Improving the design and management of alarm systems

B Sherwood Jones BSc(Hons), MSc, FERGS, J V Earthy BSc(Hons), PhD, Ed Fort BSc, Duncan Gould CEng, BEng, BSc, MIEE

Lloyd’s Register, UK

Synopsis

Alarms and alarm lists are common areas of complaint among seafarers. Concerns include:

- distraction from nuisance alarms that take them away from the task in hand
- excessive workload accepting multiple alarms caused by a single incident
- alarm messages that are confusing or unclear in their meaning.

They are also a challenge to many design organisations, requiring information flow through the supply chain that is difficult to support technically and contractually.

Important concerns not immediately apparent arise from the inappropriate use of alarms to convey non-critical information to the operator e.g. mode and status indications. This has consequences for mode awareness, and changes the role of the operator from one of being actively in control to one of passive machine minding (driving to alarms) with the result that effective response to alarm indications has become critical to safe operation.

The state of an alarm system can be taken as an indicator of the extent to which the associated equipment or the corresponding ship’s operations are under management control. For example, large numbers of standing or shelved (inhibited, faded-out) alarms suggests less than complete control, with root causes in the management.

Lloyd’s Register has developed two complementary services to demonstrate conformance with good practice in alarm system design and management. These services have drawn on good practice in other industries such as aviation and process control as well as from experience gained within the maritime sector and are outlined in the following paper.

INTRODUCTION

Alarms affect operation in most parts of the ship. They have been described as the biggest single issue affecting navigation safety. Their impact on modern Engine Control Room operations is no less significant. Alarms also appear in the machinery spaces and accommodation areas. The design of local controls and indications is important, particularly for emergency operation.

This paper describes current regulatory activity related to alarms and summarises the issues currently facing the maritime sector and the seafaring operator. It then examines sources of information for improving design and operation, and discusses the way ahead in the longer term. Finally, the paper describes the approach taken by Lloyd’s Register (LR) to provide support to the design and management of alarm systems.

Terminology note

‘Alarm system management’ assesses the extent to which the organisation (at sea and ashore) takes management action to ensure that the alarm system itself is operating safely and effectively for example, crew activity to reduce nuisance alarms. This is in contrast to ‘alarm management’ which is typically the prioritisation of alarms within an onboard computer system.
CURRENT REGULATORY ACTIVITY CONCERNING ALARMS

Guidance to the marine industry for the design of marine alarms is provided by the IMO Code on Alarms and Indicators\(^1\). This is intended to bring consistency, reduce confusion and reduce the number and variety of alarms and indicators. However, it is somewhat out of date for complex computerised systems with multiple operating modes and has shortfalls for modern alarm systems. At the time of writing, work on updating the code has started at the IMO DE Sub-committee, but the change is expected to be evolutionary.

MSC/Circ. 982\(^2\) has extensive guidance on the design of bridge alarms. Work has also started at the IMO Navigation Sub-committee to write a Bridge Alarm System performance standard, but at the time of writing, this is at a very preliminary stage. The aspiration is that this can progressively increase in scope from an initial baseline of Integrated Navigation System requirements.

However, it can be argued that the regulation of alarms needs to catch up with their implementation. Wood\(^3\) puts it quite forcibly:

"...There is therefore an urgent need to produce a regulatory solution to what is, in effect, an uncontrolled growth in alarm functionality. Without such a solution, we could easily reach the situation where, ironically, the distraction caused by so many alarms could seriously affect the safe operation of the vessel".

There is a tendency towards increased legislative requirement for alarms. Prescribing particular alarms might be considered to improve safety on a particular topic. The cumulative effect, however, is to make the alarm problem worse. The regulatory community needs to consider the cumulative effect when increasing the number of signals to be alarmed; there also may be better ways of improving safety on the specific topic.

While Lloyd’s Register’s Rules also include requirements for alarms and programmable electronic systems generating those alarms, we also recognise that non-regulatory approaches also have a great deal to offer owners who wish to be assured of safe and effective operation. Alarm system design and alarm system management are topics that can benefit considerably from informed independent review aimed at achieving just such safe and effective operation.

ALARM DESIGN ISSUES AND THEIR OPERATIONAL CONSEQUENCES

Traditional indicators and mimics are being replaced by increasing numbers of computerised alarm systems of growing complexity. The underlying systems have also changed. These changes have led to a number of system design issues, discussed in this section.

An effective response to alarm indications has become critical to safe operation. Although automation and increased functionality can provide operational benefits and reduced crew workload, these benefits are only realised if the design, management and operation of the alarm systems follow ergonomic principles. Particular problems that arise when there are shortfalls in these areas can include:

- frequent spurious alarms, causing distraction to watchkeepers (and the risk of a genuine alarm being ignored or discounted);
- long standing alarm lists, where it can be hard to distinguish real problems from ongoing issues of lower concern;
- cascades of alarms when there is an incident, causing difficulty in diagnosis and excessive workload (e.g. cancelling alarms becomes a full-time job during the incident);
- alarms that are difficult for the operator to interpret, or where the correct course of action (or even the degree of urgency) is hard to determine.

The increasing number of alarms for both deck and engineering operations has been caused by a number of factors. The number of alarm signals from external sources has increased, including Global Maritime Distress and Safety System, Automatic Identification System, e-mail and fax. Increased marine automation and modern instrumentation bring with them increasing numbers of alarm channels. The number of systems onboard capable of generating alarms has increased, and the number of alarms associated with...
each system has increased. The number of non-critical Commercial Off The Shelf (COTS) devices with internal beepers and buzzers has also grown considerably. For the operator, this can lead to distraction by large numbers of alarms, and confusion from alarms whose sources and implications are not understood at a time when complex propulsion and platform system alarms on the bridge warrant close attention.

For alarms to reduce workload, the operator needs to be spared the task of monitoring the relevant parameters. However, as Lützhöft⁴ points out, “the rules and regulations dictate that relying only on alarms is not appropriate practice”.

The selection of appropriate alarm channels is not necessarily simple, and prescribed alarm channels may not be appropriate for particular system designs or configurations. The introduction of redundant systems and multiple reversionary operating modes complicates alarm system design considerably. Concerns that are less immediately apparent arise from the inappropriate use of alarms to communicate with the operator e.g. as a substitute for clear mode and status indication. Without effective displays to support mode awareness it is difficult to convey the state of the system to the operator. Combined with the increase in automation, the use of alarms for status indication can change the operator role to one of passive machine minding (driving to alarms) rather than being in active control of the system. The issues of ‘supervisory control’ are well-known in other sectors and have been investigated on the bridge⁴.

The bridge team may be surrounded by alarms from discrete devices all around the bridge. Responding to such alarms is manpower intensive and can be distracting. To address this issue, there is a trend towards centralising alarms on the bridge, which is more compatible with the low manning levels typical of modern ships. The discussion of a ‘centralised alarm system’ has mixed up the centralised location of alarms in a section of a console with implementation by integrated computerised hardware; it may be possible to obtain the benefits of centralisation without relying on an integrated solution. Owners may be missing an opportunity here and at worst trading one set of problems for another. The dependency requirements for an integrated bridge alarm system are quite onerous and potentially costly.

The general failure to specify and achieve true or fully integrated alarm and monitoring systems for ship’s machinery, equipment and systems has led to a tendency to integrate those alarms which can be readily integrated and leave the processing and presentation of those alarms which cannot to their associated systems, albeit probably presented as a computerised alarm list at the same ECR console. The consequence for the engineering team is the likelihood of inconsistent terminology, messages, indicators, priorities and operating philosophies for increasingly interdependent systems. When the ship’s operating philosophy depends on the full availability and use of the alarm and monitoring system the end-to-end maintenance demands are considerable in both manpower and skill levels. This has yet to be widely recognized, with consequent difficulties for many crews.

DESIGN PROCESS ISSUES

This section examines aspects of the design process that affect the operability of the resulting alarms. Improving alarm operability is not solely a matter of imposing new design criteria; the impact on the design process also needs to be considered.

The ‘EEMUA report’ on alarm systems⁵ points out that with modern computer-based systems it is so easy to introduce alarms that there is a tendency for them to be configured without putting in any real design effort and without considering the operational benefits which they will confer. As each extra alarm is introduced, the chances of overloading the operator increases and the alarm system overall becomes less effective as a line of defence. It recommends the following:

“For safe and effective ship operation every alarm, whatever its source, should be justified, properly engineered and be consistent with the overall alarm philosophy and operational risk assessment. The design of each alarm should follow a systematic structured procedure in which design decisions are documented. A formal design process should be followed so that all the key aspects of an alarm are considered from the outset and at a time when changes can be made at minimum cost.”
It points out that there is also the tendency for designers of individual systems to adopt a parochial approach and to propose alarms from their particular system without a proper regard for the operational importance of their alarms compared against alarms from other areas. Safety reviews also tend to result in the addition of alarms as extra defences against potential hazards. Reducing the number of alarm channels, inhibiting them in particular circumstances, or even prioritising them, can become entangled in liability issues and concerns over design authority. Without reductions, inhibition and prioritization however, the operator remains swamped.

From the operator point of view, an alarm set point should not give rise to spurious alarms and should give sufficient time for corrective action before the problem gets worse or the plant trips. Without a good understanding of the context of use, it is difficult to determine set points, and the interests of plant protection may conflict with effective operation. The consequences for the operator are spurious alarms and alarms that are ineffective because they do not give sufficient notice.

Human-Centred Design\(^6, 7\) needs user input and learning from user feedback. This can be difficult to achieve with long supply chains and COTS equipment. However, it is invaluable in achieving timely and unambiguous messages and an operating philosophy that matches the intended use.

The alarm specification for complex systems requires analysis from a functional viewpoint. This can present difficulties to design teams accustomed to detailed prescriptive specifications and the immediacy of physical systems. The consequences for the operators can be quite subtle misunderstandings of how the system is to be operated, which can have severe consequences in abnormal conditions. There is a definite role for an integrator in such design activities. There is a need for the involvement of owner and crew in understanding risk when designing complex systems.

Alarms pose challenges for design teams and for ships in the initial stages of operation. Achieving a good user interface, gaining a sound understanding of the system, and removing nuisance alarms are all difficult time-critical tasks. Although a transitory problem, resolving initial problems adds to workload and difficulty at a high-risk time.

**ALARM SYSTEM MANAGEMENT**

Alarm systems need looking after when they are operational. Sensors can fail or go out of calibration, operational circumstances can change (requiring different settings), changes to manning arrangements may require changes to the alarm system, and there will inevitably be some nuisance alarms, messages that are unclear, and alarms that do not meet operational needs. Equipment changes and refits may have subtle knock-on effects. Incidents and near-misses provide an opportunity to review the effectiveness of the alarm system and make improvements e.g. whether alarms helped or hindered, and whether changes to alarms would really help with prevention or just provide a distraction.

The state of the alarm system can be taken as an indicator of the extent to which the equipment under control or the conduct of the ship is under management control. For example, large numbers of shelved (suppressed, faded-out) alarms are a sign of less than complete control and indication, with root causes in the management of the system. The process sector\(^5, 8, 9\) has advocated quite extensive reviews and metrics. A more informal approach may be better suited to the marine sector. For many types of alarm such management procedures could be considered purely ‘operational’ and within the scope of ISM (Part A, 10). An alternative view of such procedures is that they are necessary to maintain the design intent and therefore ship safety and should be included within the scope of Classification as are other essential systems, machinery and components. The latter view is preferred because alarm system management is seen as maintaining the basis of the safe design, and because of:
- the need for significant technical involvement,
- the standardised nature of a maturity assessment scale and
- the specific nature of the topic in relation to a company Safety Management System.

In particular, technically competent people are required to set priorities and work through them e.g. reviewing alarm behaviour during an upset and assessing performance, and reviewing standing alarms and the reasons for them.
A management strategy for monitoring and improving the state of the alarm system provides assurance that the alarm system will provide effective support to the operators in critical situations. A strategy allows corrective actions and improvements to be prioritised in an informed manner. Aspects of the system management include reviews of spurious, nuisance, and standing alarms. Areas where learning from experience can yield improvements include investigating the precursors to incidents, or investigating the unproductive use of time chasing nuisance alarms. Improvement opportunities include developing business cases for improved control and surveillance, and using refits as opportunities to make such improvements.

LEARNING FROM INCIDENTS

Poor alarm design and lack of mode awareness appear quite often in incident investigation reports. Additional alarms are also proposed as recommendations. The MAIB report of a complex incident, the impact with the quay by the Aquitaine in 2000, includes a number of issues of alarm system design. The impact arose from loss of control of the Controllable Pitch Propellor because of damage to the rotary vanes on the hydraulic oil shaft driven pump and a number of system design issues. The lessons to be learned as regards alarm design include the following:

- ensure adequate provision of aids to monitoring and diagnosing the state of a system, rather than rely on a few alarm channels.
- consider all the hazards envisaged (loss of propulsion and loss of control) when identifying alarm requirements.
- ensure that alert settings will be triggered when the system becomes non-functional.
- provide warning of loss of performance before it is demanded in a critical situation rather than provide a distraction at that point.

LEARNING FROM OTHER SECTORS

The nuclear, process control, aviation and military sectors have each developed and applied requirements and guidance that are considerably more advanced than those in the shipping sector. Alarms are still an area of concern, but good practice in these sectors offers considerable potential for technology transfer. Wood makes the point that “the ‘Alerting System’ requirements for the cockpits of large aeroplanes, as specified by the European Aviation Safety Agency (EASA), are a model of clarity and logic” in contrast to current shipping requirements.

The major guidance document in the public domain from the process sector is the EEMUA Guide. This large document includes extensive guidance on many topics and is generally some way in advance of the marine sector.

In the case of Royal Navy warship design and operation, the key document for alarms and warnings has been NES 599/Def Stan 02-626. It is planned to update this standard using material developed under the ‘PMS Alerts’ project. The ‘PMS Alerts’ project has examined the alignment of crew, platform systems, and control and instrumentation for the future warship. In the longer term, there will need to be less reliance on alarms or discrete alert messages and better presentation of the state of the system (or state of the world, as appropriate). Techniques such as functional hierarchy displays or ecological displays may provide the necessary abstraction and presentation resources. The implications for intelligent alerts for requirements specification and project management have also been examined.

ASSESSING ALARMS

Human variability and adaptability frequently make assessment of the human element more demanding than traditional marine equipment testing. Many aspects of user interaction are very difficult to assess out of context – “It all depends...”. The need to consider the ‘context of use’ in many human element assessments limits the value of prescriptive design guidance. Assessment approaches that take context into account are also new to much of the marine sector. Lloyd’s Register has been in the vanguard of...
developing standards that can be used to assess these aspects of user interaction with complex systems, using approaches based on process assessment and principles.

In the case of alarm design, however, many of the essential features can be readily assessed using well established ergonomic design criteria. Aspects related to operator workload do need to be assessed in a (simulated) trial situation as their assessment requires information to be obtained from the user. Topics that relate to the task of using the alarm system and which can be assessed include:

- interpretation of information – diagnosing the causes of the alarms, the use of ordering alarms on displays and grouping of alarms.
- aids to navigation through the alarm system and access to diagnostic aids.

The design of facilities used to present alarms can be assessed, ranging from workstation design, through display design to the design of individual alarm messages and the design of audibles. Topics related to the various locations of alarms can be examined, e.g. alarm aspects of the bridge, the engine room, the engine control room, and accommodation spaces. Some aspects of alarm system design can be examined, including any mix of computer and traditional alarms and the integrity of the system. The need for procedures for responding to alarms, and for the management of the alarm system can be examined, including topics such as handover of shelved alarms, and transfer of station in control.

THE WAY AHEAD

A study by Lloyd's Register of alarms on newbuilding and recent ships confirmed the general findings of the EEMUA Report. Some aspects of alarm system design are determined by regulatory requirements and recommendations such as the IMO Code, but there are many aspects that are not. Supply chain management and liability issues can complicate the achievement of a successful solution.

Taking into account our own experiences, we have also drawn on best practice from other sectors, adapted it for maritime use and have developed two new services to assist owners and yards in design, management and operation of alarm systems. These services do not require specialist ergonomic expertise and have been designed to be carried out in conjunction with regular classification survey activity following tailoring of standard design assessment checklists to suit ship type, classification notations and the alarm system technology.

Support to the design stage includes guidance at a system level and for aspects related to the equipment under control such as prioritisation and grouping, as well as guidance for user interface design.

Support to effective management of alarms examines the activities undertaken to ensure that the alarm system alerts, informs and guides the watchkeeper in taking timely action. This service is based on the premise that the effective management of alarm systems has become important to the safe and effective operation of modern ships. The extent to which the activities are performed is assessed based on a maturity scale, where evidence of improvement activity is sought rather than the achievement of a specific level.

It is considered that these alarm services will provide considerable benefits to safety and ease of operation, and will continue to give clients an advantage for some time to come.

CONCLUSIONS

Alarms are a significant problem for watchkeepers, technical management and for design teams. The design of alarm systems can be aided and assessed. The assessment of alarm system management and the crew response to alarms is a good indicator of the maintenance of design intent and can be assessed as the basis for improvement. There are a number of developments under way to improve the regulation of alarms, but it is too soon to say how radical the resulting changes will be. Additional non-regulatory support to design and operation is likely to remain useful to owners for some time to come.
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REFERENCES

1. IMO Code on Alarms and Indicators (1995)