pilot on the bridge wing to the officer operating the control levers. A successive series of commands are given for gradual reduction in ship speed. The speed of the ship is gauged by the pilot on the bridge wing monitoring the progress of the ship relative to fixed objects ahead and beside him. It is judged that the ship is travelling too fast, and a command for full-astern power is given. The ship does not decelerate but merely continues at increasing speed on a collision course.

This situation is not untypical and illustrates a number of serious deficiences in the command/control strategy. The pilot is issuing instructions which he believes implicitly are being obeyed. The officer operating the bridge controls is moving the lever to his command assuming that the controls are responding normally to the lever movement. The delay to the response introduced by the machinery and the ship leaves a period during which it is impossible to determine that the exact command has been implemented, and thus a failure in the control or machinery system can remain undetected to a point where it is impossible to take remedial action.

In the case of a controllable-pitch propeller system having bridge control of propulsion by a combined propeller/engine power lever system, the moving of the lever to a full-astern position with an undetected pitch-control failure can cause the normal remedial action taken by the operator to aggravate the incident to a point which completely negates the effectiveness of any safety measures.

Who is to blame in this situation? The control system designer? The pilot? The bridge operator? The training systems? Under no circumstances can it be said that the operator is wholly at fault but because he is present at the incident he carries the initial blame.

Commanding Officers are beginning to make their presence felt in evaluation of propulsion machinery control systems. In some of the latest gas-turbine propulsion machinery systems, naval architects have apparently been over-generous in the provision of astern pitch ratio on CP propellers: this can be judged by available torque and thrust performance data. A recent difficulty arising from the control of shaft speed during severe manoeuvres prompted a suggestion that the astern propeller pitch be reduced as a means of curing the difficulty. Theoretical studies showed that the pitch provided was too high and apparently served no useful purpose. During a discussion with the bridge operators, this was hotly resisted and it was pointed out that, although the astern pitch ratio may be considered to have no effect on the ahead/astern manoeuvring characteristics, the high astern pitch provided a paddle wheel effect during low-speed manoeuvres such as docking which was essential to the bridge operator. Information of this type is invaluable. The bridge operators do not define such problems mathematically and neither should they be expected to be able to do so. Their language of mathematics could be defined as 'seat of the pants' judgement and there is a 'design communication problem' with respect to performance requirements and standards.

Co-ordination of Machinery Operations

Machinery control rooms (or centres) in warships have been widely established for some fifteen years. A review of this period has some considerable bearing on the subject of operational problems and may well illustrate and support some of the opinions being expressed.

Early forms of control and surveillance from MCRs did not differ fundamentally from the pattern already developed for local control in machinery spaces; the same basic controlling elements were located remotely from the machinery and remote reading instrumentation was introduced. The engineering designer was essentially responsible for the scope of remote controls and instrumentation provided.

Although some success was achieved, in that more rapid co-ordination of related variables became possible, reliability problems were identified, particularly with remote reading instrumentation. Conflicting readings between local and remote stations became common place. Calibration to new standards became necessary and this process continues. Was this the beginning of the engineer operator's judgement changing from seat-of-the-pants to a more numerical basis?

Design studies of the operational problems, including operational sequences, task analysis, manning levels and standards, have been undertaken in various establishments and with various motivations. Two of the prime motivations are reductions in manning levels and increases in plant availability. These are contradictory without the presence of a new methodology being derived to engender teamwork between the designers and operators of both machinery and ship. It is not unheard of to have plant operators combine to fight the plant and the influences of 'bridge' participation in the palace of engineering.

Recommendations

General Observation

It is suggested that significant improvements in overall design will result only if the operational aspect is considered from the outset. The literature (Refs. 1, 2, 3 and 4) illustrates many useful contributions to the study and application of human factors and ergonomics. Some time must elapse before any quantitative judgement of results will be possible and it may be that subjective estimates will continue to dominate. So the authors must continue to express the opinion that the design task must include features which will enable the eventual operator to discharge a fair and reasonable function under normal and abnormal circumstances.

Operational Acceptance

The non-mathematical or non-quantifiable aspect of operator opinion has already been touched upon. It is worthwhile considering what has been done in another industry. Bearing in mind the motivation which arises from the knowledge that to shut-off power leads to unpleasant effects, the aircraft pilots have in fact applied a scale of opinion for some years (Ref. 5). The essential features of the Cooper Rating are reproduced in TABLE 1. Everyone is familiar with opinions in the marine industry on some scale of good to bad and beyond. What the aircraft pilots did was to apply a common scale of opinion with regard to aircraft handling qualities. It is surprising that such a scale could be derived, but success was achieved. The designer was able to relate measured behaviour to the opinion (which, of course, is a varying relationship for different aircraft size in particular) and thereby bridge the communication gap.

One aspect of the Cooper Rating system as applied by pilots (at the research and development phase) is the power of veto. The marine industry may find it difficult to accept the concept of rejection by an operator but this is a logical step if operator error reduction is a serious endeavour. Given that this is a worthwhile task, the derivation of a ship-handling rating system would be fairly straightforward although it would take some time to correlate with performance measurements. The authors hesitate to contemplate a rating system for

TABLE I—*Cooper ratings*

	Adjective rating	*Num. rating*	*Description*	*Primary mission achieved*	*Can be landed*
Normal Operation	Satisfactory	1	Excellent includes optimum	Yes	Yes
		2	Good, pleasant to fly	Yes	Yes
		3	Satisfactory, but with some mildly unpleasant characteristics	Yes	Yes
Emergency Operation	Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes	Yes
		5	Unacceptable for normal operation	Doubtful	Yes
		6	Acceptable for emergency condition only*	Doubtful	Yes
No Operation	Unacceptable	7	Unacceptable even for emergency condition*	No	Doubtful
		8	Unacceptable—dangerous	No	No
		9	Unacceptable—uncontrollable	No	No

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* Failure of a stability augmeter.

the engineering co-ordination function which includes direct manipulation of people. Bridge control of propulsion machinery enables an individual to deal with ship handling as a co-ordinated task, analogous to that of an aircraft pilot.

It is recommended that firm guidelines should be devised as to what constitutes a reasonable task for the operator. A serious effort should be made to give the operator more grace time in dealing with plant malfunctions. This is one beneficial line of development to alleviate potential panic situations. Is it unreasonable to postulate a target of 30 seconds minimum, or perhaps one minute, grace time for watchkeeping duties? The plant, including control, protection and monitoring devices, should be designed with such constraints in mind.

Design Team and its Duties

The design team should embrace the necessary disciplines and ensure that a firm basis for the project is established and maintained. In long running projects, many features have to be re-assessed from time to time and opportunities for deviation arise. Expertise in the following are considered essential:

Machinery design and installation
Plant operations and procedures
Control and instrumentation equipment
Human factors; Ergonomics
Control engineering
Systems engineering

The expert in plant operations must act as a reasonable spokesman for the eventual crew. It is not being inferred that the fundamental advances in hardware, system thinking, human factors, or machinery design will be given by the operator. His contribution is one of experience in plant co-ordination or ship handling and practical guidance on many aspects of operation.

If the design team introduces innovations in some form, consideration must be given to training requirements. Considerable reliance has traditionally been placed on the use of 'on-the-job' training. Improvements, mainly through the use of simulators, are now in vogue but again the designers must realize their responsibilities in identifying new areas of training, in advance of construction.

One of the most far-reaching innovations in marine systems of the present decade is the introduction of computers of various sizes and powers. Systems are being constructed which contain significant elements of decision making related to plant operation. Such systems cannot be successful unless operators participate in the design process.

Conclusions

Present technology, theoretical modelling techniques, advances in human engineering, in ergonomics, and in displays, offer the capability of providing palliatives for any problems likely to be encountered in the marine industry. So why are there so many discrepancies between the theory and the practice? Why are there so many operator-aided incidents? Why is system availability not improving in proportion to the financial expenditure on design resources and physical hardware? The solution to these questions may stem from an examination of conceptual system-design methods including the continuity of awareness of the design objectives and the establishment of the design reference points made in the evaluation of the total system.

Technology has not recognized the latent value of abilities which cannot be defined by 'n^{th}' order mathematical equations. Indeed many practicing technologists who have much to offer are lost in the depths of 'hobbyist' self-indulgence studying micro-systems, the interfacing of which to a total system is of no interest or concern of theirs. Perhaps this comment does not only apply to the technologist. The fragmented approach appears to be exacerbated by the modern educational system which has created narrow-minded specialization. The design environment must be organized to ensure that the specialists work together.

Acknowledgements

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