Alarm Management in the Maritime Industry

Volume 1

A field investigation into the watchkeepers' experiences on watchfulness in a connected world

Digital Transformation Research Programme

Report information

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Foreword

"I am delighted to introduce this research into best practices and challenges on alarm management on operational ships, as I believe it provides benefits to the Maritime Industry. Not just the benefit of the report content and conclusions, but also the benefit of a project design that allows us to share anonymised, federated data for further research. From my perspective, information and knowledge extracted from data is where value lies, not in the raw data itself. Enabling appropriately controlled data sharing provides a richer source for the entire Ocean Economy to learn from.

LR's goal in developing and publishing Classification Rules is that, in conjunction with proper care and conduct on the part of the Owner and Operator of a ship, they will provide for the safety and reliability of the propulsion and steering systems amongst other essential functions. We have understood for some time that those standards and their operational outcomes are linked through consideration of the human element. Therefore, effective system design and integration should deliver systems that can be used safely by a properly trained and experienced crew, or operator. Recognising evidence of challenges faced by crew to deal with the volume and frequency of alarm information from modern ship systems, particularly in urgent or time pressured situations, we started this project to assess the scale of this challenge and to examine what already works well. The chosen methodology of onboard interviews with watchkeeping seafarers and analysis of actual alarm data in context, permits us to draw on their real-world experience. The conclusions demonstrate the unintended consequences of many individual alarm requirements being assembled together in a ship system, and shines a light on the possible pathways to address this matter.

My thanks go to the authors for their hard work and to the ship operators who trusted us with access to their ships and data."

Duncan James Duffy

Global Head of Technology – Electrotechnical Systems.

Contents

List of abbreviations

Abbreviations	Definition
ABS	American Bureau of Shipping
AIS	Automatic Identification System
ANS	American Nuclear Society
ANSI	American National Standards Institute
ARPA	Automatic Radar Plotting Aid
BAM	Bridge Alert Management
BMS	Battery Management System
BSC	Basic (Process) Control System
BWTS	Ballast Water Treatment System
CAI	Code on Alerts and Indicators (IMO)
CAM	Central Alarm Management
CRISP-DM	CRoss Industry Standard Process for Data Mining
CSV	Comma-separated values
C&I	Control and Instrumentation
DMAIB	Danish Maritime Accident Investigation Board
DNV	Det Norske Veritas
DP	Dynamic Positioning System
DST	Data Science Trajectories
EASA	European Union Aviation Safety Agency
ECDIS	Electronic Chart Display and Information System
ECR	Engine Control Room
EEMUA	The Engineering Equipment and Materials Users Association
EMSA	European Maritime Safety Agency
ESD	Emergency Shutdown System
ETO	Electrotechnical Officer
FKIE	Fraunhofer Institute for Communication, Information Processing and Ergonomics
GBS	Goal Based Standards
GDPR	General Data Protection Regulation (EU)
GMDSS	Global Maritime Distress and Safety System
HMI	Human-Machine Interface
HSE	Health and Safety Executive (UK)
IAS	Integrated Automation System
IACS	International Association of Classification Societies
IBS	Integrated Bridge System
IEC	International Electrotechnical Commission

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Abbreviations	Definition
IMO	International Maritime Organization
INS	Integrated Navigation System
ISA	International Society of Automation
ISM	International Safety Management (IMO)
LR	Lloyd's Register
MAIB	Maritime Accident Investigation Board (UK)
MASS	Maritime Autonomous Surface Ship
MED	Maritime Equipment Directive (EU)
MFD	Multi-functional display
MSK	Copenhagen School of Marine Engineering and Technology Management
NSIA	Norwegian Safety Investigation Authority
NSTB	National Transportation Safety Board (US)
OEM	original equipment manufacturing
OOW	Officer of the Watch
PID	Proportional – Integral – Derivative (Controller)
PLC	Programmable Logic Controllers
RHFP	Rules Human Factors Panel
ROPAX	RORO ship with passenger (PAX) accommodation
RORO	RORO ((roll-on/roll-off) vessel built for freight vehicle transport
RSA	Rivest–Shamir–Adleman public-key cryptosystem
SCADA	Supervisory Control and Data Acquisition Systems
SDU	Southern University of Denmark
SIGTTO	Society of International Gas Tanker & Terminal Operators
SMCS	Safety Monitoring and Control System
SMS	Safety Management System (IMO)
SOLAS	The International Convention for the Safety of Life at Sea
SRtP	Safe Return to Port (IMO)
SSH	Secure Shell Protocol
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TCA	Time-critical action
TCP	Touch Control Panel
UPS	Uninterruptable power supply
UR E	(IACS) Unified Requirements E (E = Electrical and Electronic Installations)
VDR	Voyage Data Recorder
VHF	Very High Frequency (Maritime Radio)

Formal project background

This report relates to the alarm systems provided to watchkeeping officers in the engine control rooms and navigational bridges on board ships in the maritime industry. It has been produced as a part of a research project funded by the Technical Directorate at Lloyd's Register (LR) under LR's Technology Programme – project no. COC4615. One of the project's aims was to survey alarm systems in the maritime industry and report both observed best practices and challenges. To address this specific aim, the extent of the topic is studied under three subtasks:

(1) exploring the watchkeeping officer's opinion and user experience,

(2) analysing shipborne alarm data in generalisable modes of ship operations, and

(3) exploring objective and practical ways of quantifying time response design criteria for safety-related operator actions.

The outcome of this work is intended to guide LR's internal rule and policy development processes. Aligned with LR's values, its results are likewise shared freely with the industry as trusted advice aimed at informing future regulations, guidelines, and best practices on the subject. The output of this report presents the initial results generated through subtask (1).

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Formal project background

These results provide the foundation for the succeeding subtasks (2) and (3). Subtask (1) included a number of information collection activities, such as:

- Engaging with the people on board 15 ships. On some ships, up to 14 days were spent on board while collecting information.
- Conducted semi-structured interviews and collected questionnaire responses from 65 watchkeeping seafarers on their opinion of the alarm systems they use daily. These experiences and opinions form a set of rich narratives from the end users' perspectives.
- Field observations of the alarm load on the bridge officers on board two modern technical sister ships for similar end-to-end voyages. Ships with fully integrated bridge systems, enhanced navigational safety awareness and likewise fully compliant with the bridge alert management (BAM) standard.
- Obtaining more than 12 years of alarm/event log data from the sampled ships in order to establish an open-source dataset as input to the succeeding activities (2) and (3).
- Speaking with more than 10 distinct ship owners about the challenges and opportunities of increased automation and the management of alarms in both tender, procurement and operation. These discussions were held with various designated people ashore, representing operational, engineering, and technical staff, many at the executive level.
- Discussions on alarm management with the technical executives of the EEMUA 191 publication, voting members of the ISA 18 (.2) committee which included delegates of the IEC SC65A covering IEC 62682. In addition, the Research Group at Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE), and LR's independent advisory panel on human factors, the RHFP, were consulted in great detail throughout this project.

These various sources of information have been analysed and used to write this report. The work was conducted in collaboration with the Copenhagen School of Marine Engineering and Technology Management (MSK), which provided two graduate marine engineering students, *Magnus Selvejer* and *Mark Munch Jacobsen*. Both contributed to this work while undertaking their final five-month internship at LR. During this period, they were supervised internally by the projects manager, *Asger Schliemann-Haug*, and by their academic supervisor and associate professor at MSK, *Jan Runge*.

The second subtask (2) output is conducted in collaboration with the University of Southern Denmark (SDU), where *Nicklas S. Jensen* investigates the collected data in more detail as part of writing a master's thesis in data science. The dissemination of this work is expected to be available ultimo 2024. During this thesis period, Nicklas is supervised internally by the projects manager, *Asger Schliemann-Haug*, and by the academic supervisor and assistant professor at SDU, *Panagiotis Tampakis*.

The third output of subtask (3) was planned to be an externally funded and cooperative effort involving a small and highly agile industry task group. The subtask has been supported by external funding from The Danish Maritime Foundation. The task group includes Aarhus School of Marine and Technical Engineering, Fredericia College of Marine and Technical Engineering, DFDS Seaways, LR, and The Maritime Hub (IT University of Copenhagen). The output of that project is anticipated to be disseminated by mid-2025.

1.1 Disclaimer

The contents of this report, including any opinions and conclusions expressed, are those of the authors alone and do not necessarily reflect the current policy of LR nor the opinion of any mentioned parties.

While significant efforts have been made, certain aspects may not have received the depth of investigation they deserve. Not all readers will necessarily agree with every word in this report. However, it is hoped that these ideas will provoke thought and lead to fruitful discussions. The project team at LR remains open to input on further exploration and refinement as the work progresses. The data is likewise made available so that critical stakeholders can form their own opinions (and hopefully disseminate them), see *Additional resources*.

1.2 Acknowledgements

More than one hundred individuals have participated in the project in one way or another. The success of this project was only possible because of the broad involvement and active contribution of multiple companies and individuals. Companies and people who believe this work can drive positive change and provide the necessary understanding to progress with the succeeding activities. Without such people, the project would have made very little progress, if any at all. LR would like to thank all of them. Besides the advisory panel mentioned further below, some people deserving special mention are:

Richard Vie (Independent), Robert Doncom (Independent), Nanna Thit Hemmingsen (DFDS Seaways), Kristoffer Kloch (Independent), Thomas Doncom (Independent), Christopher Stein (Maritime Cyber Guild), Katie Aylward (Dept. National Defence, Canada), Tommy Birkebaek (MSK), Florian Motz (FKIE), Stephanie Hochgeschurz (FKIE), Edward Kessler (EEMUA), John Lilly (EEMUA), Peter Brown (LR & The 61508 Association), Lieven Dubois (ISA 18 committee voting member and CEI delegate in IEC SC65A), Robert Turner (Yokogawa UK), Duncan James Duffy (LR), Jonathan Earthy (LR), Volkan Arslan (LR), Stefan Verhoven (LR), Jacob Plum(LR), Henriette Weijs (LR) and Rikke Gagatek Bevilacqua (LR).

LR would like to make a special mention of the watchkeeping officers who participated in the interviews and answered the questionnaires. Although anonymous, your responses and narratives are the most significant contribution. In addition, a special thanks goes to all the ship owners and ship management companies who contributed with their time, resources, and operational data.

In adherence to privacy, representatives from the participating shipowners are not explicitly mentioned. However, your crucial contributions were indispensable; without your involvement, this project would not have been achievable. We extend our gratitude for placing trust in LR to distil the information into insights that can benefit the maritime industry at scale.

1.3 Advisory panel

Concurrent with LR's internal experts, an independent advisory panel on Human Factors provided ad hoc directional and technical consultation for the duration of this project. During this period, five of its members were represented individually or organisationally on the LR Technical Committee (TC), and four on the LR Naval Ship Technical Committee (NSTC).

Although discussions were loud at times, the alternative would have been an echo chamber. LR thanks these members deeply for their vigilant contributions in kind.

1.4 Intellectual property

This report includes descriptions of methods and designs for handling the management of alarms, which have been supplied by third parties. Readers should be aware that the intellectual property rights of these methods and designs may be held by those third parties or by others. This is especially true for fully quoted content of certain ISA[1]/IEC[2], ANSI[3]/ANS[4] standards, and for a particular best practice publication distributed by EEMUA[5] in their Publication 191. LR obtained the written permission of these organisations before including their content in this report.

Any original part (non-referenced) of this report may be quoted. Credit lines should read:

> *"Extracted from Lloyd's Register Alarm Management in the Maritime Industry – Volume 1 – A field investigation into the watchkeepers' experiences on watchfulness in a connected world – 2024, with permission of the publisher, Lloyd's Register."*

While every effort has been made to ensure the accuracy of the references listed in this report, their future availability cannot be guaranteed.

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1.5 Target audience

It is essential to note that this report is written for individuals possessing a fundamental understanding of supervisory control and data acquisition systems (SCADA), distributed control systems (DCS), programmable logic controllers (PLC), including the operational context of a ship and the utilisation of alarm and control systems by watchkeeping officers in both machinery and navigational operations. This report is not an introductory resource for those unfamiliar with the subject matter, as it does not provide fundamental theoretical explanations nor definitions.

This report is aimed to inform a number of different readers, such as:

- Policymakers and organisations involved in formulating rules and regulations for maritime alarm and control systems. This includes equipment or components that may generate alarms as stand-alone or as a part of a system (of systems).
- Control and instrumentation engineers (C&I engineers) who are tasked with implementing maritime alarm systems or performing modifications to existing ones.
- Project teams engaged in the procurement of new alarm systems.
- Technical maritime executives with an interest in performance-shaping processes.
- Marine engineering officers/superintendents with sufficient degrees of freedom to influence the engineering decisions of the integrated automation systems on board their ships. This may be at the time of build (build engineers), during normal operations or scheduled docking.
- Researchers looking into enhancing socio-technical systems within the maritime domain.

1 International Society of Automation
2 International Electrotechnical Commission
3 American National Standards Institute
4 American Nuclear Society
5 The Engineering Equipment and Materials Users Association

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1.6 Structure of the report

Applying a report structure that linearly aligns the sections for the above-listed audiences is impossible. The key managerial messages are presented in the conclusion. For this reason, it is separated into succeeding parts, each with individual results and discussion sections. The results are synthesised by evaluating all parts in unison. This includes the perspective of recognised good practices of adjacent industries, in addition to established knowledge within the maritime domain on the subject of alarm management. The latter informs a conclusion to the questions contained in the introduction, followed by suggestions for further work (Figure 1). It is recognised that this report contains extensive amounts of information. Therefore, both the evaluation and the conclusion point directly to the referenced content in the report.

1.7 Appendices

It is essential to highlight that these appendices play a significant role in the overall report. A summary of their contents is outlined below:

Appendix A – Operator questionnaire results

1.7.1 Additional resources

Much of the data collected is too comprehensive for a "physical" appendix. Therefore, a digital repository is available at the link below. The digital repository encompasses a comprehensive dataset overview, visualisation, and the supporting codebase utilised in the project.

Link: https://deepnote.com/app/alarm-management/Alarm-Management-4fc1b659-ac27-46a0-b7af-56e052b70264

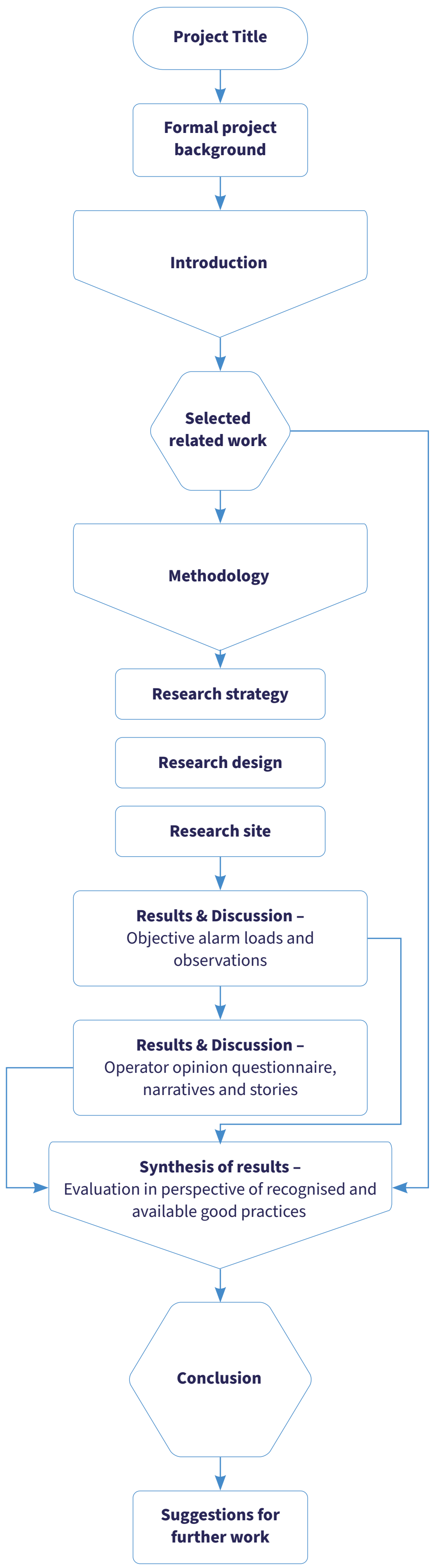

FIGURE 1.
Structure of this report

Introduction

Watchfulness – the state of being constantly attentive and responsive to signs of opportunity, activity, or danger.

The perils of the sea have never been disputed. Throughout the history of seagoing transportation, ships have relied on the watchful eyes of the seafarers. Far from stable land and with no assistance available but their own, the *officer of the watch* was entrusted with the lives of those sleeping soundly below the waterline, along with ensuring that the vessel and its cargo would ultimately reach safe havens.

In the maritime setting, *watchfulness* has always meant more than a pair of eyes fixed steadily on the horizon. Some would say it has been a fundamental philosophy rooted in the commitment to *safety* ever since the industry first began to govern its practices on such matters. This unbreakable tie is best depicted by the two circular paintings representing *watchfulness* and *safety*, Gerald Moira's tondos (circular paintings) hung on the landing of the first floor in the historic LR (Collcutt) building. Both are positioned directly above the entrances to the *General Committee Room* and the *Chairman's Corridor* (Figure 2).

While maritime safety regulations have come a long way since these paintings were first created, the dangers of the sea remain ever-present. According to the International Maritime Organization (IMO), today's seafarers face daily risks in one of the world's largest and most hazardous industries [1]. The 2023 report from the European Maritime Safety Agency (EMSA) reported 2510 casualties or incidents concerning EU-flagged vessels, of which 25% were *serious* or *very serious*. Of these hundreds of cases, 74 (≈10%) underwent investigation, with the majority of investigations conducted for the *very serious* cases [2, pp. 12, 27]. Globally, the 3rd quarter of 2022 marked the highest number of maritime casualties in 14 years, with 60% linked to machinery damage, failure, and collisions, while the first three quarters of 2022 attributed machinery damage to 57% of all casualties [3] [4].

The risks of maritime operations may not affect only those on board. A resulting financial liability to the beneficial ship owners naturally follows the spectrum of maritime risks, be it directly or indirectly. The beneficial

FIGURE 2.
Watchfulness and Safety Moira's tondos (circular paintings) in the blind bull's-eye openings seen from the landing of the first floor in the historic LR (Collcutt) building [83]

owner may lose expensive assets and cargo, experience reputational damage, and sometimes face costly litigation in the aftermath of severe incidents, especially if public outrage followed as a result. This has a damaging effect on the business as a whole. For instance, the frequency of container fires and losses in recent years has led to a notable increase in insurance premiums, particularly targeted on container ships as a distinct category [5].

While technological advances have evolved considerably to control risks, so have the practicalities of watchfulness. Today, the modern seafarer is relieved of bearing the biting winds within the crow's nest. Instead, today's watchkeeping officers have become highly reliant on human-machine interaction. The human-machine systems used on modern ships are equipped with an array of sensors, control elements, and switching devices. These work continuously to detect degradations or abnormalities and alert any to the watchkeeping officers on board. Traditionally, this alerting is achieved by the provisioning of brightly coloured and noisy alarms, engineered to immediately attract the attention of any human in its vicinity.

In its operational essence, an alarm is but a cue. A cue to alert the operator about the need to execute a time-critical action to avert an unwanted consequence. A consequence likely to be the result of inaction (Figure 3).

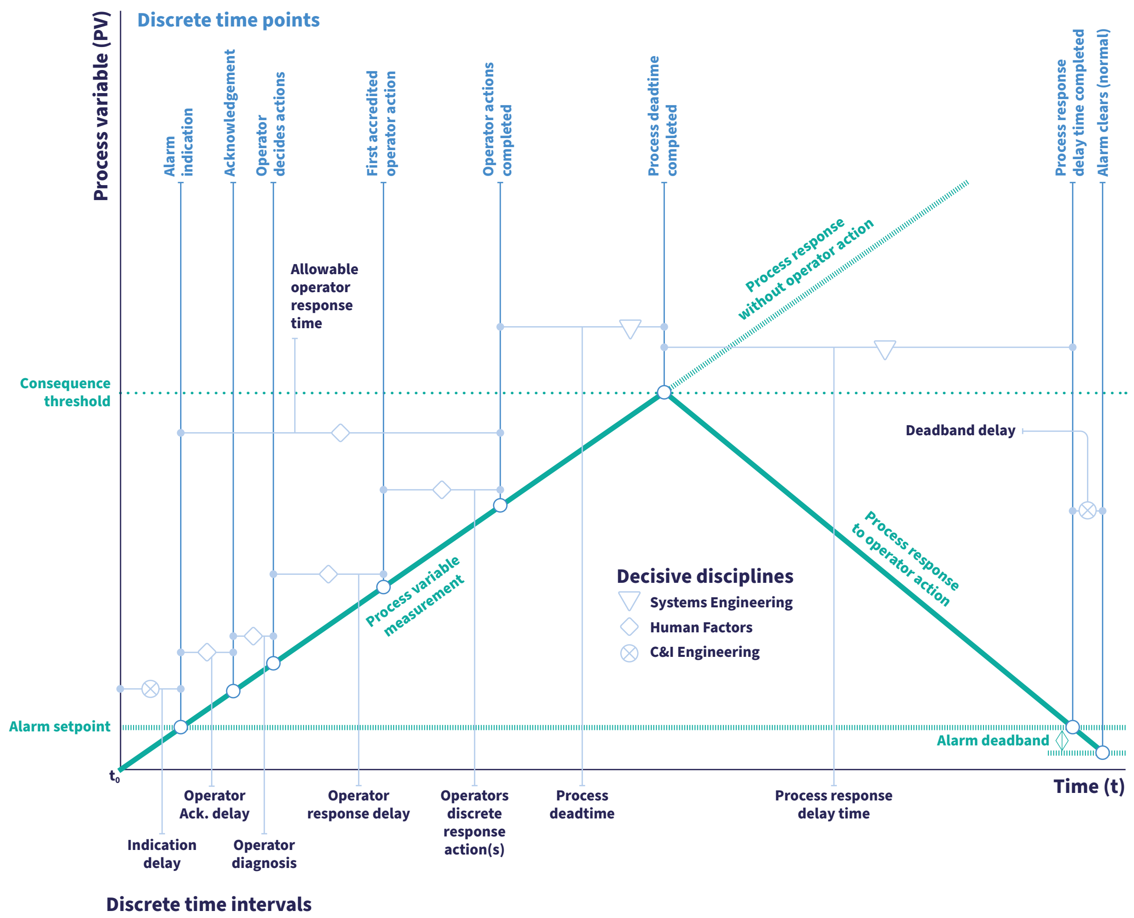

FIGURE 3.
Alarm response timeline. The disturbance of a continuous process variable (PV) begins at t0. The "Allowable operator response time" is decisive, representing the window for operators to avert the PV from reaching the "Consequence threshold". Any delay beyond this window renders subsequent effort ineffective, as the "Process deadtime" and "Process response to operator action" dominate the result. These depend on the engineered system's characteristics, e.g., pipe lengths, dimensions, and pump capacities. The "indication delay" depends on the selected field instrumentation (sensors) and alarm strategy (e.g., the use of a deviation vs. an absolute alarm setpoint). The operator-specific time intervals depend on human performance shaping factors, such as training, and also on the spatial positions of manual control elements, e.g., valves. The engineering decisions made by the disciplines on either side of the "Allowable operator response time" either prolong or shorten the time available. Logically, this significantly influences the operator's chance of success. Illustration inspired by [18, p. 31 Figure 4] [19, pp. 2-4 Fig 3]

As previously stated, the rooted safety tradition of watchfulness means that these alarms form an important element of the maritime safety assurance philosophy found within the Regulations set forth by the *Organization* (IMO), the additional requirements by the ship's national *Administration* (flag state), and the applicable Rules defined by its respective *Classification Society* (Class).

However, beneath the surface, there is more to an alarm than meets the eye. From a C&I engineering perspective, an alarm point is a pointer—pointing at limitations in a system. Typically, the points are found close to the outer edges of a system's operational envelope (Figure 4). At other times, these limits shine light on a weak spot, a hole in the ground, or what could be said to be a residual weakness in the system that was not "engineered out". As each alarm correlates with an envelope limit and its associated consequences, they can tell a great deal about the engineering quality that went into that system.

In general, the more alarms, the more limitations. This, in turn, necessitates greater demand for human intervention and resources. Moreover, when the operational envelope approaches the consequence threshold too closely, it indicates a skewed optimisation for one objective. For example, installing undersized brakes on a car to minimise weight, cost, and fuel consumption will prolong the time it takes for the vehicle to respond to the driver's actions in reducing speed—the *Process response to operator action* (Figure 3) is extended. Consequently, the driver must react faster on a collision warning; the *Allowable operator response time* (Figure 3) becomes contracted.

From a historical perspective, these alarm points tell of hard lessons learned. Lessons often linked to tragic events. The industry's response to such events has sometimes involved the addition of further alarms as a precautionary measure. While seemingly straightforward in individual cases, this approach does not consider the overall impact of the human-machine interaction and its associated alarm burden on operators. Experts within the maritime safety community have previously suggested that at some point, each additional alarm merely increases the chances of overloading the operator, making the overall alarm system less effective as a line of defence [6, p. 3]. This view was likewise shared by safety experts in adjacent industries, such as the process and power industries, several years ago [7, p. 116] [8, p. 212 Table 38] [9, p. 61]. In resonance with these safety experts, several incident reports have expressed concerns regarding the number of alarms announced both before and during the incident's occurrence [10] [11] [12] [13, p. 8]. Some events even attribute incidents to alarms (and their associated shutdowns) activating inadvertently [13, p. 7] [14, p. 14] [15]. Other incident reports testify to a deliberate deactivation of alarms by seagoing personnel [16] [17, p. 18].

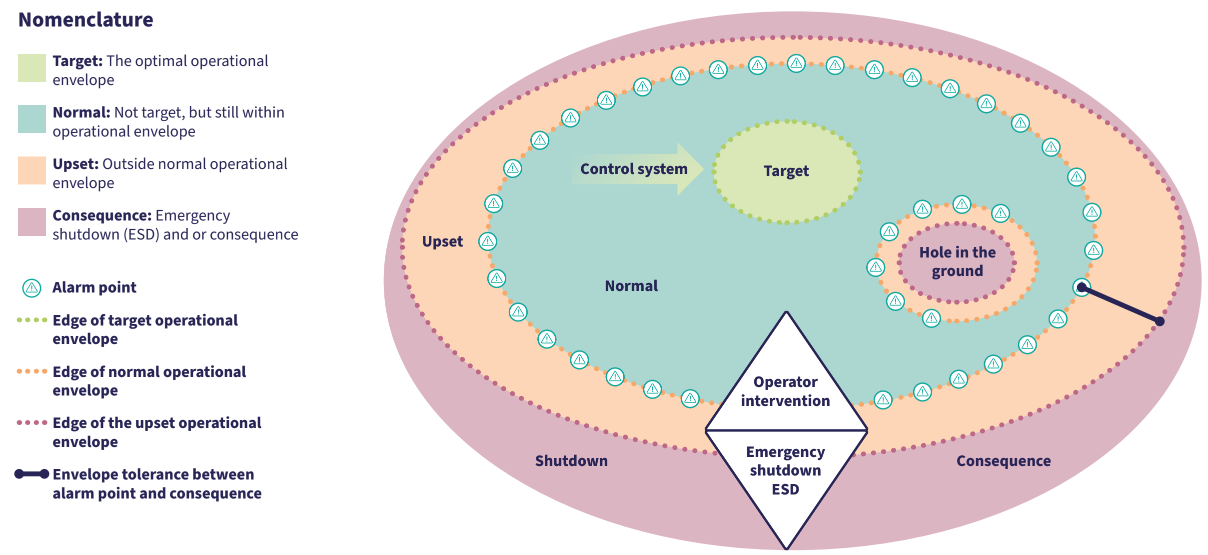

FIGURE 4.
A continuous system's operational envelopes and alarm points. The control system works continuously to keep the system state within the "Target". The control system can be either closed-loop or open-loop. Each alarm marks the point at which the operator must take action and intervene to prevent the onset of an unwanted consequence or shutdown. Illustration inspired by [8, p. 27 Fig. 11]

In one incident, the Danish Maritime Accident Investigation Board (DMAIB) reported that the crew on *Stena Scandica* lost 45 minutes in preventing the total blackout following a fire. The crew did not immediately note that the emergency generator was not supplying power to the emergency switchboard. Although this specific issue was annunciated in the alarm monitoring system, it was not observable due to the high number of simultaneous alarms, also referred to as 'alarm flooding':

> *"The crew did not notice the failure on the emergency switchboard until approx. 45 minutes after it occurred … the signals indicating the loss of power from the emergency switchboard were easily overlooked, as the multiple failures flooded the alarm monitoring system." – [10, p. 56]*

An experienced officer identified the problem by noticing that the uninterruptable power supplies were still discharging. At this point, it was too late. The vessel lost all power and drifted for hours while helicopters evacuated passengers, until the power was eventually restored. The crew on Stena Scandica had years of ship-specific experience, and some engineering officers were also qualified as electrotechnical officers, according to STCW III/6. The report details how these competencies were instrumental in restoring electrical power on the emergency switchboard [10, pp. Fig. 50-54]. The DMAIB concluded that human performance had, in fact, saved the day:

> *"For many years, accident investigation focused on the shortcomings in human performance as a safety-critical issue. The fire and blackout on STENA SCANDICA highlight the opposite…" - [10, p. 74]*

Another incident report on the flooding of the engine room on *Emma Maersk* describes how the alarm system overwhelmed the crew in their attempts to recover from the situation:

> *"Throughout the entire course of events, the officers and crew were constantly disturbed and highly stressed by the sound of countless alarms, which made it extremely difficult to concentrate on the many challenges that appeared one after another." – [12, p. 53]*

Fortunately, the ship did not end up blocking the Suez Canal. Like the fire incident on *Stena Scandica*, *Emma Maersk* was fortunate to have a highly skilled and experienced crew on board. The second engineering officer held a certificate as a chief engineer, and when considering the cumulative years of company-specific experience, the captain, chief mate, chief engineer, and second engineer totalled 61 years [12, p. 6]. In summary, dealing with the flooding was truly a heroic effort:

> *"When operating the handwheel, a steel pin broke and the handwheel could not be used. The engineer then crawled under the floor plates and used a wrench to open the valve while standing on the tank top in water to the knees." - [12, p. 27]*

In recognition of these testimonies showing the importance of human capacities under abnormal conditions for ensuring the ship's safety, these two reports created contemplation of the impact of alarm floods on watchkeeping officers. It seems that alarm floods can inhibit those human capacities. Yet, the extent of alarm flooding on modern ships cannot be determined from these two reports alone.

Other incident reports indicate that alarm floods are not the only challenge. The UK Maritime Accident Investigation Board (MAIB), which investigated the *RMS Queen Mary 2* blackout, reported that the engineering officer of the watch (OOW) was continuously exposed to an overwhelming rate of alarms:

> *"The frequency of alarms on the IAS[6] at around one every minute, in addition to alarms from the P1200 system is most likely to have overwhelmed the watchkeeper, and it is not surprising that the propulsion motor alarms were not acted upon." – [11, p. 54]*

Considering the impact of such alarm loads on watchkeeping personnel during everyday operations initiated concerns about their responsiveness, and thus, operator reliability. It raised questions about the ability to act on the correct alarm at the right moment. At such moments, unattended alarms can be associated with safety shutdowns. However, these shutdowns can still make systems fail dangerously despite being intended as fail-safe measures.

6 Integrated Automation System

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Introduction

The National Transportation Safety Board (NTSB), which investigated the collision between the cargo ships *Damgracht* and *AP Revelin*, reported an example of such instances. The report details how a false alarm from an oil mist detector, along with its associated shutdown of *Damgracht's* main engine, led to $3.4 million in damage to the *AP Revelin* [14, p. 14].

Another incident exemplifying the implication of a similar false alarm was Maersk reporting that the container ship *Maersk Eindhoven* had lost 260 containers overboard and with an additional 65 damaged on the deck. The incident happened during a three-to-four-minute loss of manoeuvrability in heavy seas. Maersk said this was caused by a false oil pressure alarm and its associated shutdown of the main engine [15].

The costs of this incident remain unreported. However, a brief look at the numbers can indicate the scale of its financial implications. At the time of the incident, *The Economist* reported that the freight rate of a 40-foot container was up to $7900 [20]. At these rates, the lost turnover of the lost containers would alone exceed $2 million. Adding to this figure is the price of each container, the value of its cargo, and the fact that the vessel was "off-hire" for repairs until March 2, 2021 [15]. In addition, the media SHIPPINGWATCH announced on October 24, 2023, that Maersk was undergoing litigation by Starr Indemnity for this incident, claiming suit values upwards of $5.8 million [21].

Stories such as these present a dollar value view of the risks that simple inadvertent alarms and their associated safety shutdowns can pose to a company's bottom line, also when they do not result in loss of life.

Traditional maritime reliability engineering has often relied on adding redundant machinery to control such single points of failure. However, since safety shutdowns and their associated alarms are mainly configured uniformly on identical (redundant) machinery, they represent a vulnerability as an inadvertent common failure. For instance, the preliminary incident report on *Viking Sky* recounts a scenario in which a common failure condition caused the ship's diesel generators to shut down inadvertently. One of the common conditions was high rolling and pitching caused by bad weather, which is not unusual for modern ships. However, in combination with operating the diesel generators with only the minimum amount of lubrication oil in the oil sumps, it became another story entirely. Each diesel generator's low lubrication oil pressure sensor activated a non-cancellable shutdown. As the ship is diesel-electric, these shutdowns caused a loss of all propulsion. The ship was dead in the water, drifting towards the shore.

A key distinction is that, unlike previously presented incidents, the common failure on the *Viking Sky* was not sudden or instantaneous. Hours before the incident unfolded, the Norwegian Safety Investigation Authority (NSIA) detailed that the crew had accepted 18 alarms on low lubrication oil levels in just four hours and that these had happened in the morning, before the onset of the incident:

> *"On the morning of 23 March, between 0500 and 0904, 18 lubricating oil low level and low volume alarms were registered by the operational DG[7]. Each alarm, having been accepted, cleared within a few seconds." – [13, p. 6]*

The restoration of power occurred at the very last moment. The recent and concluding incident report estimated that the ship was within a ship's length of grounding on the rocks off the coast of Norway [22, p. 27 Fig. 14]. At that point, it had taken the engineering crew 39 minutes to diagnose the low lube oil level as the cause, transfer 10.8m3 of lubrication oil to the sumps, and recover the availability of the power system [22, p. 119]. The report stresses that troubleshooting had been challenging due to the number of alarms that went off following the blackout:

> *"Troubleshooting was therefore challenging when a total of approximately 1,000 alarms went off in the IAS within the first 10 seconds after the blackout." – [22, p. 6]*

The *Viking Sky* incident received substantial attention from the maritime safety community, however, much of the investigation was conducted behind closed doors. It is important to emphasise that the author group of this report had no access to the investigation work of the *Viking Sky* incident, despite substantial involvement of LR's technical performance teams. When highlighting that the MAIB had included the alarm/event log within the annexes of the *RMS Queen Mary 2* incident report [11], our request for the final *Viking Sky* incident report

7 Diesel Generator(s)

to include the same was refused by both NSIA and the technical performance team within LR.

Nevertheless, we expected the *Viking Sky* investigation would address the management of engine room alarms in more detail, as it explicitly mentions this subject in the interim report's section on further investigation [13, p. 8]. This expectation has been confirmed, as engine room alarm management was included as one of the 14 safety recommendations in the final report:

> *"The investigation has found several design and configuration issues related to the engine control room alarm system that likely had a negative impact on the effectiveness and efficiency of engineering officers on watch. Ships' engine room alarm management are not subject to any regulation equivalent to the Bridge Alert Management (BAM) performance standards, with the result that many of these systems, such as the alarm system on Viking Sky and its sister vessels, do not have an optimal design and configuration.*
>
> *The Norwegian Safety Investigation Authority recommends that the Norwegian Maritime Authority make a proposal to the International Maritime Organization (IMO) that an engine room alarm management performance standard shall be developed." – [22, p. 134. Safety Recommendation Marine No. 2024/18T]*

It is noteworthy that the safety recommendations mention the *Bridge Alert Management* performance standards. To the best of our knowledge, there is no available information confirming the effectiveness of these performance standards in addressing the management of alerts on the bridge. Something this work investigates in more detail.

These stories highlight the notion that even basic control systems (BSC) can be programmed and configured with a virtually unlimited number of alarms. However, unlike standard practice in adjacent industries, the maritime sector has yet to establish a comprehensive approach to managing the collective performance of shipborne alarms. A noteworthy difference given that modern ships are typically equipped with several hundreds and sometimes thousands of alarms.

This notion resounded considerably within LR when one of its dominating market segments (liquified gas carriers) developed and released its own alarm management guidelines in response to alarm-related challenges. Here, SIGTTO[8], a non-profit organisation in the maritime sector holding consultative status with the IMO, introduced its own segment-specific *Recommendations for Management of Cargo Alarm Systems*, intended to address all gas carriers [23, p. 4]. Their recommendations point directly to the good practices of adjacent industries (IEC 62682) [23, p. 11].

Reading between the lines, it was a message to Class indicating that current maritime assurance practices (Rules and Regulations) do not adequately control the risks of liquified gas cargo control systems—at the ship's end. Risks that terminal operator of critical energy infrastructure, such as LNG terminals, were no longer willing to accept.

In response to SIGTTO's recommendations, LR examined its own assurance approach internally and in the process an ongoing distinction resurfaced; Alarms need people to work. It was apparent that the provisioning of alarms cannot credit safety alone. The crew's appropriate and timely response—the human element—is needed as well. With modern ships provisioned with thousands of alarms, it could appear that this dependency on the human element is assumed to be true by default and without flaw. Considering the custom of attributing incidents to human errors in the maritime industry, this is quite a paradox [24] [25]. Thus, a question arose to what extent the opinions of watchkeeping seafarers are taken into account with regard to their ability to deal with the collective number of alarms. Moreover, to what extent human limitations are taken into consideration around alarms within the general maritime policies and practices—*the maritime alarm philosophy?*

1. **To what extent does the overall maritime alarm philosophy consider human limitations?**

Answering this question can prove pivotal for the industry's ambition of increased levels of automation, digitalisation, and the adoption of hazardous net-zero fuels in its decarbonisation pathway. An example of newly provisioned alarms is the two alarms recommended

8 Society of International Gas Tanker & Terminal Operators

in the executive summary of the *Recommendations for Design and Operation of Ammonia-Fuelled Vessels Based on Multi-disciplinary Risk Analysis* [26, p. 4]. This collaborative endeavour aims to inform regulations, guidelines, and best practices, ensuring the safe operation of ammonia-fuelled vessels for seafarers [26]. It offers a glimpse into a safety approach for these future fuels—one continuing the track of applying alarms, including its reliance on manual interventions and associated safety shutdowns. Similarly, the mandatory introduction of cyber resilience alarms by IACS UR E26 underscores the ongoing efforts to enhance maritime safety in an ever-increasing interconnected maritime future [27, pp. 27, 28]. Furthermore, despite its emphasis on autonomy, as the IMO MASS[9] Code evolves, considering the human element remains imperative in managing shipborne alarms from remote operations centres (ROC's).

In any way, the number of alarms seems unlikely to decrease any time soon. Especially not with the adoption of additional and more complex technology. Suppose that the answers to the first question fall short of current (and thereby future) expectations. How can it be determined whether an alarm system's performance is acceptable for the maritime setting, and what discernible traits are exhibited with regards to high performance in the management of maritime alarm systems?

2. **How can it be determined whether an alarm system's performance is acceptable for the maritime setting, and what discernible traits do high performers exhibit in this regard?**

To answer these questions, this project sought to understand how the end-users, the watchkeepers, experience the collective sum of alarms. The first phase was the inquiry into the perspectives of the seafarers, who are at the front line of maritime ship operations. At sea, where alarms can mean the difference between life and death, in other words—where it matters.

These findings aim to shine a light on the approaches taken by high performing ships and their organisational management to navigate this complexity, particularly in the absence of legal instruments addressing the cumulative impact of alarms. It does so by revealing best practices, as well as improvement opportunities (challenges) related to managing alarm systems in a maritime setting. It is expected that the industry would benefit greatly from the insights of 65 watchkeepers from 15 ships, managed by 10 distinct companies, who freely shared their thoughts, experiences and data.

The responses to the posed questions indicate that the maritime industry may need to establish consensus on pathways forward, particularly concerning certain serious challenges identified. This report offers recommendations and strategies to chart a course of action in these instances.

That IMO introduced a revised version of the Code on Alerts and Indicators (CAI) in 2009 was widely known prior to the commencement of this project. However, the CAI offers only general design guidance beyond promoting uniformity of type, location, and priority category level for alerts and indicators required by SOLAS[10] and other statutory regulations. As such, it does not extend guidance on (alert) alarm management or beyond.

It is encouraging that extensive work has already been done in adjacent industries to address what has been referred to as the *alarm problem* [9, p. 109]. Holistic approaches have been available for decades, including the application of interdisciplinary methods from human factors/ergonomics, control and instrumentation engineering and systems thinking. These approaches concur that to the human operator an alarm system has one primary quality attribute—usability, e.g., [8, p. xxi]. With further emphasis that this shall be considered in relation to normal operations as well as in cases of abnormal or upset conditions [8, p. 96].

Given the maritime industry's diversity, global competitiveness, and compliance-driven nature, adopting the generally recognised good practices of adjacent industries is no guarantee of success. As has been done in adjacent sectors, the maritime industry may need to chart its own course, discovering and validating practices within its unique contexts. As a trusted advisor, LR aims for this work to serve as a lighthouse for an industry navigating such unchartered waters.

9 Maritime Autonomous Surface Ship
10 The International Convention for the Safety of Life at Sea

Selection of related work

1.8 Overview

The section reviews selected related work specific to the management of alarm systems.

1.9 Strategy and Scope

First, selected work from adjacent industries is presented. As the topic has been extensively researched in these adjacent domains, a formal literature review could exceed 1000 pages. In 1998, Jenkinson reviewed more than 100 items of related work in the second volume of the HSE CR 166 report [9, p. 77]. Thus, this report focuses mainly on the consolidated outputs of the following activities: publications, standards and reports from membership organisations, governmental institutions and standardisation bodies. These entities have consolidated a substantial programme of work to address the management of alarm systems within their respective industries.

Second, we present specific selected outputs known internally at LR to have influenced the content of the CAI, the classification rules and the IMO navigational performance standards, including the Bridge Alert Management standard (also IEC 62923-1/2), but also particular work which has followed since. We have deliberately excluded a semantic search of incident reports, as some have already been presented in the introduction. LR would encourage any academic organisation to undertake a more rigorous and systematic review of related work that includes incident reports.

The findings are summarised with a comparative review of the most recent version of the IMO Code on Alerts and Indicators. This is presented immediately following the summary table of the reviewed material.

1.10 Analysis of reviewed material and scope

An effort has been made to organise the reviewed material into a sequence that provides the reader with the foundation that supports the work going forward and informs the reasoning behind choices made in the research design and methodologies.

TABLE 1.
Summary review of good practices and regulations of adjacent industries and the IMO, related to the management of alarm systems

Adjacent industries and the IMO code on alerts and indicators

Standard, good practice, regulation, investigation	Current/First	Deals with	Lifecycle approach incorporating objective metrics to assess alarm system performance	Address *timeliness* of alarms in detail	Address integrity of the alarm system	Incorporate diversity of evidence in validation of provisioned alarms
IEC 62682	2022/(2009 for ISA 18.2)	Management of alarm systems	Yes	No	Partly	No
IEC 61511-1	2017/2003	Risk reduction claims of alarms	Yes	Yes	No	No
EEMUA 191	2013/1999	Management of alarm systems	Yes	Partly	Partly	No
ANSI/ANS 58.8	2019/1984	Objective time design criteria for alarm rationalisation	Yes	Yes	*NA*	Yes
HSE CR 166	1997	Complete 360-degree view of the then (at that time) current state of affairs, including a summary of identified best practices, results of field investigations, and an extensive literature review on the topic	Yes	No	Yes	No
HSE Chemicals Sheet No. 6	2000	A practical and concise guide to begin an alarm management improvement journey within an organisation	Yes	Partly	Partly	Yes
EASA CS-25	2023/2003	Crew alert systems	No	Yes	Yes	Yes
IMO, Code on Alerts and Indicators	2009/1995	Standardisation of abstract priority levels, colours and position of alerts and indicators, intended to aid designers	No	Limited	Limited	Limited
IEC 62923-1	2018/2018	Bridge alert management performance and testing to demonstrate satisfying the goals of IMO - Resolution MSC.302(87)	No	Limited	Limited	Limited
IEC 60092-504	2023(draft)/2016	Automation, control and instrumentation on ships.	No	Limited	Partly	Limited

TABLE 2.
Review of selected related work on the management of alarm systems

Selected related work specific to the maritime Industry

Author(s)	Year	Theme	Page count	Research	Ships	Participants: Bridge/Engine	Major findings
M.H. Lützhöft, S. W. A. Dekker	2002	Automation surprise	14	Qualitative: analysis of the human-machine interaction of the *Royal Majestic* incident	1	0	Observability, Future-oriented representation is important to human operators working with automation systems.
M. Baldauf, K. Benedict, E. Wilske, P. Grundvik, and J. Klepvisk	2008	Navigational enhanced alert management	8	Qualitative: quantification of provisioned navigational alarms implemented on the bridge. Propose a risk-based solution for dealing with navigational alarms.	1	0	The number of provisioned alarms increases with the level of integration. Algorithms for alarms are "fixed" with no adaption to the operational context of *open sea, coastal* or *confined waters*.
B.S. Jones	2007	Knowledge transferability from other industries	1	Qualitative: Raises awareness of the alarm problem in the maritime industry and proposes solutions used in adjacent industries	0	0	Good practices of other industries are transferable to the maritime industry.
Ø. Rødseth, M. Knight, R. Storari, H. Foos, and A. Tinderholt	2007	Field studies of alarm management on ships	10	Quantitative: Investigate alarm load on various ship types, including normal end-to-end operation and partial blackout on a shuttle tanker. Further investigates the nuisance factor on board one cruise ship.	3	Unknown	A partial blackout on a shuttle tanker found that 206 alarms were generated in the first 115 seconds. End-to-end cruise ship observation in the engine room found that 42% of the 370 alarms during the 40-hour voyage required no operator intervention. On ship investigation reported 78 alarms per hour on average.
B. S. Jones & J.V. Earthy & E. Fort & D. Gould	2006	Improving the design and management of alarm systems	7	Qualitative: Raises awareness of the alarm challenges in the maritime industry and proposes solutions used in adjacent industries. Reports on experiences from internal efforts to manage the problem.	0	0	Recommends applying good practices from other industries such as aviation and the process industry. From the experience standpoint: The paper points out a tendency for designers of individual systems or equipment to adopt a narrow-minded approach to proposing alarms for their own sake.
Later, R. Hudson, P. Traub	2008	Knowledge transferability from other industries	12	Qualitative discussion of the similarities and differences in approaches to alarm management between the rail and maritime industries.	0	0	Both industries face problems such as excessive alarm rates, spurious alarms, and difficulties in prioritising critical alarms. It details how the rail sector implemented formal requirements for safety-critical alarms, prioritisation, and integration of human factors.

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Table 2 continued

Author(s)	Year	Theme	Page count	Research	Ships	Participants: Bridge/Engine	Major findings
R. Thomas	2007	User experience	1	Describes how an end user (himself as a chief engineer) experiences an increase in automation and makes a wish list for the regulatory and design community.	0	0	Wish list of the possibility to suppress non-critical alarms during large upsets and wishes for alarm sound to be initially soft rather than immediately "heart stopping sound."
Motz F., Höckel S., Baldauf M., Benedict K	2009	Field studies of bridge alert management on ships	6	Quantitative and qualitative: Recording of alarm load on the bridge during seagoing voyages. Qualitative interviews with bridge officers.	6	13	Field studies indicate a lack of a harmonised alarm management. Bridge officers adopted coping strategies at times of high alarm loads.
S. Hochgeschurz & F. Motz & R. Grundmann & S. Kretzer & L. Thiele	2021	User opinion about Radar and ECIDS functionality	9	Analysis of online survey data using ANOVA and characterising decomposed functionality of ECIDS and Radar into priority levels in one of three presented navigational situations.	NA	167 (80 analysed)	This study concluded that the navigators regarded almost none of the functionalities (<1%) as extremely unimportant, although it also concludes from its analysis that approximately half of these are situation dependent. Of the 167 participants, only one showed up for a transcribed interview.
MAIB and the DMAIB	2021	Field investigation into the user experience of ECIDS	94	Qualitative: Semi-structured interviews (questions not presented) followed by independent analysis using autocoding software (NVIVO).	31	155	Instead of ECDIS alerts assisting the bridge team in identifying risks and abnormal situations, and making diligent and proper responses to these, they become a hazardous distraction by increasing the mental workload and cognitive stress of its user.
SIGTTO	2019	Best practice guidelines	34	Qualitative: Adopts guidelines from IEC 62682 and projects them onto the cargo alarm systems domain (context of gas carriers).	0	0	Inform its members of industrial best practices for the cargo alarm and control systems on board liquified gas tankers and do so in alignment with IEC 62682. In doing so, it parts away from the Code on Alerts and Indicators concept, but without stating this explicitly. Its title reveals it.
A. M. Nizar, & T. Miwa & M. Uchida	2022	Use of AI (machine learning) to contain chattering alarms and mitigate alarm flooding.	7	Applies novel performance indexes (classification) to alarms using machine learning. The novel indexes are denoted as a "chattering index" for categorising nuisance alarms, "similarity indexes" between non-unique alarms, and alarm floods.	1	0	The study claims that its analysis of real ship data demonstrates the efficacy of the alarm performance assessment in identifying nuisance alarms and alarm floods. It does so, acknowledging that the assessment evaluates only a fraction of the human-machine interface. The study does not consider all defined characteristics of a nuisance alarm. Only the chattering characteristic is considered.

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Selection of related work

1.11 Synthesis results of related work

The maritime industry invested some effort into the subject area between the early 2000s and the present, with a majority of the activities carried out prior to the revision of the second version of the CAI, 2009. Recent studies and work indicate a reawakened interest or need in the industry. This is supported by the reports on the usability of ECDIS for the bridge context and the incident reports presented in the introduction on engine room related alarms; these incidents were from vessels contracted and constructed after adopting the revised version of the CAI in 2009, including the BAM performance standard in 2014.

The maritime industry's focus on "ingredients" and "taste":

There seems to be an overemphasis in the maritime sector on creating bespoke solutions. Namely for specific equipment, at specific positions on board the ship, for specific crew roles, and for specific use cases only. This tendency is prevalent, whether it is implementing machine learning algorithms for alarm pattern mining, developing novel risk models for collision prevention, or designing centralised alert management displays (CAM-HMI's) for bridge alert management. This perpetual search for bespoke solutions often revolves around satisfying prescriptive parts of regulations ("ingredients") and achieving desired outcomes ("taste"). Perhaps it is a natural limitation of what goal based standards (GBS) can achieve.

Adjacent industries focus on "recipes" and the evidence trail of "breadcrumbs":

In contrast, the adjacent industries have spent significant time and effort refining the governing processes ("recipes") to ensure the intended effect, or "taste", of the applied solutions ("ingredients"). Their adopted processes, such as alarm rationalisation, the tangible commitment to implement continuous assessment and performance monitoring, the adoption of so-called TCA programs, and factoring in alert system integrity, testify to such approaches. Approaches that all asses the "breadcrumbs" or evidence trail of the processes' appropriate sequence (Table 6).

What it took for adjacent industries to get so far:

Based on the review of the related work in the maritime industry, it is understood why certain authors advocate for applying the extensive good practices of these adjacent industries in a maritime context. It is, however, also apparent that it took a significant amount of time and effort for these industries to adopt these processes as holistic lifecycle management philosophies. This effort appears to be greater than what has been invested in the maritime sector.

The maritime industry may not be alone. The HSE CR 166 report and the ANS/ANSI 58.8 standard versions show that specific industries had sound management practices around alarms and time-critical actions for a long time, with practices in place long before the first EEMUA 191 publication. In the CR 166 report, the literature review in the CR 166 report even had to separate the nuclear industry from the rest of the reviewed literature, since it was so extensive. The chemical (process) and power industries appear to have needed a friendly "nudge" from a national (and highly regarded internationally) regulating entity (the HSE) to make it happen.

A half-hearted approach to prioritisation:

It is understandable why the related work favoured the concept of *alerts* from the field of aviation. Specifically, its approach to prioritisation was considered to be a future solution to many challenges experienced at that time, whether it was a decision to reject the use of alarm filtering or abandon the minimisation approach of alarm rationalisation. Excuses were plentiful and were attributed mainly to a lack of resolve from the shipyards and system manufacturers. The challenge further aggravated by an adversarial setting around design liability, whenever the Regulator, Owner, or Class attempted to intervene. In such a design environment, it is understandable that the hypothesis of simply prioritising and presenting the most important information to the users seems so appealing at first glance.

However, the maritime industry adopted only the abstract alert priority categories while leaving out the requirement of prioritisation to work within each individual category, nor did it insist on processes around establishing the timeliness attributes of the alerts (part of alarm rationalisation). Without this attribute, it is difficult to assess how anyone can establish the urgency of an alarm or alert. This effectively renders any heuristic for prioritisation implausible or, at best, subject to subjective opinions.

In summary:

Based on the review of the related work alone, the following conclusions can be made:

1. First, the coined *alarm problem* appears to have been known in the maritime industry for several decades. Both before and after the adopted revision of the CAI, aspects of this have been reported from several research outputs and incident investigations. As a GBS regulation, none of the content within the CAI prescribes the processes identified by adjacent industries. SIGTTO has made efforts to address the issue within its segment, but only for the cargo and transfer systems. In light of this, there is no reason to believe that risks associated with poor alarm management have come under control in the maritime industry.

2. Second, without a rationalisation process that establishes relevance (consequence of inaction) and timeliness (time to respond) quality attributes of an alarm, its urgency cannot be established. Without these, even basic prioritisation (which does not consider the necessary or optimum sequence of responses to the alarms) cannot be established for alerts of the same priority category. In short, prioritisation is likely the most challenging part of alarm management rather than the panacea it was first envisioned to be.

3. Third, none of the policymakers within the maritime industry, such as the Organisation, Administrations or Classification Societies, impose and validate a minimisation process (rationalisation) on the number and quality of alarms. Nor do these entities define objective performance criteria, such as engineered composition limits of priority distributions, allowable response time design and maximum alarm rates per watchkeeping officer on watch at the specific control station. Considering these aspects, there is no rationale for shipyards, equipment and systems manufacturers, and even regulators as to why an alarm should not be implemented. On the contrary, it becomes a “just in case” or a “quick fix” that does not solve deeper problems. It is cheaper and easier to implement an alarm than it is to determine whether it actually adds value to safety management.

The future of the IMO’s Code on Alerts and Indicators:

It is questionable whether IMO initially intended the CAI to be a stepwise approach to continuous improvement. The resolution document detailing its adoption, Resolution A.1021(26), explicitly requests that two of its committees keep the CAI under review and update it as necessary:

> *“3. REQUESTS the Maritime Safety Committee and the Marine Environment Protection Committee to keep the Code under review and update it as necessary” – IMO resolution A.1021(26).*

The resolution document has a watermark in its bottom right corner: *“2010 – YEAR OF THE SEAFARER”*. It is unclear as to when these committees last sought out the opinion of seafarers with regard to the effectiveness of the CAI; any such undertaking could not be identified. This could explain the reason that the CAI has not been revised for 15 years (so far). A similar length of time passed between 1995 and 2010 before the first edition was revised.

In the light of these indicators, the alarm is blinking red on the action to investigate the need for an update. This time, it would be wise to involve the actual users—the people expected to respond to the alarms.

1.12 Selection of related work in adjacent industries

1.12.1 IEC 62682

Management of Alarm Systems for Process Industries [18]. Historically, the process industry has experienced challenges with alarm management. The industry has always used alarms to help operators operate processes safely (explained further in the review of IEC 61511) under normal and abnormal conditions. As technology has increased in basic process control systems (BPCS) and safety-related systems, the ease of creating alarms has improved (simple reconfiguration of software allows for a virtually unlimited number of alarms).

As the ease of creation has improved, so has the ability for commercially off-the-shelf platforms to automatically create their own alarms. This led to an exponential increase in the number of alarms on each system. Each process plant is often composed of several systems that could produce similar uncoordinated alarms or alarms with a common root cause, potentially resulting in alarm floods for a single incident. Considering that a process plant is an asset with a long life and that alarms are easily created, it is very likely that the number and extent of alarm floods would increase over time (e.g., through modification, expansion, and degradation).

In 2009, the International Society for Automation (ISA) developed ANSI/ISA 18.2, Management of Alarm Systems for Process Industries, while taking into account other guidance such as EEMUA Standard 191, Alarm Systems: A Guide to Design, Management and Procurement, as the first significant standard to address alarm management issues in the process industry. ANSI/ISA 18.2 was one of the documents used as the basis of the development of the first international standard on alarm management, which was IEC 62682, Management of alarm systems for the process industries, which was initially released in 2014 with the latest version being released in 2022, which still credits EEMUA.

More details of the IEC 62682 standard will be provided in the review of EEMUA 191, as much of their contents intersect. While the alarms implemented in a safety instrumented system (SIS) are included in the scope of the standard, it refers to IEC 61511 for the design of safety-related Human-Machine-Interface (HMI), including the design and management of safety instrumented systems.

1.12.2 IEC 61511

This section, IEC 61511, on Functional Safety, was contributed in its entirety by Peter Brown, Chair of the 61508 Association.

The concept of functional safety applies in many sectors and applications. Functional safety can be defined as the *part of the overall safety relating to the process and the BPCS which depends on the correct functioning of the SIS and other protection layers* (IEC 61511-1:2017+A1:2017 clause 3.2.23 for the process industry). In some functional safety standards, any alarm is a side element or output of functional safety, but in the process industry an alarm is allowed as part of the formal risk reduction for safety.

Allowing an alarm as a layer of protection requires that the alarm and its elements are independent from the initiating cause and any other layers of protection. For example, if the initiating cause could be a sensor failure, this same sensor cannot be used for the alarm. Also, the sensor(s) for the alarm cannot be the same sensor(s) as those used for the associated safety instrumented function (SIF). In essence, the alarm is a means of risk reduction by reducing the demand rate on the SIS. For example, a high-pressure alarm is defined significantly below a high-high pressure trip (SIF) ensuring that the SIF remains in the “low demand” band (caution: poor alarm maintenance and response can push the SIF into the “high demand” band).

In the process industry, as in many other sectors, it is acknowledged that alarms may only be of limited use for response to safety issues. This is because, although the front end of the loop is automated, the back end of the loop is reliant on human reaction. This human reaction can easily be blocked or hampered by many factors including, but not limited to, resource limitations, performance, competence/training and alarm/system design. Claiming an alarm (including the associated human reaction) as a layer of protection is therefore limited to a risk reduction factor (RRF) of ≤10 (a restricted value). Claims better than this are possible, but it means applying the approaches of IEC 61511-1 (and therefore probably IEC 61508 as well) to the alarm system and operator (or crew). This is process is significantly more onerous and the majority of duty holders (companies) minimise this approach.

IEC 61511-1 requires that any claims for risk reduction from an alarm layer of protection should be supported by a documented description of the necessary response for the alarm and justification that there is sufficient time for the operator to take the corrective action as well as assurance that the operator will be trained (initially and on an ongoing basis) to take the preventive actions. IEC 61511-1 also requires that each alarm used as a layer of protection has a verification process for the alarm set points (repeated checking that they are valid and correct).

It is worth noting that other functional safety standards e.g., IEC 62061 for industrial machinery, give no credence to risk reduction from alarm systems. In the creation of this international standard, the sector acknowledges that industrial machinery operators frequently, and for various reasons (e.g., competence, attention/ distractions, shift patterns, commercial pressure), ignore alarms and continue operation regardless. The reliance on alarms to contribute to risk reduction is not always appropriate; the reasonably foreseeable use and misuse of alarms should also be considered.

1.12.3 EEMUA publication 191

Alarm systems: a guide to design, management, and procurement [8].

The guide was published in 1999 and soon became a globally accepted and leading guide for good practices in alarm management [8]. It is now in its third edition and is the most cohesive collection of material available on the topic. Unlike IEC 62682, it comprises not only what to do, but also why to do it and how to do it. The publication covers definitions and guidance for the principles of alarm system design at the beginning of the process of forming and designing the alarm system, as well as for alarm systems that are already operational. It includes general and specific assessments, how to implement an alarm management system in a company and how to define an alarm philosophy. It presents a comprehensive approach to managing alarms effectively for the entire lifecycle of an asset. It does so by introducing the concept of an *alarm Management Lifecycle*, that includes sequential and iterative steps with multiple points of entry to the lifecycle. Entry points are rounded shapes (Figure 5).

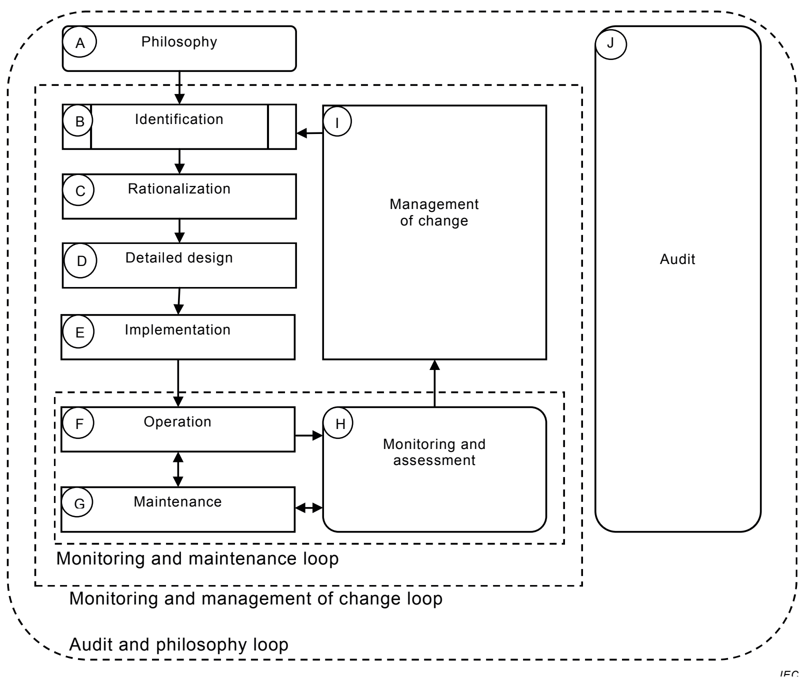

FIGURE 5.
Alarm Management Lifecycle – IEC 62682:2014 [18, Fig. 1], Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch, (borrowed from IEC 62682, as these are not rounded in the EEMUA document)

Going into each step of the lifecycle would be too extensive, but it is worth describing some of its key concepts related to the work disseminated in this report.

The *Alarm Philosophy* is a consensus document in which all relevant stakeholders (including senior management) agree on the scope of each lifecycle step. An example could be how to monitor and assess the performance of the alarm system in operation, which is step *H* within the *Monitoring and maintenance loop*. Only the activities of the *Audit* stage may inform improvements to the philosophy document.

This *Monitoring and assessment* stage describes and suggests both objective and subjective ways of assessing the overall performance of the alarm system. EEMUA 191 objective methods include analysing quantitative data, whereas the subjective methods entail conducting qualitative investigations (Table 3). In contrast, IEC 62682:2014 and its later 2022 version primarily defines objective (quantitative) performance metrics (Table 4), and move the qualitative assessments into its *Audit* stage [18, p. 77]. For qualitative assessment, the EEMUA 191 publication applies an adapted operator questionnaire used in a semi-structured interview approach and an usefulness questionnaire used to gauge operator alarm nuisance factor [8, p. 177]. These questionnaires were first presented as a survey in the HSE CR 166 [9, p. Appendix 6].

The *Rationalisation* stage *C* (Figure 5) is a likely prerequisite to achieving the quantitative performance figures in either Table 4 or Table 3. This stage is an activity that enforces hygiene on the (usually many) proposed alarms from the previous *Identification* stage *B*. It is a vigorous activity that justifies that each alarm provides value to the human operator, meaning the human(s) who are later made responsible for responding to the alarm.

It imposes a set of key quality attributes that make an alarm fit for purpose. The three most prominent are:

- Every alarm should have a defined purpose.
- Every alarm should have a defined response.
- dequate time should be allowed for the operator to carry out this response.

The publication explicitly states that if the rationalisation cannot satisfy these qualities, then the signal should not be an alarm. The guide elaborates on no fewer than eight quality attributes (Table 5).

TABLE 3.
Monitoring and assesment performance indicators defined within EEMUA 191 [8, p. 94 Table 13]

What to measure	Type of measurement	How
Performance during a major upset	Quantitative	Measure major plant upset alarm rate per 10 min. period during upset
Performance in steady state operation	Quantitative	Measure average alarm rate. Per X time period/number of 10 min. periods
Alarms which are occurring most often (and hence causing most problems)	Quantitative	Measure individual alarm frequency per X time period
The distribution of alarm priorities	Quantitative	Measure percentage priority distribution of all alarms on the system
Alarms which have been active on the system for a long period	Quantitative	Measure the number of alarms which have been active for X period
Number of alarms configured	Quantitative	Measure total number of alarms on the system
Operators general satisfaction with the system	Qualitative	Operator questionnaire
Operators view of how useful the individual alarms are and the quality of the alarms	Qualitative	Alarm usefulness questionnaire
Operator response time	Quantitative/Qualitative	Measure time
General performance during a plant upset	Qualitative	Recording and analysing alarm data when a plant incident has occurred

TABLE 4.
Monitoring and assesment performance metrics defined in IEC 62682:2014 [18, Table 7], Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch

Alarm performance metrics based upon at least 30 days of data		
Metric	**Target value**	
Annunciated alarms per time	Target value: very likely to be acceptable	Target value: maximum manageable
Annunciated alarms per day per operator console	~144 alarms per day	~288 alarms per day
Annunciated alarms per hour per operator console	~6 (average)	~12 (average)
Annunciated alarms per 10 minutes per operator console	~1 (average)	~2 (average)
Metric	**Target value**	
Percentage of hours containing more than 30 alarms	~< 1 %	
Percentage of 10-minute periods containing more than 10 alarms	~< 1 %	
Maximum number of alarms in a 10-minute period	≤ 10	
Percentage of time the alarm system is in a flood condition	~< 1 %	
Percentage contribution of the top 10 most frequent alarms to the overall alarm load	~< 1 % to 5 % maximum, with action plans to address deficiencies.	
Quantity of chattering and fleeting alarms	Zero, action plans to correct any that occur.	
Stale alarms	Less than 5 present on any day, with action plans to address.	
Annunciated priority distribution	3 priorities: ~80 % low, ~15 % medium, ~5 % high or 4 priorities: ~80 % low, ~15 % medium, ~5 % high, ~< 1 % highest Other special-purpose priorities (e.g. system diagnostic alarms) excluded from the calculation.	
Unauthorized alarm suppression	Zero alarms suppressed outside of controlled or approved methodologies.	
Unauthorized alarm attribute changes	Zero alarm attribute changes outside of approved methodologies or MOC.	

TABLE 5.
Characteristics of a good alarm – EEMUA 191 [8, p. 4 Table 1]

Characteristics of a good alarm	
Relevant	i.e. not spurious or of low operational value
Unique	i.e. not duplicating another alarm
Timely	i.e. not long before any response is needed or too late to do anything
Prioritised	i.e. indicating the importance that the operator deals with the problem
Understandable	i.e. having a message which is clear and easy to understand
Diagnostic	i.e. identifying the problem that has occurred
Advisory	i.e. indicative of the action to be taken
Focusing	i.e. drawing attention to the most important issues

To the best of our knowledge, neither classification societies nor administrations require a review of the breadcrumbs (evidence trail) of a minimisation process of the number of alarms (or alerts in the maritime syntax).

Such would entail reviewing the *Alarm Master Database*, which is the output of the rationalisation stage for each alarm. A consolidated view of each lifecycle stage, its activities, inputs and outputs are depicted in Table 6.

TABLE 6.
Inputs and outputs of activities in the Alarm Management lifecycle – IEC 62682:2014 [18, Table 1], Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch

Alarm management lifecycle stage		Activities	Clause number	Inputs	Outputs
Stage	Title				
A	Philosophy	Document the objectives, guidelines and work processes for alarm management, and ASRS.	6,7	Objectives and standards.	Alarm philosophy and ASRS.
B	Identification	Determine potential alarms.	8	PHA report, SRS, P&IDs, operating procedures, etc.	List of potential alarms.
C	Rationalization	Rationalization, classification, prioritization, and documentation.	9	Alarm philosophy, and list of potential alarms.	Master alarm database and alarm design requirements.
D	Detailed design	Basic alarm design, HMI design, and advanced alarming design.	10,11,12	Master alarm database and alarm design requirements.	Completed alarm design.
E	Implementation	Install alarms, implementation testing, and implementation training.	13	Completed alarm design and master alarm database.	Operational alarms and alarm response procedures.
F	Operation	Operator responds to alarms, and refresher training.	14	Operational alarms and alarm response procedures.	Alarm data.
G	Maintenance	Maintenance repair and replacement, and periodic testing.	15	Alarm monitoring reports and alarm philosophy.	Alarm data.
H	Monitoring & assessment	Monitoring alarm data and report performance.	16	Alarm data and alarm philosophy.	Alarm monitoring reports and proposed changes.
I	Management of change	Process to authorize additions,	17	Alarm philosophy and proposed	Authorized alarm changes.

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Specifically for safety alarms, EEMUA describes the reliability as a chain. An alarm functioning as a layer of protection is only as strong as its weakest link. As an example, if the sensor that measures the process variable (e.g. gas concentration) has a low reliability score and tends to drift easily, thereby requiring lots of recalibration and cleaning (maintenance), that may be the weakest link of the provisioned alarm. Like 62682, IEC 61511 is referenced for the topic of safety alarms within EEMUA 191. As the EEMUA 191 highlights data is readily available for certain parts of such an analysis, such as the reliability and integrity of sensors; *Process Measurement* (Figure 6).

On the other hand, data is limited for the human reliability aspects, *Operator Response* (Figure 6). Here, the EEMUA 191 states the importance of proof testing the alarm by scenario testing. However, there is no mention of any specific methodologies or references to good practices in designing and conducting such scenario testing. Likewise, IEC 62682 details the word *Measurement* in its description of the feedback model of operator-process interaction, where the human operator sub-system is decomposed of three stages: *Detect, Diagnose* and *Respond* (Figure 7). It is likewise silent on how to conduct such measurements. It further mentions factors that shape the performance of this sub-system, such as workload, HMI design and ergonomics, fatigue, the user's level of training, past experience, and situational awareness in the given situation and environment.

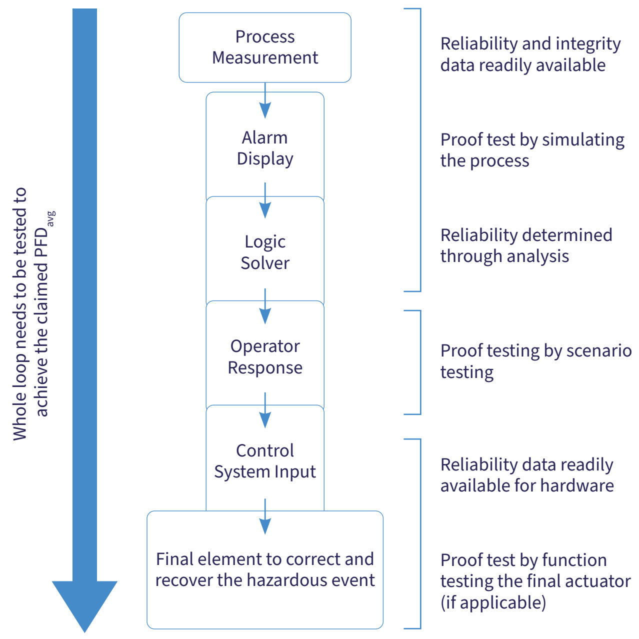

FIGURE 6.
Proof testing of safety related alarms – EEMUA 191. [8, p. 23 Fig 10]. Re-drawn for image clarity

The human factors aspect of these features is well-understood and established. Human factors professionals know how to design user-friendly HMI and ergonomic control centres. Also on ships. They also know how to create and implement efficient training programmes and resource management. Similar to other industries, a seafarer must demonstrate tangible levels of minimum seagoing experience and accomplished formal education to become a licensed officer of the watch (OOW), which is governed by the STCW[11] convention.

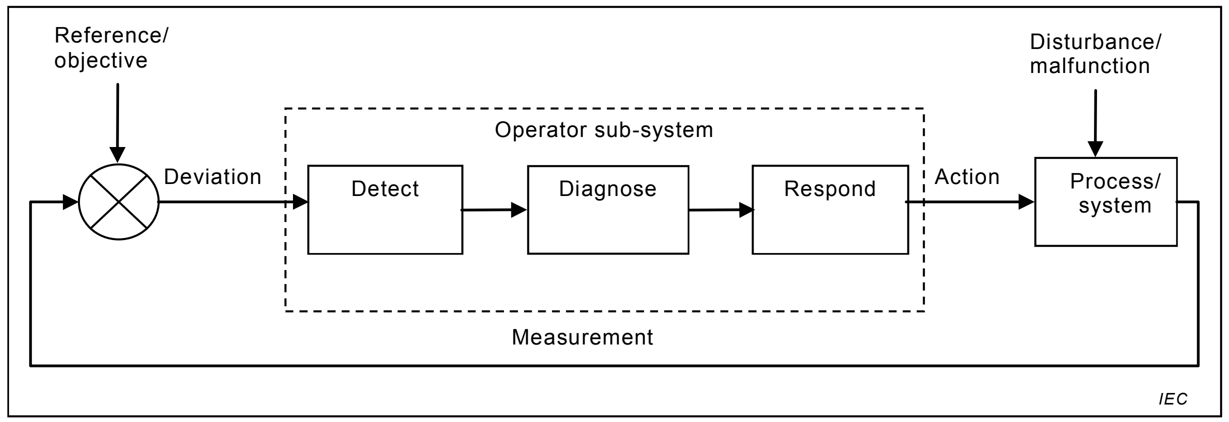

FIGURE 7.
Feedback model of operator-process interaction – IEC 62682:2014 [18, Fig. 5], Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch

11 International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

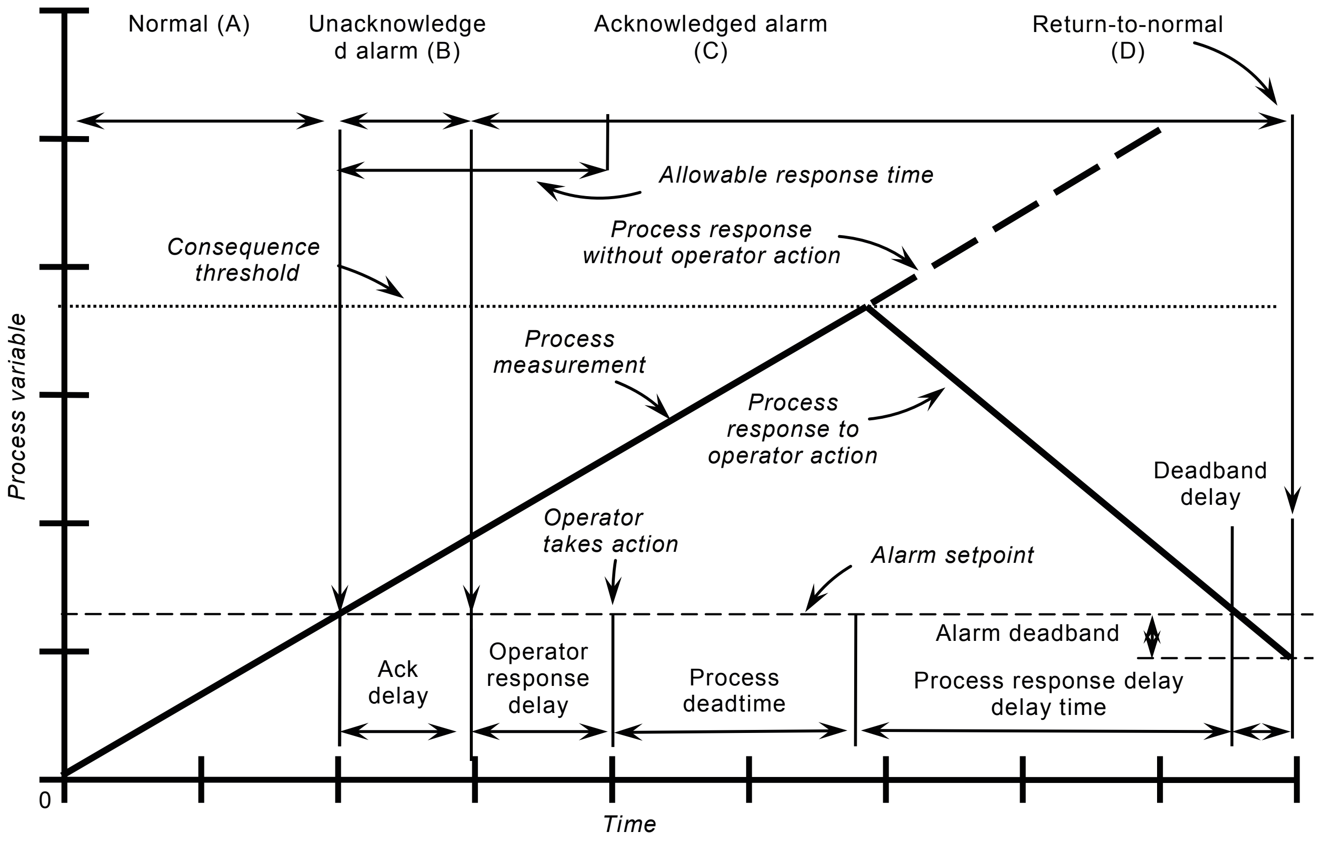

FIGURE 8.
Alarm Response Timeline – IEC 62682:2014 [18, Fig. 4], Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch

What is not well understood is the *time response design* criteria or the so-called alarm quality attribute of *timeliness*. Observing the *Alarm response timeline* from IEC 62682 (Figure 8), it is evident that without quantifying and validating the *available response time*, any claim that the operator (user) has sufficient time to respond comes with a high degree of uncertainty.

Although the EEMUA criteria that *"Adequate time should be allowed for the operator to carry out this response"* is one of the three primary quality attributes of any alarm, it is likely the most challenging attribute to rationalise in practice. This is because it depends on many external and unbound factors. Yet, such uncertainty in the rationalisation stage of an alarm will merely propagate downstream to those who may need to action it at some point.

Correspondence with the executives and product owners of the EEMUA 191 publication confirmed that the alarm quality attribute of *timeliness* is a challenge in their experience. In addition, conversations with expert alarm management practitioners, some of whom are voting members on the ISA 18 committee, utilise project specific design rules for the allowable response time. Typically, a limit of 10 minutes is decided within the alarm philosophy. Other organisations specialised in alarm management report that values of fewer than five minutes rarely make the case during rationalisation [28]. Also, the IEC 62682 standard explicitly excludes the management of the operator. Its only exception is a requirement to ask operators during audit interviews if they have sufficient time to respond to alarms [18, p. section 18.4 (c)]. In the same way, EEMUA 191 does not provide detailed guidance on how to assess the performance criteria of the *timeliness* quality.

1.12.4 ANSI/ANS 58.8 (RE2017) (Withdrawn)

Time Response Design Criteria for Safety-Related Operator Actions [19].[12]

Although it has been withdrawn and replaced by its 2019 version (reviewed next), the standard is an example of how one industry worked to manage the problem of the timeliness quality attribute for alarms. The ANSI 58.8 (RE2017) applies a set of scalable yet conservative design rules for the minimum allowable operator response time, and that automated safety functions must be completed before a consequence occurs. It also incorporates the flexibility to allow the use of empirically observed human performance data as a viable pathway to demonstrate the performance criteria which is a 95% confidence level.

The introduction of the R2017 standard refers to a "ten-minute rule", which had gained some acceptance in the respective industry, but reviewers subsequently raised concerns as to whether the time allowance was inadequate in some cases. The standard was therefore further developed to adopt a more comprehensive approach and, in some cases, a more conservative set of requirements. The earliest version of 58.8 (1984) used times based on simulator measurements of operator performance and nuclear plant data collected from actual events. That approach continued, and the applied times were recalibrated or verified using similar methods during the years the standard underwent multiple reaffirmations. Its appendix describes these activities in greater detail. Perhaps the most noteworthy aspect was the inclusion of non-licensed operators (undergoing licensing) and experienced operators (undergoing relicensing) in statistical sampling and analysis.

The statistical analysis provided the basis for defined time intervals (design rules) on the specific minimum duration for the operator to successfully respond at a 95% confidence level. This includes the necessary time length for an operator to diagnose the condition based on a statistical probability of the plant being subject to a plant condition caused by the design basis event (DBE) (Table 7). While the standard does not credit an assignment of a given confidence level that the operator's action will be correct, it assumes that these time lengths will ensure that other performance shaping factors (e.g. HMI-layout, training level, procedures) that dominate success. Not the "time available" in a collective probability of human operator response error. It aims to ensure that system designers have engineered sufficient *allowable response time* into the systems DBEs (alarms).

Similar to IEC 62682, the ANSI 58.8 standard defines discrete time points and the time intervals between each of these points. It has more time points than the IEC 62682 standard. These are used within the design rules of the standard (Figure 9). One example being that the "t_{SAC}" (time point of completed safety action(s)) is completed before the delays in the process response time would not anyway activate an automated safety function ("t_{SFC}").

An example specific to the maritime industry could be opening a manual valve for additional cooling to an overheating auxiliary engine. There is a process delay time before the cooling water reaches the destination, which depends on design constraints such as pump capacity, pipe length and heat exchanger sizing. If the valve is opened too late, the unit may still trip (shut itself down) as a safety function, even though cooling was already on its way.

This safety function "t_{SFC}" must complete, in sufficient time for the engine not to reach its design requirement limit "t_{lim}", or it may blow its head gasket or something worse. The minimum time required for the operator to diagnose and perform manual safety actions can be derived from the tables within the standard mapped to the DBE likelihood. Here each discrete manual safety action, such as opening a watertight door (and closing it again) to get to the valve, possible located in the machinery space, accounts for the variable "*n*" in (Table 8). In this context the standard also considers the cognitive difficulty ($TI_{diagnosis}$) and the sequence of necessary safety actions ($TI_{operator}$) which can depend on spatial attributes and resources available. It further prescribes that the designer must account for a single operator failure in a sequence of necessary safety actions. After all, humans are not 100% reliable.

12 Extracted from American National Standard ANS-58.8-1994 (withdrawn) (R2017) with permission of the publisher, the American Nuclear Society.

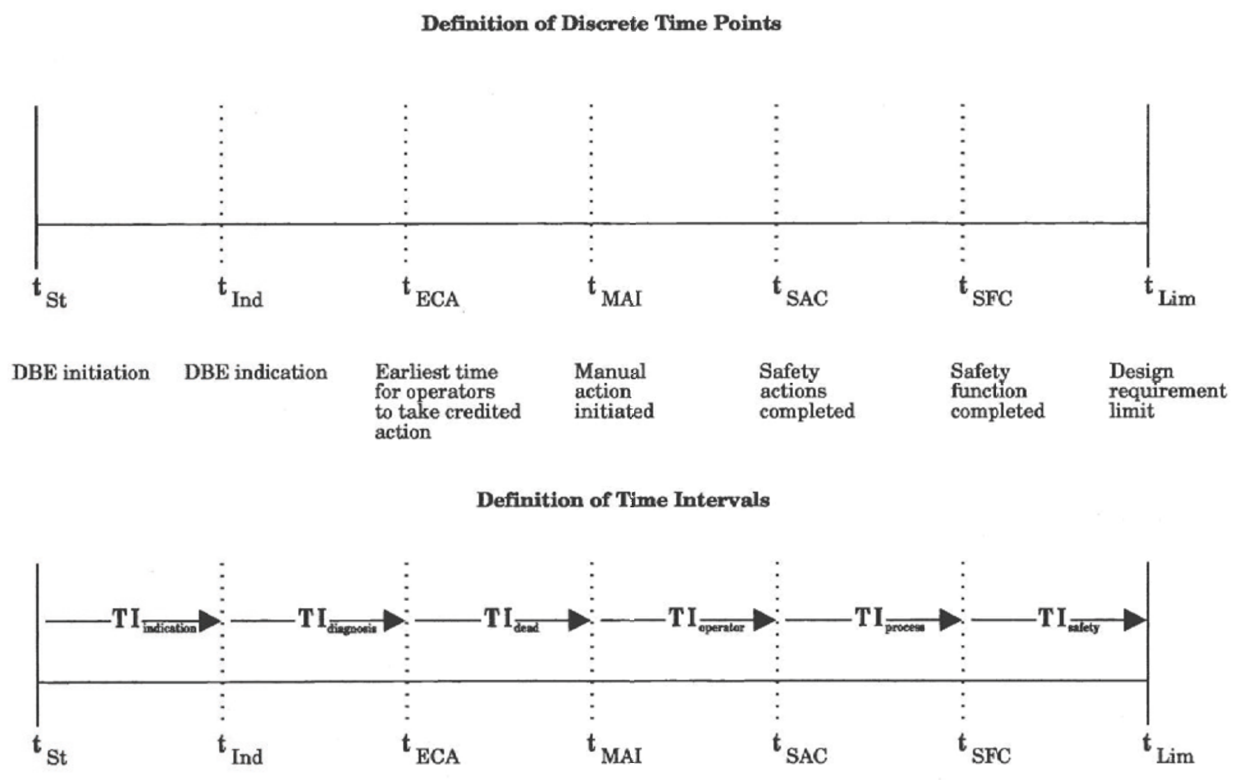

FIGURE 9.
Time intervals and discrete time points of a DBE - ANSI/ANS 58.8 (RE2017)Withdrawn [19]

TABLE 7.
Best Estimate probabilities of DBE's with associated plant condition mapping used within the standard - ANSI/ANS 58.8 (RE2017) Withdrawn [19]

Plant Condition	Best Estimate Frequency of Occurrence (F) per Reactor Year
PC-1	Normal Operations
PC-2	$F \geq 10^{-1}$
PC-3	$10^{-1} > F \geq 10^{-2}$
PC-4	$10^{-2} > F \geq 10^{-4}$
PC-5	$10^{-4} > F \geq 10^{-6}$

TABLE 8.
Time for Operator Diagnosis of DBE and for discrete safety actions – ANSI/ANS 58.8 (RE2017)Withdrawn [19]

Minimum $TI_{diagnosis}$ for Each PC

Plant Condition	Minimum $TI_{diagnosis}$
2	5 minutes
3	10 minutes
4 and 5	20 minutes

$TI_{operator}$ Sub-intervals (minutes) for Each PC and for Actions to be Taken Outside the Control Room

Plant Condition	Fixed	Variable*
2	1 +	*n*
3	3 +	*n*
4 and 5	5 +	*n*
Actions Outside Control Room	30 +	*n*

* *n* signifies the number of discrete manipulations to complete a specific, single operator action.

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1.12.5 ANSI/ANS 58.8 (2019)

Time Response Criteria for Manual Actions at Nuclear Power Plants, 2019 [29].[13]

The new title shows the reformation of the previous practice. The working group of ANSI/ANS 58.8 had concluded from industry feedback that the data background for the previous time intervals was perhaps a bit outdated. The basis of that conclusion is attributed in its introduction to the fact that much more advanced forms of simulators have become available over time. Some of these are also mentioned as incorporating virtual reality.

In contrast to the previous standard (RE2017), the 2019 version now requires specific calculations of the discrete time points similar to those described within ANSI/ANS 58.8 (RE2017), and that the designer demonstrates at least 50% additional margin in the design phase, and at least 20% additional margin during preoperational validation:

"

1. *Performance times should have a margin [refer to Item (2) below for margin calculation method] of not less than 50% when estimated during design and shall not be less than 20% when validated prior to and during operations. Users of this standard should assess the sources and level of uncertainties in their calculations to judge the adequacy of the recommended margins for their application. Lower margin during design means proceeding with design at risk, since preoperational validation with actual procedures and site-specific simulator or walk-downs shall be required to meet the margin requirements as described herein.*

2. *Method to determine margin:*

    - *Time zero (T-0) is the initiation of the condition during an event that requires manual actions. It might be the initiation of the event or when the condition emerges during the event. If the operational cue is different than the initiating condition, users shall determine the time from T-0 until cue to initiate manual action. This cue may be an alarm or anything else that alerts the operator that the action is required.*

    …example omitted…

    Performance Time = (time from cue until action completed)

    Available Time = (time from cue until analysis requires the action completed)

    …example omitted…

$$Margin = \frac{(Available\ Time)-(Performance\ Time)}{(Available\ Time)} \cdot 100\%$$

" – [29, pp. 5, 6]

In addition, the standard prescribes that each site shall implement an administrative control program to contain activities or the lack of activities that may affect *Time Critical Actions* (TCA). Its section on the TCA Program states that the performance criteria of any TCA shall be validated no less than three times using different performers (operators). It further prescribes that this shall be performed with more than one crew [29, p. 11].

1.12.6 HSE Contract Research Report No. 166

Bransby, M. L. and Jenkinson, J. – The management of alarm systems, 1998 [9].

Addressing the chemical and power industries, an extensive (242 page) research report was published in 1998 by the United Kingdom Health and Safety Executive (HSE), which was contracted in part due to the 1994 Milford Haven incident. An incident in which the operators were hindered in intervening with the situation due to annunciated alarms occurring every two to three seconds for hours [30].

The best practices (at that time) in the chemical and power industries on procurement, design, and management of alarm systems were explored and reported. No fewer than 15 different plants were visited, and 96 plant operators filled out a survey questionnaire to determine their opinions of the alarm systems. The authors of the

13 Extracted from American National Standard ANS-58.8-2019 with permission of the publisher, the American Nuclear Society.

HSE report also visited three Company Engineering and Research and Development (R&D) centres to discuss company generic standards on the design and procurement of alarm systems and what research they had conducted on the matter. Furthermore, discussions were conducted with members of the Engineering Equipment and Materials Users Association (EEMUA) on the management of alarms.

The report identified multiple improvement points and raised many unanswered questions worth further consideration. Its authors reported that several actions could be taken to benefit the financial and safety aspects of several plants—benefits achieved from proper due diligence in the management of their alarm systems.

To list a couple of their improvement points:

1. Have operator performance models to understand how they use the alarm system.

2. Minimise audible warnings, which were a severe nuisance during plant upsets because of the continuous distraction of high sounds.

3. Documentation and formalising the management of alarm procedures in the companies, and to have industry standards relating to the design and management of alarm systems.

The report created a consolidated base for further work on alarm management. As noted in its Volume 2, section 3.4, 'Liaison with EEMUA', at the time of writing, the authors of the report [9, p. 71] considering publishing a guidance document on alarm management. This became the EEMUA 191 publication.

1.12.7 HSE Chemicals Sheet No 6

The HSE information sheet, *Better alarm handling*, was an actionable output of the Texaco Milford Haven refinery incident investigation and the HSE Contract Research Report No. 166, which it recommends for further reading [31, p. 4]. It is a short and concise four-page guide on assessing and improving the management of alarms across a plant or even an organisation. It uses three succeeding steps. Each step contains a series of questions that guide the process of obtaining objective information, subjective information from the human operators, information from senior management, and lastly, using that information to improve the performance, propagate improvements to other sites, and remain on top of what has been achieved.

1.12.8 EASA, CS-25.1322

European Union Aviation Safety Agency (EASA), Rules for Large Aeroplanes, 25.1322 – Flight Crew Alerting – 30th January 2023 [32].

The design rules governing the crew alert system within CS-25.1322 align with using three priorities similar to IEC 62682 (low, medium, high), but with a different approach of using the abstract type of "alert" with the following definitions:

> *"(b) Alerts must conform to the following prioritisation hierarchy based on the urgency of flight crew awareness and response:*
>
> *(1) Warning: For conditions that require immediate flight crew awareness and immediate flight crew response.*
>
> *(2) Caution: For conditions that require immediate flight crew awareness and subsequent flight crew response.*
>
> *(3) Advisory: For conditions that require flight crew awareness and may require subsequent flight crew response." – [32]*

Interestingly, the use of the word "alarm" is absent. The CS-25.1322 enforces prioritisation within the alert categories (levels) of the *Warning* and *Caution* priority types:

> *"(c) Warning and Caution alerts must:*
>
> *(1) be prioritised within each category…"- [32]*

Like IEC 62682, CS-25.1322 prescribes that the prioritisation must consider multiple factors such as the urgency (in most basic form a combinate of the consequence of inaction and the time left to respond), and also the necessary sequencing of the flight crew response. This is explicitly defined for events in which multiple alerts of the same category (such as warnings) are presented simultaneously, as this may confuse the crew or when the sequence of the crew response is important. It further prescribes that the priority category should adapt to changes in urgency:

> *"Managing Alerts. Prioritise alerts so that the most urgent alert is presented first to the flight crew.*
>
> *a. Rules and General Guidelines*
>
> *(1) All flight deck alerts must be prioritised into Warning, Caution, and Advisory categories… omitted…*
>
> *(2) To meet their intended function(s), alerts must be prioritised based upon urgency of flight crew awareness and urgency of flight crew response… Normally, this means Time-critical warnings are first, other Warnings are second, Cautions are third, and Advisories are last…*
>
> *(3) Depending on the phase of flight, there may be a need to re-categorise certain alerts from a lower urgency level to a higher urgency level. Furthermore, prioritisation within alert categories may be necessary if the presentation of multiple alerts simultaneously would cause flight crew confusion, or the sequencing of flight crew response is important.*
>
> *(4) The prioritisation scheme within each alert category, as well as the rationale, should be documented and evaluated…" – [32]*

Interestingly, the literature review presented within the HSE CR 166 report summarises some of the literature related to nuclear power, in which one paper discusses some basic aspects of the term referred to (at that time) as *the alarm problem*. It highlights that the reviewed paper attributes this problem to a design philosophy of *single input, single output*—an approach that is valid only when there are few provisioned alarms in total, and when these alarms are sufficiently independent with respect to their conditions of activation [9, p. 109] [33].

It appears that the aviation industry aims to deliberately prevent such simplified alert implementations as *single-input, single-output*. This conclusion is drawn from the requirement to validate the alerts not only in isolation but also in combinations, and throughout the expected operational scenarios, including foreseeable operational and environmental conditions. This drives the design to incorporate more situational awareness into the alert system. This awareness is necessary to correctly prioritise the alerts within the same priority category, especially when a specific sequence of crew response actions is important. It is also needed to implement what the regulation describes as "collector messages", which is a way to prevent directing the crew to non-relevant response procedures in the presence of more than one fault condition, such as the total degradation of the aeroplane's hydraulic systems, and not just one of them.

The approach of validating the prioritisation scheme requires a documented rationale, similar to 62682 rationalisation, but more extensive, as it includes aspects of human ergonomics. Further, the regulation prescribes this rationale to be based on a combination of diverse engineering approaches:

> *"(2) The validation of the performance and integrity aspects will typically be accomplished by a combination of the following methods:*
>
> - *Analysis*
> - *Laboratory test*
> - *Simulation*
> - *Flight test*
>
> *(3) Evaluate the alerts in isolation and combination throughout the appropriate phases of flight and manoeuvres, as well as representative environmental and operational conditions."- [32]*

A final and worthwhile highlight is that the regulation is hard on nuisance alerts. It recognises that nuisance alerts contribute to human error and an unnecessary increase in their workload. It thus requires the design to minimise the effects of false and nuisance alerts (what EEMUA 191 would define as an alarm lacking the "relevance" and or "uniqueness" quality attributes):

> *"12. Minimising the Effects of False and Nuisance Alerts.*
>
> *As much as possible, the alerting functions or system should be designed to avoid False alerts and Nuisance alerts, while providing reliable alerts to the flight crew when needed. The effects of Nuisance and False alerts distract the flight crew, increase their potential for errors, and increase their workload. CS 25.1322(d) requires that an alert function be designed to minimise the effects of False and Nuisance alerts. Specifically, a flight crew alerting system must be designed to:*
>
> *a. Prevent the presentation of an alert when it is inappropriate or unnecessary." – [32]*

While the IEC 62682 standard has a zero tolerance for chattering and fleeting alarms within its objective performance metrics (*monitoring and assessment* lifecycle stage H), the CS-25.1322 considers the absence of false and nuisance alerts as an integral performance criterion of alert system integrity:

> *"7. Alerting System Reliability and Integrity*
>
> *e. The integrity of the alerting system should be examined because it affects the flight crew's trust and response when assessing an alert. Since the individual assessment of a False or Nuisance alert for a given system may lead to a specific consequence, the impact of frequent False or Nuisance alerts increases the flight crew's workload, reduces the flight crew's confidence in the alerting system, and affects their reaction in case of a real alert. For example, if False or Nuisance alerts are presented the flight crew may ignore a real alert when it is presented." – [32]*

In hindsight, the literature review presented within the HSE CR 166 report discovered similar concerns. Here, it summarised a study investigating the human performance effects when an operator has an *a priori* probability opinion of an alarm being false or real. In their review of the study from 1995, "Decision making in a dynamic situation: The effect of false alarms and time pressure", the reviewers stated:

> *"Experiments using a mental decision-making task showed that as the probability of an alarm being false increased, subject waited longer before starting a troubleshooting process and that they invested less mental effort into the task. Under increasing time pressures, subjects did not choose their intervention strategies to optimise the outcome. Instead, they requested confirmatory information." – [9, p. 117] – referencing [34]*

From the CS-25, it appears that the aviation industry takes such integrity issues very seriously. It seems that even "simple" aeroplanes subject to the CS-25 regulation are imposed with much more rigorous requirements on crew alerting than a large passenger ship carrying thousands of people.

1.12.9 IMO Code on Alerts and Indicators, 2009.

The *IMO Code on Alerts and Indicators* (2009) (CAI) aims to assist designers and operators by compiling references to priorities, aggregation, grouping, locations, and types of shipboard alerts and indicators. In cases where specific alerts are not specified by IMO instruments, the Code provides such information to promote uniformity [35, p. part 1]. It follows an alert approach similar to the aviation industry:

> *"3.1 Alert. Alerts announce abnormal situations and conditions requiring attention. Alerts are divided in four priorities: emergency alarms, alarms, warnings and cautions.*
>
> - *.1 Emergency alarm. An alarm which indicates that immediate danger to human life or to the ship and its machinery exists and that immediate action should be taken.*
> - *.2 Alarm. An alarm is a high priority of an alert. Condition requiring immediate attention and action, to maintain the safe navigation and operation of the ship.*
> - *.3 Warning. Condition requiring no immediate attention or action. Warnings are presented for precautionary reasons to bring awareness of changed conditions which are not immediately hazardous, but may become so if no action is taken.*
> - *.4 Caution. Lowest priority of an alert. Awareness of a condition which does not warrant an alarm or warning condition, but still requires attention out of the ordinary consideration of the situation or of given information." – [35]*

While the aviation industry applies only three alert priority categories (Warning, Caution, and Advisory) aviation includes a concept of *time-critical warnings* (EASA CS-25 review) or "Master warnings". The latter appears to the analogy of the *Emergency Alarm* priority category within the CAI.

Only two clauses contain high-level goals on nuisance and the minimisation (rationalisation) of alerts, with the minimisation being reserved for the bridge alone, not for the machinery space:

> *"4.17 Means should be provided to prevent normal operating conditions from causing false alerts, e.g., provision of time delays because of normal transients." – [35]*
>
> *"4.18 The number of alerts and indicators which are not required to be presented on the navigation bridge should be minimized." – [35]*

The Code allows the application of Aggregation:

> *"3.10 Aggregation. Combination of individual alerts to provide one alert (one alert represents many individual alerts), e.g., imminent slowdown or shutdown of the propulsion system alarm at the navigation bridge." – [35]*

Including functional grouping of alerts according to primary functions:

> *"3.11 Grouping is a generic term meaning the arrangement of individual alerts on alert panels or individual indicators on indicating panels, e.g., steering gear alerts at the workstation for navigating and manoeuvring on the navigation bridge, or door indicators on a watertight door position indicating panel at the workstation for safety on the navigation bridge." – [35]*

An important distinction is that the Code does not claim to be intended at improving the usability of the alert systems for the users. Instead, it claims to be written primarily for designers and ship operators. However, there is one operational requirement for the Administration (Flag) to ensure that the crew is trained, drilled and familiar with alerts:

> *"4.13 Provision should be made for functionally testing required alerts and indicators. The Administration should ensure, e.g., by training and drills, that the crew is familiar with all alerts." – [35]*

In summary, the CAI is very limited in respect to usability requirements and appears instead to be an index catalogue of what a ship designer needs to remember. The usability goals are primarily defined in the grouping and aggregation section within the Code. But the application of grouping and aggregation are only prescribed *"as far as practicable"* – [35]

> *"9.5 The purpose of grouping and aggregation is to achieve the following:*
>
> - *.1 In general, to reduce the variety in type and number of alerts and indicators so as to provide quick and unambiguous information to the personnel responsible for the safe operation of the ship.*
> - *.2 On the navigation bridge:*
>   - *.1 to enable the officer on watch to devote full attention to the safe navigation of the ship;*
>   - *.2 to readily identify any condition or abnormal situation requiring action to maintain the safe navigation of the ship; and*
>   - *.3 to avoid distraction by alerts which require attention but have no direct influence on the safe navigation of the ship and which do not require immediate action to restore or maintain the safe navigation of the ship.*

- *.3 In the machinery space/engine control room and at any machinery control station, to readily identify and locate any area of abnormal conditions (e.g., main propulsion machinery, steering gear, bilge level) and to enable the degree of urgency of remedial action to be assessed." – [35]*

1.12.10 IEC 62923-1

The IEC 62923-1, *Maritime navigation and radiocommunication equipment and systems – Bridge alert management* [36], details operational requirements and required test results from equipment under test (EUT). Performance with this standard is required under the EU Marine Equipment Directive (MED). Since 30 August 2021 it has been a mandatory requirement for the relevant equipment installed on EU (incl. EEA) flagged ships.

While the standard is comprehensive, its key takeaways are in alignment with *MSC.302/5.2* and *MSC.302/8.1*:

> *"5.2 If practicable, there should be not more than one alert for one situation that requires attention" – [37]*

> *"8.1 The alert messages should be completed with aids for decision-making, as far as practicable." – [37]*

Here, the IEC 62923-1:2018 standard describes the interpretation of assessing performance with the 5.2 requirement:

> *"6.1.2 Number of alerts for one situation:*
>
> *…omitted…*
>
> *Unless required by IMO, if there is a situation that requires attention, a functional alert… shall be raised, while the underlying causes (e.g. technical situations or symptoms) shall not provide (additional) audible alerts(s)." – IEC 62923-1:2018 [36]*

This means that the watchkeeping bridge officer should only receive a single functional alert informing the necessary decision-making to deal with the situation. Cascade alarms, such as those that indicate loss of electrical power, communication loss and other symptoms, must therefore be suppressed.

The decision-making process for the 8.1 requirement aligns with the concept of *Highly managed alarms* defined within 62682. Here, alarms can belong to a different class than safety, such as *maintenance, commercial loss*, or even *environmental protection*. It sums up nicely what the 62923-1 defines as the problem of presenting non-functional alerts to the human operator:

> *"E.4.2 Functional alerts*
>
> *…omitted…*
>
> *"It is important to recognize that equipment may indicate problems to users with different (and in some cases combined) roles.*
>
> *1) The operator role is a type of user that amongst others oversees equipment to execute some function (e.g. an autopilot to keep the ship on a defined heading). The operator expects the equipment to alert him/her if there is a problem with that function. Bridge alert management requires that this alert should be such that the operator not only recognizes that there is a problem, but also how the problem affects the quality of service and, if the operator has to act, what that action should be. Of course the operator may also set a function to provide an alert if some operational situation occurs (e.g. radar has to alert about potential collisions).*
>
> *2) Someone with the role of service engineer has little need for such functional alerts. The service engineer is interested in troubleshooting and mitigation of a problem with the function. The service engineer would like to be informed about the root cause of the problem, or to receive guidance (data, symptoms) to find that root cause, in order to know what he/she can do to remedy the problem (if possible)." – [36]*

Besides these relevant clauses, the IEC 62923-1:2018 contains no objective criteria for assessing integrity (nuisance). Nor defines what rates of alerts per bridge officer are likely to be manageable. Finally, it does not include details, such as timeliness, to alert quality attributes.

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1.12.11 IEC 60092-504

The standard, *IEC 60092-504 – Electrical installations in ships Part 504: Automation; control and instrumentation* [38], is being revised for release to supersede its current 2016 version. It has therefore been omitted from a detailed review. Still, the draft contains more detailed guidance on how to assign abstract priority levels, but not how to prioritise alarms within the same priority category as otherwise required within EASA CS-25.1322. It also aims to ensure the integrity of the alarm system by describing a goal that all alerts must be relevant to the operational context:

> *"Alerts shall be defined such that they are only raised when relevant to the operational context." – [38]*

It does not contain objective performance metrics, such as IEC 62682, nor does it have methods to quantify the relevance of alerts raised within an operational context.

1.13 Selected related work – maritime industry

0

M.H. Lützhöft and S. W. A. Dekker's paper *On Your Watch: Automation on the Bridge (2002)* delves into the impact of automation on maritime operations, specifically focusing on the navigational bridge on ships [39]. It does so from the outlook of the incident of *Royal Majesty*. Even if information is technically available, it may not be effectively observed if the human operators are not actively attending to or processing it.

The highly influential paper promotes that a test of observability is whether an indication helps operators see (discover) what they did not expect to see or more than they expected. It further details how the critical GPS-fix alarm in the incident on *The Royal Majesty* went unnoticed as it was only annunciated once and produced a sound similar to that of a digital wristwatch.

Two years later, M. H. Lützhöft wrote: *"the rules and regulations dictate that relying only on alarms is not appropriate practice." – [40]*

1

In the paper, *Combination of navigational and VDR-based information to enhance alert management (2008)*, M. Baldauf, K. Benedict, E. Wilske, P. Grundvik, and J. Klepvisk, highlighted the surge in provisioned alarms due to the industry's transition from "stand-alone" to integrated navigation systems [41].

Their paper stated that although the IMO prescribes only 48 mandatory bridge alarms, their empirical studies found samples with higher numbers. Numbers which increased rapidly with the interconnection to other navigation systems and consequently the level of integration. It shows an example where the provisioned alarms for "stand-alone" *Automatic Identification System* (AIS) was 24 alarms, "Stand-alone" *Electronic Chart Display and Information System* (ECDIS) was 44 alarms, but when *Automatic Radar Plotting Aid* (ARPA) was connected to AIS and ECDIS there was 108 alarms. Lastly a complete *Integrated Navigation System* (INS) was found to contain 173 provisioned alarms in total.

The paper then moves on to introduce a novel risk-based approach to collision avoidance, which does not appear to have seen wider applications.

2

In his article *Making alarms more manageable*, B.S. Jones presented a narrative of the challenge seafarers face due to the surge of provisioned alarms on board ships [42]. References are made to the nuclear, aviation, and process industries, as sectors with established good practices on alarm management. The article claims that most of these practices could be used in the maritime industry. The article includes a reference to comparative analysis presented in 2005 describing some of the lessons that the aviation industry learned during its pursuit of increased automation, *Lessons from Aviation: Twenty years later on the wrong heading dead ahead?* (2007).

3

Around the same time, Ø. Rødseth, M. Knight, R. Storari, H. Foos, and A. Tinderholt presented a paper *Alarm Management on merchant ships (2006)* [43] as part of a larger consortia activity, DSS_DC. Here MARINTEK (today SINTEF), Carnival Corporation & Plc (UK), and Kongsberg Maritime (NO), investigated alternatives that could support the officers of the watch better than traditional implementations of alarm systems. The paper also reports results from various field investigations. One of these were a partial black-out test[14] on a shuttle tanker, conducted to get an indication of the peak alarm rates occurring under such a failure scenario. A total of 206 alarms were generated in the first 115 seconds. Another reported result was one investigated ship which had 78 alarms per hour on average. The paper further reports its own work from a field investigation on a cruise ship. Here the observed engine room alarm rates were recorded during an end-to-end voyage of 40 hours. Here, 370 alarms were observed. It was also reported that 42% of these required no operator intervention.

14 Partial black-out means that only the starboard or port side of the main switchboard is fully de-energised.

4

At the same conference as the previous paper, Lloyds Register, B. S. Jones & J.V. Earthy & E. Fort & D. Gould presented their paper *Improving the design and management of alarm systems (2006)* [6]. The paper points out a tendency for designers of individual systems or equipment to adopt a narrow-minded approach to proposing alarms for their own sake (safeguarding against warranty claims could be an example). This is without proper regard for the operational importance of their alarms compared against alarms from other areas of the ship. It states how the experience of using safety reviews merely tend to result in adding alarms as extra defences against potential hazards. In contradiction, the effort of reducing the number of alarm channels or inhibiting them can become entangled in liability issues and concerns over design authority. The paper emphasises that without alarm reductions, inhibition and prioritisation, the operators remain swamped. The paper then explains the need to draw on experiences from adjacent sectors.

5

Later, R. Hudson, P. Traub presents the paper *Alarm management strategies on ships bridges and railway control rooms a comparison of approaches and solutions (2008)*, which compares the challenges between alarm management on ship bridges and railway control rooms [44]. It reports progress on strategies in the rail sector that could contribute to further improvement of marine alarms. Both industries face problems such as excessive alarm rates, spurious alarms, and difficulties in prioritising critical alarms. It details how the rail sector implemented formal requirements for safety-critical alarms, prioritisation, and integration of human factors. The importance of considering human factors in automation design is emphasised, citing incidents in which automation failures or "surprises" led to incidents.

6

The seagoing chief engineer, R. Thomas (BP shipping), describes in his article, *A chief engineer's perspective (2007)*, how the adoption of technology has led engineers to rely more on automation [45]. Negative side-effects caused by this shift, an example being the operator's reduced ability to manually control the plant (ship machinery) are highlighted. The article then details the author's "wish list", one of which would be a "*selector switch*" that hides all non-critical alarms. That specific wish is bound in the description of the situations in which a blackout or other major failure event gives rise to an enormous number of alarms. When presented on visual displays, such alarm flooding is described as being "too much" and hindering the engineering watchkeeper from responding to the actual situation at hand. Another wish is for the audible annunciators within cabins to annunciate with a "soft" start, rather than what the author describes as a "heart stopping sound."

7

Motz F., Höckel S., Baldauf M., and Benedict K., present a paper, *Development of a Concept for Bridge Alert Management (2009)*, which reports on investigations of the, at that time, state of affairs on alarm loads on ship bridges [46]. This is done by collecting alarm data in the field to sample the occurrence of alarms and collect the related experiences of the navigational officers (watchkeepers). Referencing another conference paper for the field investigation [69]. The investigation was conducted on six vessels, three passenger ships comprised of two ferries and one cruise ship, and three container ships. It consisted of manually recording the annunciated alarms on the bridge and conducting semi-structured interviews with the 13 bridge officers. It does not show how these officers were spread across the six ships. The paper details that these observations consisted of the alarm's timestamp, the kind of alarm, the specific alarm system, alarm setting and limits, visual or audible indication, the reaction of the bridge officers, the navigational situation and additional remarks. In addition, the bridge officers answered a semi-structured questionnaire from their point of view on the presentation of the alarms, operational problems regarding the presentation, and the occurrence of alarms. The investigation showed that the average number of alarm rate was relatively low, but that peak values were considerably higher. It was also noted that the frequency of the alarms depended on the navigational situation, and that bridge officers adopted coping strategies at the times of high alarm loads.

Based on the later outputs of that work, the International Maritime Organisation (IMO) recognised the situation and revised the Integrated Navigational Systems (INS) performance standard. This revised INS standard details the requirements for an alert management system for navigational systems. Additionally, the IMO decided to develop a Bridge Alert Management (BAM) standard that comprises all alerts occurring on the bridge, and that a correspondence group from Germany should progress this work. The research group at FKIE was part of the German correspondence group.

8

The same research group at FKIE attempted to conduct a similar field investigation in early 2020s but was challenged by COVID-19. Instead, S. Hochgeschurz, F. Motz, R. Grundmann, S. Kretzer and L. Thiele published a paper, *Which Radar and ECDIS Functionalities Do Nautical Officers Really Need in Certain Navigational Situations? (2021)*, which was based solely on questionaries and survey data [47]. A total of 80 out of 167[15] responses were analysed. This study concluded that the navigators regarded almost none of the functionalities (<1%) as extremely unimportant, although it also concludes from its analysis that approximately half of these are situationally dependent.

Further conversations with the FKIE highlighted that while 167 responses had been received in an anonymous setting, only a single watchkeeping bridge officer showed up for a recorded (transcribed) qualitative interview intended to develop the applied online questionnaire. The applied questionnaire is non-disclosed in the proceedings. Post discussions with FKIE, LR has been granted permission to publish the applied questionnaire used by FKIE for both the 2008 and 2021 field collection studies (see Additional resources). In addition, FKIE is awaiting the German Ministry of Transport's permission to disseminate the collected alarm data and the anonymised survey answers.

[15] Only 80 responses are reported in the article, but conversations with the author group revealed that 167 responses were received in total.

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Selection of related work

9

Another comprehensive user experience study reported at the same time, *Application and usability of ECDIS (2021)*, was conducted by the MAIB and the DMAIB, which aimed at generating a more nuanced understanding of the practical application of ECDIS for the viewpoint of its users [48]. The numerous investigations of grounding accidents [48, p. 82 appendices], indicate that ECDIS is at times a contributing factor to these events occurring, which is due in part to a mismatch between the way the ECDIS is used by navigators and how it is intended to be used by international performance standards and system designers. Consequently, the knowledge and performance of the ECDIS users were called into question although evidence suggests that the ECDIS itself did not meet the needs of the end-users in these situations.

To study this issue, the DMAIB and MAIB visited 31 ships of various types on four-day voyages in European waters, conducting one-hour interviews of 155 navigators and observing their use of the ECDIS, comprising eight different manufacturers. The organisations also interviewed 15 deep-sea pilots, 13 ship managers and operators, five ECDIS manufacturers, an undefined number of ECDIS trainers and representatives of the hydrographic and technical community. Furthermore, the IMO performance standards on ECDIS (Res. A.817(19)/1995 and Res. MSC.232(82)/2006) were also scrutinised and compared to the experiences of the interviewees to search for any tangible discrepancies between the actual use and the intended use of the ECDIS. Consequently, the ECDIS has introduced an array of challenges that cut across designs and practices.

These are most noticeably centred around (1) the distraction of alarms, which leads to coping strategies ranging from normalising alarms (i.e. not reacting to them) to physically disabling and silencing them; (2) the lack of proper prioritisation of alarms, which leads to them being ignored and increases the risk of users missing safety critical alarms amongst a flood of trivial alarms; and (3) the impracticality of the safety settings that should trigger these alarms, which leads to workarounds (official as well as unofficial) or the improper use of the aforementioned functionalities.

Alarm floods often occur at times when deeper concentration is required, such as areas with high congestion and/or a geography that necessitates precise navigation. In some cases, the quantity of alarms may make it practically impossible to investigate each alarm, determine its source, relevance, priority, and, most importantly, how to (re)act to the event associated with the alarm given their often unclear or ambiguous meaning. As pointed out in the study, most ECDIS users do not explicitly distinguish between the different alert categories (alarms, warnings, cautions), nor their different sources (chart data, monitoring function, sensor input, etc.).

Although the ECDIS alerts are intended to assist the bridge team in identifying risks and abnormal situations and making diligent and proper responses to these, the alerts become a hazardous distraction by increasing the mental workload and cognitive stress of its user. This is also due in part to the ineffective way users need to continuously make adjustments on their provisioned ECDIS system, depending on the dynamism of the navigational and environmental contexts. Often, this results in one of two extreme responses: removing all alarms by disabling or silencing them; or normalising alarms by ignoring them. Neither of these are aligned with the underlying objective of the ECDIS in assisting navigators in their tasks.

For a study that focuses on the application and usability of ECDIS, i.e. with no direct focus on alarm management practice, it is noticeable that the words "alarm" and "alert" are mentioned a combined number of 215 times in the report. At 94 pages including appendixes, that is an average of more than twice per page. The executive summary concludes that:

> *"Decisions to automate and 'alarm' the safety contour seem to have been based on the technical ability to do so rather than on an adaptable blending of human and machine capabilities to complete identified tasks in differing scenarios and environments" – [48, p. 5]*

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Selection of related work

10

While most related work focuses on the bridge context, SIGTTO released the *Recommendations for Management of Cargo Alarm Systems (2019)* intended to inform its members of industrial best practices for the cargo alarm and control systems on board liquified gas tankers [23]. The liquified gas terminals are not only very expensive assets, but for many countries, they also form part of the energy-critical infrastructure and thus energy security in general (e.g., Europe in the wake of the Russian invasion of Ukraine). The ship-side management of the cargo safety systems and the critical dependency of the ship-side crew in correctly operating these systems were considered by multiple terminal operators (SIGTTO members) to be an unmanaged risk. Certain members had experienced incidents with loss of containment (liquified gas spillage) caused by poor alarm management. SIGTTO therefore identified the need to recommend the implementation of alarm philosophies for the cargo alarm systems on gas carriers.

The recommendation further states that the CAI is an adopted but non-mandatory code published by the IMO and that the CAI does not contain information from the International Gas Carrier (IGC) Code 2016th edition, issued also by the IMO. The body of the recommendation follows the alarm management lifecycle outlined in IEC 62682:2014; each chapter heading is a brief summary of each lifecycle section. In the final section, a novel concept of a critical alarm and action panel (CAAP) is introduced. Similar artifacts have been the practice in offshore domains [49] [50, p. 45].

One noteworthy use of wording is the recommendation explicitly states that "trickle down" training approaches are not fit for purpose and that the shore office needs training on alarm management as well, not just the seafarers:

> *"Relevant personnel, on ships and in the office ashore, should be trained on alarm management. Operators should be trained on the appropriate response to relevant alarms, prior to assuming responsibility for responding to those alarms.*
>
> *The trickle down method of training is not considered to be sufficient for this concept. It is not sufficient to train the initial delivery crew teams and rely on the knowledge being passed on during handover. Any person that joins a ship should ideally receive training and familiarisation prior to assuming a position of responsibility for alarm management." – [23, p. 16]*

This is an industry organisation "override" of the STWC code – Table A-V/1-2-1; Specification of minimum standard of competence in basic training for liquefied gas tanker cargo operations, which lists *approved in-service experience* as a sufficient method for demonstrating competence for liquefied gas tanker cargo operations.

The recommendation informs the IMO *International Safety Management* (ISM) code as being the intended instrument for its implementation. This is attributed to the requirement within the ISM code of the ship management company to implement a *Safety Management System* (SMS) encompassing both the ship and shore side. This includes objectives such as assessing all identified risks and establishing appropriate safeguards. However, the recommendation does not map which specific clauses could bring its recommendation into effect. Yet, this can be readily identified to be clauses such as 1.2.3.2 — Ensuring guidelines recommended by "maritime industry organisations" (such as SIGTTO) are "*taken into account*":

> *"1.2.3 The safety-management system should ensure:*
>
> *.1 compliance with mandatory rules and regulations; and*
>
> *.2 that applicable codes, guidelines and standards recommended by the Organization, Administrations, classification societies and maritime industry organizations are taken into account." – [51]*

It is straightforward to credit the intention of the recommendation, including the positive safety effect it may provide for the maritime industry in the long term. Gas carriers are expensive assets, operated with high safety standards. They are typically kept by the owner for many years. It is therefore an ideal platform for the maritime industry to proof-test the concept of alarm management as a lifecycle approach aligning with IEC 62682 or similar generally good practices.

Still, it is important to distil some of pitfalls identified in the recommendation, such as:

- The recommendation acknowledges the CAI, which uses the word "alert" as an abstract priority type (category), for which each cue (alarm, warning, caution, etc.) must be instantiated with one of its defined priority levels. However, although the recommendation references IEC 62682 and most of its structure is organised according to that standard, it misses the opportunity to highlight that the word *Alert* means something entirely different in IEC 62682 and EEMUA 191, which define an (operator) Alert as the following:

  > *"3.1.65 – Operator alert : audible and/or visible means of indicating to the operator an equipment or process condition for evaluation when time allows which could result in a response." – IEC 62682:2022 ed-2.0. Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch*
  >
  > *"An Alert is used to attract the attention of the operator to changes that may require assessment or action when time allows." – EEMUA 191 – [8, p. 14]*

Other generally accepted good practices referenced in these standards (IEC 61511 and 61508) do not use the word "Alert" but "Alarm". The recommendation fails to describe the key difference that rather than using an abstract priority class for cues (Alerts), the IEC 62682 standard applies alarm classes for safety, maintenance, environmental, financial. And also alarm types (rate-of-change, deviation, etc.) and priorities (low, medium, high, highest). The first two can be easily confused with the CAI definition of alert functionality grouping and types. The recommendations highlight the inconsistency between the CAI and the IGC code, but remains silent on these distinctive differences between the CAI and IEC 62682.

Based on the decision to use the word "Alarm" and not "Alert" in its title, it appears the working group at SIGTTO made a similar conclusion, yet decided to leave out these points with no explanation.

11

A. M. Nizar, & T. Miwa & M. Uchida presents a paper, *Human-Machine Interface Evaluation in Engine Supervisory Control through Alarm Performance Assessment (2022)* [52], which digs into the challenges posed by onboard ship alarm systems, which its authors introduce as frequently perceived nuisances, and in extreme cases, implicated in incidents. To address these presented concerns, it initiates an alarm management process by conducting an alarm performance assessment using actual data from an ocean-going vessel. The dataset includes alarm names (tag IDs), message text, activation and clearance timestamps, and sensor reading values. The study applies novel performance indexes (classification), drawing inspiration from the existing knowledge base of the objective alarm performance metrics of EEMUA 191 and ANSI/ISA 18.2. The novel indexes are denoted as “chattering index” for categorising nuisance alarms, “similarity indexes” between non-unique alarms, and for alarm floods. The study claims that its analysis of real ship data demonstrates the efficacy of the alarm performance assessment in identifying nuisance alarms and alarm floods.

Subsequently, the paper advocates for post-analysis application of traditional alarm management practices to mitigate or eliminate discovered issues, including alarm set-point reconfiguration, the application of delay times, and the development of response strategies for alarm floods. While acknowledging that the assessment evaluates only a fraction of the human-machine interface, it emphasises the added value of such evaluations in the era of digitalisation and extensive data communication. The paper concludes by highlighting the potential of alarm performance assessment as a crucial consideration for both on board operators and shore management to uphold safe maritime operations.

Its analysis of nuisance alarm is limited to chattering and fleeting indexes. Yet, the referenced background materials, such as EEMUA 191, define a nuisance alarm as more than these two properties:

> *“Alarms which do not generate a specific action or response from the operator.” – [8, p. 238]*

Likewise, the IEC 62682 defines a nuisance alarm as:

> *“Alarm that annunciates excessively, unnecessarily, or does not return to normal after the operator response is taken” – IEC 62682:2022 ed.2.0, Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch*

This means that the paper did not analyse (1) if the alarm was considered important to the operator (unnecessary), and (2) whether it generated a specific response from the operator. Such data would be necessary in order to have the complete analysis of a nuisance factor. The referenced material (EEMUA 191) contains and credits an established method (usefulness questionnaire) which can be applied to compute a so-called *Nuisance Score* [8, p. 177].

Methodology

The following section outlines the study's methodology, detailing the research strategy, research design, studied site, applied methods, and finally, its known limitations.

1.14 Research Strategy

The overall research strategy adopts a *Critical Perspective* by giving a voice to the seafaring watchkeepers regarding their opinions of their provisioned alarm systems and the management thereof. It does so from the position that alarms matter to those who hear, see and feel their consequences—something the watchkeepers have little power to influence in terms of its provisioned design and how it works in operation. Thus, the watchkeepers are empowered to bring to the table the meanings ascribed to their realities. In a compliance-driven industry, these insights help those in power, such as regulators, make more informed decisions and adopt policy changes as necessary. It also assists ship owners, shipyards, manufacturers, and other relevant stakeholders in making more informed decisions on the procurement of technology, technical decisions and product development.

1.15 Research Design

While the watchkeeping seafarers' narratives are an interesting and unique set of cases in and of themselves, their collective voices remain anecdotal unless supported by observable, objective and quantifiable facts. A counterargument is that numeric data have credibility in our society that often extends beyond its intended strength, as it fails to portray the experienced realities of what such numbers mean to the people involved. Both propositions are negative. However, combined, their product is positive, as they cancel out each other's weaknesses.

Thus, a significant focus of the research design has been to line up the watchkeepers' accounts next to objectively quantifiable facts and related work findings. This approach necessitates using mixed methods, yielding results that can bridge the watchkeepers' subjective perspectives with empirical evidence, and improves the consistency of these findings compared to related work already conducted in this field.

In summary, the overarching characteristics of the applied research design are:

1. **An inductive approach:** the study is exploratory rather than confirmatory.

2. **A naturalistic orientation:** the study (including most of the identified related work) takes place in the natural setting, in the field—on board a ship.

3. **Researcher involvement:** This study operates under the premise that its researchers serve as crucial lenses through which the realities of participating watchkeepers are captured. It recognises that *counterfactual prediction* or *causal inference* requires the incorporation of domain expertise. This is needed not only in formulating the research questions and goals, but also in identifying the data sources and formally describing a system's causal and correlative structures. And importantly, in telling the latter two apart.

   While the insider perspectives of the researchers are acknowledged as valuable assets, steps are taken to mitigate bias contamination by minimising data reduction and comparing the interpretations against the objective and quantifiable facts sampled in the field, including those of the related work.

4. **Unique case orientation:** the study applied a set of rigorous sampling criteria to select the most information-rich cases rather than relying on random selection. However, it still aims to have enough breadth of unique cases to discover the invariant context-free generalisations common for all watchkeepers' experiences.

5. **Mixed methods:** the study applies multiple data collection and analysis methods during the knowledge discovery process.

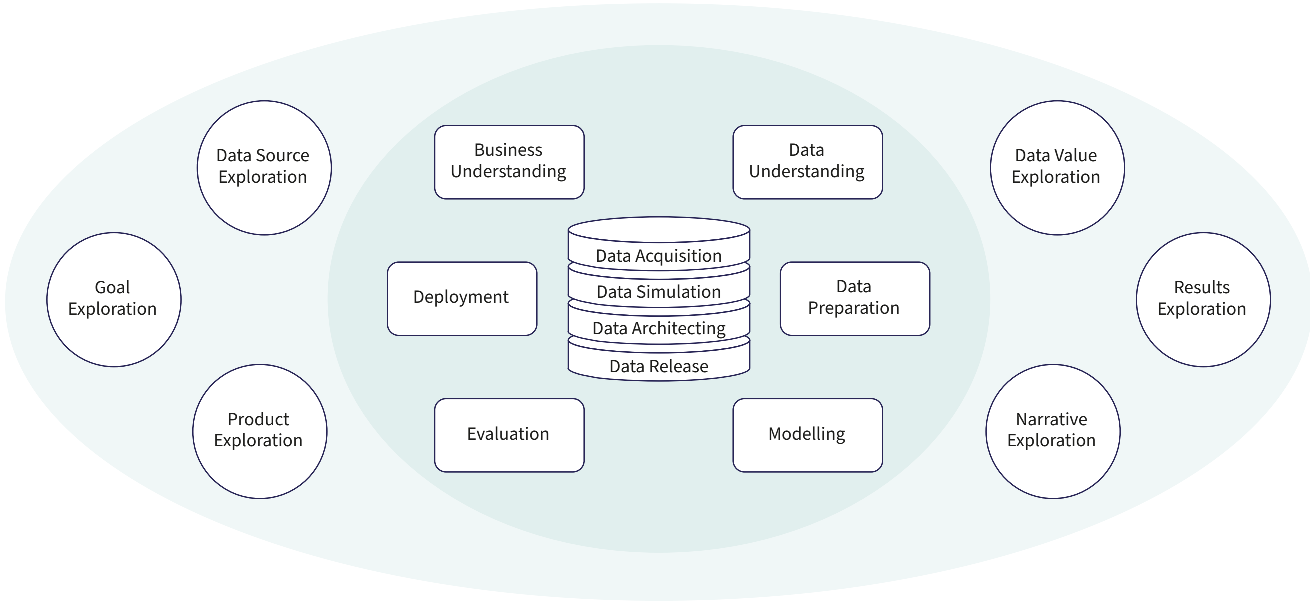

FIGURE 10.
Data Science Trajectories (DST), with the traditional CRISP-DM in the centre [53, p. 5 Fig. 3]

Seeing the *Inductive Approach* as a trajectory in time and space, a more flexible knowledge discovery model was needed in comparison to the traditional one of *CRoss Industry Standard Process for Data Mining* (CRISP-DM). Therefore, the research design utilised an expanded version of CRISP-DM also known as *Data Science Trajectories* (DST) [53] (Figure 10).

In approaching a topic of this complexity, it was recognised that attaining complete knowledge of the problem domain would not be achievable. The field is dynamic, meaning that neither the subjective experiences of the watchkeepers nor the quantitative data can be assumed to be static. Nor can the related work, as it is naturally expected to grow. In addition, the nature of alarms is that they are symptoms of other problems. Namely, the problem of a system's operational limit approaching a point of being exceeded. This can happen for a plethora of reasons, such as how the system was designed, installed, commissioned, operated, maintained, or, more likely, the combined effects of all such factors. As such, the *alarm problem* has no stopping rule. It is therefore intractable or unbounded, often described as "wicked" [54]. Such problems have no optimum solutions; therefore, any knowledge discovery process into applied best practices must consider how to lessen the problem and avoid worsening it.

Although DST is more fuzzy than "pure" CRISP-DM, its primary strength is its adaptability to leverage opportunities and circumvent experienced challenges while undertaking an explorative knowledge discovery project. This is deemed essential for the naturalistic and inductive settings in this study. As such, the adaptability of DST is intended to be robust in the face of evolving data dynamics. The DST syntax is detailed as follows:

"

- *A DST chart is a directed graph that only includes activities (once) and connections (transitions) between them (as directed solid arrows).*
- *All arrows are numbered from 0 to N, showing the sequence of transitions between activities. Consequently, we cannot have unlimited loops.*
- *We use three different types of boxes for activities (circles for exploration activities, rounded squares for CRISP-DM activities, and cylinders for data management activities).*
- *If two or more arrows have the same number, it means that they take place in parallel (or their sequential order is unattested or unimportant).*

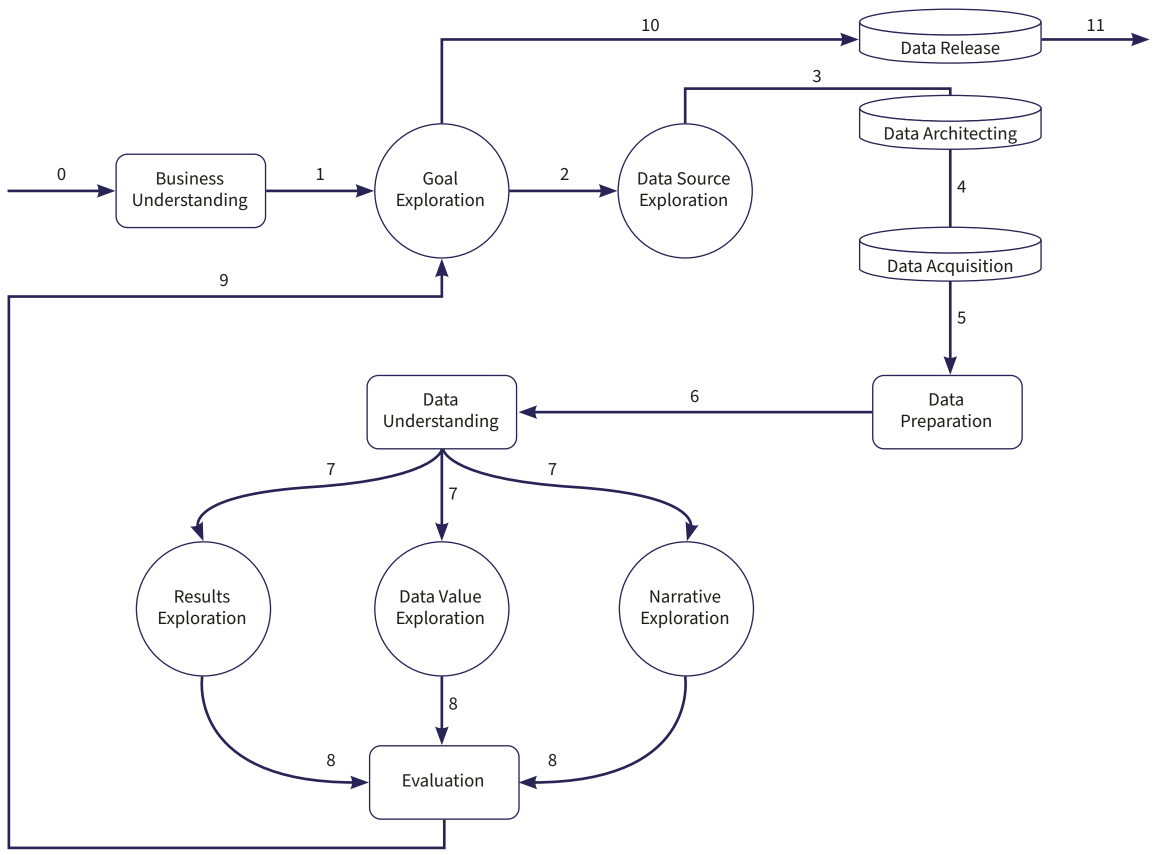

FIGURE 11.
The Data Science Trajectory applied in this study

- *A trajectory can go through the same activity more than once. If the trajectory moves from A to B more than once, we will annotate this as a single arrow with a single label, showing as many transition numbers as needed, separated by commas.*

- *Every trajectory has an entrance transition (with number 0 and not starting from any activity) and an exit transition (with number N and not ending in any activity).*

" – [53, p. 6]

The trajectory of the knowledge discovery process of this study (Figure 11) is outlined as follows:

Business Understanding: The trajectory started by reviewing related work conducted within the maritime industry (including a limited set of incident reports). Furthermore, the consolidated regulations and good practices of adjacent industries were also reviewed. These were compared with the current applicable maritime regulations, codes and guidelines on managing alarm systems, including SIGTTO´s published recommendation on managing cargo alarm systems. It became apparent that adjacent industries have done substantial work around managing alarm systems.

Other initial sources of information were internal discussions with LR field surveyors and auditors of both in-service vessels, including vessels undergoing construction. These field colleagues serve as the eyes and ears of the classification society at the frontline of the industry. With their boots on the deck, these people act as touchpoints (links) for a wide range of industry stakeholders on the ships under LR class. Stakeholders include shipyards, marine equipment manufacturers, shipowners, and the crews on board audited or surveyed ships, to name a few.

Goal Exploration: More detailed aims were defined by looking at the gaps in the present business understanding. The HSE information sheet, *Better alarm handling*, contained many subquestions guiding a step-by-step process of gathering the information needed to assess the performance of alarm systems on a plant basis [31]. These subquestions were chosen for further investigation to address the main research questions introduced in the introduction.

Data Source Exploration: Standing on the shoulders of giants (the work of others), the goal exploration activity had already given a fair idea of what to look for. These resonated with several of the narratives recounted by surveyors. These narratives were typically passed on by officers aboard ships undergoing repair under LR survey. Repairs were needed due to damages associated with the inaction of an alarm and its associated automation surprises from the integrated control system. The automation surprises were recounted as being inadvertent and unexpected.

As highlighted in the introduction, the majority of incidents are not investigated formally. One case in particular emphasises the trajectory decision of considering the ship and its crew to be a primary source of information:

> *"Dear Asger,*
>
> *… a story of an incident happened on a large cruise vessel ([Surveyor Name] and I attended the ship under repair in an [Country] dry dock)… and it is an example of the negative effects of the 'shower of alarms'.*
>
> *When the ship was at anchor (limited duties on the bridge), a black out happened and hundreds (if not thousands) of 'alarms' initiated. This created in the crew on duty the typical confusion and impossibility to give the right priority to those alerts. Among those hundreds of indications, there was the indication of the propulsion levers under UPS battery: that was expecting the engineers to reset the UPS and switch the propulsion levers power supply to ship power supply, when available (i.e. after recovery from black out). But this did not happen and the levers continued to be powered by UPS battery for more than half an hour. The voltage to the propulsion levers decreased due to discharge of UPS battery and that caused the levers to give the propulsion system the signal associated to that of low-voltage, i.e. 'full astern'. The officer on watch on the bridge saw the levers moving to 'full astern' but could not control that. Final result: the ship rapidly moved to rocks and the propeller had damage stopping the ship's operation for weeks.*
>
> *In the end, failing to reset the UPS was reported as human error."*" – A principal electrotechnical specialist and field surveyor at LR.

Simply put, the ship's crew deal with alarms during real life situations, and their accounts can be supported if sampled and compared with objective sources of information available on board. But, with the thousands of ships in today's world fleet, it was necessary to decide where to begin.

With the knowledge of data sources used in adjacent industries (and a deeper understanding of the field of research), the trajectory decision was to create the sampling criteria which established the research site (section 1.16.1).

Data Architecting: With awareness of the available data sources and the studied site, the data architecting could be defined. A questionnaire and interview guide were developed to gather the opinions and experiences of the watchkeeping crew in the field. These included the applied digital acquisition tools. The questionnaire was sourced from the HSE-endorsed good practices document, EEMUA 191 – Appendix 9 [8], and the HSE CR 166 Report – Appendix 5 [9]. Its adoption and use within the maritime context are further detailed in the section on interview methods.

Besides the subjective (qualitative) data architecture, the objective (quantitative) architecture was also engineered. This aligned with a practical interpretation of the IEC 62682:2014 against a preliminary alarm/event log sample, which included what/how to analyse this objective data from the ships.

The architecture also considered how to sample the data in a way that could maintain the confidentiality of the participating parties.

Data acquisition: The studied site was visited to collect the quantitative data from machinery spaces (retrieving event/alarm logs from integrated automation systems) and bridges (observing alarm loads in operation) as well as conducting qualitative interviews and obtaining the survey responses from the watchkeeping officers.

Data Preparation: The collected data underwent consolidation, post-processing, and structuring to facilitate the comparison of qualitative and quantitative data. This involved arranging the objective data alongside questionnaire responses, contextual notes, and narratives provided by the watchkeeping officers, as well as linking these to specific spatial attributes for the alarm load observations conducted on a selected set of ship bridge(s).

Data Understanding: Once the data had been prepared, it was possible to review it in deeper detail using data visualisations, computational statistics and qualitative methods.

Data Value Exploration: Understanding the data led to an appreciation of the value it could bring to the problem domain of alarm management. It became apparent that objective alarm/event logs could reveal a great deal about the quality of ship conduct and that such data is far easier to obtain and manage than the personal opinions of the seafarers.

Narrative Exploration: A storytelling tactic was adopted to extract the valuable stories, both visual and textual, of the seafarers' watchkeeping experiences in relation to alarms. It harnesses the concept that humans are better at recalling and relating stories than they are at remembering pure numbers and human quotations.

Result Exploration(s): Concurrently discovered narratives and value theme(s) were examined in relation to results exploration. This entailed analysing and pairing the data with all the notes of context and narratives from the watchkeepers as well as using objective observations, such as alarm loads, to underpin the human experience. Without juxtaposing the impact of these alarms from the watchkeepers' perspective, the data loses substantial value in a broader context.

Evaluation: The results from the various exploratory activities were compared to actual findings, i.e. synthesised results. This included scientifically mirroring existing literature to validate or nullify the findings.

Goal Exploration: The synthesis of the results from the evaluation, revealed goals/aims for the maritime industry to move forward in adopting the identified good practices, including the need for further research/work.

Data Release: The insights from the evaluation and the final goal exploration were consolidated, followed by the data release of this report and its supplemental material – exiting the data science trajectory at 11 (Figure 11).

1.16 Research Site

This section describes where the study took place, hereunder the sampled ships, crew and other relevant demographics. It informs where the data was collected and sets the backdrop for the context of the results, evaluation and conclusion presented later in the report. For cohesion, the sampling criteria is detailed as well.

1.16.1 Sampling criteria

To comprehensively answer the research questions, the navigational bridge and machinery spaces were studied concurrently, and the ship was considered as one platform. The project applied a philosophy of combining *Criterion*, *Maximum variation*, and *Convenience* sampling [55, p. 19]. This was done in succeeding (nested) order and for the primary purposes:

1. **Criterion:** Sampling high performers (ships) was considered decisive in discovering the applied best practices. Suppose solid indicators of challenges regarding alarm management were found across a diverse population of high performing ships. It is likely that these challenges could also be present on ships of lower performance than the selection criterion.
2. **Maximum variation:** Variation is needed to assess if the applied best practices and challenges are generally decisive across various ship types, their management, and operational contexts.
3. **Convenience sampling:** Selecting only shipowners willing to support the project for a common cause.

1.16.1.1 Criterion sampling – high performance ships

The criterion for sampling applied a *Purposive sampling* procedure to select the ship population based on relevance to the subject, which was conducted using a *critical case sampling* approach [56, pp. 230, 236, 237]. Here, a small population can be pivotal when investigating a specific topic. The method does not provide a direct basis for statistical generalisations. However, logical generalisations can be made, provided the population is decisive. A case can be considered decisive if it is true that "If it happens here, it likely happens anywhere."

The criteria to select the shipping companies, ships, crew, and thereby the sampled population were:

1. At the time of sampling, the vessel must not have been detained by a flag state within the last three years, according to S&P Global's world shipping directory [57].
2. The interviewee or survey respondent must be an engineer or navigational officer, who has been on watchkeeping duty recently, captains and chief engineers included.
3. The ship's flag state should have the best possible excess factor score on the MoU lists.
4. The ship's flag state should have received no red marks on the following performance metrics defined by the Shipping Industry Flag State Performance Table, developed by the International Chamber of Shipping [58]:
    1. Port State Control
    2. Ratification of Conventions
    3. Recognised Organisations (RO) code
    4. Reports

A ship sailing under the flag with an excess factor below zero and achieving the performance criteria of the above metrics was regarded as a vessel with excellent performance.

For the quantitative alarm rate observations on the navigational bridges, additional criteria were established:

1. The ships must be technical sisters built according to the same approved plans, and both must have been built in the same yard and flagged by the same national administration.
2. The ships must sail under the same flag and be surveyed by the same classification society.
3. The ships must have the same beneficial ownership.
4. The same ship management company must manage both ships.
5. The ships must have a fully integrated bridge system, enhanced navigational safety qualification comparable to LR's IBS and NAV1 notations, and be fully compliant with the bridge alert management (BAM) standard.
6. The ships must sail worldwide, meaning fixed route ships are discarded from the sampling pool even if they satisfy all other criteria.

These criteria intend to assert the operational effects of the BAM and MED requirements, which are in conjunction with IEC 62923-1/-2, for navigational and bridge communications equipment. Sufficient research on empirical observations for ships not built to these standards already exists [46].

1.16.1.2 Maximum variation sampling

The first sampling criteria naturally limits variability (intentionally). Within the population remaining from the first criterion, the maximum variation sampling criteria was:

1. Diversification within each segment is encouraged for additional samples of the same segment.
2. The sampling population should contain ships with varying ages, segments, companies, flag states, classification societies, crew composition, and technical/operational management.

1.16.1.3 Convenience sampling

LR is the preferred trusted partner to a significant share of the ship owners within the maritime industry. Because of this established trust, access to operational data, documentation such as drawings, and people's time on board was swift and non-complicated. In all instances, the crew needed to feel reassured that their management ashore supported the activity and that they would be anonymous. Within the population remaining from the first two criteria, the convenience sampling criteria were:

1. Every shipowner must be a client of LR and be on good terms before the field sampling.
2. Every shipowner must provide a designated person ashore to facilitate contact with the ship, including managing access to and from the vessels.
3. Agree to participate at the senior management level.
4. Agree to receive no direct utility from the findings except those consolidated in this report.

The sampling criteria ensured that only high performing ships were considered for the sampling, and that variation across segments, operational contexts, and management structures was achieved.

1.16.1.4 Ships and segments

A total of 15 ships from 10 distinct shipping companies participated in the study. These included:

- **1 RO-RO (roll-on/roll-off).**
- **4 ROPAX[16]:** These were operated and managed by three different companies. Two were fully electric. One was a hybrid vessel with battery storage as an alternative power source, and another could be powered by a novel fuel type.
- **3 Tankers (Chemical, LPG, Product):** Each were owned, operated and managed by their beneficial owners.
- **1 Multi-Purpose Offshore Vessel:** DP (AA) and diesel electric.
- **1 Tug**
- **5 Passenger cruise ships:** Four different companies operated these. Some were among the biggest cruise ship operators in the world. Others operated smaller and more specialised ships. Overall, these ships varied in size from 6000+ passengers to fewer than 1000 passengers; both figures exclude the crew on board. Two of these five ships were technical sisters[17], which did not vary in terms of their internal systems.

In parts of this report, the *N* ships are labelled as *Ship No. 1* and *Ship No. N*. These labels have been randomised, such that the ships and segments do not correspond to the order given in the above list, nor any other collection within this report.

The sampled ships shared a common characteristic: their owners primarily operated multinational companies with annual turnovers exceeding billions of USD.

16 The acronym ROPAX describes a RORO ((roll-on/roll-off) vessel built for freight vehicle transport along with passenger (PAX) accommodation.
17 Ships built to (largely) the same plans appraised by its classification society and the ships national administration, including its other recognised organisations (ROs), if any.

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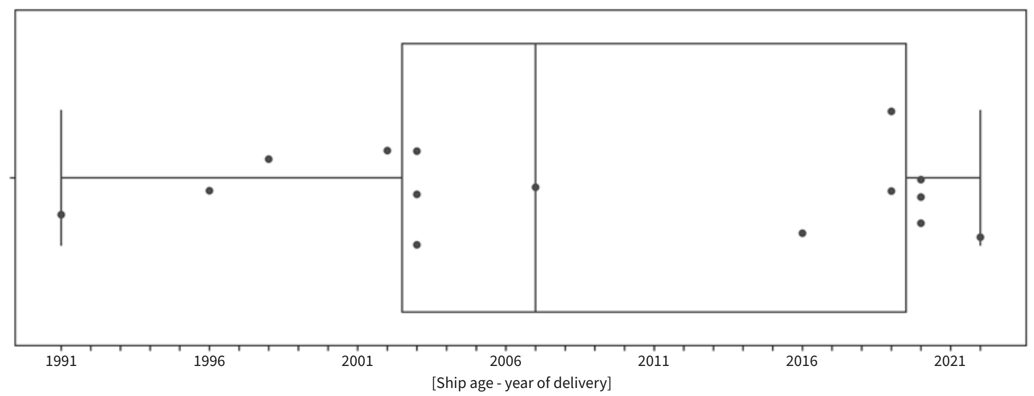

FIGURE 12.
Box and whisker plot of sampled ship age. Each dot represents a sampled ship

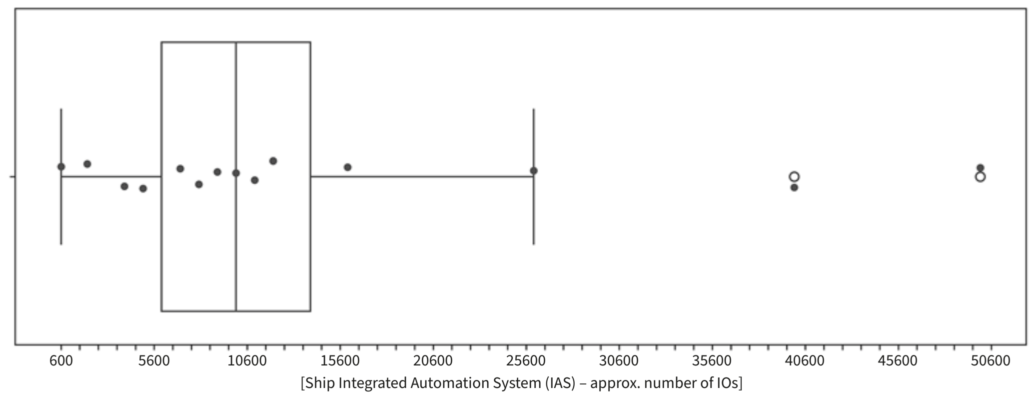

FIGURE 13.
Box and whisker plot of sampled ships number of IOs integrated into its automation system

1.16.1.5 Composition of ship and crew

Due to differential privacy considerations, disclosing a complete set of ship and crew demographics is not possible. Not even for partially complete sets (a minority) of the sampled ships. The following presented distributions and characteristics have been engineered with confidentiality in mind. As such, they are selected outputs of a privacy-preserving process. One aimed at striking a balance between the important characteristics and features in the studied site data, versus the information loss necessary.

At the time of sampling, the ships were operating under survey by one of the following classification societies: American Bureau of Shipping (ABS), Det Norske Veritas (DNV), and Lloyds Register (LR). Those who surveyed the ships under construction are non-disclosed. However, all were members of the International Association of Classification Societies (IACS) at the time of build.

Moreover, the vessels were flying the flags of one of the following national administrations: Bahamas, Denmark, Malta, Norway, Sweden, and the United Kingdom.

At the time of sampling, the age of the ships spanned from less than two years after its delivery to upwards of 33 years of operation (Figure 12).

The ship's degree of (integrated) automation varied widely, from a few hundred input-outputs (IOs) upwards of 50.000 (Figure 13). There are undefined but substantial inaccuracies associated with reporting these IO figures.

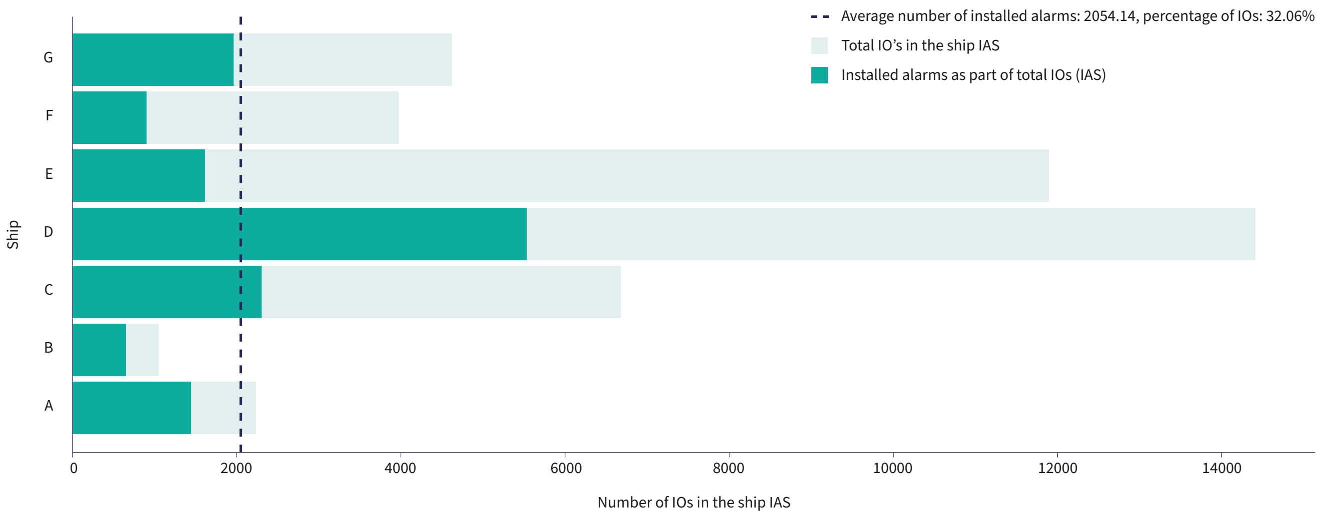

FIGURE 14.
Alarms provisioned/integrated in the ships´ integrated automation system of seven ships recently built to LR class

The uncertainty is attributed to the notion that multiple systems are "stand-alone" or partially integrated. Therefore, these numbers are likely understated, as their "dark figure" remains undefined.

During the field investigations, obtaining the collective number of provisioned alarms was not easy. Generally, neither the ship nor its management knew how many alarms there were. Only on rare occasions did the IAS provide a single database of all the alarms it could generate or forward from sub-systems.

As a classification society, LR had access to the documentation on only a subset of the sampled ships. This is because some were surveyed by LR under construction, while others were surveyed by a different classification society. As a compensating measure, LR had a team of plan approval specialists investigate a representative range of ships which had been delivered recently to LR class (within 24 months of this report). The team quantified the number of provisioned alarms, their priority distribution, and allocation between the various systems. Overall, roughly one third of the IOs within the integrated automation system (IAS) are provisioned as alarms (Figure 14).

On board the 15 ships, a total of 65 watchkeepers completed a questionnaire, of which 34 were engineering officers, while 31 were navigational officers (Figure 15). Experience with the alarm system(s) on their specific ship spanned from a few months to 18 years. Stratification between the engineering and bridge officers highlights an approximately equally divided population of engineering officers working with the current alarm and control system on board the ship for one to five and a half years, with a median of roughly three years.

The bridge officers had a median of one and a half years of experience working with the current alarm and control system on board the ship, with the lower and upper quartiles spanning from one to two and a half years.

Certain engineering officers held comprehensive (unlimited) licenses, fulfilling roles on board as both engineering officers (STCW III/1 & III/2) and electrotechnical officers (ETO – STCW III/6). A few navigational officers held even more comprehensive dual licenses (STCW II/2 & III/2). However, none of these served such a dual function (combined captain and chief engineer) on the sampled ships.

60 or 92% of the 65 questionnaires were conducted as semi-structured interviews, and five (representing eight percent) were completed as online questionnaires (survey form) without the presence or influence of the interviewers.

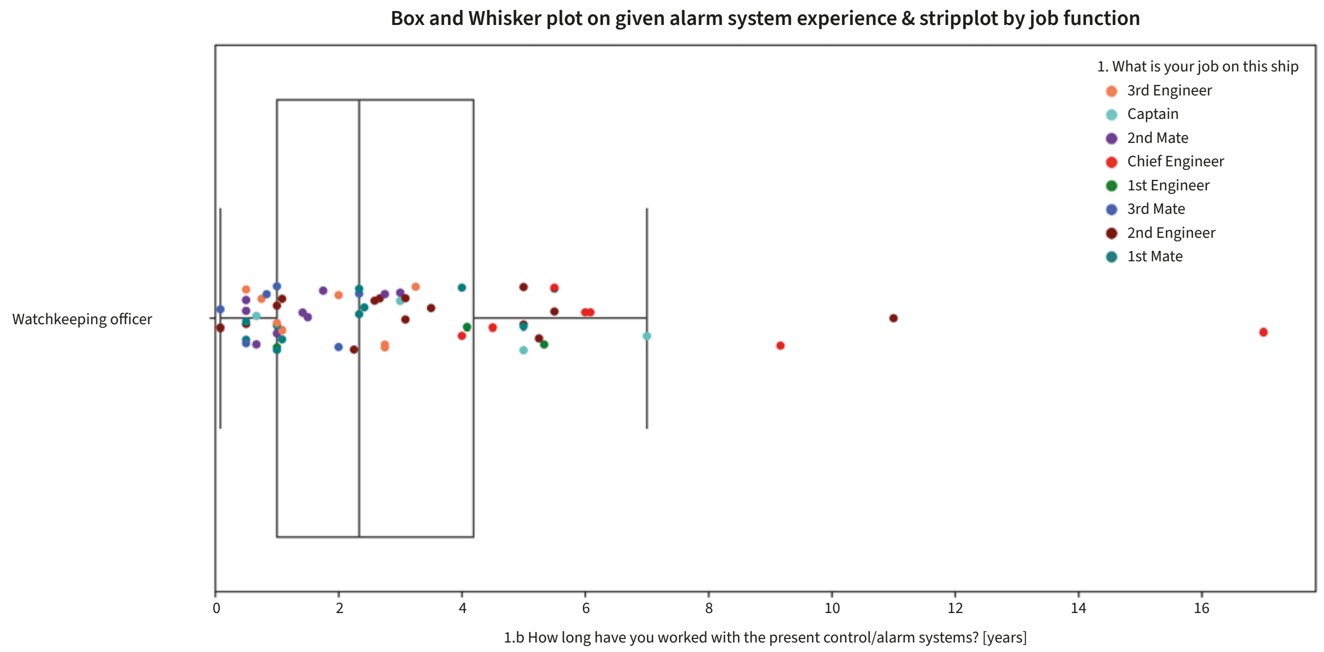

FIGURE 15.
Box and whisker plot of distributions of rank and experience with the alarm/control systems on board

The time spent by the project team on board varied from half a day up to 14 days. Appropriate time was prioritised for each interview, focusing on quality rather than quantity. Interviews were conducted on the bridge or within the engine control room (ECR) while the ship was underway and were performed primarily in the areas of Northwestern and Southwestern Europe.

1.17 Scientific approach—validity and reliability

This section highlights limitations and uncertainties concerning the studied site, including how these may influence the external validity.

1.17.1 Trust and anonymity

The study necessitated the willing participation of the ship operators to obtain the required permissions for conducting research on board their ships and for the crew to volunteer to contribute with their opinions and experiences. The project team needed to gain sufficient trust from these companies by assuring complete anonymity. A breach of anonymity could be problematic for the participating companies since reports of poor alarm performance on a specific vessel could severely affect the reputation of the company and directly impact the bottom line—a risk that few companies are willing to accept. Likewise, the watchkeeping seafarers needed to be safeguarded against direct and indirect identification, as is also required by general laws on data privacy and data ethics. These were conflicting constraints, as the companies initially expressed great interest in knowing the opinions of the crew on board, while the ship's crew wanted to know how they compared with other ships collectively.

Eventually, the participating companies agreed to gain no direct utility from participation in this project, since criteria for participation required the acceptance of not receiving company-specific results. Only the consolidated results containing data from all respective ships would be made available. Individual results would therefore be obscured among the many other participants (an approach inspired by the field of secure multi-party computation). Therefore, company participation relied solely on the motivation to contribute to the better understanding of alarm management practices across the maritime industry.

1.17.2 Lack of statistical generalisation

These sampling constraints rule out the traditional *probability sampling* approach, in which the population is defined based on randomised draws from a sampling pool (world fleet). It is improbable to gain access to a representative population size of the global merchant fleet. A fleet consisting of thousands of vessels [59]. Such would require the project team to gain physical access to ships and crews, in random countries and ports across the globe. Due to resource limitations, it would not be feasible to do so.

1.17.3 Segments missing from the critical samples

For the duration available to the project, it was not possible to sample a ship from the segments:

- Container
- Bulk carrier
- General cargo
- Crude oil tankers
- Naval defence/warship/subsurface
- Miscellaneous

The limited breadth of the sample population can impact the results to an uncertain degree. Suppose the alarm performance and best practices deviate substantially from the reported results in this report; this could potentially distort the overall picture, thereby reducing its validity.

The naval ship community is conducting a similar investigation, the result of which will remain classified. Naval ship community readers are advised to contact the NSTC members of the project advisory panel for further information.

It is possible that a later revision of this report will include these remaining segments, provided that differential privacy can be guaranteed. Many of these segments were not sampled due to constrained availability of resources. Not due to unwillingness of the industry.

1.17.4 Omission of crew demographics

It is a given that certain groups within industry and academia will work to create statistical models to infer alarm performance from the watchkeeper's opinions. The data may also be used for something entirely unanticipated.

For this reason, there is a legitimate concern that disseminating demographic features, such as nationality, could unintentionally reinforce stereotypes or biases, compromising the ethical integrity of this reporting. A broader ethical consideration drives the decision to withhold this information, in the awareness that seemingly harmless or neutral demographic data, if disclosed, could be misused by external entities to develop "Weapons of Math Destruction" (WMDs) [60]. Unless implemented with sound ethics, such models would not only be opaque to the seafarers, they would also be unregulated and difficult to contest.

As further detailed in the methods section on conducting interviews, factors such as the cultural backgrounds of the crew, are considered influences. Likewise, as anticipated, the stratification of demographic features indicated sensitivity concerning the opinions of watchkeepers.

For parties interested in conducting similar studies, one takeaway is to expect that the degree of honesty varies depending on the degree to which the person being interviewed can afford the risks of being honest. People with low job security, working contract to contract, and who may have multiple people dependent on their income may not feel that they can afford a high degree of honesty in voicing their opinions. Especially if the opinion is not what they believe management wants to hear. The sampling criteria of the studied site sought to mitigate this aspect.

We encourage readers to interpret results with the awareness that unreported demographic variations may influence certain aspects of the findings in this report.

Despite these limitations, it was decided to remain steadfast in upholding and fostering an inclusive and global maritime industry in which a seafarer is a seafarer, regardless of demographic background.

1.17.5 Non-sampling of seafarer's total seagoing experience

The reported ranks of the interviewed watchkeepers serve as an indicator of their minimum experience and competence. This is based on the minimum period of approved seagoing service and the competencies required to attain the necessary license to serve in the rank on the specific ship. The STCW convention describes this in more detail, while the ship's national administration issues or endorses the seafarer's license. On this basis, an officer of the watch today may have achieved the watchkeeping license yesterday or years ago. Regardless, this person will still be in charge of the watch, attending firsthand to possible alarms.

It quickly became apparent that total seagoing experience is an "expensive" feature to validate in terms of resources and information available. It could be debated whether seagoing experience should only include time served as a watchkeeping officer, as a cadet, or even time as a rating. Still, this would require difficult data validation from sources like the Seaman Service Book (a personal document and record of service). Nevertheless, even its content has inherent uncertainty. Just because seagoing time is in the Seaman's Service Book does not necessarily mean that it was approved by the ship's national administration (the flag that initially issued the seafarer's license).

Although the seagoing experience is a desired quality feature in any human-centred dataset, the cost of collection or "expense" was not deemed proportionate, nor is it likely to be available for such extensive quality validation. The project aimed to utilise features that can be easily scaled in practice.

1.18 The applied questionnaire

This subsection describes the origin and development process of the questionnaire used in the study. It further argues for the relevance of answering the research questions in the introduction.

A questionnaire (see Additional resources) was developed and served as an interview guide. The questions in the questionnaire were adopted and adapted by the project team from the *operator opinion questionnaire* found in the EEMUA Publication 191 – 2013 [8], from which most of the questions were sourced from the HSE contract research report no. 166 [9]. The questionnaire was adapted to suit a maritime context, employing an iterative refactoring process.

The first basis for selecting this set of questions was that they are system and platform agnostic. They focus on quality processes and the breadcrumbs of these (or lack thereof). Some of its questions extract the operator's opinions on the experienced alarm quality attributes. Other questions assess the due diligence of previous stages in the alarm management lifecycle, such as the number of configured alarms (rationalisation stage). Further questions probe how well the overall systems on the plant keep score (monitoring and assessment stage), how changes are managed (management of change stage), the system's performance during upsets and normal operation (operation stage) and so forth.

Due to these characteristics, the questions in the questionnaire are timeless. They do not focus on the ingredients (technology and solutions) like the other questions explored in previous related work. Instead, they focus on the applied recipes (processes) that make the system perform well—when well prepared (designed) and well looked after (managed).

A second basis is that a dataset exists for the power and process industries for 96 operators at 15 plants, allowing comparisons with the results disseminated in this report [9, p. 165].

A third basis was a plethora of consulting work conducted by the Human Factors department at LR, for which this questionnaire had been successfully applied, typically following more significant incidents. This body of knowledge was available for the project team at LR. In summary, the questions used had already been proven in the field.

1.18.1.1 Questionnaire design

Recognising time constraints for the watchkeepers, the interview was limited to a maximum of 90 minutes. This allowed the watchkeepers to plan their work schedule and integrate the interview into their otherwise busy day.

A consent of participation form was designed to be presented and acknowledged by the interviewee before commencing the interview. The form provided the interviewee with essential information about the study, including but not limited to the study purpose, study responsibility, personal privacy matters, the interviewees' rights and contact details in case of inquiries. This ensured transparency and that the interviewee was fully informed of the circumstances surrounding their participation. It empowers the interviewee to ask questions about the study and informs them of their fundamental rights and authority to stop the interview whenever they see fit, including their legal and privacy rights. This is central to ensuring best practices when interviewing. LR's legal department reviewed the form and questionnaire prior to sampling.

The final questionnaire is a result of the following agile iterations:

1. First, the adopted questions were initially designed for native English speakers. Therefore, the purpose of the first iteration was to user trial the questions on a watchkeeping engineering officer without interaction—an engineer who did not have English as the native language nor the working language on board the ship. Afterwards, the questions within the questionnaire were evaluated in consultation with the engineering officer. The purpose was to identify and reformulate ambiguous and unclear questions so that the questionnaire could be used online if necessary. The result was the implementation of descriptive notes on some questions. The purpose was to make the answers obtained from the questionnaire as comparable as possible so that all respondents would respond with shared understanding of the same contextual background.

2. The second iteration aimed to identify improvement areas to adapt the questionnaire to the operational context of the maritime industry. This was done by conducting four semi-structured interviews on one ship based on the questionnaire. For the engineering officers, the questions fit well. This was expected because the ship's machinery is, at its core, a power and process plant transforming liquid energy into electrical power and distance. The questions were initially developed for that environment. However, it became evident that the questionnaire needed to provide questions with more options to the bridge officers. As a result, specific questions for bridge officers and examples relevant to their operations were implemented in the questionnaire. Subquestions were implemented to provide additional context for some answers. These changes offer a contextual understanding of the answers, which can add essential perspectives when analysing the data later. It was also made possible for the respondent to upload material such as alarm and event logs, screen dumps or pictures, or anything that would support or supplement the answers given in the response.

3. The third iteration sought feedback from LR's independent advisory panel on human factors. Here, structure, wording, and content were scrutinised. The group recommended the implementation of question 26, which was subsequently done. It also requested additional due diligence in preserving the privacy of its respondents. As a result, the legal department of Lloyd's Register reviewed the questionnaire and confirmed that it was designed in compliance with data privacy regulations, such as GDPR.

1.18.1.2 Questionnaire digital platform

To store and process the data gained via the questionnaire, JotForm.com was used as a digital platform. It is designed to collect, store, encrypt, and handle data in compliance with data privacy regulations such as GDPR [61]. This enabled responses to be logged electronically and be agnostic to the primary device types (tablet, laptop, smartphone). Further, it should work online and offline; ships are Faraday cages and connectivity cannot be guaranteed in the field, especially not in the ECR or machinery spaces.

The first page of the questionnaire was the "consent of participation", which the participant had to scroll through, read and accept to consent in order to proceed with the interview. The questions were grouped based on their content. On the last page of the questionnaire, an algorithm generated a unique randomised ID number for each submission. The ID number was the only way for participants to identify submitted information if they wanted to delete or change their answers at any point.

One repository was created for each sampled ship. Asymmetric public-key cryptography was used to encrypt the questionnaire by generating a key pair comprising a private key and a public key. The form is encrypted as the respondent fills it out using RSA-2048. It is fully encrypted prior to being transmitted via SSH to a dedicated server within the EU. The private key is kept secret and known only to the authors of this report. The public key can be freely shared with any participant, who can then use their public key to encrypt a message before sending it to the authors over an untrusted network. Here, the data remained encrypted while at rest. Only the authors of this report are able to decrypt the data using the corresponding private key.

To avoid false submissions, each repository requires a unique password to access the form, which means that only respondents with this password could complete the questionnaire.

Each repository was given a title of a random number *n* of the *N* sampled ships. The randomised number would be assigned another randomised number *n*' of the *N*' sampled ships, which is used to enumerate these in the data dissemination. The link between the two sets of randomised numbers is analogue (a piece of handwritten paper) and is kept in physical form somewhere safe and secret. In this way, no one could establish a connection between ship-specific data in JotForm and the disseminated results. The information would be unattributed, and an adversary would not learn anything other than what is already disseminated.

1.18.2 Interview methods

The following section introduces and discusses the methodological approach for the interviews and describes how they were performed.

Interview sampling was conducted until informational redundancy is reached and nothing new was apparent. Data saturation aims to capture the nuances and depth of the problem domain adequately. Different definitions of data saturation exist within scientific communities.

It is important to note that there is no scientific consensus about the number of interviews needed to achieve saturation [62] [63]. Typically, such figures are defined by the publishing entity when qualitative researchers submit a paper for a journal, conference or the like. The saturation criterion was determined to be reached when:

> *"New data tend to be redundant of data already collected. In interviews, when the researcher begins to hear the same comments again and again, data saturation is being reached… It is then time to stop collecting information and to start analysing what has been collected" – [62].*

Determining the precise moment at which data saturation occurred proved challenging. The nuances of the problem domain were thoroughly discussed through continuous dialogue between the interviewers. Consensus was eventually reached when the perceptions converged and further interviews and observations yielded no significant additional insights.

During a majority of the interviews one person would conduct the interview and one would be an observer. The interviewer conducted the interview and recorded the answers in electronic format (JotForm). The observer's primary task was to record narratives, quotes, and additional information and make observations during the interview. This ensured that no important information, data, or central points were missed.

Furthermore, the observer occasionally asked elaborative questions and investigated discrepancies between answers. The observer was in a more favourable position to engage in a dialogue suggesting alternative perspectives since the observer was not engaged verbally in the interview. The observer was mindful not to disrupt the interview unless apparent discrepancies needed to be elaborated upon, and not to manipulate the interviewee's answers directly, for example, by asking leading or loaded questions. The observer intervened primarily in cases in which the interviewee appeared complacent or showed a lack of reflection on the questions.

1.18.2.1 Accounting for cultural influences

The interviewees consisted of people with various demographic backgrounds representing the entire world. A considerable proportion was from European regions, where different *cultural dimensions* can be assigned to different nationalities [64].

Hofstede's six cultural dimension model is a framework that can be used to understand cultural differences based on several factors. The framework is widely used to understand communication and etiquette across cultures. The interviewers were aware of these dimensions while conducting the field studies and took measures to mitigate any friction that might occur between the interviewers and interviewees.

As an example, some cultures are prone to show a high level of *power distance*, which can be described as:

> *"This dimension deals with the fact that all individuals in societies are not equal–it expresses the attitude of the culture towards these inequalities amongst us. Power distance is defined as the extent to which the less powerful members of institutions and organisations within a country expect and accept that power is distributed unequally" – [65]*

As a result, the interviewers worked to position themselves on the same hierarchical level by showing personal traits that people of authority usually do not exhibit. This was to reduce the potential impact of the *good-subject effect*, in which the interviewee attempts to confirm their perception of the interviewers' hypothesis [66].

It was the interviewer's perception that some interviewees would be subject to this effect when the interviewers were perceived as strong authority figures representing a classification society like LR. This is known as a *demand characteristic* [66], which can cause a wide range of biases depending on factors such as the interviewers' interaction with participants, the study settings, and the study procedure. The commonality is the indicators that might disclose the interviewers' objectives to the participants. Therefore, the interviewers strived to reduce the influence of these biases.

1.18.2.2 Conduction of interviews

Upon arrival for on the ship, a primary objective for the interviewers was to communicate the purpose of their presence to counteract potential resistance from the crew. The interviewers were mindful of the authority associated with representing LR and the implications that might be associated with it. Building rapport with the interviewees before conducting the interviews was deemed fundamental. The interviewers aimed to position themselves as insiders. This was accomplished by leveraging industry knowledge, specific phrasing, and terminology, demonstrating a general understanding of the facilities and systems present on board. But also by showing empathy and genuine interest in the well-being and interest of the crew. The interviewers strived to be sincere and transparent about the study's objectives, and avoided disclosing information that could introduce biases, such as demand characteristics.

Before conducting the interview, a brief introduction of the study was presented to the interviewee, emphasising anonymity, outlining the aim, interview structure and their rights. Subsequently, all interviewees accepted the consent of participation before the interview was initiated.

Whenever possible, the interviewees were secluded from the remaining crew to create a space of confidentiality. In many cases, it was not possible to change the interview's physical settings while the interviewee was on watch. However, the interviewers would try to keep maximum distance from other crewmembers. The presence of other crewmembers could contribute to a behavioural change as the subject could become an *apprehensive subject* that produces socially desirable answers in correlation with what the interviewee perceives as the social norm and is thereby a subject to *social desirability bias* [67]. If the interviewee is familiar with the interviewer's predisposed opinion about the research area, they could likely answer in correlation with that opinion. On this basis, the interviewers aimed to be as objective as possible.

While conducting the field studies, the interviewers were conscious about their appearance, and attempted to dress in a style that aligns with the norms of the interviewee in order to build better rapport. The interviewers avoided wearing LR surveyor boiler suits, helmets, gas detectors, etc. Furthermore, having an open and positive body language and adapting it to the interviewee also helped establish rapport.

The complexity of the spoken language was also adapted accordingly. This was done to establish simple and clear communication and avoid ambiguity and misunderstandings.

If interviewees were found to be highly complacent with the systems and unable to answer the questions with minimal reflection or contradicted their previous statements, in some instances, the interviewees would question the statements and prompt them to reflect upon their answers.

The interviewers were aware of potential biases and considered the context, cultural nuances, and impact their questioning could have on the reliability and validity of the data collected. It was deemed essential to encourage thoughtful reflection while ultimately respecting the authenticity of the interviewees' responses.

The interviewers, all maritime domain professionals, tested their assumptions about the alarm system while conducting the interview. This was to give the interviewee the possibility to correct, nuance and give perspective to the perceptions that the interviewers had developed.

In addition to the interview structure in the questionnaire, the interviewer only asked questions when there was a need to catalyse the monologue of the interviewee as the story/narrative unfolded.

As a result, natural breaks were allowed during the interview, during which the interviewee would decide the pace and content. In these sections, *active listening* allowed the interviewees to speak freely about the topics that mattered most. The interviewers would request elaborations on topics by asking neutral open-ended questions. Whenever possible, the narratives and quotes were recorded simultaneously with the interview.

1.18.2.3 Method for analysis of the questionnaire

The accumulated data from the questionnaires was organised in tables to provide a visual overview. The data was visualised by dividing it into the respective ships, dividing the number of participants, and distributing the answers. The overview provides a clear view of the data when analysing the data and identifying tendencies. The overall results are compared with those found within the HSE CR 166 report.

Then the percentual distribution of the answers to each question was presented in a stacked column chart for the ECR and the bridge, respectively, and for the entire ship. Quotes from the watchkeepers and observational notes relevant to each answer were placed adjacent to the respective answer in the column chart. This juxtaposition provides context and highlights the interconnectivity, producing a visual rhythm in the presented data. By representing the data in a recognisable pattern, the reader is supported when identifying similarities between the quantitative questionnaire results and the qualitative quotes and observations [68].

1.19 ECR – alarm and event data

This section describes how the engine room alarm data was collected from the field.

To analyse the alarm load of the ECR (Figure 16), the quantitative alarm and event data from the integrated automation system (IAS) were collected on board the ship or by using the option to attach data within the survey response form. Complete alarm/event logs could typically be extracted as comma-separated values (CSV) files. On some ships, extracting the event and alarm log was not possible. Some ships lacked access rights to the event database. Others experienced so many alarms and events that the structured database queries crashed the historian server. The engineering officers sometimes had to query relatively small time intervals to extract the event log into available workable memory.

An initial analysis of a provided alarm/event log was conducted for computing the objective performance metrics according to IEC 62682:2014. The 2014 version contains a more extensive set of metrics than the revised 2022 version.

Detailed methods (applied algorithms and data structures) and source code used to compute these metrics are provided in the second output introduced in the project background. An open and interactive environment is provided with executable code and data (see Additional resources).

FIGURE 16.
The ECR on board an LR classed ship. Courtesy of Stena Line

1.20 Bridge – alarm load recording

To quantify the combined alarm load on the bridge, manual alarm load recordings had to be conducted to consolidate the alarm load from the IAS, navigational systems, and stand-alone systems. Although claimed to be fully integrated, numerous systems on the bridge are still stand-alone or only partly integrated. A few examples include indications of the watertight doors, the window wiper, and the heat tracing system within the glass glazing. This is also the situation in the ECR, but to a lesser extent.

Thus, only manual observations and recordings can be utilised to obtain the quantitative alarm log on the bridge. Similar approaches were deemed necessary in related work [69]. This requires physical attendance for the entire end-to-end alarm load recordings. It is a very resource-intensive data collection method that necessitates shiftwork of at least two people. It also requires extended time on board for preparation and time for actual observations. For these reasons, it was conducted on two ships only.

Two technical sisters from a series of passenger ships were selected for sampling to make their two datasets comparable. Both had fully integrated bridge systems and navigational systems and were built and appraised to the Det Norske Veritas (DNV) NAUT-AW notation, which requires the bridge design to enable a single Officer of the Watch (OOW) to perform navigational duties unassisted at all times during normal operating conditions [70]. These notations are comparable to LR's NAV1 [71] requirements. The two selected ships were less than three years old, so their navigation and radio communication equipment on board complied with the BAM regulations under the EU Marine Equipment Directive (EU MED) [72].

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FIGURE 17.
Picture of centre console panel on a general bridge. Courtesy of Shutterstock

To make the bridge data recordings as comparable as possible, two similar routes were planned with consideration of the length, duration, time of the day, and traffic density. In addition, a third alarm load recording was conducted while passing through the Strait of Gibraltar at night. This was conducted on the same ship as the first recording. This third alarm load recording was initiated on the bridge 45 minutes prior to reaching coastal waters and terminated the recordings when entering open sea. The itineraries were analysed visually on a traffic density map [73] using a route planner.

Prior to the alarm recordings, the observers familiarised themselves with the bridge layout for the alert systems. A general bridge layout (Figure 18) consists of a centre console (1) with diagonal sides (2) and two integrated chairs (3). Behind the centre console are one to two consoles or workstations (4). On the two far sides of the bridge are two consoles (5), referred to as port- and starboard-wing, used for manoeuvring during arrival or departure. Common systems on the bridge are ECDIS, radar, firefighting and detection, Global Maritime Distress and Safety System (GMDSS), radiocommunication equipment, steering, and propulsion. All these systems have bespoke HMI and indicator panels; an example is shown in Figure 17.

The two end-to-end alarm load recordings were initiated approximately one hour prior to departure. This was done to record the annunciated alarms during the startup phase. During this phase, bridge officers perform various essential tasks, such as route planning and stability calculations. The recording of alarms during this hour is important in terms of the officers' distraction level.

The alarms were noted manually with a pen on paper to avoid light pollution (at night) and noise. Dialogues with the officers were permitted if the purpose was

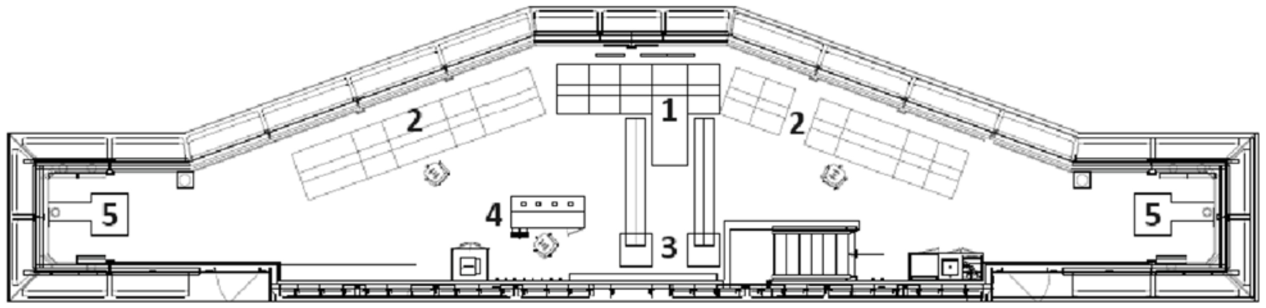

FIGURE 18.
Generic layout of a bridge. Courtesy of Lloyd's Register

to identify unknown alarms and to gain contextual knowledge of alarms and the officers' experience of them. The observations were terminated when the propulsive machinery was shut down after arrival. The alarm data recordings from the bridge were consolidated in a spreadsheet and joined with the extracted alarm log from the IAS.

The dataset was divided into regular time intervals, starting from the initiation of the alarm data recordings and the total alarm load for each time interval. Furthermore, the alarms were divided into sea areas according to previous related investigations [69], to be able to compare the alarm load recordings:

- Open sea: no natural constraints/ no artificial constraints
- Coastal: natural constraints/ 10 or less nautical miles to nearest coast
- Confined waters: harbour/ anchorage/ pilotage

Additional spatial attributes emerged in discussions with several navigational officers, including:

- Harbourage
- Pilotage
- Anchorage
- Traffic separation scheme

The dataset was limited to cover the time interval in which the observers had conducted alarm load recordings to make the two datasets comparable. The dataset was divided into discrete time intervals, using a zero-based index, starting from the initiation of the alarm data recordings on the bridge.

Results and Discussion

This section presents the results of the alarm load on the navigational bridges for two technical sisterships, which also includes the alarm load of the machinery space for one of these two ships. Hereafter the section presents the aggregated questionnaire results in relation to the findings from the HSE CR 166 report. From here the section moves forward presenting the questionnaire in juxtaposition with associated narratives from the officers on the bridge and for the machinery spaces, respectively.

1.21 Objective alarm loads and observations

The bridge alarm load recordings were conducted using the described methodology (section 1.20). For the methods and analysis of the presented quantitative performance metrics in relation to IEC 62682, readers are referred to the link in the background section under *Additional resources*. These datasets are inappropriately large for inclusion in any written appendix.

1.21.1 Results of bridge alarm recording 1

Route 1 (Figure 19)Minorca, Spain to Mallorca, Spain, distance of around 160 nautical miles, from afternoon, through the night, until the following morning. Note that some noise was added on top of the ship's path. The weather conditions were calm seas with good visibility.

The time series interval plot from the alarm load recordings are presented in Figure 20. The total observation took 15 hours and 49 minutes.

A total of 352 alarms were observed on the bridge, while the ECR received 728 alarms during the first bridge recording. The peak rate in the ECR was 111 alarms per hour, while it was 56 per hour on the Bridge. Of the bridge alarms:

- 66 alarms were annunciated from the ECDIS,
- 60 from the radar,
- 50 alarms were additionally attributed to either the ECDIS or radar, (MFD). These alarms could not be distinguished because of similar sounds and restricted visual confirmation during departure and arrival or due to quick acknowledgement from the officers.
- 59 alarms were observed from the propulsion control panel,
- 24 alarms from the IAS, which were primarily ECR-relevant,
- 13 alarms were annunciated from the TCP,
- 5 alarms from the SMCS,
- 1 alarm the VDR,
- 74 alarms were not identifiable.

This system distributions are illustrated in Figure 21.

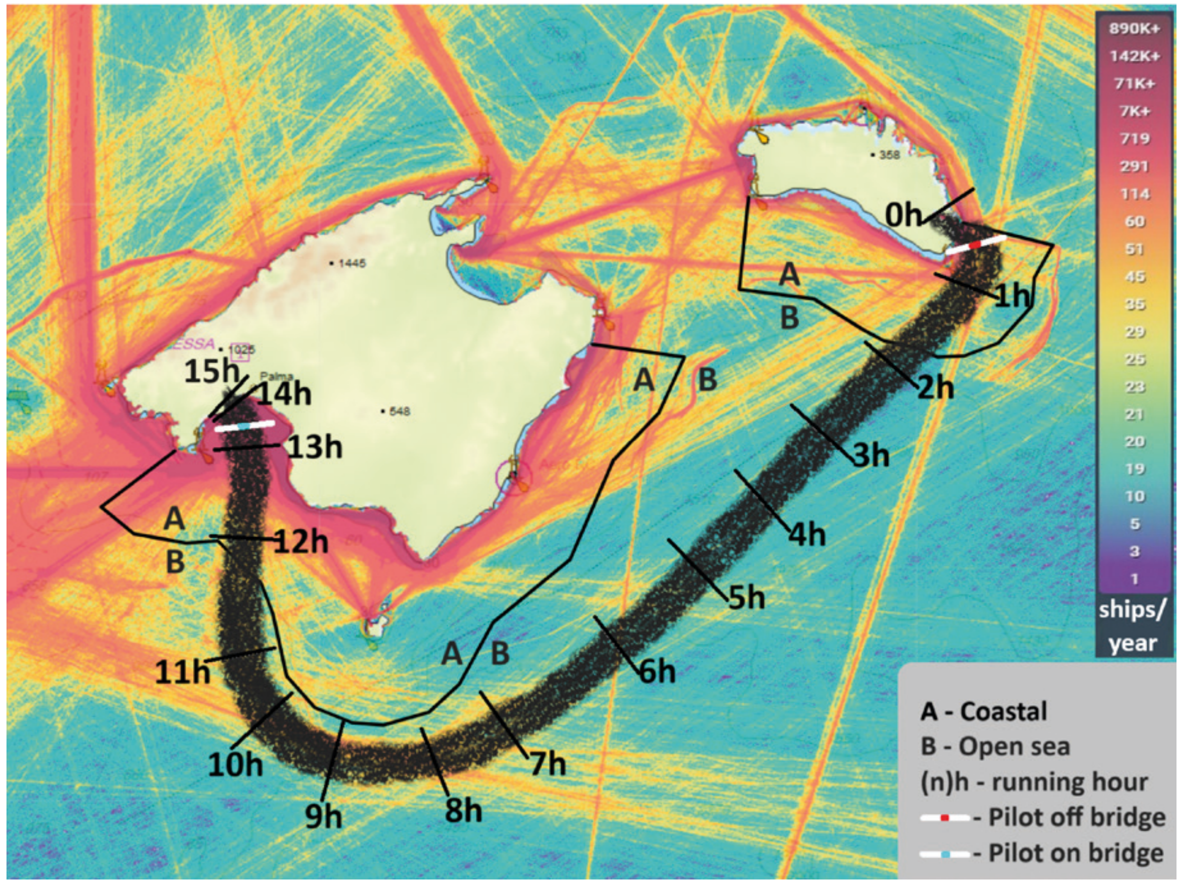

FIGURE 19.
Route 1 sketched on a traffic density map with timestamps and sea areas

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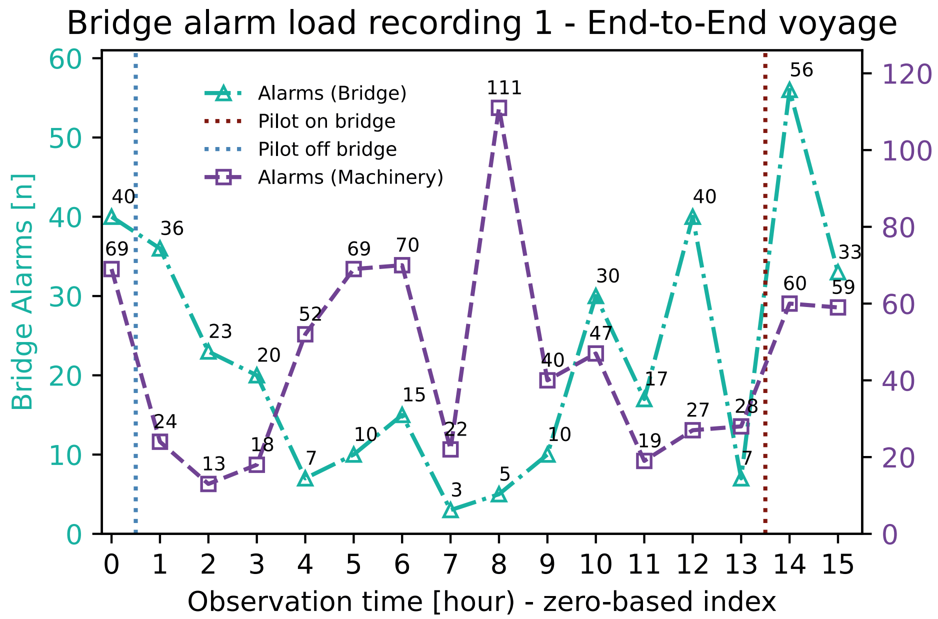

FIGURE 20.
Scatterplot of annunciated alarms respectively from the bridge and ECR during Bridge alarm load recording 1

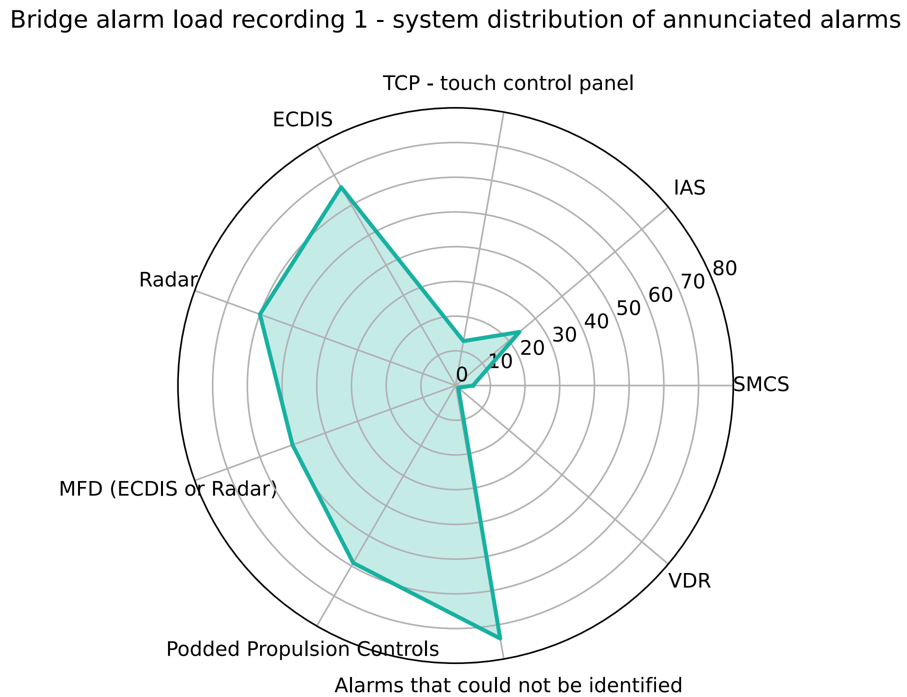

FIGURE 21.
Radar chart of the annunciated alarms from the respective system during Bridge alarm load recording 1

1.21.2 Results of bridge alarm recording 2

Route 2 (Figure 22): La Palma, Spain to Tenerife, Spain, distance of around 160 nautical miles from afternoon, through the night, until the next morning. Note that some noise was added on top of the ship's path. The weather conditions were calm seas with good visibility.

The time series interval plot from the alarm load recordings are presented in Figure 23. The total observation took 15 hours and 42 minutes.

A total of 105 alarms were observed on the bridge. It was not possible for the vessel to extract the ECR alarms due to logging server issues. The manually recorded alarms on the bridge included:

- 43 alarms were from the IAS,
- 28 alarms were from the ECDIS,
- 11 alarms were from the SMCS,
- 9 alarms were from the VHF,
- 4 alarms from the bow thrusters and propulsion control panel,
- 2 alarms from the TCP,
- 1 alarm from the echosounder,
- 1 alarm from the fin stabilizers.
- 4 alarms were not identifiable during the observation.

This system distributions are illustrated in Figure 24.

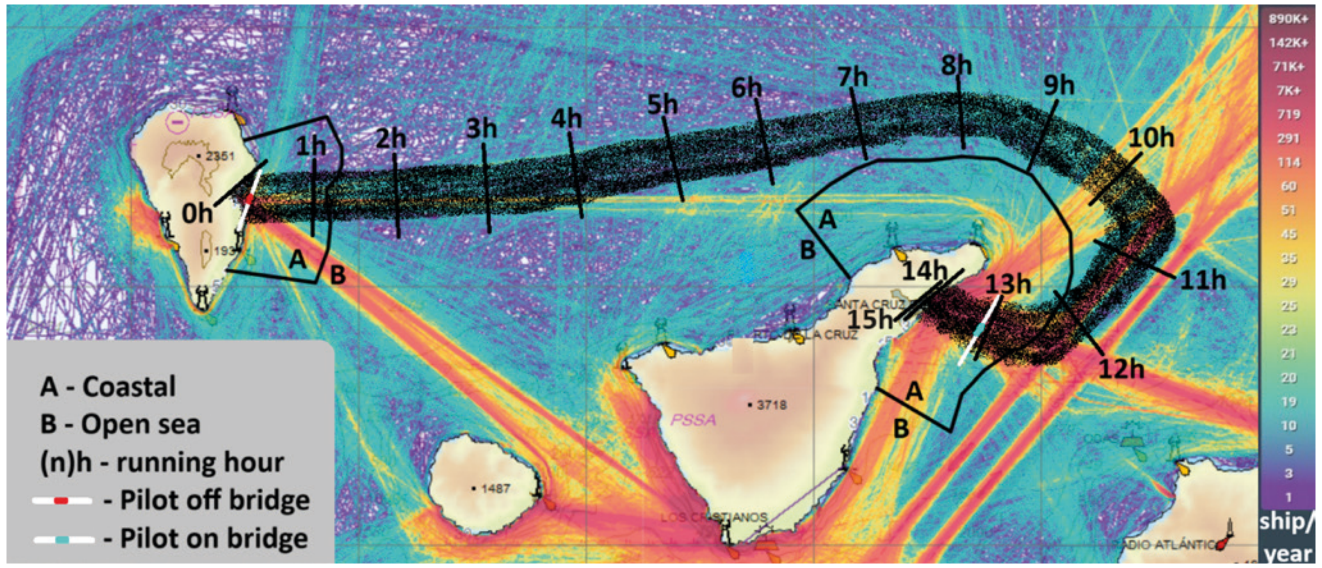

FIGURE 22.
Route 2 sketched on a traffic density map with timestamps and sea areas

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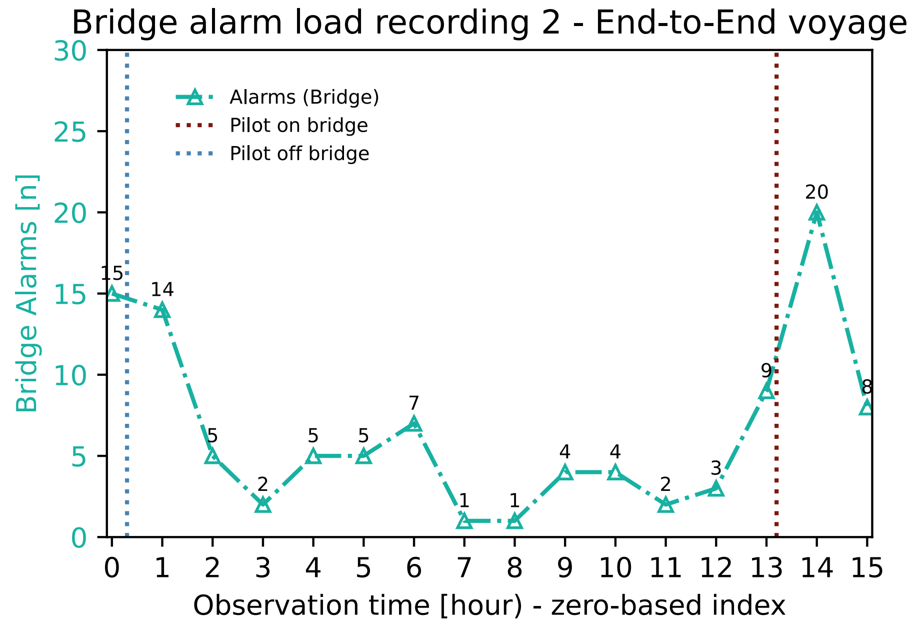

FIGURE 23.
Scatterplot of annunciated alarms from the bridge during bridge alarm load recording 2

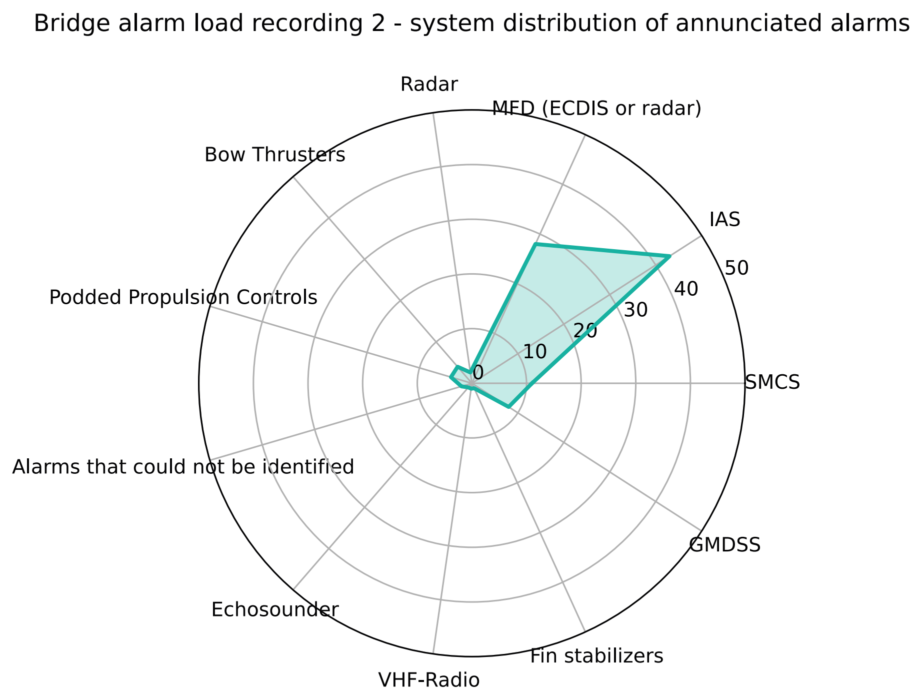

FIGURE 24.
Radar chart of the annunciated alarms from the respective system during bridge alarm load recording 2

1.21.3 Results of bridge alarm recording 3

Route 3 (Figure 25): From the Mediterranean Sea into the Atlantic Ocean, distance of around 55 nautical miles. The vessel path is not exact. The weather conditions were calm seas with good visibility.

The time series interval plot from the alarm load recordings are presented on Figure 26. The total observation took two hours and 41 minutes on the bridge.

A total of 163 alarms were observed on the bridge. 110 alarms were annunciated in the ECR during this same period. Almost all of bridge alarms were annunciated from the ECDIS and radars. The system distributions are depicted in Figure 27.

The surroundings and context of this observation rely on it being nighttime, with observation starting at around midnight. Two bridge officers and two quartermasters (lookouts) were on watch.

The officers stated that it was a quiet passing, with lesser than usual traffic through the Strait of Gibraltar. The observers noted that the officers relied primarily on the visual confirmations from looking out the bridge windows rather than focusing on the radar and ECDIS displays, where most alarms were annunciated. When asked, the officers estimated that there had been a total of 50-70 alarms during the alarm load recording.

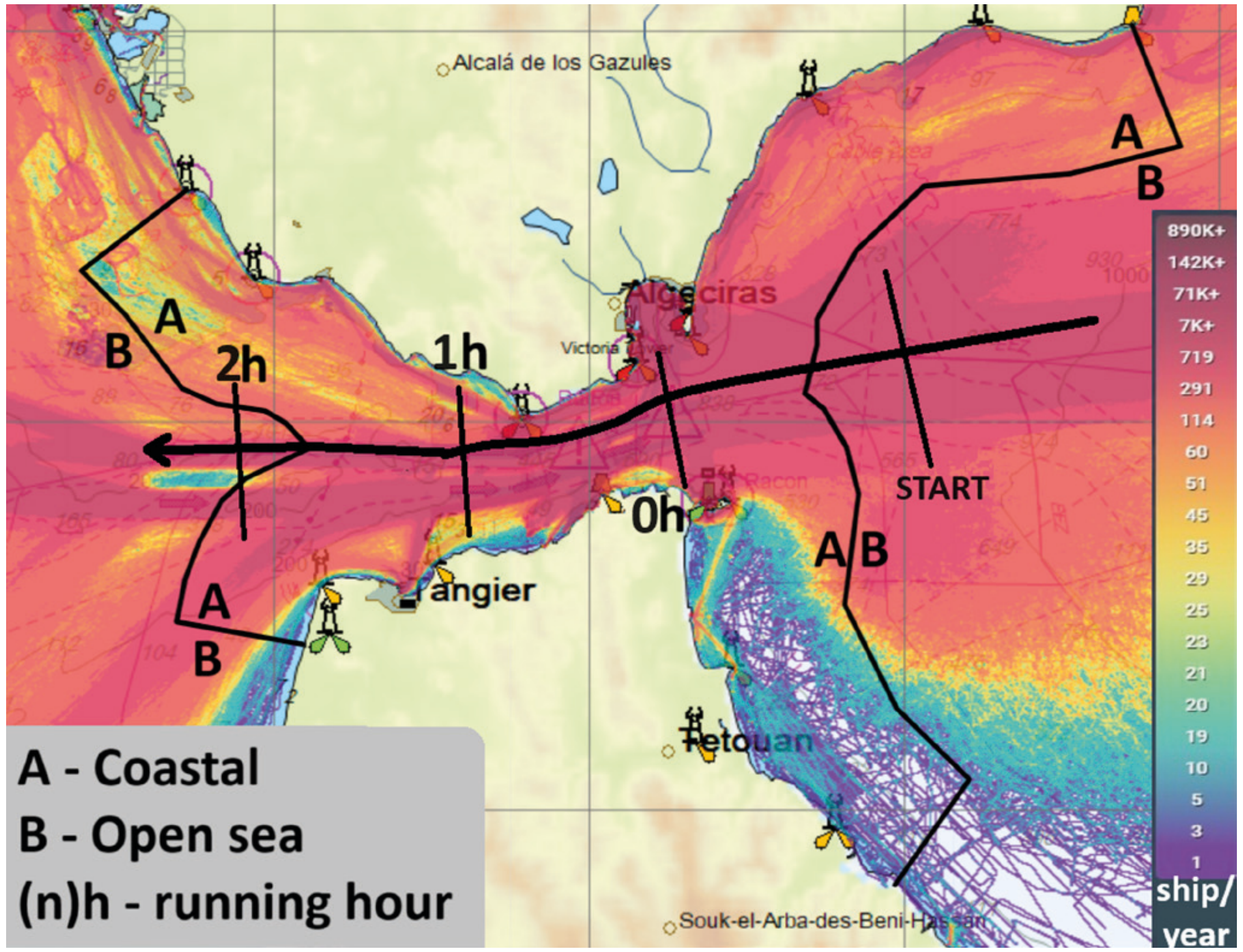

FIGURE 25.
Route 3 sketched on a traffic density map with timestamps and sea areas.

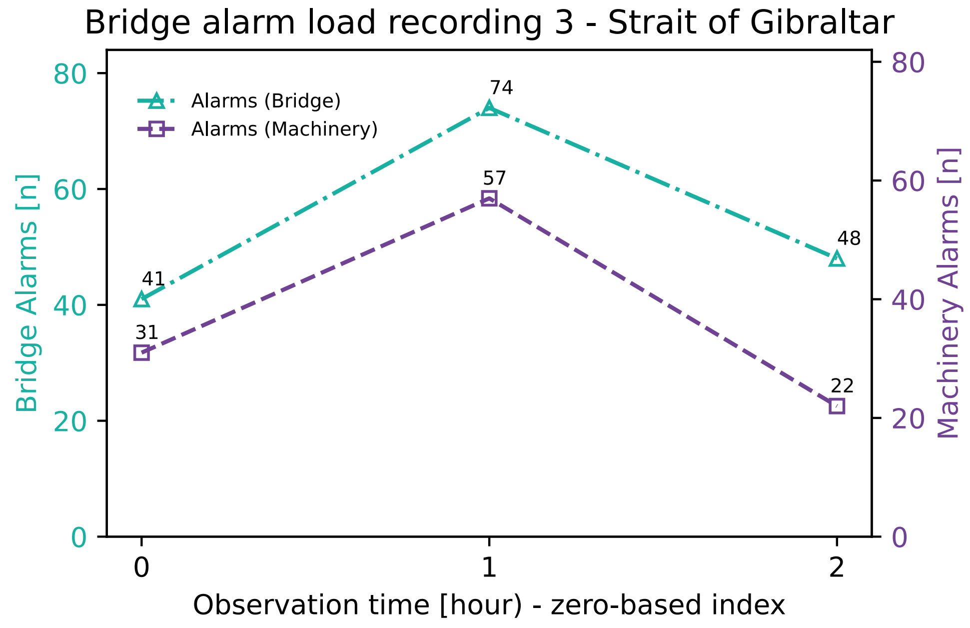

FIGURE 26.
Time series of annunciated alarms respectively from the bridge and ECR during Bridge alarm load recording 3

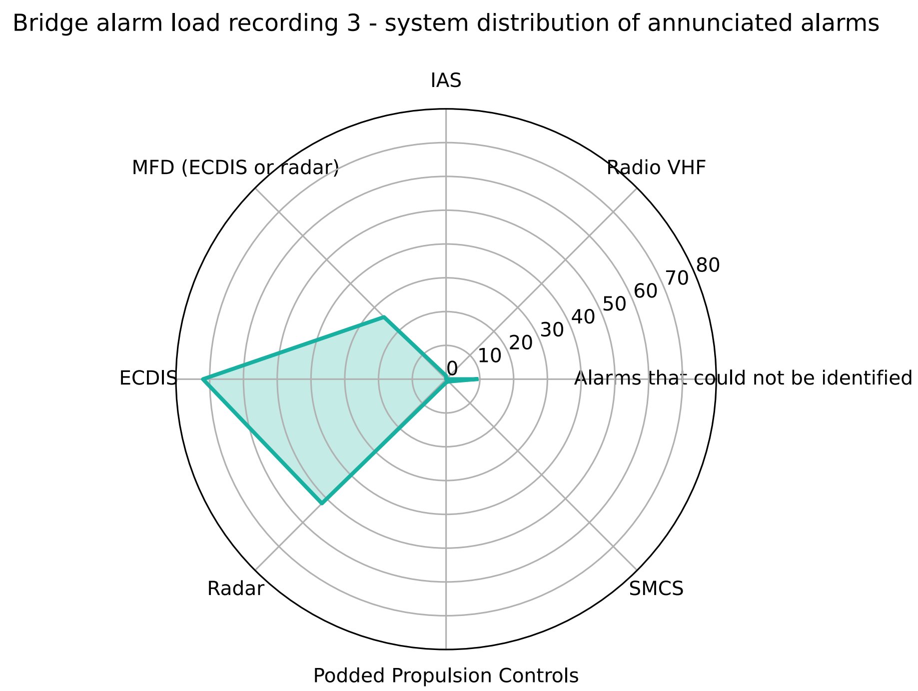

FIGURE 27.
Radar chart of the annunciated alarms from the respective system during bridge alarm load recording 3

1.21.4 Discussion of bridge alarm load observations

The time series interval plot from the alarm load recordings shows varying alarm load patterns on the bridge under different operational circumstances. For both ships, the largest number of annunciated alarms on the bridge occurred in proximity to departure, arrival, and traffic separations. These alarm rates were highest during operational circumstances for which the navigating officers must be able to focus, notably while arriving, departing or passing through highly trafficked waters. As such, alarms can pose a considerable source of distraction and nuisance.

A substantial difference in alarm load was observed between the first and second alarm load recordings. The second recording showed approximately one-third of the alarms compared to the first. While the routes were similar regarding traffic density patterns, distance, and spatial attributes, various external factors contributed to the difference in the observed values:

1. The entries and departures from the ports were different, potentially impacting the alarm load significantly. The first route, starting at the port of Mahon, Minorca, Spain, has a long port entrance, whereas the other three ports are open and not surrounded by shore. This would likely create more navigational alarms in the first port caused by radar and ECDIS alarms.
2. The observations were conducted roughly one month apart, which could influence the traffic density because of the time of year. The authors observed slightly less traffic during the second observation.
3. There was a difference in applied navigational settings on the ECDIS and radar. The first ship used the settings according to company policy, whereas the second ship was sailing under the captain's orders for other settings, the latter being more relaxed. This tendency was noticed on multiple other sampled ships.

Regarding the last point (3), the authors attribute a tendency of shoreside ship management not to practise a validation of the effectiveness and usability of their imposed policies and procedures. In such instances, the master is therefore faced with a decision to either go against company procedures or exercise own professional judgement, a dilemma also reported in the aviation industry [74]. For the maritime industry, SOLAS is crystal clear on the master's justification for doing so:

> *"The owner, the charterer, the company operating the ship as defined in regulation IX/1, or any other person shall not prevent or restrict the master of the ship from taking or executing any decision which, in the master's professional judgement, is necessary for safety of life at sea and protection of the marine environment." – [75]*

A detailed narrative example that emphasises the rationale behind masters choosing these options can be seen in a captain's letter (Table 9). This letter was attached within the survey response from a captain on board one of the world's 10 largest cruise ships. The captain has the overall responsibility for the safety of more than 6000 passengers, plus crew, on an asset valued at over one billion USD. The letter expresses frustrations with the navigational alarm system, and the lack of resolve from technical management and the system vendor to address these concerns.

Out of consideration for anonymity, names or other indicators that could contribute to the disclosure the captain's identity, as well as that of manufacturers and specific systems, have been replaced with [Anonymous], [Ship], [Manufacturer] or [System]. The letter is presented in *italics*.

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TABLE 9.
Captain's letter

Here is a brief summary regarding Alarms intensity on the BRIDGE and ECR:

1. BRIDGE – NAVIGATION ALARMS
*period: [date]-[date] (14 days) ---> **2748** audible events/alarms --> average per day: **196***

2. BRIDGE – FIRE DETECTION/ESD
*period: [date]-[date] 2023 (256 days) ---> **15740** audible faults/alarms/prewarning --> average per day: **61***

3. ECR - MAS
*period - 7 days - **15024** events ---> average per day: **2100***

As for the alarms on ECDIS for [Ship]. It has been a struggle from day one. There are two issues, namely volume (loudness) and frequency (number). The volume of the alarm itself is excessive due in part by to the fact that the alarms sound on 12 MFD's, which is basically all bridge MFD's, and the fact that with these new generation of monitors the alarm speaker is buried deep inside the unit and almost impossible to access. I know it is not allowed to modify them in anyway but putting a piece of electrical tape across the buzzer/speaker was about the only way to reduce the noise in the past. There are rules that specify the volume, which I have attached here for reference, but even when [Manufacture]/[System] was presented this they still were not able, or willing, to address the issue satisfactorily. We have on [ship] an exceptionally quiet bridge, which is a beautiful thing but it makes the alarm volume standout all the more. The rules allow for 10 decibels above ambient and our bridge is between 55 and 60 decibels ambient so it would stand to reason that we should have our alarms sounding at no more than 70 decibels. We are currently seeing the alarms at +85 decibels. This combined with the number of alarms makes it a distraction that is of legitimate concern. The alarm that sounds the most is "Out of Route Corridor" during arrivals and departures. These alarms are on all MFD's and the sound is not synchronized so it sounds like loud cacophony. Since it is a requirement that we maintain the route corridors right up the piers, as in Pier to Pier, we suffer from a continuous string of alarms about every 10 or 15 seconds and sometimes more during arrivals in particular. The ability to adjust the route corridors in [System] to more accurately follow the shape of the channel is limited at best and one of my biggest complaints. As a result of having to keep the corridors narrow, so we don't cover any dangers, the predictor is forever touching or crossing the route corridor boundary and triggering an alarm, even when the predictor is set to 120 sec. Seeing to 90 sec doesn't help much either. The real concern is that the bridge team, including myself, are suffering from "alarm fatigue" and the likelihood that we will miss an important alarm is higher than it should be. As well the volume of the alarms is enough that the QM/helmsman can't always hear helm orders and the team not being able to hear the closed loop communications on the bridge. As a result of not getting any help or support from [System] I am left with having to find ways to reduce the number of alarms any way possible. This we have done to the fullest. Any more and we may compromise the functionality and intent of the ECDIS itself. It is a safety issue in my opinion.

Anyway, sorry for the long dissertation on this subject but it is a real issue here and one which you may face on [other ship]. I have had this conversation with Capt.[Anonymous] and she/he suggested that we get together and discuss.

On IMO Resolution A.1021(26) under CODE ON ALERTS AND INDICATORS, 2009

On Resolution MSC. 337 (91).

Considering the above, the peak alarm rate imposed on the bridge officers during departure and arrival raises concerns about applicable industry policy. Both ships were compliant with BAM, which aims to improve the situation on alarms. Nevertheless, the bridge officers still experienced several alarms which were irrelevant at the given moment. Notably, the first ship received many "crossing area" and "approaching waypoint" alerts on the ECDIS. The crossing area alert was observed as a common occurrence on multiple ships and was generally ignored by the officers.

In the IMO definition these two alerts are *warnings*, but from the observations of the authors, not a single interviewed officer (also engineering officers) differentiated between these terminologies, not even when made aware of the alert terminology. In short, if it sounds annoying and blinks like an angry fruit salad, in their minds it is an alarm.

Of the 30 interviewed bridge officers, one chief mate was asked what value those crossing area alerts bring while navigating. The answer was, "Honestly… it brings none." This highly experienced and competent officer could only think of rare instances in which it could be useful and added that everybody on board had become entirely numb to these alerts.

For the third bridge alarm load observation, it became apparent that the officers, who had both estimated 50-70 alarms over the period, although they were actually subjected to 163 alarms, were experiencing alarm fatigue. In fact, they had abandoned using the alarm system and with good reason. With a peak rate of 74 alarms per hour, the watchkeeping officer would have to read, acknowledge, analyse, decide, and act on an alarm more than once a minute.

This observation suggests that officers may underestimate their subjected alarm load, emphasising the need to combine objective, quantifiable data with qualitative narratives and observations to get a more accurate picture. The authors who were on board for the recordings were pleased to observe that the navigating officers decided to look out the window instead. Instead, it was the quartermaster who went around and muted the alarms.

1.21.5 Comparing bridge alarm load observations with related work

It was deemed worthwhile to compare the observed alarm load to the ones reported by previous field investigations which took place nearly 20 years ago. In previous investigations, the observed average alarms rates on three passenger ships were [69]:

- 3.22 at open sea,
- 10.8 in coastal areas,
- 26.2 in confined waters

Note that the related work reported on no routes, nor any defined sampling time period. The combined average alarm rate per hour for this investigation (bridge recordings 1 and 2) were:

- 9.5 in open sea
- 18.3 in coastal areas
- 27.9 in confined waters

Comparing the alarm load recordings with the previous investigations (Figure 28), there were ~197% more alarms per hour at open sea, ~70% more alarms in coastal areas and ~6% more alarms in confined waters. This is concerning, considering these recordings were consolidated on two technical sister ships, both assured against the IMO's BAM resolution, and classed with enhanced navigational awareness. Compared to ships built 20 years ago, ships built today are likely to be fitted with more technologies, sensors, and settings in the systems.

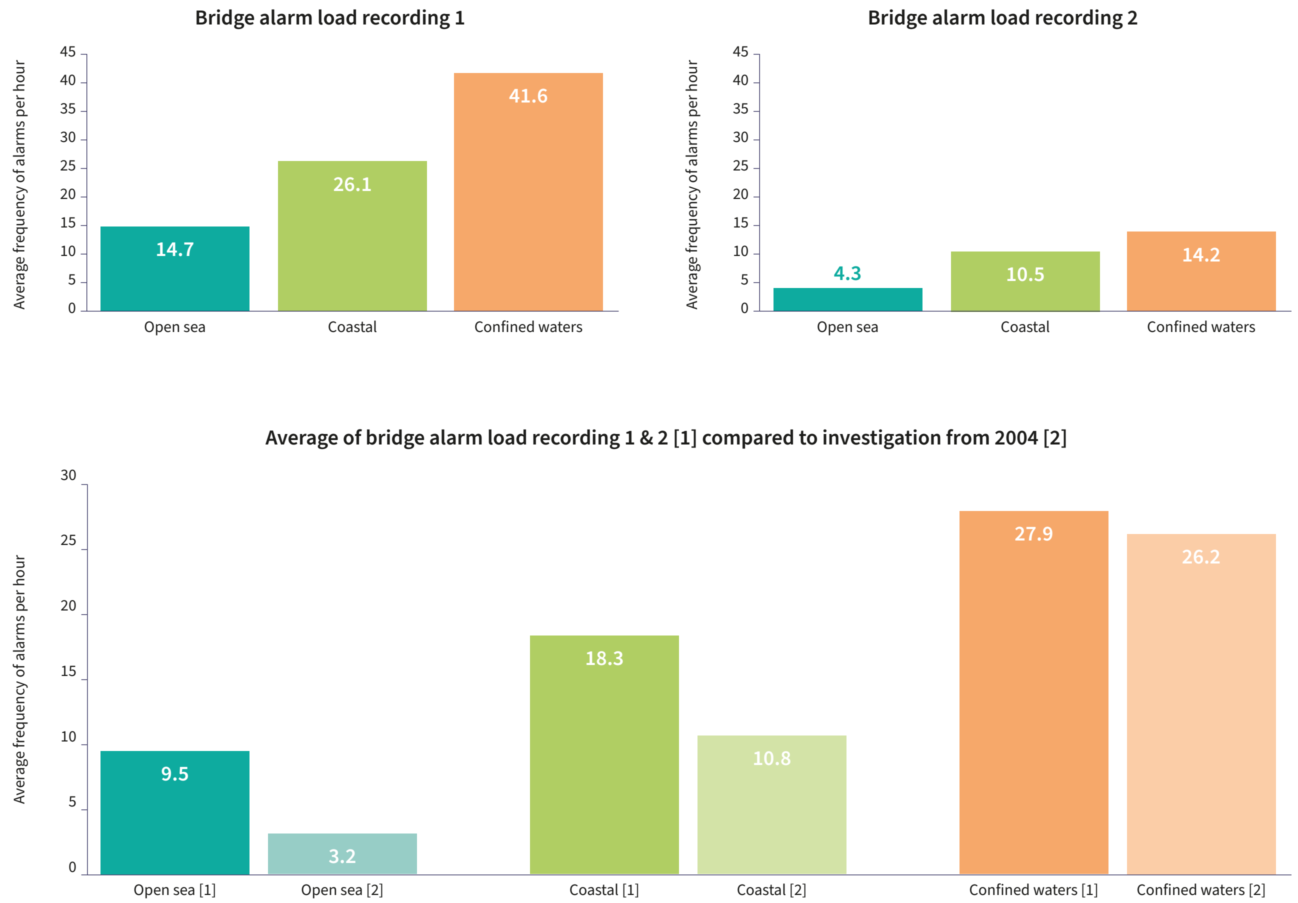

FIGURE 28.
Three column charts illustrate the average alarm load on the bridge per hour, at open sea, in coastal areas, and in confined waters, as well as a comparison of the alarm load observed by the authors and the alarm load observed in 2004 by F. Motz and M. Baldauf [69]

In summary, neither the CAI, nor the BAM regulation appear to achieve stated goals, not even on sophisticated ships like modern cruise vessels. It is possible that this could be attributed to a lack of rationalisation or minimisation conducted in practice, including a lack of quantitative and objective performance criteria for the assurance assessment under construction with specific regard to alarm loads, priority distributions and integrity (nuisance factor).

1.21.6 ECR alarm records in relation to bridge alarm load observations

For the ECR, the alarm load seems more random and does not appear to correlate with spatial attributes. However, this is a question that needs further research.

As reported for the first bridge alarm load observation, 728 alarms were annunciated in the ship machinery spaces. The peak rate was 111 alarms per hour. These recorded alarm rates are more than nine times higher than the upper bounds of performance metrics from other industries: In IEC 62682[18] , one metric defines an alarm rate of 12 alarms per hour per operator (watchkeeper) as the upper bound of being likely acceptable. A likely consequence of such a high alarm rate is alarm fatigue, which can adversely impact the watchkeeping engineering officer's operational awareness and overall performance.

Overall, the ship exhibited an alarm rate of ~2500 machinery alarms per day. Some alarms clear before being acknowledged (fleeting or chattering behaviour) or are muted instead of acknowledged to prevent re-annunciation (Figure 29). This "mute only" strategy was observed to be adopted by multiple engineering and navigational watchkeepers on other ships as well.

These numbers may seem excessive at first glance, but similar cruise vessels were found operating at similar rates.

1.21.7 Alarm load and observed human behaviours

On the ship of the first bridge alarm load recording the authors noted that only a single engineering watchkeeper used the alarm list display in the ECR. It was also noted that no one used it on the sister vessel. Although no fewer than six large monitoring displays were available, the other watchkeepers preferred displaying other IAS mimics with various machinery P&IDs and sensor readings, such as the auxiliary boilers, the power management system, and propulsion systems. This was common for other cruise ships and larger passenger vessels sampled in this report. This tendency is understandable considering the substantial mental effort required to extract actionable information from these continuously growing collections of strings (text) printed onto the alarm HMI screen (Figure 30).

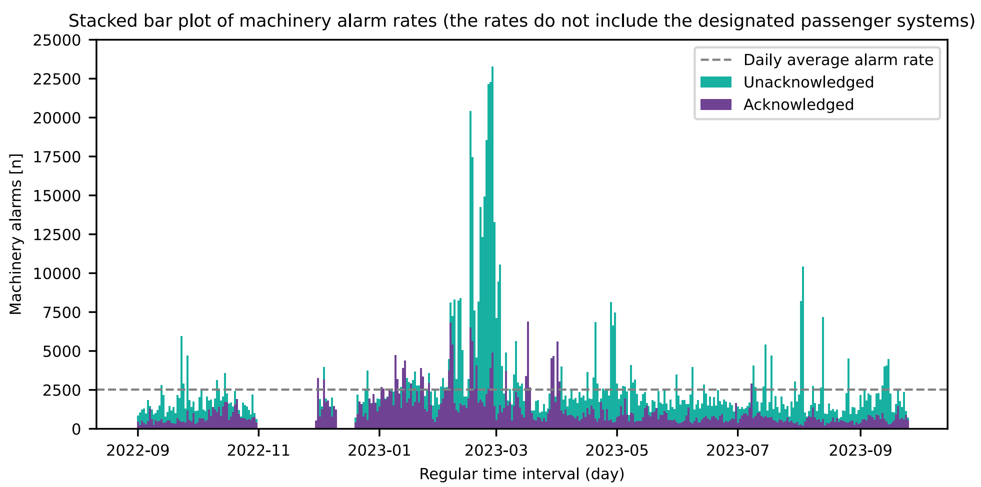

FIGURE 29.
Daily alarm rates – Machinery alarms – the zero values for specific dates indicate missing data, not zero alarms

18 See section on related work for a more thorough review of the IEC 62682

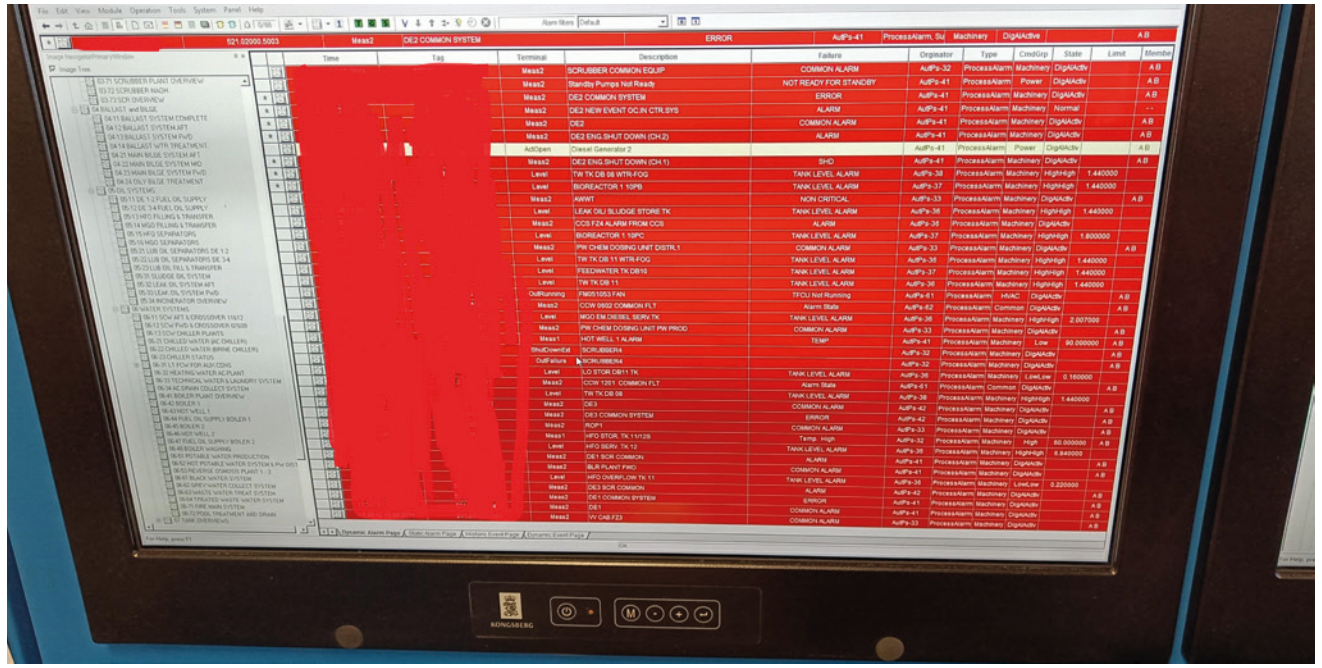

FIGURE 30.
ECR HMI Alarm list on board the ship from bridge observation 1. Same situation on sister ship from observation 2

The authors' observations reinforce fundamental human factors principles in that the intent of providing actionable information to a human via text-streaming makes it unlikely that the message will get across.

The watchkeeping engineer who did not switch off the alarm list display was one of the senior engineering officers. Having experience from multiple contracts (periods of seagoing service) on board the particular ship, the officer appeared to have developed a finely-tuned mental model of the overall system. The mental model enabled the officer to perform as an expert system and multivariate predictive controller, capable of combining alarms and their incoming sequence with relationships to the system's physical processes.

The authors generally observed that watchkeeping engineering officers on back-to-back contracts who simultaneously functioned as ETOs licensed to STCW III/6, exhibited similar characteristics when having a few years of experience on their given ship. For these engineering officers, a typical complaint was so-called "common" alarms, as these did not immediately convey any actionable information. Instead, the officers had to break from what they were doing and locate a local HMI panel elsewhere on board to read the alarm description on the affected machinery.

1.21.8 General Bridge vs. ECR alarm load impact on watchkeepers

While conducting field studies on other ships of different types, the authors likewise noticed that many alarms are generally annunciated in the ECR. It is perceived that, in general, the alarm rate in the ECR is higher than on the bridge. Only a few ECRs had considerably fewer alarms, e.g., an ECR on board a visited chemical tanker; Only three annunciated alarms were observed during an eight-hour visit. The visit included departure, a short seagoing voyage and many manoeuvres, including arrival.

While the alarm rate in the ECR may be higher, it appears that nuisance or non-relevant alarms impose a higher nuisance to the bridge officers. This is understandable as the control loops are open, requiring constant manual input and adjustment to steer and navigate the ship. In contrast, the control loops are closed for most processes in the machinery space and ECR. The authors are unaware of any engineering officers who need to manually control and continuously adjust the amount of cooling water flowing to an engine.

Based on these findings, it must be recognised that the performance metrics from 62682 are process and power industry specific. For this reason, they are not directly comparable to the bridge on a ship where the officers have many different tasks and must respond to alarms while manoeuvring.

In addition to the bridge, the engineering officer may need to leave the ECR to complete a set of sequential discrete time-critical actions in response to an alarm. The latter depends on the machinery systems' degree of automation and instrumentation. Operators in modern process plants can perform many time-critical actions directly from the control station. Such centralisation brings with it other risks, such as operators losing their hands-on overview of the real systems [76].

With this in mind, it must be questioned whether the performance metrics from 62682 are too optimistic for ship operations. Defining a set of objective performance metrics specific to the maritime contexts is a highly worthwhile question for future research. Until then, the IEC 62682 performance metrics[19] appear to be sufficiently ambitious.

1.21.9 IEC 62682 Metrics for Maritime Performance: What to keep in mind.

The 62682 standard recommends that at least 30 days of data is available to compute its presented objective (quantitative) performance metrics [18]. Many of the metrics require continuous analysis of alarm records that contain information produced by the alarm system when alarms occur. The standard further recommends that batch operations (different operational states) are analysed based on data corresponding to several similar batches. For ships, that would entail stratifying the time-series data into operational scenarios such as manoeuvring, underway, loading, off-loading, and so forth.

Relying purely on continuous time may strongly dilute or artificially blow the up performance. Ships may spend a large majority of their time underway with few alarms, only to experience a lot of alarms when approaching traffic-intensive waters or while loading/off-loading their cargo.

An example of this can be found in Figure 31. Here, a 20+ year old sampled RORO ship is analysed for the percentage of the time the alarm system is in a flood condition. IEC 62682:2014 defines this condition as the first regular 10-minute interval where the alarm rate is above 10 alarms [18]. The system remains

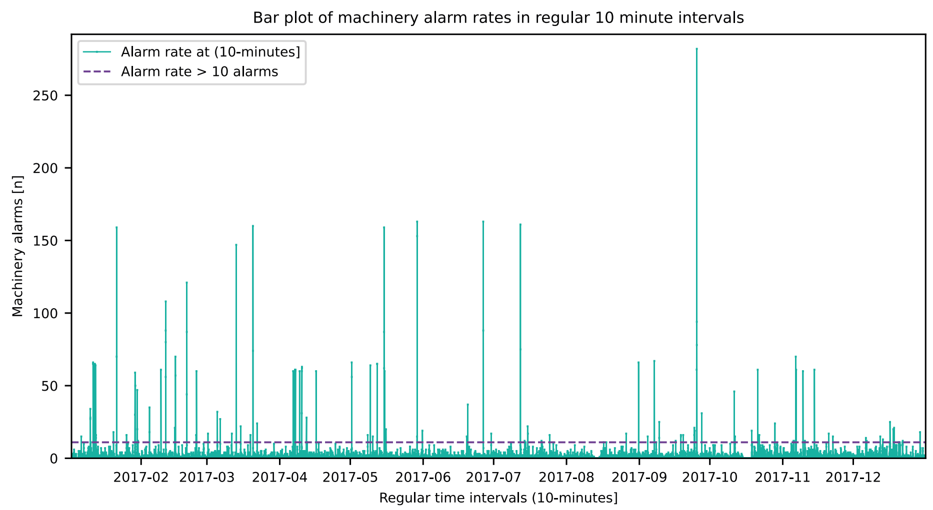

FIGURE 31.
RORO ship – Alarm rates for 10-minute regular intervals

19 The IEC 62682 performance metrics are presented in the section on related work

in an alarm flooding condition until the alarm rate falls below five alarms in a succeeding 10-minute regular interval.

Although the subject ship achieves an alarm flood performance of only 0.42% (performance level is any value less than 1%), the engineering watchkeepers still experienced 218 alarm floods in the period. The longest lasted 60 minutes, and the magnitude of the highest was 282 alarms in 10 minutes.

Because the use of pure time-based metrics may dilute the picture, the standard includes these additional reported metrics:

> *"Both the peak and average alarm rates should be taken into account simultaneously because either measurement individually could be misleading. The number of intervals exceeding 10 alarms and the magnitude of the highest peaks should be reported." – IEC 62682:2014 section 16.5.3*

Based on this example, and the observed alarm loads on the bridge being so dependent on spatial and operational attributes, further work should establish whether a stratified approach to assessing objective and quantitative alarm performance for ships is appropriate. At the very least, differences in performance between discrete operational states versus using a continuous time approach should be quantified.

1.22 Watchkeeper questionnaire responses and narratives

This section outlines the results and discussion of the questionnaire responses obtained from the 65 watchkeeping officers. The number of participants varies across different vessels. Certain ship segments are thus more heavily represented than others. Nevertheless, the survey is considered successful in capturing the viewpoints and experiences of the watchkeepers in the maritime industry. While the questionnaire could be further improved in terms of its specificity to the maritime industry, it effectively illustrates the timelessness and context-agnostic nature of the questions used in the HSE CR 166 report [9, p. 163].

This section proceeds by presenting and discussing the results in three formats:

1. The questionnaire responses are summarised collectively. This is arranged alongside the corresponding response distributions from the HSE CR 166 report. Next, similarities and differences between this current investigation and the dataset from 25 years ago are discussed.

2. The questionnaire questions are then categorised into overarching themes reflecting the watchkeepers' perspectives on the following:

   a. General satisfaction with the alarm system

   b. Alarm system performance in normal steady operation

   c. Alarm system performance during a major upset or demanding operation

   d. Procedures and management´ resolve

   e. Suggestions from open questions

Questions related to the theme are juxtapositioned (presented alongside) quotes, narratives, and observations collected during interviews (and a few online forms). If a watchkeeping officer selected answer option "A" to question "N", the associated qualitative narrative, quote, or observation is directly associated with that question. The juxtaposed results are presented in a stratified format between the engineering and the bridge officers.

3. A series of stories are presented to vividly illustrate the experiences of the watchkeepers. These are integrated within the overarching themes and their corresponding questions.

More details of the questionnaire responses are available as tables in *Appendix A – Operator questionnaire results*. These tables offer breakdowns of responses from the participating ships and are fully stratified between bridge and engineering officers. They facilitate the observation of consensus levels on the questions when multiple participants from the same vessel have responded.

1.22.1 Collective summary of the opinion questionnaire

Table 10 details the responses from the 65 watchkeeping officers from the 15 surveyed ships from the 10 participating companies. Percentages are rounded to zero decimals (ceiling). The results from the HSE CR 166 survey responses are included here for quick reference [9, pp. 169-172]. Here, the number of participating operators are rounded as well (floored; meaning 36.5 operators are counted as 36).

TABLE 10.
Questionnaire results summary

Nr.:	Question	Note: HSE Contract Research Report No. 166 are marked with shaded background			
1	**What is your job, and on what ship?**	Describe (Captain, Chief Engineer, etc.): Note: - (See section on Research Site for more demographics)			
2	**How long have you worked with the present alarm system?**	Years: 5 (average) 6 (average)		Months: 10 (average 7 (average)	
3	**How well does the alarm system support you in normal steady operation?**	Very good: 27 (42%) 36 (37%)	OK: 32 (49%) 51 (54%)	Poor: 6 (9%) 8 (8%)	Very poor: 0 1 (1%)
4	**How well do the alarm systems support you during system faults or trips?**	Very good: 11 (17%) 30 (32%)	OK: 32 (49%) 37 (40%)	Poor: 18 (28%) 19 (20%)	Very poor: 4 (6%) 7 (8%)
5	**What about the number of the alarms in the system?**	Too many: 26 (40%) 41 (41%)	Many but necessary: 31 (48%) 47 (51%)	Few but adequate: 7 (11%) 4 (4%)	Too few: 1 (2%) 0 (0%)
5b	**Can you distinguish between alarms generated from different parts of the system?**	Yes: 20	Partly: 33	Not at all: 9	
5c	**What generates most alarms? (1st being the highest)**	**1st:**	**2nd:**	**3rd:**	**4th:**
5c.1	**Operational conditions (bad weather with heavy rolling, dense traffic, narrow waters, approaching traffic separations, cargo operation, etc.):**	21	6	11	22
5c.2	**Equipment (Components breaking down etc.):**	8	18	18	14
5c.3	**Communication system (loss of connection etc.):**	12	16	19	12
5c.4	**Instrument faults (faulty sensors such as oil mist, level transmitters, pressure switches, etc.):**	17	21	13	8
5c.5	**Others than listed:**	4	1	1	6
6	**How many alarms do you get in normal steady operations?**	Per hour: 13 34			
7	**How often do you find that an alarm that comes up is a repeat of an alarm you have already seen in the last 5 minutes?**	70-100% of alarms: 7 (11%) 15 (25%)	40-70% of alarms: 14 (22%) 25 (42%)	20-40% of alarms: 19 (29%) 8 (14%)	Less than 20% of alarms: 25 (39%) 11 (19%)
8	**Do you suffer from the following alarms?**	**Often:**	**Sometimes:**	**Rarely:**	
8a	**Alarms which are wrongly prioritised?**	19 (30%) 12 (21%)	21 (33%) 37 (65%)	24 (38%) 8 (14%)	
8b	**Alarms from equipment that is shut down?**	12 (19%) 24 (41%)	21 (33%) 28 (48%)	31 (48%) 7 (12%)	
8c	**Two or more alarms occurring at the same time that mean the same?**	17 (27%) 10 (17%)	25 (39%) 29 (50%)	22 (34%) 19 (33%)	

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Nr.:	Question	Note: HSE Contract Research Report No. 166 are marked with grey background				
8d	**Alarms occurring in a trip which are only relevant in other modes of steady operations? Examples could be alarms at sea, which are only relevant at port and vice versa.**	9 (14%) 22 (38%)	14 (22%) 21 (36%)	41 (64%) 15 (26%)		
9	**What proportion of alarms are really useful to you in operating the ship?**	All essential: 14 (22%) 5 (6%)	Most useful: 40 (62%) 75 (82%)	Few useful: 10 (15%) 10 (11%)	Very few useful: 1 (2%) 1 (1%)	
10	**Do you fully understand each alarm message and know what to do about it?**	Always: 12 (19%) 35 (37%)	Mostly: 46 (71%) 58 (61%)	Sometimes: 7 (11%) 2 (2%)		
11	**Consider a normal operating situation and the 10 most typical alarms.** **How many of the 10 alarms:**	**Number of alarms:**	**Percentage of total:**			
11a	**Require you to take positive action, e.g. operate a valve, speak to an assistant?**	177 183	29% 26%			
11b	**Cause you to bring up a screen and monitor something closely?**	129 170	21% 24%			
11c	**Are noted as useful information?**	162 188	27% 27%			
11d	**Are read and quickly forgotten?**	142 162	23% 23%			
12	**How many alarms would you get during a large system fault, trip, or demanding operation?**	**Number:**				
12a	**In the first minute?**	43 89				
12b	**In the next 10 minutes?**	12 73				
12c	**In the next hour?**	14 77				
12d	**What facilities help you now manage alarms during a large system upset, trip or demanding operation?**	Describe:				
13	**Do you bring up an additional alarm list display during a large system fault, trip, or a demanding operation?**	Yes: 30 (46%) 31 (55%)	No: 35 (54%) 25 (45%)			
14	**How often do you look through the alarm list display during a large fault, trip or demanding operation?**	Several times a minute: 21 (32%) 17 (36%)	Once every couple of minutes: 13 (20%) 19 (40%)	Once every 10 minutes: 9 (14%) 4 (9%)	Less than once every 10 minutes: 22 (34%) 7 (15%)	
15	**How often during a large fault, trip, or demanding operation do the alarms come too fast to take them in?**	Always: 14 (22%)	Mostly: 17 (27%)	Sometimes: 17 (27%)	Rarely: 14 (22%)	Never: 2 (3%)
	Converted into 3 options used in the HSE CR 166 questionnaire:	Mostly: 14 + 17 = 31 (48%) 34 (60%)	Sometimes: 17 (27%) 11 (19%)	Rarely: 14 + 2 = 16 (25%) 12 (21%)		
16	**How often in a large system fault, trip, or demanding operation are you forced to accept alarms without having time to read and understand them?**	Always: 19 (29%)	Mostly: 11 (17%)	Sometimes: 15 (23%)	Rarely: 10 (15%)	Never: 10 (15%)
	Converted into 4 options used in the HSE CR 166 questionnaire:	Always: 19 (29%) 5 (6%)	Quite often: 11 (17%) 20 (21%)	Sometimes: 15 (23%) 23 (25%)	Rarely: 10+10 = 20 (30%) 45 (48%)	

Nr.:	Question	Note: HSE Contract Research Report No. 166 are marked with grey background			
17	**Does the alarm system help you to pick out key safety related events during a large system fault, trip, or demanding operation?**	Very well: 18 (28%) 14 (24%)	Some help: 20 (31%) 33 (56%)	Little help: 18 (28%) 15 (15%)	A nuisance: 9 (14%) 3 (5%)
18a	**What do you think about the procedures for getting changes made to alarm settings, etc.?**	Over-restricted and cumbersome: 7 (11%) 14 (35%)	Strict but safe: 20 (31%) 25 (41%)	easy to use – but you have to be careful what you do: 36 (56%) 10 (17%)	sloppy and uncontrolled: 1 (2%) 4 (7%)
18b	**Are you aware of a procedure that is used when alarms are modified?**	Yes: 53 (83%)		No: 11 (17%)	
19	**Compared with the other things they do to improve your control systems, does your management put enough effort into improving the alarm systems?**	Too much: 2 (3%) 0 (0%)	About right: 26 (41%) 22 (37%)	Too little: 36 (56%) 38 (63%)	
20	**What features of the alarm system do you like the best?**	Describe:			
21	**What features of the alarm systems do you like the least?**	Describe:			
22	**If you could change any part of the alarm systems, what features would you add to help you run the system?**	Describe:			
23	**What features would you remove because they do not help, or you do not like them?**	Describe:			
24	**Can you add any other comments which might help us improve alarm systems?**	Describe:			
25	**What is the number of I/O's interfacing your alarm system(s)?**	Number: (See section on Research Site)			
26	**Considering the questions you already answered in this survey, is there a question you feel we have forgotten to ask? If so, what would the question be, and what would be its answer?**	Describe:			

For several questions, there is a notable similarity in response distribution between this study and the one conducted by Bransby and Jenkinson, first reported in 1997. Without more recent and comparable survey data from the chemical (process) and power industries, it is not possible to conclude that its operator opinion response distributions have shifted since then. Determining this would require the HSE or another independent entity to conduct a similar study.

The results indicate a correlation between the views of watchkeeping seafarers and the historical experiences of the control room operators in the process and power industry over 25 years ago, when alarm management was not yet widely embraced as good practice.

The following sections examine the qualitative and contextual meaning of the closed-form responses to the questions, something which the HSE CR 166 report did not disseminate in deeper detail. Included here are narratives and quotes from the open questions as well.

1.22.2 General satisfaction with the alarm system

This section examines the watchkeepers' general satisfaction with the alarm system (Table 11). It begins the conversations with *grand tour questions* at the beginning of the questionnaire, and also reverts back to this topic later in the sequence of questions.

While the initial outlook of the watchkeepers is positive overall, substantial room for improvement surfaces after the initial grand tour questions.

TABLE 11.
Questions related to the general satisfaction with the alarm system

Question	Question No.	Theme
How well does the alarm system support you in normal steady operation?	3	General satisfaction
How well do the alarm systems support you during system faults or trips?	4	
What about the number of the alarms in the system?	5	
Can you distinguish between alarms generated from different parts of the system?	5.b	
What features of the alarm system do you like the best?	20	
What features of the alarm systems do you like the least?	21	

1.22.2.1 Question 3. How well does the alarm system support you in normal steady operation?

Very good: 3.1E - An engineer stated that the system supported the engineer very well because the needed information was presented. Information that was not important was automatically filtered out by the engineer. The engineer stated that once you know the system and what to filter out, it supports the engineer well.

OK: 3.2E - One engineer mentioned that it was difficult to compare the ship's system to others. Overall, he/she believed it supported OK because it was the average performance on the ships, he/she had experience from, even though simple improvements could be done.

3.3E - The 'Genuine alarms' support the operators well, but not the nuisance alarms.

Poor: 3.4E - The alarms annunciated from the IAS are informative, but there is no proper prioritisation of the alarms neither visually nor acoustically.

Very poor: No respondents

Very good: 3.1B - The information received from alarms suit the officers' individual needs to a great extent, since personal settings can be applied to parts of the system.

OK: 3.2B - Most of the alarms are useful in the proper context. Several officers state that some alarms are annunciated at the wrong time or are irrelevant to the operational situation.

Poor: 3.3B - Selected alarms from the ECR are annunciated on the bridge: "95% of all alarms through IAS is of no use" – "It's not in my job description."

Very poor: No respondents

It is a general tendency that the engineering officers are of the opinion that the alarm system supports them *Very good* (~56%) or *OK* (~38%) during normal steady operation. Only a few officers reported *Poor* (~6%) support from the alarm system. None found the alarm system to be *Very poor*.

The bridge officers generally have the same positive opinions, although with slight differences. Here, the majority of the bridge officers find the system *OK* (~61%), with fewer stating it *Very good* (~26%). Twice the number of bridge officers state *Poor* (~13%) support from the alarm system in normal steady operation. However, on a positive note, none found the alarm system *Very poor*.

According to some engineers, they filter out non-essential alarms—mentally (3.1E). This is due to the engineer's ability to construct a mental model of the system as they gain experience and systemic knowledge of the overall plant. The engineers emphasise that the nuisance alarms do not support them (3.3E). Some engineers can suppress these alarms by their mental model. Regardless, they still shift focus towards the alarm system temporarily. It is important to note that the officers' frame of reference can influence their answers (3.2E).

As narrated by some bridge officers, alarms can become a disturbance when annunciated at inconvenient times or if the alarm has little relevance in the given situation (3.2B). IAS alarms in particular can be a big nuisance to the bridge officers and add confusion around who is expected to act upon them (3.3B).

1.22.2.2 Question 4. How well does the alarm system support you during system faults, trips, or demanding operations?

Very good

4.1E - The IAS is the only platform that provides a direct feed of information about the processes and are therefore invaluable when analysing the trips.

4.2E - The IAS' CAM system prioritises important alarms during a blackout.

OK

4.3E - The system provides the needed information by alarms, but there are also some alarms that are not needed and take up space on the alarm list.

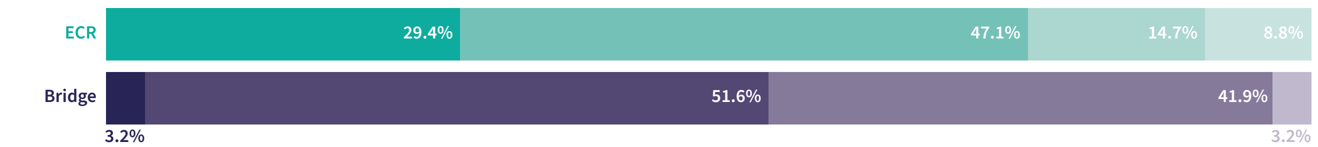
Poor

4.4E - The alarms are presented in chronological order on the alarm list. Newly annunciated alarms are presented at the top of the alarm list, displaying existing ones downwards, resetting the display to the top whenever an alarm is annunciated. When engineers receive upwards of 100 alarms in a few minutes, it prevents them from looking at the alarms first annunciated, which are often the ones indicating the root cause(s).

Very poor

4.5E - When a common alarm is received on the auxiliary engines the watchkeeper must radio a 3rd engineer in the machinery space and have him/her go to the local panel to read the alarm description and radio back the information. The local alarm panel does not have time stamps for the alarms, not even relative to one annunciated previously (Figure 32). The communication is challenged by the noise in that machinery space, including language and cultural differences in communication styles.

4.6E - During a large trip/blackout, "All we are doing is silencing alarms."



Very good

No contextual answer

OK

4.1B - The ECDIS and radar settings are very adaptable to the officers' preferences.

4.2B - When the operators hit the *mute all* button it clears all the alarms so that the origin cannot be located. Many other bridge officers do not use the button for this reason.

Poor

4.3B - "You can mute alarms from the CAM system, but you have to acknowledge it from one specific monitor MFD-4".

4.4B - When a particular alarm is annunciated, it must be acknowledged on the bridge, the ship-radio, and the satellite bridge console station (two decks below).

4.5B - The officers stated that alarms without contextual importance would often be annunciated during demanding operations. Depending on the context, the officers relied heavily on visual orientation and on communication between officers. A higher frequency of alarms constitutes a disturbance to their level of concentration.

Very poor

4.6B - The officer states that he/she is very dissatisfied with the layout of the bridge systems. It does not support the operators well and makes the operator's response time longer.

For demanding operations, ~29% of the engineering officers found that the system supports them *Very good*, while ~47% said it was *OK*. Roughly, the remaining answered *Poor* (~15%) or *Very poor* (~9%).

For the bridge officers, the opinions were different. Here, only one officer found it to be *Very good* (~3%), while the remainder were almost equally divided between *OK* (~52%), *Poor* (~42%) and *Very poor* (~3%).

For multiple engineers, the system provided invaluable information for system analysis after a critical piece of machinery had tripped (4.1E). It became the interviewer's understanding that while the system was tripping, it generated an excessive number of alarms, causing an alarm flood. The alarms would be muted and acknowledged until the alarm flood ended. From that point, the engineers would use the mimics and alarm list on the HMI to check and recover the ship's critical systems.

Usually, when engineers thought that the system supported them well, it was due to it presenting information that otherwise would have to be collected manually in the machinery spaces. It was not due to a logical and effective presentation of actionable information.

One centralised alarm management (CAM) system had an embedded blackout protocol that suppressed non-critical system alarms in a blackout situation (4.2E). The engineer reported this to reduce the time needed to analyse and locate system-critical errors. This feature was observed on only one single ship. The engineering officers on board had extensive experience with the system. They had also been part of the rationalisation and choices behind the suppression.

Some engineers reported that traversing the alarm list during an alarm flood mainly was impossible, as the page reset with each new alarm annunciation (4.4E).

It was not uncommon for retrofitted or remote systems to generate common alarms, which required the engineers to acquire the necessary information from local HMI panels not present in the ECR (4.5E). This undermined the effectiveness of the alarm system. It also consumes a proportion of the time available to respond to an alarm since no actionable information becomes available before reading it on the local HMI panel.

A mute-all button located at the centre of some visited bridges appears to be a very risky patch to a deeper issue around the design of the alarms. It could be observed that multiple navigational officers gave up pinpointing which alarm they had just muted/acknowledged (4.2B).

Several bridge officers stated that some alarms had to be acknowledged on consoles outside of reach (4.3B, 4.4B, 4.5B), or in worst cases, on other deck levels (4.4B). A general example observed widely on the sampled ships, was watertight door panels. Watertight doors open and close multiple times during departure and arrival. This is because engineering officers move around in the machinery spaces. Alarms generated from watertight doors left open a bit too long must be acknowledged from its dedicated panel. The officers had to tolerate the sound of alarms or move away from the navigation and manoeuvring position (such as the bridge wing) to silence or acknowledge these alarms from panels located at the centre consoles on the bridge.

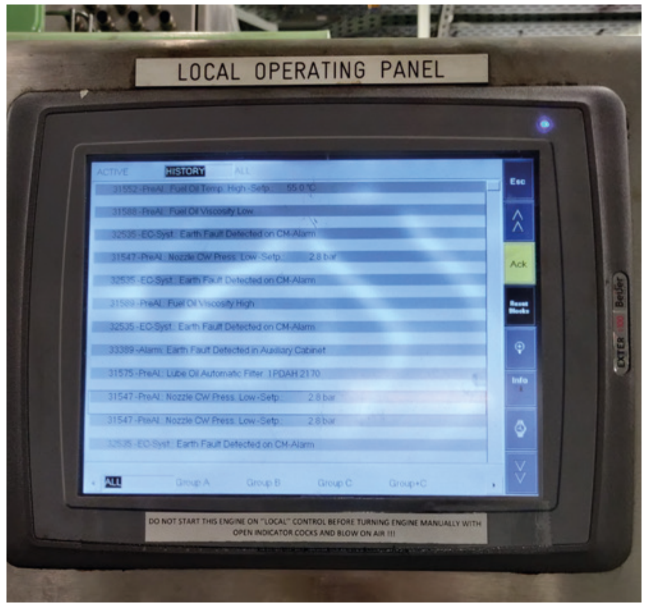


FIGURE 32.
Local auxiliary engine HMI panel. There are no timestamps in the alarm history, not even a relative one. The touch panel interface also does not work with the engineers' PPE gloves

1.22.2.3 Question 5. What about the number of the alarms in the system?

Too few

5.1E. - "Each alarm must be identified not common alarms."

Few but adequate

No contextual answer.

Many but necessary

5.2E - There are a lot of alarms, but every one of them can be important, so no one is dispensable.

5.3E - "We need all the information we can get." – The engineer likes to be able to filter the alarms.

5.4E - There are many alarms because of the complexity of the ship.

Too many

5.5E - Chief Engineer - "I've never known as many alarms as we get here".

5.6E - Sometimes, spa pool alarms come in every millisecond for minutes. Operators take turns to sit and mute them.

5.7E - When asked "What do you like the least?" the response is "All the alarms."

5.8E - "At some point you go crazy with all the alarms."

5.9E - "Too many non-critical alarms sound."

Too few

No respondents

Few but adequate

5.1B - The settings (in the ECDIS) can be adjusted to a minimum.

Many but necessary

5.2B - The alarms are there for a reason. Most of them can provide very valuable information.

Too many

5.3B - "70-80% of the alarms we don't need".

5.4B - "We need to get rid of some alarms".

5.5B - "We need filtering of the alarms, so we don't get the unimportant ones."

5.6B - "We should have a new position as 'Alarm Officers'."

5.7B - "Sometimes the alarm 'tank level gauge' sounds for 5 hours straight.

- Literally, it is constantly annunciated. You have to dedicate one guy to silence it."

A majority of the engineering officers state that the number of alarms in the system are *Many but necessary* (~68%), with the second largest distribution believing it instead to be *Too many* (~21%). The remaining stated *Few but adequate* (~9%). Only a single engineering officer stated *Too few* (~3%).

In contrast, the majority of the bridge officers reported *Too many* (~61%), followed by *Many but necessary* (~26%), and a minority (~13%) stating *Few but adequate*. No bridge officer desired more alarms, with zero respondents saying there were *Too few*.

5.1E was the only engineer answering *Too few*. The engineer´s task consisted primarily of operating systems on board that could only generate common alarms. It was expressed that these alarms provided no informational value and delayed the diagnostic and decision process until the real alarm was read at the local alarm panel.

Some engineers (5.2E, 5.3E and 5.4E) explain the observed tendency of a desire for more information (5.2E and 5.3E). For others, it appears to be a byproduct of complexity (5.4E).

On several modern ships, a general tendency observed was that chief engineers found the alarm system to be too provisioned with alarms (5.5E). Most often, these senior engineers have worked with several different systems and different ship segments. As such, they have built experience on what is necessary or not for the operation of the ships, providing them with a more knowledge-based rationale of the needed number of alarms.

A key theme of the officers who responded *Too many* relates to the assumption that more provisioned alarms mean more annunciated alarms in operation (5.7E). Most participants considered the question to be around the number of configured or provisioned alarms. Still, others interpreted the question to be about the number of annunciated alarms, especially if it was considered an issue (5.6E, 5.7E, 5.8E, 5.9E, and 5.7B).

Some bridge officers who had the possibility (and managerial green light) of adapting the ECIDS settings were more positively inclined towards the question (5.1B).

The general perception of the bridge officers shows that they consider their system to contain too many alarms to handle (5.3B, 5.4B, 5.5B, 5.6B). A handful of bridge officers have mentioned with a sarcastic tone, yet serious look in their eyes, that they need an "alarm officer" whose job should consist solely of muting and acknowledging the alarms coming in (5.6B).

1.22.2.4 Question 5.b. Can you distinguish between alarms generated from different parts of the system?

Yes (ECR)

5.b.1E - The alarm list can be selected to be displayed in specific system categories.

Partly (ECR)

5.b.2E - Some systems provide priority by colour, sound and description, others do not at all.

Not at all (ECR)

5.b.3E - "You know the alarm sound from the panels individually, but if everything goes off at once, for example during a blackout, you cannot distinguish them from each other. It's very overstimulating and you cannot find the source."

Yes (Bridge)

5.b.1B - The systems are not integrated into one; therefore, the alarms have different sounds from the manufacturers.

5.b.2B - Alarms and warnings sound differently in the ECDIS.

Partly (Bridge)

5.b.3B - "I would prefer if alarms with different priority had different sounds."

5.b.4B - The officers of the watch state that it takes about one month of experience on the bridge to be able to distinguish radar alarms from ECDIS alarms. Several alarms are indicated with three beeps but with different volumes. The difference in volume is not subtle and hard to distinguish.

Not at all (Bridge)

5.b.5B - The officer stated that; Sometimes the officer receives 'undefined' alarms from the IAS – they walk around the bridge listening for the alarm.

5.b.6B - "You cannot distinguish audio between pre-alarms and alarms."

5.b.7B - The yellow-prioritised warning from the ECDIS all give two beeps and the same sound. You cannot distinguish between them by sound.

5.b.8B - One needs 2-4 weeks to learn to distinguish between critical and non-critical alarms from the ECDIS because the alarm tone/sound is almost the same.

5.b.9B - The sound for the fire alarm is the same as when a shell door is being opened when annunciated in the IAS system. All SMCS audio alarms are the same as in IAS.

The majority of the engineering officers state they can distinguish only *Partly* (~44%) or *Not at all* (~22%) between the alarms of the system. Only one third of the engineering officers responded *Yes* (~34%) to the question.

Similarly, less than a third of the bridge officers state *Yes* (~30%). With the majority reporting that they can only *Partly* (~63%) or *Not at all* (~8%) distinguish between the alarms.

A general tendency of the officers who answered *Yes*, was that they were working on board ships with lower levels of integration. This meant more individual panels from different suppliers and thus different sounds (5.b.1B).

For most ships, it was not possible to note a difference in the sound from the alarms within individual systems. The officers mentioned that this is because the individual system panel has the same sound for each alarm. This was observed often to be the case when the individual systems were from the same manufacturer (5.b.9B). Another challenge observed on board was that the SMCS was undimmable, so the officer completely lost the night vision when attending to an alarm from the SMCS during a night watch.

On some ships, the alarm system had no visual prioritisation, or there would be a clearly wrong prioritisation (5.b.2E).

On the other hand, a couple of the ships that were visited had perfected the distinguishing of alarms, according to themselves, by sound and coloured priority (5.b.1E). The engineers on these ships stated that it was time-consuming but worth the time and money. They claimed it made their job more manageable. They added that it helped save them critical time during potentially stressful situations—time needed to avoid potential incidents.

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FIGURE 33.
Phase failure alarm for the HV shore connection panel – while underway, disconnected and many miles from shore

The response distributions to the question together with the officers' narratives describe a general sign of a failed implementation of the four priority levels defined in the IMO Code on Alerts and Indicators. It appears that alerts (such as warnings and alarms) tend to mean the same to the officers, especially if implemented equally loudly and with similar sounds. Learning to distinguish between these different sounds and priorities is reported to take significant time (5.b.4B, 5.b.8B). This implies a lack of sound engineering for the system as a whole (5.b.3B, 5.b.6B, 5.b.7B).

Despite the gain in "distinguishability" achieved by the diversification of system vendors as a result of low integration levels, this was reported to be a challenge during large upsets or trips (5.b.3E).

The reason for this was attributed to the situation in which the watchkeeper cannot observe the sequence of annunciations, because a list with chronological timestamps is not available from an integrated system. In addition, local instrumented panels cannot suppress *cascade alarms*, meaning alarms caused by another failure elsewhere. An example is *communication loss* alarms. Such alarms automatically trigger for many systems following (thus the name *cascade alarm*) a loss of electrical power (blackout).

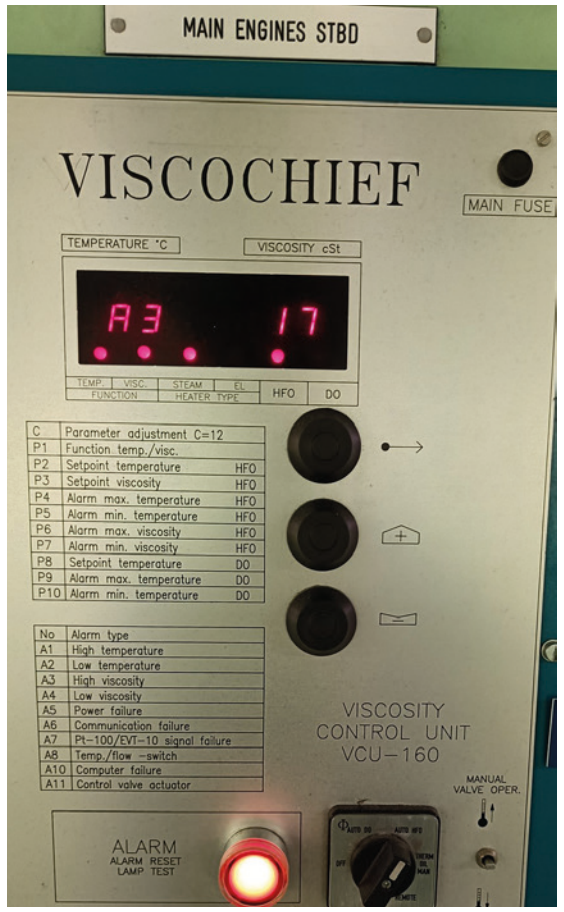


FIGURE 34.
HFO fuel system – High viscosity alarm on local panel while underway and using LSMGO as a fuel

Most of these local panels have no deeper logic to account for the overall operational context. They appear to be engineered as single input, single output. For some systems, alarms are active merely because the system is off and not in use at the moment. One visited ship was subject to this status with a plethora of alarms on local panels which had no relevance in the present context (Figure 33 and Figure 34 show examples without revealing the ship).

1.22.2.5 Question 20. What features of the alarm system do you like the best?

The analysis identified a set of themes from the open questions as *HMI*, *Alarm quality*, *Advanced alarming capabilities* such as prioritisation and filtering, and *Spatial adaptability* of attending alarms.

Of the extracted narratives from both bridge and engineering officers, the following is summarised:

In response to the question regarding the most liked features of the watchkeeper's alarm system, engineering officers express appreciation for functionalities that enhance HMI navigation and visibility. These include features like direct links to mimics, shortcuts to process pictures, red markings for displayed alarms on mimics (20.1E, 20.2E, 20.3E, 20.4E, 20.5E). They value the ability to utilise trend views for investigation and benefit from highlighted labels indicating setpoint deviations (20.6E, 20.7E).

Bridge officers highlight the utility of the SMCS system, providing a comprehensive 2D view of all systems with access to decision support procedures during events like fires (20.2B). They appreciate features like colour-coded prioritisation, a fully integrated alarm log, and different tones for acoustic alarms (20.3B, 20.4B, 20.5B). Specific mentions include the ability to filter information on the SMCS to avoid confusion (20.5B) and the use of different sounds for various systems, emphasising colour prioritisation (20.6B).

In terms of alarm quality, officers commend the absence of "common" indications for most alarms in the system, accompanied by a helpful to-do assistance log (20.8E). Bridge officers note the system's provision of useful information, offering a heads-up in sufficient time prior to required actions (20.7B). Additionally, features like suggested actions on radar alarms and the flexibility to design alarms for specific operations are valued (20.8B, 20.9B).

Regarding prioritisation capabilities, engineering officers appreciate automatic suppression of unnecessary alarms and the ability to filter alarm lists on the local panel by groups (20.9E, 20.11E). Bridge officers note proper prioritisation and an appropriate number of alarms for fire panels and DP systems (20.10B).

Lastly, spatial adaptability is acknowledged, with alarms directed to radios and control system screens on both the bridge and the ECR (20.11B). The officer favoured alarms that are effectively directed to radios, alarm/control system screens on the bridge, and the ECR, as these contribute to spatial adaptability, meaning they do not have to be on the bridge while loading cargo.

HMI:

> *20.1E – "That it directs you to the mimic (equipment) so you don't have to look for it in the system."*
>
> *20.2E – "Shortcut to process pictures."*
>
> *20.3E – "Red marking on displayed pictures/screens/pages for the given alarm."*
>
> *20.4E – "The mimics, the accessibility from the [manufacture system" … "Colours of the new display, nightshift for colours, the ability to split screens."*
>
> *20.5E – "The shortcut from the alarm list that takes you directly to the page where the alarm is happening, the mimics."*
>
> *20.6E – "Mimic that corresponds to exact system that we have, Trend view for investigation."*
>
> *20.7E – "The highlighted labels when a value for a setpoint is too high/low, a shortcut in the alarm list that sends you to the mimic where the alarm is."*
>
> *20.1B – "For the fire alarm you can quickly see where exactly where the fire is located."*
>
> *20.2B – "SMCS system. Complete 2D view of all the system that helps a lot. Access decision support systems that give you a procedure of what to do during a fire, for example, and then you're able to operate the ventilation."*
>
> *20.3B – "The colour coded prioritisation."*
>
> *20.4B – "The complete alarm log, fire alarms being transferred to ECDIS, the acoustic alarms have a different tone."*
>
> *20.5B – "The colours and symbols on the SMCS. You can filter things so you only see specific things on the SMCS so you don't get confused by other things appearing."*
>
> *20.6B "That there are different sounds for different systems, colour prioritisation of alarms."*

Alarm quality:

> *20.8E – "Most alarms are not indicated as 'common' in this system, and (it) has 'to-do assistance log.'"*
>
> *20.7B – "Usually it provides useful information—heads up before you need to make an action."*
>
> *20.8B – "The suggestion of actions on alarms on the radar."*
>
> *20.9B – Talking about navigational alerts: "You are allowed to design most alarms, so you only get the alarms that you want, regarding narrow operations."*

Advanced alarming capabilities:

> *20.9E – "Automatic suppression of (at the moment) unnecessary alarms."*
>
> *20.11E – "The ability to filter the alarm list on the local panel by groups."*
>
> *20.10B – "In regard to the fire panel and DP system; It has the right amount of alarms and they are prioritized properly."*

Spatial adaptability:

> *20.11B – "Alarms are directed to the radios as well as the alarm/control system screens on the bridge and the ECR."*

1.22.2.6 Question 21. What features of the alarm system do you like the least?

The analysis identified a set of themes from the open questions, such as *HMI*, *Alarm quality*, *Advanced alarming capabilities*, e.g., prioritisation and filtering, *Spatial adaptability* of attending alarms, and *Management of change*.

Of the extracted narratives from the bridge and the engineering officers, the following is summarised:

- For HMI, watchkeepers encounter challenges with alarm mimic locations (where to find them), setpoints, and the fact that tuned system settings are being resets during updates (21.1E). Frustrations extend to slow system response (21.2E, 21.7E), inefficient alarm log scrolling, and the mandatory chronological acknowledgement of alarms. Colour-related difficulties (21.3E), unintentional colours in diagrams, and complications during watch changes are reported (21.5E). Additionally, some officers express displeasure with the piercing sound of alarms (21.6E, 21.8E, 21.2B).
- Regarding Prioritisation Capabilities, there is discontent with the absence of priority in alarms. Users emphasise the need for improved prioritisation, especially when distinguishing between different subsystems. Concerns are voiced about the priority of alarms going to the radio (21.10B) and the overwhelming quantity of alarms during emergency operations (21.11B).
- In terms of Alarm quality, the watchkeepers report alarms lacking useful information during major faults (21.11E, 21.12E). Issues encompass incorrect importance (urgency), the absence of descriptions, and the prevalence of common alarm notifications (21.18B). Bridge officers express frustration with numerous navigational radio alarms, especially distress signals, and irrelevant engine room

alarms. Complaints extend to unnecessary alarms persisting after acknowledgement (21.13B) and challenges in distinguishing between alarms, warnings, and prompts (21.7B). Specific concerns are raised about ECDIS, radar alarms, and audible alarms during standby mode. Criticisms include the quantity and issues with alarm details (lack of actionable information) received through the alarm system.

- Spatial Adaptability concerns arise as users express frustration with the need to acknowledge the same alarm in multiple systems without universal silencing (21.20B).
- In terms of Management of Change, users raise concerns about the authority to change alarm settings and the lack of proper documentation and signatures when altering alarm parameters.

HMI:

21.1E – "Alarm mimic locations and setpoints that are not set correctly especially during an update which puts the system almost to yard set up."

21.2E – "Too slow sometimes and that you can't scroll up and down on the alarm log page; you have go through different pages."

21.3E – "I don't understand why one has to acknowledge alarms in a chronological order."

21.4E – "The colours in the IAS—I'm colourblind."

21.7E – "Not intentional colours in the PI-diagram pages."

21.5E – "When changing 'the watch'. You have to select harbour mode in order for the bridge not to get an alarm. Dead man (switch) starts every time an alarm occurs."

21.6E – "Sound. It's piercing."

21.7E – "Current system very poor at looking back through alarm history."

21.8E – "The noise (the alarm tone). When you have acknowledged an alarm you don't need to see it five times again, because you acknowledge it, so you know that the alarm is there."

21.1B – "ECDIS – off track, safety contour."

21.2B – "The volume of the alarm sound."

22.3B – "Wireless bridge watch alarm. When tested, it fails 7 out of 10 times so we mostly turn it off."

21.3B – "Alarm sound is highly pitched and the volume too high."

21.4B – "The presentation of the system is not optimal. The way that the VDR gives an error message if the ECDIS and radar is not present on the predefined screen."

21.5B – "ECDIS is not user friendly when changing alarm settings. That the internal alarms in the propulsion system are not distinguishable from each other."

21.6B – "The bridge ergonomics and how rigid the systems are. The ship is designed as a DP (dynamic position) ship, but is sailing directly on routes all the time."

21.7B – "The fact that the system is integrated into one system, but it doesn't distinguish audibly between the different subsystems."

21.8B – "The same sound for all the alarms so you can't distinguish priority by sound."

Advanced alarming capabilities:

21.10E – "The lack of priority in the alarms."

21.9B – "Not enough prioritization in alarms."

21.10B – "The priority of the alarms that are going to the radio."

21.11B – "Amount of alarms received in emergency operations."

Alarm quality:

21.11E – "Alarms that don't contain useful information during a major fault. Together with a critical alarm, for example, low lube oil pressure—several of these alarms follow."

21.12E – "That alarms are not correctly prioritised, the lack of description of alarms and the lack of intended response or action plan."

21.13E – "that it only state common alarm."

21.12B – "Too many radio alarms about distress. Too many alarms from the engine room that are not relevant for the bridge."

21.13B – "Unnecessary alarms and alarms that can't be switched off after acknowledged."

21.14B – "Nuisance alarms, lack of prioritisation of what are alarms, alerts and prompts."

21.15B – "ECDIS alarms and radar alarms."

21.16B – "Audible alarms during standby mode."

21.17B – "Amount of alarms and tone/volume of the alarms."

21.18B – "The sound of the alarms, the lack of details describing common alarms."

21.19B – Talking about the IAS: "All of the alarms received through the [manufacture name] system."

Spatial adaptability:

21.20B – "The fact that you have to acknowledge the same alarm in two or three systems. They don't silence the alarms all places when it's being acknowledged on one."

21.14E "The fact that we get common alarms and you have to go the local panel."

Management of change:

21.21B – "Authority to change the alarm settings."

21.22B – "Changing alarm parameters without logbook and signature."

1.22.3 Performance in normal steady operations

This section examines the watchkeepers' general opinion on the performance of the alarm system in steady operation (Table 12). It contains the same group of questions as used in the HSE CR 166 report. The conversation continues from the endpoint of question 5.b by asking the watchkeeper to reflect on what actually generates the most alarms (5.c), including how many alarms they think they get in normal steady operation.

TABLE 12.
Questions related to the performance in normal steady operation

Question	Question No.	Theme
What generates most alarms?	5c.1,…,5c.5	Performance in normal steady operation
How many alarms do you get in normal steady operations?	6	
How often do you find that an alarm that comes up is a repeat of an alarm you have already seen in the last 5 minutes?	7	
Do you suffer from the following nuisance alarms?	8.a,…,8d	
What proportion of alarms are really useful to you in operating the ship?	9	
Do you fully understand each alarm message and know what to do about it?	10	
Consider a normal operating situation and 10 typical alarms. How many of the 10 alarms:	11.a,…,d	

1.22.3.1 Question 5.c. What generates most alarms?

The watchkeepers report that *Operational conditions* are the most predominant factor in the generation of alarms, followed by *Instrument faults*, *Communication systems*, and lastly the *Operational conditions* again (Figure 35). For many categories in each level, the bridge and engineering officers give nearly equal votes. An exception is the 4th level. Here, six bridge officers reported *Other than listed*, while the engineering officers reported none (Figure 36 and Figure 37).

Officers stating *Others than listed* were inclined to report system specific alarms. Fire alarms, mooring winch alarms, and common alarms were present among most of the participants selecting this category.

The answers should be viewed in the light that few of the officers had the facilities to compute which categories created the most alarms. Only one of the sampled ships had IAS alarm systems implemented with objective performance features. As such, these figures are subjective estimations. Still, it does indicate that operational context has the most significant impact. This is a matter which the analysis of the objective alarm data alongside vessel position and its operational modes could bring to light.

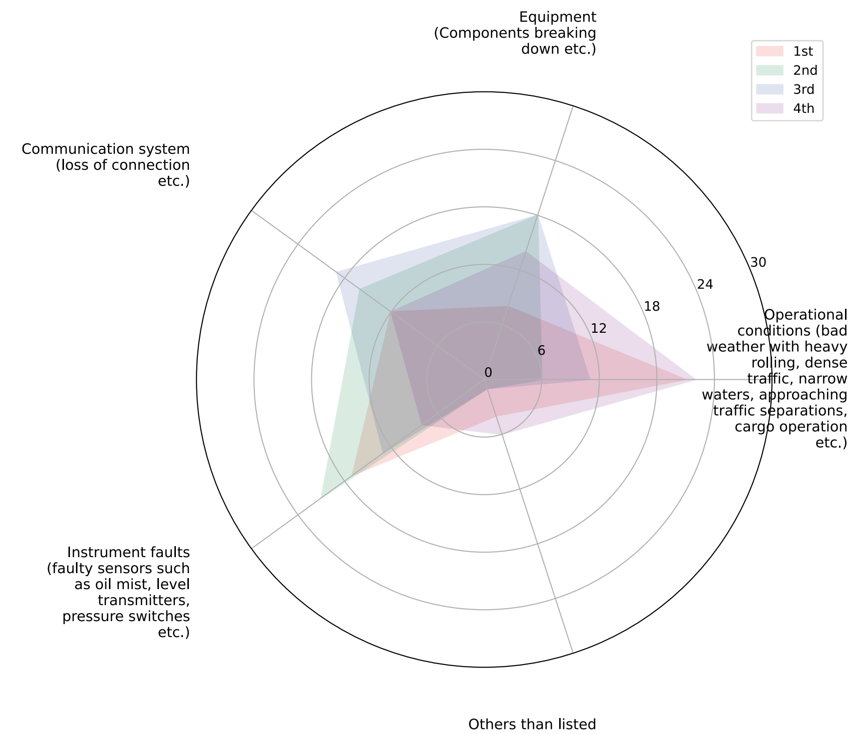


FIGURE 35.
Radar chart, layered of the watchkeeping officers votes (sum) on what generates the most alarms

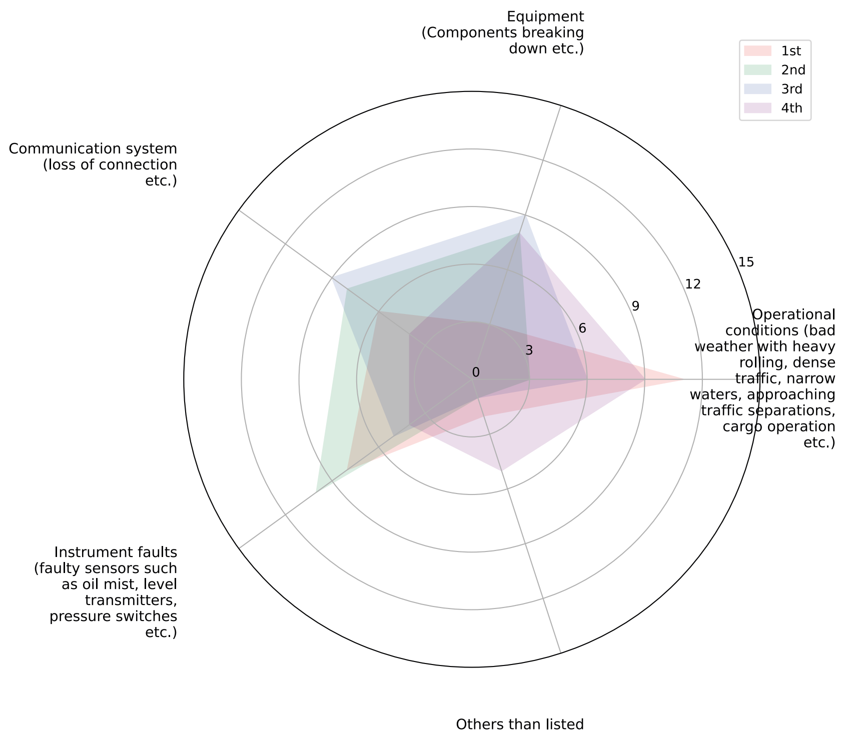


FIGURE 36.
Radar chart, layered of the bridge officers votes on what generates the most alarms

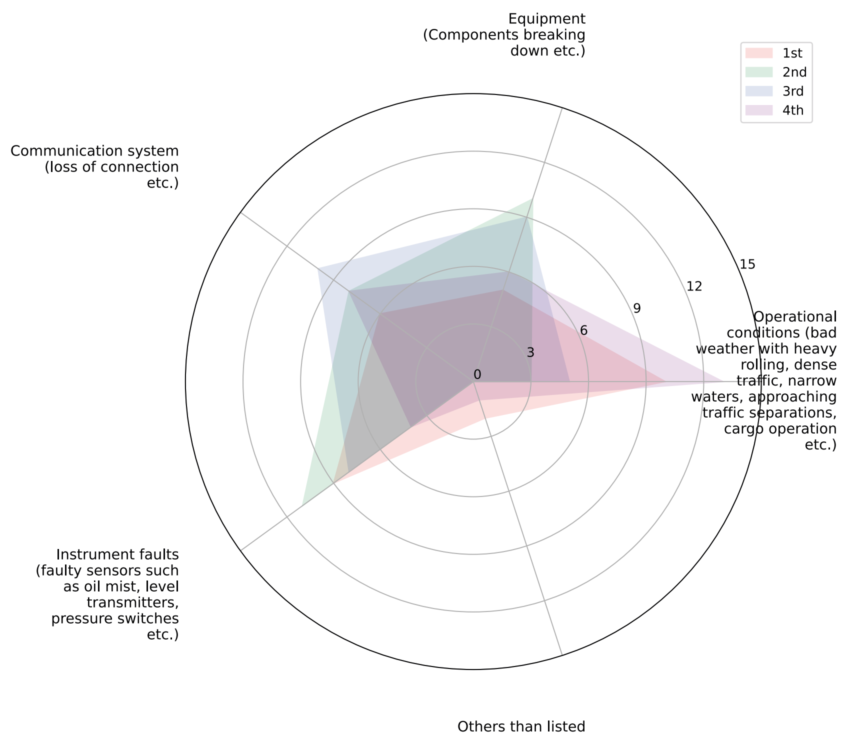


FIGURE 37.
Radar chart, layered of the engineering officers votes on what generates the most alarms

1.22.3.2 Question 6. How many alarms do you get pr. hour in normal steady operations?

According to the officers' average, ~13 alarms per hour are annunciated during normal, steady operations. However, the scale of responses varies widely between ships. Some bridge officers report one alarm per hour, while others report upwards of 50 (Table 13). Likewise, some engineering officers report less than one per hour. In contrast, others report upwards of 70 (Table 14).

The answers should be viewed in light that few of the engineering officers had the facilities to compute this figure. As such, these figures are subjective estimations.

The first results from the objective alarm load observations indicate a tendency for bridge officers to underestimate the actual rate of alarms (by a factor of two). Further analysis of the gathered IAS data from the individual ships is needed to gauge how well the engineering officers estimate this value.

From the bridge officer's perspective, it is noticeable that one ship reports 50 alarms an hour in steady operation, another 30 alarms, and one at ~23 alarms (Table 13). These are high numbers considering the operational open-loop control context on the bridge. Bridge officers on such ships provided general narratives of alarm fatigue and mental overload caused by alarms (6.1B, 6.3B). The same can be said for engineering officers (6.2E). On the other hand, ships which have managed to drive down the number of alarms in steady operation give more positive statements (6.1E, 6.2B).

6.1E – "It's not bad compared to other ships I've worked on."

6.2E – "This ship is theoretically able to be UMS, if no passengers on board, but we would never get any sleep!"

6.1B – "Fewer alarms would be healthy for our minds."

6.2B – "This is a good ship, when it comes to alarms."

6.3B – "At some point you go crazy with all the alarms."

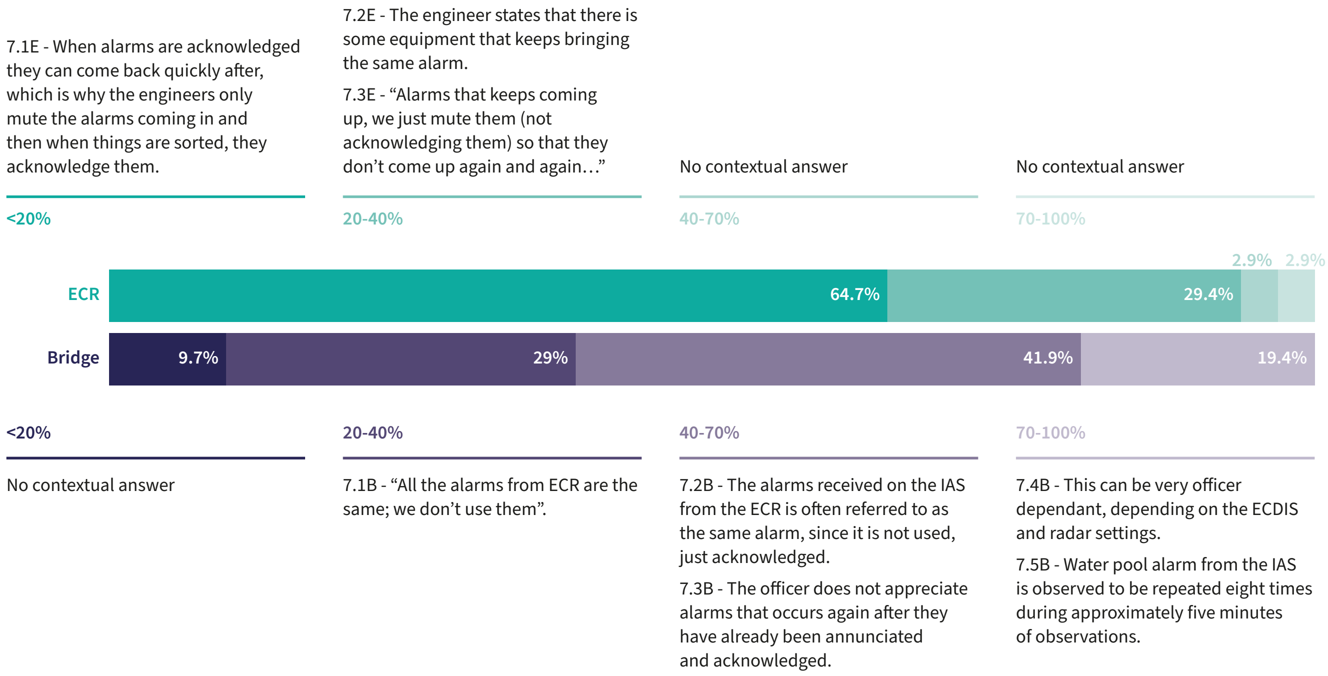
TABLE 13.
Bridge officers on the number of alarms in normal steady operations

		Bridge	
		Question 6 How many alarms do you get per hour in normal steady operations?	
Ship no.	No. of operators	Total per hour	Average per hour
1	1	8	8
2	6	136	22,7
3	2	14	7
4	-		
5	2	60	30
6	8	101	12,6
7	3	27	9
8	4	43	10,8
9	1	50	50
10	-		
11	2	15	7,5
12	1	1	1
13	-		
14	-		
15	1	11	11
Total %	31 100	466	15

TABLE 14.
Engineering officers on the number of alarms in normal steady operations

		ECR	
		Question 6 How many alarms do you get per hour in normal steady operations?	
Ship no.	No. of operators	Total per hour	Average per hour
1	-		
2	10	217	22
3	5	3	1
4	1	70	70
5	2	17	9
6	5	52	10
7	1	0	0
8	3	0	0
9	-		
10	2	7	4
11	2	19	10
12	-		
13	1	3	3
14	1	1	1
15	-		
Total %	33 100	389	11,8

1.22.3.3 Question 7. How often do you find that an alarm that comes up is a repeat of an alarm you have already seen in the last 5 minutes?



The majority of the engineering officers (~65%) stated that *less than 20%* of the alarms occur as a repeated alarm within 5 minutes, while ~29% answered *20-40%* of the alarms. This is equally spread between the ships, with a few engineers leaning slightly toward one answer over the other (Appendix A). Only one stated *40-70%* and another *70-100%*.

For the bridge officers, ~10% stated *less than 20%*, while ~29% said *20-40%*, followed by ~42% reporting *40-70%*. Unlike the engineering officers, ~19% of the bridge officers answered *70-100%*.

The bridge officers on most visited ships receive several alarms from the ECR's IAS. Some bridge officers state that it is challenging to understand the difference between these alarms. For this reason, they view them as the same alarm (7.1B, 7.2B). In addition, some bridge officers were very happy to point out the alarms continuously repeating (7.5B). They found these to be a great source of annoyance. It also seemed they had less control over such issues, relying on their engineering colleagues to resolve such matters.

Some bridge officers explained that the alarms annunciated depend on the settings in the ECDIS and radar (7.3B, 7.4B). The reason is reported to be that these systems can generate repeated alarms if the settings are not adjusted to minimise these.

Of the 27 bridge officers who answered ECDIS specific questions *2.f* and *2.g* (Appendix A):

- 9 used personal navigational settings on the ECDIS
- 7 reported to suppress and add navigational alarms (alerts)
- 2 officers responded that although personal settings were configured into the ECDIS (likely from the previous watchkeeper), these were not adapted when taking over the watch
- 18 officers responded that they did not use personal settings in the ECDIS, indicating that these were configured according to company policy or per captain's order

In summary, it implies that less than one third of the participating bridge officers make use of the option to adapt settings for navigational alerts.

Some engineering officers (7.1E, 7.2E, 7.3E) use coping strategies to deal with chattering or fleeting alarms[20] . Despite a class requirement for such alarms to "lock in":

> *"2.3.10 For the detection of transient faults which are subsequently self-correcting, alarms are required to lock in until accepted." – [77]*

The muting (silencing) strategy reflects requirements for alerts to be maintained until they have been "acknowledged" and "the fault has been corrected":

> *"4.5 Alerts should be maintained until they are acknowledged and the visual indications of individual alerts should remain until the fault has been corrected. If an alert has been acknowledged and a second fault occurs before the first is rectified, the audible signal and visual indication should be repeated." – [35]*

By only silencing the alarm, they manually achieve what the 2.3.10 clause (above) should have done for them. As such, the question reflects that some engineers are indeed subject to chattering and fleeting alarms, despite having stated otherwise. For this reason, it is better to answer this question using objective data from alarm/event logs.

While the intention of the 2.3.10 clause is straightforward, no definitions of the time intervals or similarity criteria are defined. As such, it is not easy to codify it in the system. While both IEC 62682 and EEMUA 191 attempt to define such criteria based on time alone (three or more annunciations a minute), the following story details why fixed time intervals can be insufficient in practice.

1.22.3.4 Story No. 01. The "fleeting" battery alarm and the thermal runaway

A visited RO/PAX ship outside of the sampled population had many similar end-to-end operational cycles during the day. Each cycle generated a range of alarms. The officers on board had experienced a fire or thermal runaway event in the battery compartment.

Over time, the officers had grown accustomed to getting the same alarms every time the ship charged the batteries using shore power. The IAS would forward a set of common alarms with the text *BATTERY WARNING* and *BATTERY ALARM* (Figure 38) from the battery management system (BMS) at almost every operational cycle.

The sole bridge officer (captain) had to first check the IAS alarm on an HMI located away from the helm position (which was reported as very inconvenient during manoeuvring). Since the common alarm had no description, it was necessary to ask the engineering officer (who was assisting cars and passengers in getting on/off the vessel) to travel all the way down to the battery compartments. Here, the engineering officer could finally read the actual alarm description on the local panel and then report the info back to the bridge over the VHF.

Typically, the alarm on the battery panel would indicate the batteries overheating. The ship's schedule was fixed. According to the original equipment manufacturer (OEM), the batteries were charging according to the approved design envelope, and the OEM had no intention of addressing the alarms. As such, the alarm could not be actioned and had quickly become a *cry wolf* phenomenon.

One day, the bridge officer was going to check the IAS HMI panel because a BMS common alarm had been forwarded to the bridge. The ship had left the berth already and was underway. The officers had not discovered the thermal event in one battery module until the *Battery FIFI (Foam) – Extinguishing Action* alarm was triggered. And it had done so before the *Battery FIFI (FOAM) – Pre Alarm* (Figure 38).

20 "A chattering alarm repeatedly transition between the alarm state and the normal state in a short period of time. Fleeting alarms are similar short-duration alarms that do not immediately repeat. In both cases, the transition is not due to the results of operator actions." - IEC 62682:2014-16.5.6 Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch

The event resulted in a partial blackout and system loss for all port side systems, flooding the alarm system with nine pages of alarms with 31 alarms per page. The ship managed to return to the harbour, as the starboard systems remained available. Fortunately, no one was hurt. The thermal runaway did not propagate to adjacent modules. Still, the incident took the ship out of operation for months.

The officers had extensive experience and had been part of the building and commissioning of the ship. As such, they have an unsurpassable understanding of the systems and how these interact on board. They explained that checking this annunciated common alarm during every operational cycle with the current manning resources would be impossible. The primary reason is the need to locate the local panel at the battery compartment below the bulkhead deck, or what both officers referred to as "the basement."

The narrative supports the concerns around provisioning an alarm system with no account of integrity, and of using common alarms for essential systems and services.

Had the officers been able to observe the condition and had the alarm been trustworthy, they would have kept the ship still safely alongside (in harbour). This would have saved important time evacuating the passengers if the thermal event had propagated. Likewise, it would have enabled earlier assistance in fighting the fire from the shore.

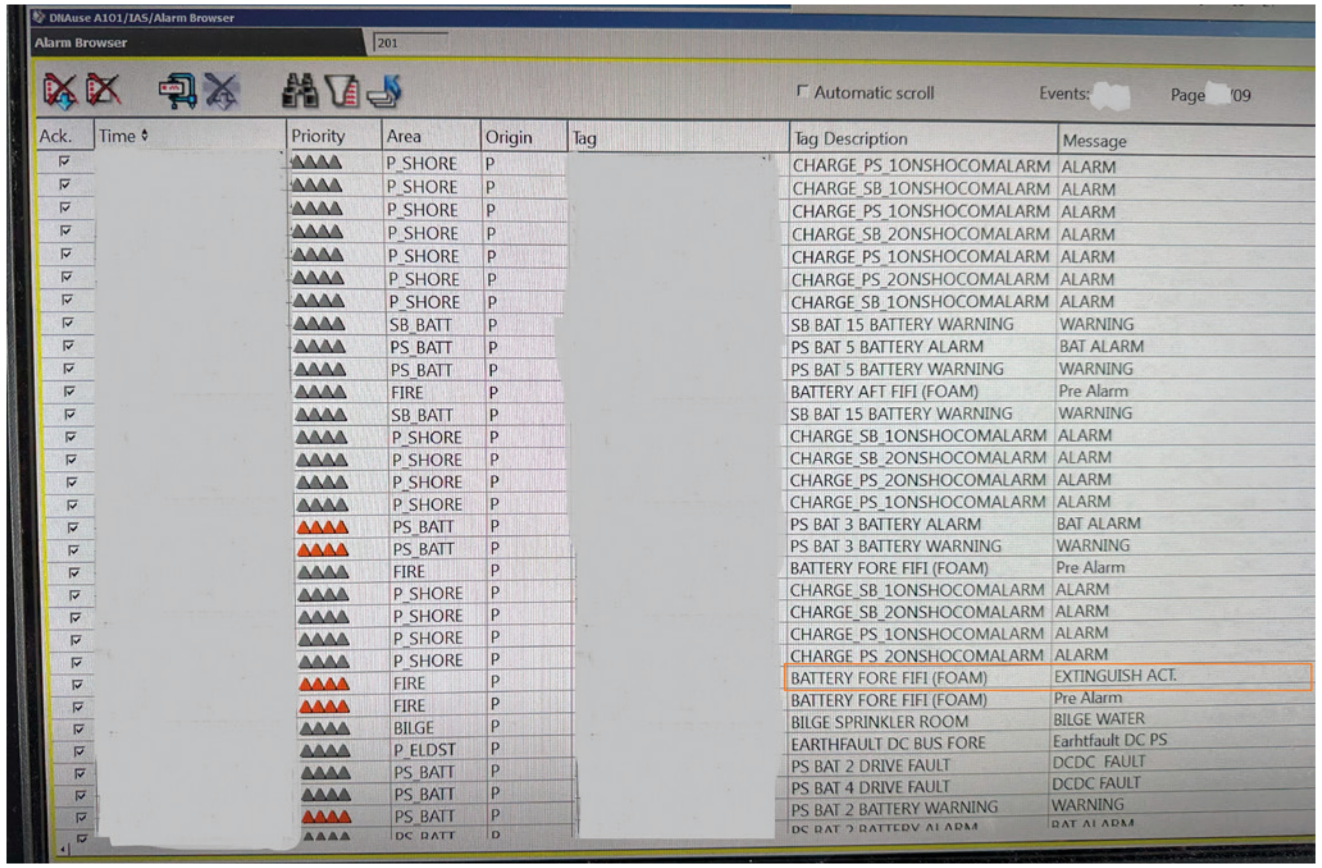
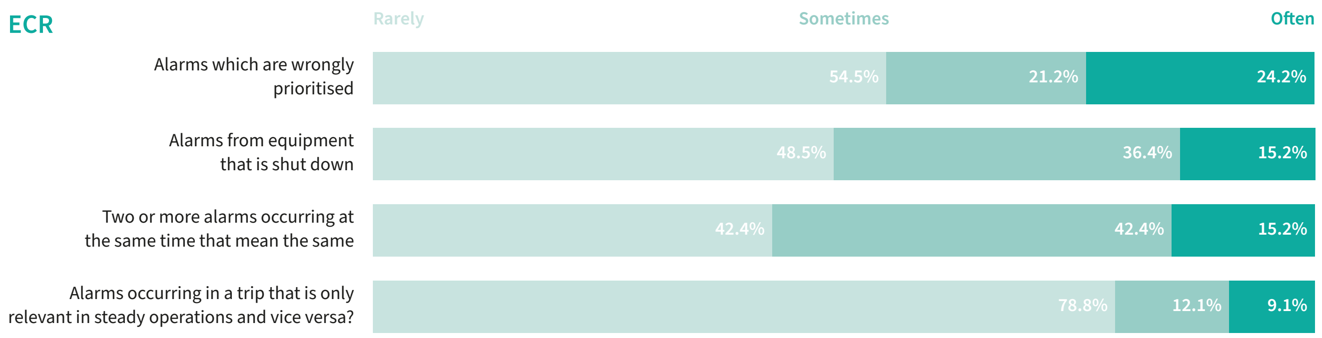


FIGURE 38.
The alarm list from the thermal runaway event on board. Time series moves from the top down; the oldest alarm is at the top. The alarms, "PS BAT (1,..,15) BATTERY ALARM", occur at almost each operational cycle. Likewise, disconnection from shore power generates foreseeable nuisance alarms: "CHARGE_SB,…CHARGE_PS_2ONSHORCOMALARM" means something like "charger starboard (or port) side X onshore common (or communication) alarm."
Looking at it from a surveyor's perspective, just a five-second glance to assess an indirect quality indicator of the overall alarm system; it is clear that the alarm description and message conventions are clumsy and inconsistent. This is evident from the mix of capital characters for the strings (text), including the mixed use of Pascal case and/or Snake case

1.22.3.5 Question 8. Do you suffer from the following 'nuisance' alarms?

QUESTION 8.
Do you suffer from the following 'nuisance' alarms?



8.a.E – Alarms which are wrongly prioritised:

- 8.1E – "Even though the IAS has prioritisation of alarms, it is not applicable. We don't have alarm prioritisation."
- 8.2E – "I can't say how often I get wrong prioritised alarms, there is only one priority." The engineer points at the alarm list display, all of which are highlighted with the same colour—red.

8.b.E – Alarms from equipment that is shut down:

- 8.3E – Alarms are muted during maintenance to avoid re-annunciation. These are acknowledged before startup.
- 8.4E – Engineers stated machinery alarms were annunciated, even though it was shut down (stopped off). It was not possible to suppress the alarms for security or technical reasons.

8.c.E – Two or more alarms occurring at the same time, that mean the same:

- 8.5E – "When a critical alarm triggered together at the same time received also common alarm."
- 8.6E – "Too many. For the same failure get a large number of unnecessary alarms. Say DG failure. Produces lots of alarms. Quickly fills page, and moving between pages takes time."

8.d.E – Alarms occurring in a trip that is only relevant in steady operations:

- 8.7E – "If there's a trip on the switchboard, then all the valves gives an alarm." The engineering officer is discussing the ballast valves and a "lost connection" alarm for each valve.
- 8.8E – "In rough weather the tank sensors will trigger intermittently. Bounce? While managed using roughly a 15 second delay for the bilge well sensors, the ballast tanks can be bad. Worse on other ships."

For question 8.a.E, ~55% of the engineering officers answered *Rarely*, ~21% *Sometimes*, and ~24% said *Often*. When asked, most engineers stated that the system did not prioritise alarms, and in some instances, the engineers were unfamiliar with the embedded prioritisation scheme. Because of this, they could not relate to alarms being wrongly prioritised. They answered Rarely as a result. This reiterates that the implementation of the IMO alert concept has not been successful.

A majority of the engineers thought that red was a generic colour, even though their system differentiates the priority by yellow (Warning), red (Alarm), and magenta (Emergency/Critical). Prevalent from the engineers answering Often was that they were aware of the alarm prioritisation but did not find it applicable (8.1E, 8.2E).

One visited ship was equipped with an alarm system incorporating effective alarm prioritisation during normal operations and system upsets. The engineering officers found the system immensely helpful. One unique attribute was the ability to effectively prioritise within each individual priority category, and not just between priority categories.

For question 8.b.E, ~49% of the engineering officers answered *Rarely*, ~36% *Sometimes*, and ~15% reported *Often*. A general tendency for the engineers who stated *Often* was successfully suppressing alarms during machinery maintenance, and also effective auto-suppression of alarms from non-active systems. Engineers answering *Sometimes* and *Often* operated systems that primarily lacked these features (8.3E, 8.4E).

For question 8.c.E, ~42% of the engineering officers answered *Rarely*, while an equal proportion (~42%) said *Sometimes*, with the remainder (~15%) stating *Often*. Most engineers answering this question were observed accounting for the same alarm being annunciated at several panels. At several different locations (8.5E). One example was a *common alarm* annunciated simultaneously in the IAS and at a local equipment panel somewhere in the ECR.

Furthermore, one abnormal process state can trigger several alarms in the system, which means the same to the watchkeeping engineer (8.6E). Engineers answering *Rarely* operated systems with good levels of integration with the IAS for the stand-alone systems that were retrofitted over time.

For question 8.c.D, ~79% of the engineering officers answered *Rarely*, ~12% said *Sometimes*, and a minority (~9%) stated *Often*. The few engineers who answered *Often*, were working on advanced cargo ships, where level alarms of the cargo tanks could be a source of nuisance during seagoing time (8.8E); they considered these alarms critical, but only during cargo operations. Other engineers considered cascade alarms as falling under this category (8.7E).

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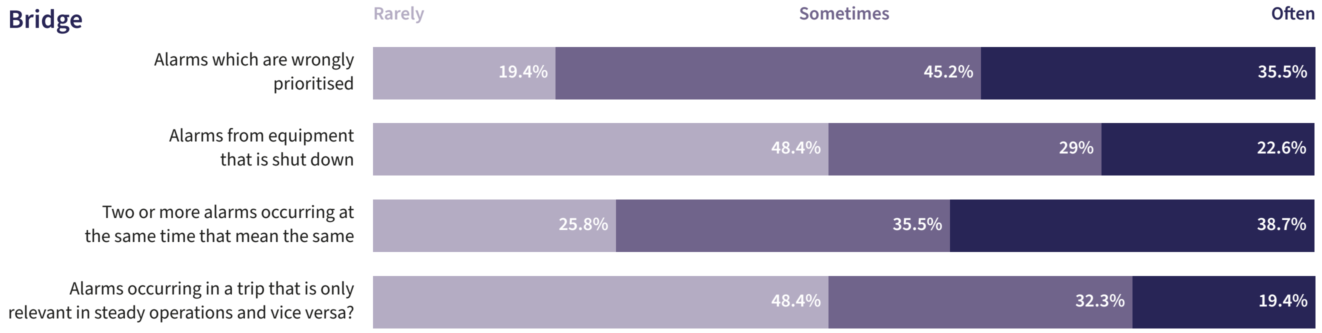
QUESTION 8.

Do you suffer from the following 'nuisance' alarms?



8.a.B – Alarms which are wrongly prioritised:

- 8.1B – It is explained that the "waterpool treatment plant" alarm is continuously annunciated in the IAS on the bridge. "It is a huge distraction."
- 8.2B – The audio and volume of the alarms do not fit the severity of the alarm. Insignificant alarms are loud. Fire alarms are low.
- 8.3B – A categorisation of alarms by colour would be helpful, according to an officer.
- 8.4B – The officer would like a *super mute button* that mutes all non-essential alarms for a period of time.
- 8.5B – "When you have to be focused, the alarms become a big distraction."

8.b.B – Alarms from equipment that is shut down:

While being safely moored alongside, some bridge officers would continuously be subject to alarms from objects picked up by their radar. They were not able to change radar settings or otherwise reduce the number of these alarms.

8.c.B – Two or more alarms occurring at the same time, that mean the same:

- 8.6B – "You have to mute watertight doors on two separate panels."
- 8.7B – "The fact that you have to mute the same alarms from different panels becomes unmanageable with the current manning."
- 8.8B – "If a shell door alarm is annunciated at the wing you have to acknowledge it at the centre console."

8.d.B – Alarms occurring in a trip that is only relevant in steady operations and vice versa:

- 8.9B – "Depth alarms are annunciated at open sea because the sensor has a maximum range of two kilometres."
- 8.10B – Author's observation on the bridge:

  02:35:20 and 02:36:20 – Two fire alarms from the galley are annunciated.

  - *The fire alarms are caused by a fire in a pot in the galley (When annunciated, they do not immediately recognise this).*
    - *The JOOW and SOOW stated that it was the first time that they experienced a fire on the vessel. They explained that they often get that exact fire alarm when they steam clean the galley. For this reason, at first they assumed it was for the same reason as usual. They stated that 99% of the time, the alarm is of no importance. The interviewer has previously observed that they would surveil that exact galley because of the same sensitive alarm. The alarm was then described as being a typical "nuisance alarm".*

For question 8.a.B, ~19% of the bridge officers answered *Rarely*, ~45% *Sometimes*, and ~36% said *Often*. Of the ~80% of the bridge officers constituting the *Often* or *Sometimes*, a general perception was that a wrong prioritisation could indicate that alarms were either incorrectly presented visually or audibly in the context of the operational situation. In other words, the alarms had little to no operational relevance (8.1B, 8.4B, and 8.5B).

On most visited ships, it was clear that the volume of alarms from the stand-alone systems did not reflect a prioritisation of the alarms, and that several officers wanted the option of adjusting the individual alarm volumes to suit their preferences (8.2B). In many cases, there was no coloured priority between alarms (alerts), which several officers stated would also be helpful (8.3B).

For question 8.b.B, ~48% of the bridge officers *Rarely*, which is close to being the same as for the engineers. A difference is that fewer (~29%) bridge officers stated *Sometimes*, while more (~15%) reported *Often*.

It was not uncommon for officers to receive alarms from equipment that was shut down, such as propulsion alarms, while being anchored. Although the system was idle or under maintenance, alarms could not be suppressed. These alarms offered no valuable information and mainly interrupted and disturbed the officers. It was remarkable that certain navigational systems (Radar) would generate alarms even while the ship was safely moored alongside.

In relation to question 8.c.B, ~26% of the bridge officers answered *Rarely*, ~36% *Sometimes*, and ~39% said *Often*. Notably, more than 74% of the officers responded that they would *Often* or *Sometimes* receive alarms signalling the same message simultaneously. This is consistent with the field observations that numerous alarms were being annunciated simultaneously on upwards of four panels (8.6B).

On several ships, several alarms annunciated on the bridge wing could only be silenced or acknowledged from the centre console (8.8B). This required the officers to leave their navigational station during operations to mute or acknowledge the ear-deafening sound or attempt to ignore it and not to be distracted (8.7B, 8.5B). Ships with so-called fully integrated bridge systems (IBS) were still subject to these situations.

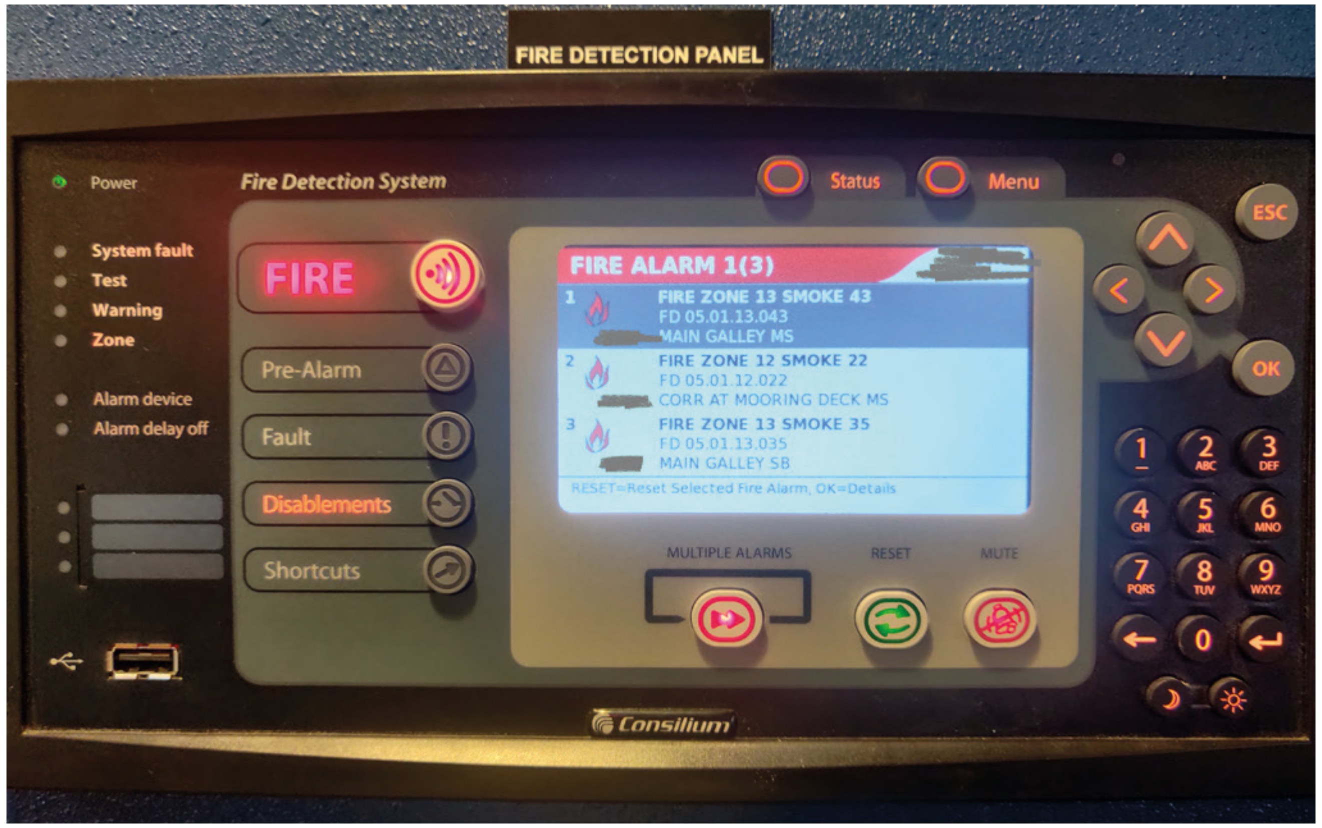


FIGURE 39.
Fire alarm panel on the bridge relating to the observation of 8.10B

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For question 8.c.D, ~48% of the bridge officers answered *Rarely*, ~32% said *Sometimes*, while 19% stated *Often*. The best examples of this are depth failure alarms, which occur continuously when the ship is underway at sea depths deeper than the sensors maximum range. Here, the range of the sensor can no longer reach the seafloor. Therefore, the depth monitoring system indicates that the sensor has failed (8.9B). When the bridge officers provide such narratives, they mean it. A glance at the integrated bridge system's alarm/event log records for that ship (where 8.9B is a watchkeeping bridge officer) reveals thousands of depth failure alarms each month. False fire alarms occurring while steam cleaning the cabins is another example. In this instance, officers were observed to seek confirmatory information before actioning the alarm on the day of an actual fire event (8.10B) (Figure 39).

1.22.3.6 Story No. 02. From the top floor to the basement

One ship had positioned the local panel of a retrofitted ballast water treatment system (BWTS) in the main engine room. Since the bridge officers managed the ship's stability and thus the ballast water, they had to travel all the way from the bridge to the machinery space to acknowledge the common alarm. The BWTS system also created three alarms for each alarm annunciated on IAS on the bridge: an "incoming" alarm, a "common" alarm, and finally, the actual alarm with a detailed description. The officers were not fond of this. The captain described the retrofit processes from shoreside technical management as "throwing the equipment on board".

Most of the bridge officers would like the management of the companies to do more to improve their alarm systems. Some officers explained that management would do something if the crew reached out (19.1B).

1.22.3.7 Question 9. What proportion of alarms are really useful to you when operating the ship?

All are essential

9.1E - “We cannot miss any information about the equipment, so every alarm is essential.” The engineers stated that all alarms contain relevant information that could be of use to them. They prefer to prioritise whether the alarm is relevant or not themselves and wish to be presented with all possible information.

9.2E - They do not trust the system to make this prioritisation on their behalf.

9.3E - “I would rather have too many alarms, than too few.”

9.4E - All information is useful, but a proper coloured prioritisation would make it better.

Most are useful

9.5E - Engineer state a wanting to be presented with relevant information from all the alarms but admits that some are of little or no use.

9.6E - “It’s the main thing that helps me monitor the systems. Lots of systems monitoring—alarms are the only way. Approximately 2/3rds of work (is) driven by the alarms, 1/3rd by list of scheduled tasks.”

9.7E - “We even get alarms that are not important for me as an engineer. (For) example, alarms for elevators, or refrigeration alarms when someone opens the doors. It can be important that these are noted somewhere. (For) example for dayworkers, we make a morning report of problems overnight that we could not fix.”

Few, but these are useful

9.8E - “That alarms are not correctly prioritised, lacking description and a intended response or suggested action.”

9.9E - “Engine failure get lots of alarms. Difficult to know where to look for the problem. Especially as forms a sequence. Say 20 alarms, then 5 important and 2 pointing at the cause. It’s not useful. Design of equipment causes multiplication: each pod has two motors for redundancy, but if you have a power failure both systems will alarm and will get alarms for the general failure. That adds up since we have four pods!”

Very few are useful

No respondents

All are essential

No respondents

Most are useful

9.1B - “80% of alarms are important to us, 20% are not.”

9.2B - Reflection after interview: There’s a strong tendency for the participants to state that most alarms are useful to them. Many stated that they would not be without the alarms. This only applies when they were discussed in general. The alarms were often annunciated in a context where they were of no use to the officer. Still, several stated that it does not necessarily always make them useless. There is a need for more context-aware alarm systems that annunciate alarms in the proper operational context.

Few, but these are useful

9.3B - Mentioned as an answer here again: “70-80% of the alarms we don’t need.”

9.4B - The officer stated that only the Hi-Fog alarms from the IAS were important to the officer. The officer found it utterly unnecessary that they received all those alarms through the IAS.

Very few are useful

No contextual answer

For the alarms provisioned in the system, ~41% of the engineering officers stated that *All are essential*, while 50% found that *Most are useful*, and only ~9% said *Few, but these are useful*. The general consensus among engineers is that alarms contain valuable information, yet confidence in the system’s ability to present information at the right time varies.

Some engineers prefer abundant information to make informed decisions (9.1E) and some do not trust the system to filter out what is important (9.2E, 9.4E). Engineers may not trust the system’s ability to present relevant information because of poorly engineered alarms (9.5E, 9.7E, 9.8E). As a general observation, some of the “let me have it all” type responses should instead be attributed as a symptom of poor performance rather than each alarm’s actual quality and usefulness (9.3E). On some ships alarms had become the primary (and primitive) means of information for watchkeeping engineers—information

they would never want to give up unless they had a better source.

A concerning narrative is the alarm system becoming the main task scheduler, driving upwards of 2/3 of the work engineers do on board (9.6E). Other engineers talk about the overload of information for specific events, which is not helpful (9.9E) or irrelevant to the engineers’ position (9.7E).

For the alarms provisioned in the system, none of the bridge officers found that *All are essential*. Instead, ~74% of find that *Most are useful*, while ~23% answered *Few, but these are useful*, and ~3% *Very few are useful*.

Overall, the bridge officers find that most alarms can be useful in the right contextual situation (9.1B). However, often it was not the case (9.2B, 9.3B). On several occasions, bridge officers would question the rationale behind alarms raised from the ECR to the IAS (9.4B); this issue was already highlighted in earlier questions (e.g., 3.3B). These alarms tend to become a nuisance and distraction to the bridge officers.

Considering the answers and narratives above, the authors found a discrepancy between what the question was intended to communicate and what the operators understood. Whether the same question phrased as a negation would arrive at the same distributions is questionable.

It was not uncommon for officers to find that multiple alarms were presented in a context that was of no use or no operational relevance. As a result, it would quickly be acknowledged and ignored. The observed consequence was a lower response rate to genuine alarms and to officers awaiting confirmatory information before deciding on a strategy of intervention (8.10B).

1.22.3.8 Story No. 03. The hidden elevator alarms

Besides the safety and machinery alarms, the engineering officers on passenger ships found it distracting to handle various designated passenger alarms, such as those related to refrigerators, elevators, and similar comfort systems (example 9.7E). From the field observations, it appeared to be a source of distraction and nuisance.

FIGURE 40.
Passenger elevator alarm panel hidden behind a desktop screen in the ECR

On one visited ship, the elevator panel was put out of sight behind some administrative desktop screens (Figure 40). Some observed elevator systems would generate alarms simply because the doors were left open too long. The ships with passenger demographics leaning towards elderly people appeared to be in a constant state of alarm.

The rationale for entangling alarms of such “comfort systems” within an essential control centre for overall ship safety is questionable. The NSIA report on the *Viking Sky* incident details similar concerns:

> *“The result was that the ECR operators were responsible for monitoring a large number of alarms, likely too many for an operator to handle, given the design and configuration of the alarm system. The scope of the alarms was very wide—from swimming pool temperature alarms and open refrigerator doors to highly critical alarms, such as the low lube oil sump tank alarm.”* – [22, p. 112]

1.22.3.9 Question 10. Do you fully understand each alarm message and know what to do about it?

Always

10.1E - A chief engineer stated that it took years to tune in the alarm parameters to reduce the number of alarms in the IAS and have personally reviewed them all.

Mostly

10.2E - "Most of them, but of course, there are some I don't know exactly that come once every other year."

10.3E - "I don't know the other engineers' alarms; it's their alarms." Talking about ETO and HVAC engineers on a cruise ship.

10.4E - When speaking about training: "Never 'trained'. All experience on the job. Came as third, was 'trained' to be second, which included the alarm system."

10.5E - When speaking about training: "No. On the job. I am still learning about the Gas Turbine and Azipod screens."

10.6.E - "Young engineers have to evolve with alarm system."

Sometimes

10.7E - When an engineer is asked: "Do you know what that is?" about a communication error alarm in IAS, with the following description: "No Com. With RIO Module on RBUS B".

- The engineer replied: "No, and I don't care."

10.8E - "Sometimes the POD alarms don't give an alarm message, sometimes they do. No system to it."

10.9E - "Very hard when I first came here."

Always

10.1B - The officer has been sailing on this ship for years and says that he knows every alarm.

Mostly

10.2B - "Sometimes you get alarms from a panel that you don't know what it means, but when you look in the manual there is no description for that alarm… This is rare, but it has happened a couple of times."

10.3B - "I consider engine room alarms more as a distraction than a help to me".

10.4B - It sometimes happens that the officer receives 'Unspecified' alarms in the IAS.

Sometimes

10.5B - For a few months in a row the officers received the alarm 'call plumber' through the IAS system. They have no idea what it meant.

When continuing the conversation about the IAS system: "Everything means 'call the plumber' for me."

10.6B - Alarm descriptions on the propulsion control panel are vague, and the officers do not know what they mean.

For the engineering officers, ~24% stated that they *Always* understand the alarm messages and know what to do about them, while ~71% stated that this was *Mostly the case*. A few 6% also said that they only *Sometimes* understand the messages and their expected responses.

For the bridge officers, ~12% stated that they *Always* understand the alarm messages and know what to do about them, while ~71% stated that this was *Mostly* the case. Around 16% said they only *Sometimes* understand the messages and their expected responses.

The narratives and conversations made it evident that the bridge officers lacked comprehension regarding the meaning and the appropriate response to the machinery alarms routed to them from the ECR or propulsion/steering systems. They found these distracting and of low operational value (10.3B, 10.4B). Bridge officers tended to perceive that these announced alarms fell beyond their expertise (10.5B and 10.6B).

Despite ~70% of all watchkeeping officers answering that they Mostly understand and know what to do about the alarms they receive, the field observations painted a more nuanced picture. It was observed that officers answered the question based on the alarms they had experienced (10.2E, 10.2B) and not the provisioned alarms on the ship. Which typically adds up to several thousand (see Research Site).

On some ships, the engineering officers had serviced for 10 years or more. When asked about the rationale behind specific alarms, they were knowledgeable and more likely to know in detail. One chief engineer had even rationalised all the engine room alarms (10.1E).

Overall, it was observed that several officers could benefit from a deeper understanding of the meaning of alarm messages. And even more so of what to do about them. This was apparent when they were asked about the meaning of one or more casually selected alarms from the alarm log display; these were alarms they had personally acknowledged during their watchkeeping duty. This need was widespread among officers who did not work on back-to-back contracts, meaning those with limited onboard duty, typically around four times in a period of three months or less. Getting familiar with the system in addition to all other maintenance and operational duties naturally takes time.

These transient officers further posed a training burden on the stable crew (10.4E, 10.5E, 10.8E). The crewing agency would assign them to a new ship when their contracts ended. As a result, there was insufficient time for these officers to thoroughly familiarise themselves with the ship's system and the respective alarms.

The authors of this report attribute the *"No, and I don't care"* statement (10.7E) to not feeling a sense of technical ownership, which is understandable. As these officers had no idea if they would ever return to the ship again, there was little observed accountability. The narrative *"It's not in my job description"* from a previous question (3.3B) underlines that general observation is also prevalent among such "transient" bridge officers.

Numerous officers expressed that they had never received training on how to react to or understand the significance of the diverse alarms. This is despite being responsible for responding to these alarms during their watchkeeping duties.

As such, they depended on *in-service experience* on board the ship to familiarise themselves with the alarms and the overall systems. While this ship-specific in-service experience is necessary for any training, it may be inappropriate for managing alarms alone. It also underlines a large gap between the reality and the regulatory expectations:

> *"4.13 Provision should be made for functionally testing required alerts and indicators. The Administration should ensure, e.g., by training and drills, that the crew is familiar with all alerts." – [35]*

1.22.3.10 Story No. 04. "It's not my alarm, it's their alarms."

Another aspect was background competencies for understanding the meaning of alarm messages and their necessary response procedures. For the sampled cruise ships, different engineers focused solely on their area of expertise and license. These watchkeeping engineers did not know what to do for electrotechnical and control engineering alarms.

The 10.7E engineer (not licensed to STCW III/6) was not aware (nor were others) that the inquired alarm informed the condition that the system in question was operating under a single point of failure (SPOF) vulnerability: A succeeding fault to the *RBUS A* network would result in a total loss of that system, since global control variables were integrated (transmitted) via the RBUS control backbone from other RIOs [21]. As such, this alarm was considered the responsibility of the electrotechnical officers (ETOs), the designated team that handled the electrotechnical aspects of the ship's systems. However, the ETO team had (according to the timestamp) yet to rectify the problem, as the alarm had been stale[22] for months.

As the ETOs do not conduct watchkeeping duty, they did not appear to have any more profound knowledge or understanding of the specific plant behaviour. As a result, there was a disconnect between these two departments; the watchkeeping engineers were unfamiliar with electrotechnical aspects, and the electrotechnical engineering team was unaware of the watchkeeping duties and the significance of certain alarms. This was observed to increase response time to alarms, left issues unresolved, and ultimately posed risks to the ship's safety and operation.

Despite this disconnect, the watchkeeping engineers were still expected to manage these types of alarms in a

21 RIO - Remote Input/Output (dedicated panels for control wiring)
22 "alarm that remains annunciated for an extended period of time (e.g., 24h)" - IEC 62682:2014-3.1.81, Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch

complex electrotechnical environment. An environment encompassing high-voltage power distribution, diesel-electric propulsion, large semiconductor converters and the advanced integrated automation systems binding them all together.

In fact, some of the observed Safe Return to Port (SRtP) actions mentioned on various control cabinets required manipulation of advanced safety-control wiring, such as emergency stop switches (e-stops), for each main propulsion converter (Figure 41). Such cabinets can easily contain hundreds of IOs (Figure 42). It is important to note that almost all other e-stops are wired as normally closed circuits (NC). Meanwhile, the propulsion e-stops are normally open circuits (NO). This is necessary to avoid a cable break causing a false trip of the propulsion.

However, it also means that if the person were to disconnect the wrong e-stop wiring, it would cause a shutdown of that machinery (which could no longer be brought back into operation until reconnected and reset manually at its local position).

With an actual SRtP scenario in mind, the authors of this report wonder how that particular action could have ever been signed off as a reasonable and realistic human performance.

FIGURE 41.
SRtP instruction to disconnect the emergency stop signal from the ECR (if lost) to each propulsion converter to avoid an unexpected loss of propulsion

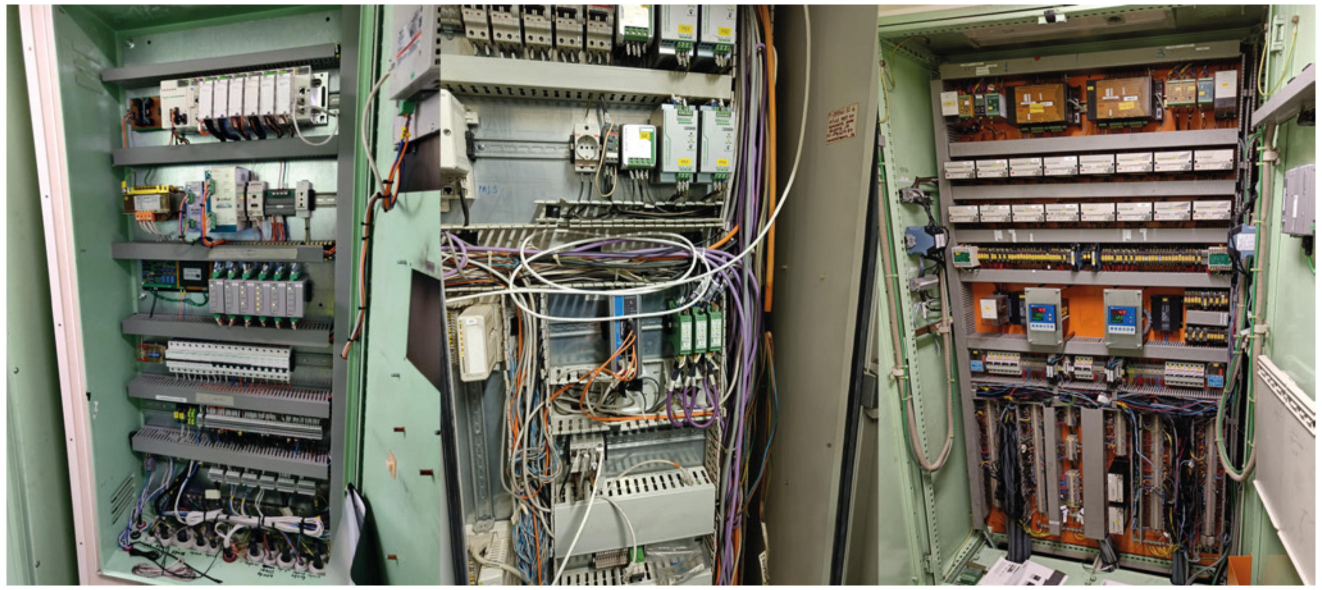
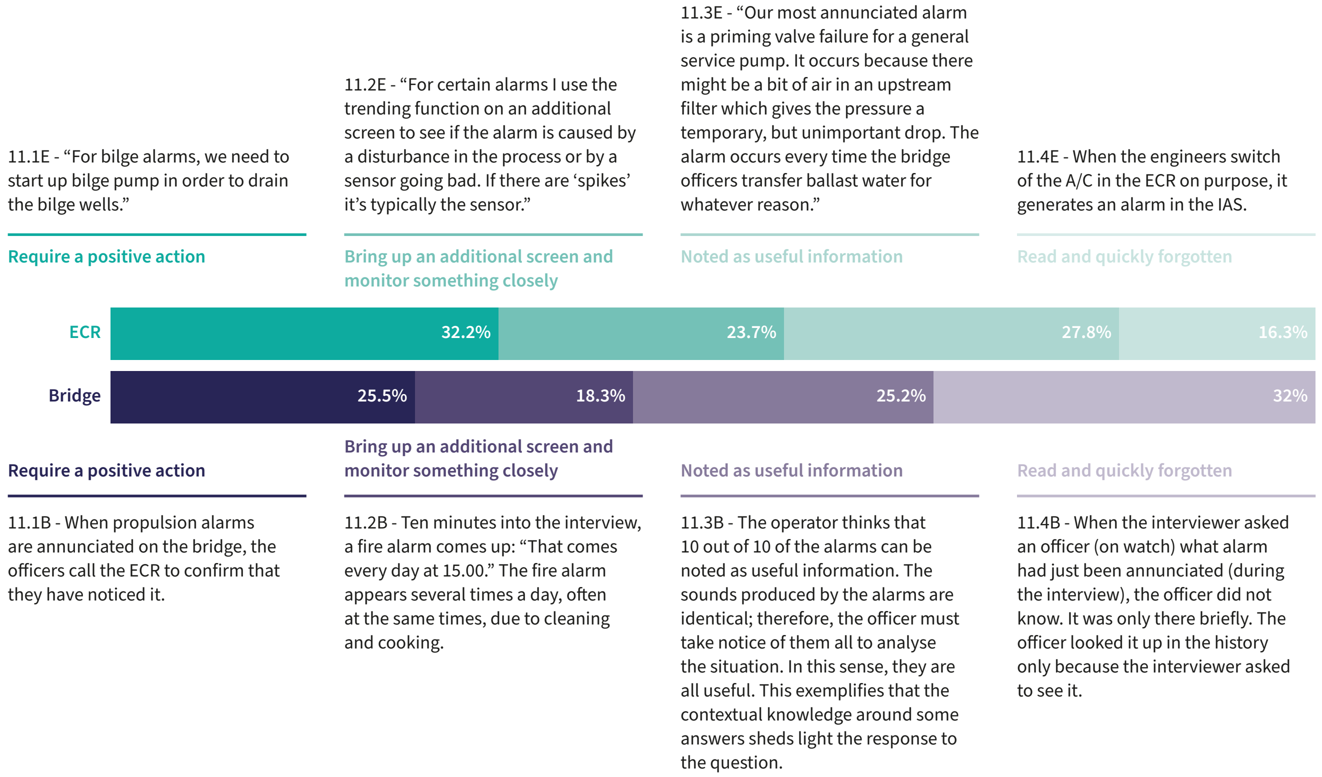


FIGURE 42.
Examples of control and network cabinets from sampled ships (not from the same ship as the SRtP sign)

1.22.3.11 Question 11. Consider a normal operating situation and 10 typical alarms. How many of the 10 alarms:



The engineers responding to this question answered that only ~32% of the 10 most typical alarms *Require a positive action*, ~24% caused them to *Monitor something closely*, ~28% were *Noted as useful information*, while ~16% were *Read and quickly forgotten*. Examples of positive actions mentioned by the engineers are opening valves, starting a pump, transferring load to other equipment or isolating parts of a switchboard (11.1E).

Of the 29 bridge officers who answered, ~26% of the 10 most typical alarms *Require a positive action*, ~18% *cause one to monitor something closely*, ~25% are *Noted as useful information*, and ~31% of the alarms are *Read and quickly forgotten*. Some bridge officers considered communication to be a positive action (11.1B).

It is important to note that the watchkeeper subjectively selected the 10 most typical alarms from their term of reference. An objective analysis of the alarm log was not performed before conducting the ship visit (what the 10 most typical alarms actually were). This could have provided an enhanced basis for conversations and would have been more objective.

Based on the notes from the interviews and observations on the bridge, the distributions of responses are likely to represent the behaviour of the system and officers (11.2B, 11.4B). Certain alarms could not be actioned for some engineering officers as operations on the bridge had caused them—operations that were outside their control (11.3E). The bridge officers reported similar narratives for IAS alarms. It appears that those responsible for implementing alarms could at times be uncertain about who is expected to respond to them.

Some engineers with electrotechnical competencies could combine knowledge of field instrumentation (sensors) and the thermodynamic processes and behaviour of the system (11.2E). One example was to differentiate between absolute alarms and what could be instrument diagnostic alarms (Figure 43).

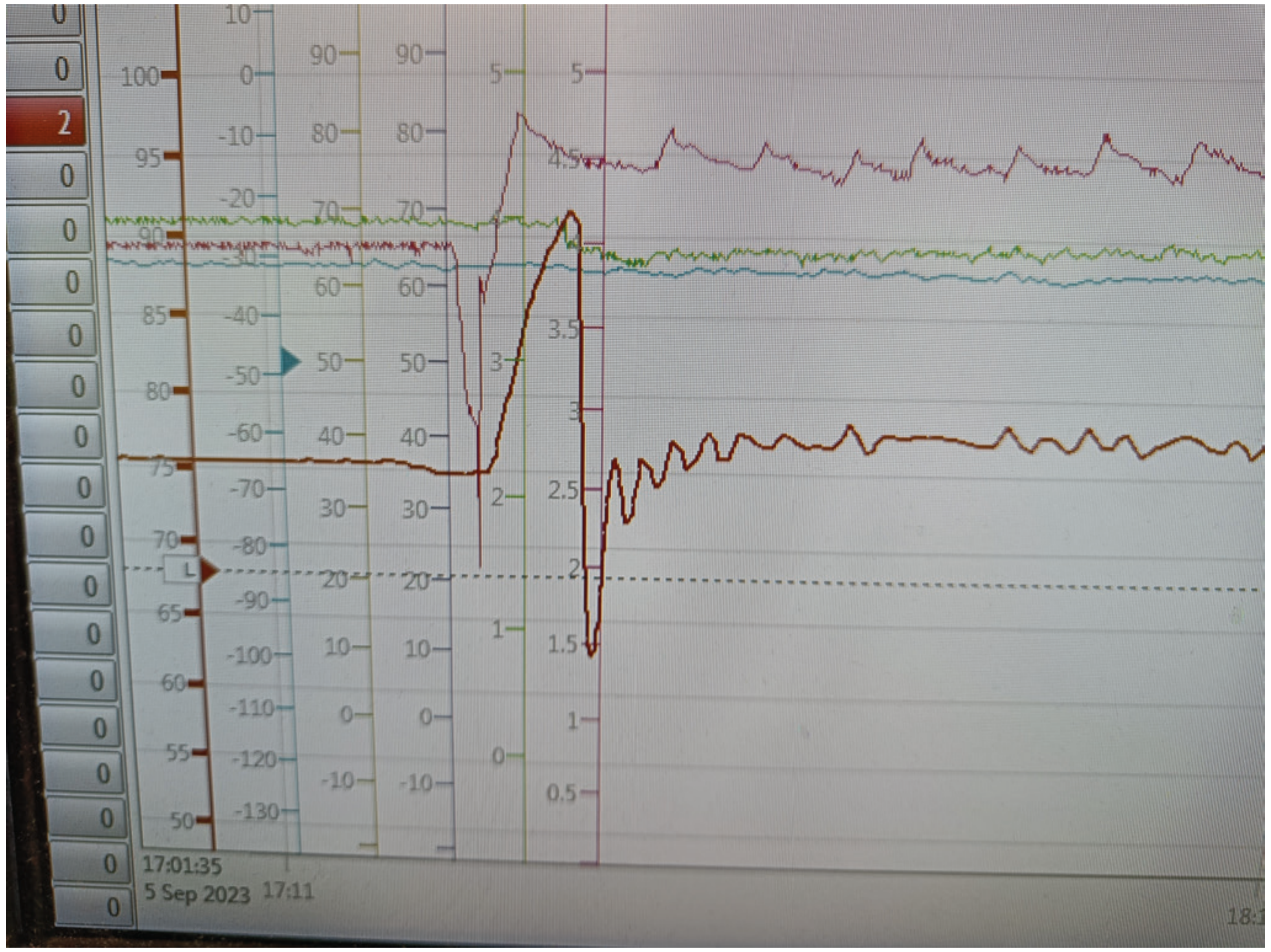


FIGURE 43.
Trend chart of sensor values. The red line represents the cooling water temperature to a main engine, the dash-dotted horizontal line is the lower limit "L" setpoint, which activates the alarm "ME X HT low-temperature" after a set delay. Due to the "smoothness" of the curve, it is not likely to be a sensor fault but something else, possibly an undershooting PID controller

The distribution of answers to the question indeed raises concerns. That less than one third of the most typical alarms require a response indicates a high level of false flags. Suppose these alarms are important in only a very minor set of circumstances. In that case, the system should be engineered with enough integrity to alert the officers only at those times. Especially from the perspective of the bridge officers, they question is: why not rely on the officer's conduct of good seamanship? After all, are car drivers not able to keep their vehicles within the designated lane without lane departure warnings?

1.22.4 Performance during a major upset or demanding operation

This section examines the watchkeepers' general opinion on the performance of the alarm system during large system faults, trips or demanding operations (Table 15). It contains the same group of questions as used in the HSE CR 166 report. The conversation continues from the endpoint of question 11 by asking the watchkeeper to reflect on how many alarms are generated during such events. This is followed by the experience and opinion of the alarm system's behaviour and decision-making support at such times.

TABLE 15.
Questions related to the performance in normal steady operation.

Question	Question No.	Theme
How many alarms would you get during a large system fault, trip or demanding operation	12.a,…,12.c	Performance during a major upset or demanding operation
What facilities help you now manage alarms during a large system upset, trip or demanding operation?	12.d	
Do you bring up an additional alarm list display during a large system fault or trip?	13	
How often do you look through the alarm list display during a large fault or trip?	14	
How often in a large system fault or trip do the alarms come too fast for you to take them in?	15	
How often in a large system fault or trip are you forced to accept alarms without having time to read and understand them?	16	
Does the alarm system help you to pick out key safety-related events during a large system fault or trip?	17	

1.22.4.1 Question 12. How many alarms would you get during a large system fault, trip or demanding operation?

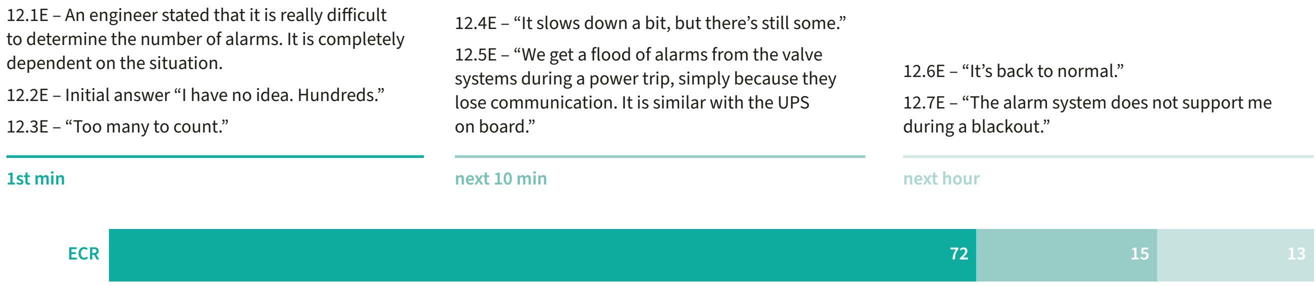


FIGURE 44.
Question 12 - Engineering officers.

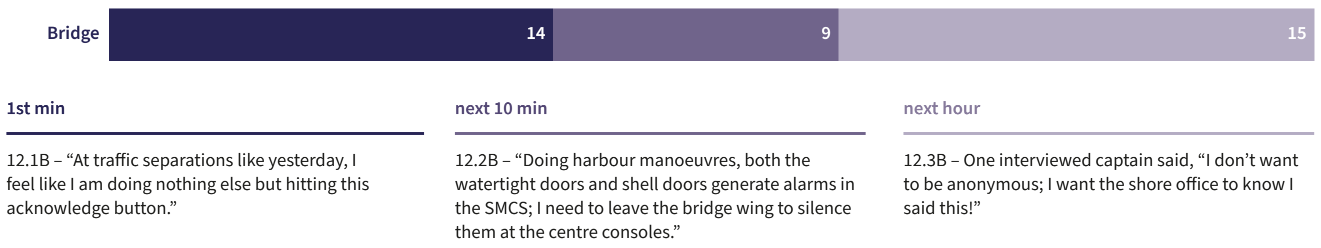


FIGURE 45.
Question 12 - Bridge officers.

According to the engineers, the average number of alarms received during the first minute is ~72, followed by ~15 in the next 10 minutes, then ~13 in the next hour (Figure 44). This average relies heavily upon the contextual situation and can vary on this basis (12.1E).

During interviews, many engineers used a blackout as the term of reference (12.5E). This is a scenario that most of them had experienced either fully or partially.

According to the bridge officers, the average number of alarms received during the first minute is 14, followed by ~9 in the next 10 minutes, then ~15 in the next hour (Figure 45). These figures likewise depend on the contextual situation. During interviews, the bridge officers used the scenario of approaching port or traffic separations as the term of reference (12.1B, 12.2B).

Several engineers report being subject to a flood of alarms during such major upsets (12.2E, 12.3E). Still, the engineering officers’ reported numbers appear to be less than what has so far been observed from reviewed alarm logs. It is also less than the narratives of certain incidents in which approximately 1000 alarms were reported to have gone off in the first eight seconds [22, p. 6].

As described earlier in the results section of question six, very few engineers had the facilities to compute these numbers in the alarm system. An objective analysis of the provided alarm data could establish the engineer’s ability to estimate these numbers.

Regardless of the discrepancy, it is still too much for engineers to comprehend in a time-critical situation.

One can argue that drawing any diagnostic value from such a large stack of alarms can be difficult, if not implausible. The IEC 62682 standard contains a section: *Detailed design: Enhanced and advanced alarm methods*, which details a set of methods successfully applied to control alarm floods [18, p. 60]. Examples are that some engineering officers see no reason to display all alarms from all the activated uninterruptable power supplies (UPS) during a blackout (12.5E).

For the bridge officers, the first two subquestions were not well suited to the operational context, as they do not deal with “trips” as such. In a navigational context, bridge officers described demanding operations with time constants of at least an hour or longer, not in minutes. This distinction is supported by this study’s objective alarm load recordings conducted on the bridge. For the bridge alarm load recording number three, the alarm rate increases into the “center” of the unfolding scenario and then decreases. Ideally, these questions could incorporate such time/spatial examples.

From the reported alarm rates of bridge officers, the average cumulative number of alarms within the hour tallies ~42. This number is too high and is reported as distracting to the officers during demanding navigational operations when they must concentrate fully (12.1B, 12.2B, 12.3B).

1.22.4.2 Question 12.d. What facilities help you now manage alarms during a large system upset, trip or demanding operation?

The responses to the open question 12.d reveal a heavy reliance on colleagues who can help silence and acknowledge alarms during such events (12.d.7E, 12.d.7B, 12.d.15B), further adding that effective resource management is critical to deal with such matters (12.d.8E, 12.d.11E, 12.d.17B, 12.d.19B, 12.d.20B). Being trained and having written procedures (on paper) for recovery is reported helpful as well (12.d.9E, 12.d.10B).

For the HMI, help facilities include features like mimics for shutdown and slowdown alarms, automatic suppression of unnecessary alarms, shortcuts to mimics through the alarm log, fast acknowledgement of alarms, descriptive text and colour coding for priority, and informational buttons for troubleshooting procedures. Audible explanations of alarms are also reported as helpful, since the officer does not have to leave the station to know what is happening (12.d.3B).

Lastly, some systems were equipped with self-recovering capabilities, which meant the officers did not have to think about those aspects during large upsets but merely observe that these “kicked in” as needed (12.d.14E, 12.d.21B).

HMI:

- 12.d.1E – “ Main Engine has a mimic for list of shutdown and slow down alarms which show what we need to rectify. There is a function to view the mimic of the alarm activated from the alarm list view.”
- 12.d.2E – “Automatic suppression of, at the moment, unnecessary alarms (CAM).”
- 12.d.3E – “Shortcut to mimic through alarm in alarm log/event log. When too many alarms occur it can be helpful to monitor stand-alone systems.”
- 12.d.4E – “Fast acknowledge (10 alarms per click). Physical blackout checklist.”
- 12.d.5E – “Descriptive text of the priority, colour coded (most are red (read: ‘not really a help’)).”
- 12.d.6E – “In the system you can see exactly where the main equipment is located.”
- 12.d.1B – “There is both primary and secondary system that gives indications that helps me get an overview of the situation.”
- 12.d.2B -“Colour coding and icons for different types of alarms.”
- 12.d.3B – “DP: audible explanation of the alarms.”
- 12.d.4B – “Info button in the system to inform you of a troubleshooting procedure and the possible root of cause.”

- 12.d.5B – “Yes, to some degree, but it is very limited in ability to differentiate by sound and frequency between important alarms and low priority alarms.”
- 12.d.6B – “Suggested action (only on the radar).”

Resource management:

- 12.d.7E – “The extra operator that acknowledges the alarms.”
- 12.d.8E – “Checklist to get up and running again. Experienced colleagues.”
- 12.d.9E – “Colleagues and internal spoken procedures. Training for blackout.”
- 12.d.10E – “Other engineers.”
- 12.d.11E – “Colleagues/ co-watchkeepers.”
- 12.d.12E – “Next officer in rank.”
- 12.d.13E – “Sleep before the watch. Be ready.”
- 12.d.7B – “Helping hands to acknowledge the alarms if there are other things to focus on. Not knowing the alarm, but you want the silence.”
- 12.d.8B – “My colleague will help.”
- 12.d.9B – “Colleague.”
- 12.d.10B – “Colleagues, procedures/checklists to help manage.”
- 12.d.11B – “Colleagues.”
- 12.d.12B – “Co-navigator/colleague.”
- 12.d.13B – “Manpower. Other officers who help diagnose the problem.”
- 12.d.14B – “Coworkers.”
- 12.d.15B – “Co-navigator/colleague(s) that are placed only to acknowledge alarms.”
- 12.d.16B – “Cadets and quarter masters (lookouts).”
- 12.d.17B – “Increasing manning level. If not, it wouldn’t be manageable.”
- 12.d.18B – “Colleagues, harbour and sea mode.”
- 12.d.19B – “The officer (usually 3rd officer or cadet) that acknowledges the alarms so the rest of the bridge have silence.”
- 12.d.20B – “Colleagues that take control of muting and acknowledging alarms.”

Automated recovery capabilities:

- 12.d.14E – “Automatic starting of standby machineries e.g. standby auxiliary engine, pumps, and fans.”
- 12.d.21B – “Emergency generator.”

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1.22.4.3 Question 12.e. What facilities would further help you to manage a large amount of alarms during a large system upset or demanding operation?

The responses to the open question 12.e reveal multiple opportunities for improvement on various aspects from Human-Machine Interface (HMI) & Ergonomics to Resource Management, Alarm Quality, and Prioritisation capabilities.

Regarding HMI & Ergonomics, individuals pointed out the necessity for features such as alarm history, trend history, and a replay function during critical alarm investigations (12.e.1E, 12.e.3E). They also emphasised the importance of having a mute button and an auto-acknowledge button, along with an “acknowledge all alarms” button for efficient rectification during immediate actions (12.e.4E, 12.e.5E, 12.e.6E, 12.e.4B, 12.e.5B). Suggestions were made for proper integration of systems into the main alarm system and the provision of a digital manual in the local alarm panel (12.e.7E, 12.e.8E).

The preference for physical buttons over touch screens was highlighted (12.e.12B), along with the desire for a silent bridge option (12.e.13B).

Respondents further highlighted the need for more physical indicators and the concentration of panels for ease of access (12.e.10E, 12.e.1B). Moreover, there were requests for a longer acknowledgement time for alarms (12.e.2B) and the implementation of a harbour mode function for all systems (12.e.3B).

In terms of Resource Management, individuals emphasised the importance of assistance from coworkers, regular drills to ensure operational readiness, and more time to familiarise themselves with the systems (12.e.12E, 12.e.13E, 12.e.14E). Better communication (integration) between different equipment on the bridge was also highlighted (12.e.15B), along with the need for additional colleagues (12.e.16B, 12.e.17B).

Regarding Alarm Quality, suggestions were made for better alarm management and alarm rationalisation, including the removal of certain alarms and the suppression of non-relevant alarms (12.e.18B, 12.e.19B, 12.e.20B, 12.e.21B).

Concerning Prioritisation Capabilities, individual officers expressed the need for a differentiation between important and less important alarms, a system for organising alarms and providing guidance to operators using voice messages rather than noise (12.e.14B), and a blackout grouping of alarms to streamline response (12.e.16E, 12.e.17E, 12.e.18E). They also suggested having the root cause of a trip displayed prominently (12.e.19E).

HMI & Ergonomics:

- 12.e.1E – “Alarm history, and trend history.”
- 12.e.2E – “Trends and alarm history.”
- 12.e.3E – “It would be helpful to have a replay function on the mimics during an investigation of a critical alarm.”
- 12.e.4E – “A mute button and auto acknowledge button for a certain amount of time.”
- 12.e.5E – “An acknowledge all alarms button will also help when rectifying immediately to see which alarms are still activated.”
- 12.e.6E – “Auto acknowledge all alarms at once. Audio suppression, that is. Furthermore there should be a function to reactivate the function”
- 12.e.7E – “Properly integrated systems into main alarm system.”
- 12.e.8E – “Have a digital manual in the local alarm panel.”
- 12.e.9E – “It would help me to be able to change the setpoints on HL (high level) or LL (low level) alarms.”
- 12.e.10E – “More physical indicators like, PI-gauge, TI-gauge.”
- 12.e.11E – “Filter or grouping of the alarms so you know what categories are important and can focus on that.”
- 12.e.1B – “Physically concentrate the panels, so it wasn’t too far apart.”

- 12.e.2B – “Want more time to acknowledge alarms before it goes on to the next step. At this point there’s only 360 secs and 180 secs for me to acknowledge before it wakes up the captain.”
- 12.e.3B – “Harbour mode function for all systems.”
- 12.e.4B – “One fully integrated system, One common button for muting.”
- 12.e.5B – “CAM-system (help manage alarm floods).”
- 12.e.6B – “The system should be able to distinguish between critical and non-critical alarms during operations.”
- 12.e.7B – “One separate CAM (Centralized Alarm Management) screen.”
- 12.e.8B – “A system that could categorise the alarms, in order to group them and make a prioritisation.”
- 12.e.9B – “Be able to have no sound/mute button when approaching port to be able to focus but still be able to get visual alarms.”
- 12.e.10B – “Bridge ergonomics to help minimise the time from one system/station to the other.”
- 12.e.11B – “Filtering the alarms, able to cut out the IAS because of, for example, HVAC alarms.”
- 12.e.12B – “I hate touch screens, so give us some hard physical buttons.”
- 12.e.13B – “A function that would keep the bridge silent.”
- 12.e.14B – “Would prefer to have the option to have a voice alarm tell us what it is. The technology to do exists and it is simple. Beeps and sirens are old school not useful in today’s complicated world.”

Resource management:

- 12.e.12E – “Assistance from coworkers.”
- 12.e.13E – “Drills to make sure that you know what to do.”
- 12.e.14E -“More time to gain familiarity with the systems.”
- 12.e.15B – “Better communication between all the different equipment on the bridge.
- 12.e.16B – “A colleague more.”
- 12.e.17B – “More colleagues.”

Alarm quality:

- 12.e.15E – “Action description/suggestion for an alarm.”
- 12.e.18B – “Better Alarm Management and prioritization.”
- 12.e.19B – “Would like to remove certain alarms such as AWW[23] .”
- 12.e.20B – “Remove the engine room alarms from the bridge.”
- 12.e.21B – “Supressing alarms that are not meant for the bridge.”

Prioritisation capability:

- 12.e.16E – “A priority of alarms, a differentiation between important and not important alarms.”
- 12.e.17E – “Having a CAM system, that can organize the alarms and tell the operator the root cause of the problem and what to handle first.”
- 12.e.18E – “A blackout grouping of the alarms so the operator doesn’t have to look through them all. Even so they could see the first alarms first.”
- 12.e.19E – “Have the root cause of the trip at the top.”

23 Advanced wastewater treatment system.

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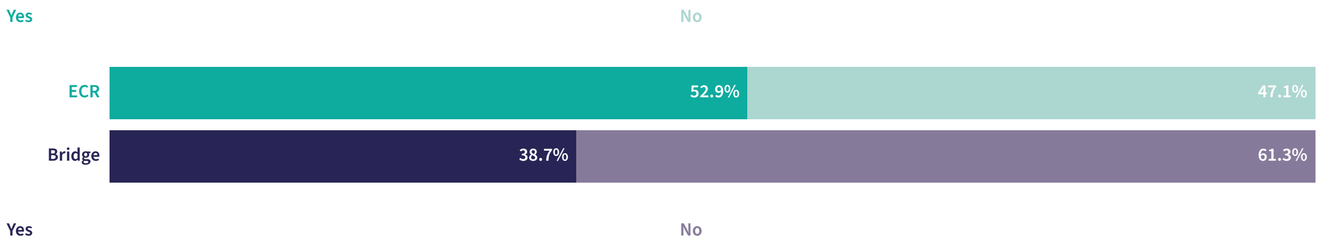
1.22.4.4 Question 13. Do you bring up an additional alarm list display during a large system fault, trip, or a demanding operation?

13.1E - As the engineers can only acknowledge one alarm at a time, two engineers have to stop doing anything else just to acknowledge them; the primary purpose is eliminating the noise to be able to think properly.

13.2E - The engineer stated that he goes through the critical pages on the HMI instead of looking at the alarm list.

13.3E - It is not necessary according to the engineer.



13.1B - The dropdown alarm list on the ECDIS is used when multiple alarms are annunciated at the same time.

13.2B - “You have to decide between the alarm list and keeping the ship safe.”

13.3B - “In 99% of the instances, it’s not necessary to look through an alarm list. You take notice as they come in”.

For the bridge officers, ~61% answered *No* to bringing up an additional alarm display during demanding operations, while ~39% responded *Yes*. And for the engineering officers, ~53% responded *Yes*, while ~47% said *No*.

While observing watchkeepers, it is noticeable that engineers do not do the same thing. This could be explained by each individual preferring one approach over another and adopting a unique strategy.

Some engineers stated that going through the mimic pages (at least 50 or more) on the HMI was easier than reading the alarm list (13.2E).

Another engineer from a visited ship explained that during a trip or large fault, two engineers are forced to acknowledge one alarm at a time (two operator consoles) to stop the alarm tone, for the sole reason of regaining the ability to think (13.1E). Using two alarm displays was mentioned as the fastest method. While both engineers performed this acknowledging sequence, they lost valuable available response time to deal with the root cause.

In general, the bridge officers on each of the visited ships were divided in their answers (Appendix A), which shows that they had individual perceptions of whether or not they found it necessary to bring up an additional alarm display.

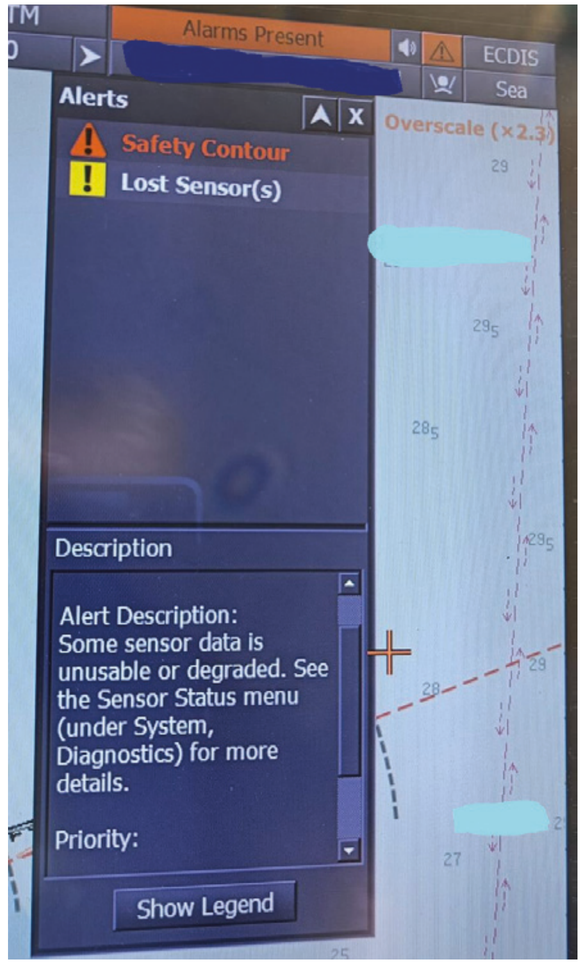


FIGURE 46.
ECDIS Alerts with a drop-down menu that does not inform which sensor was lost while the ship was manoeuvring in confined waters

In critical situations, officers said they had to ignore the alarms because they needed to look out the window and navigate the ship (13.2B). At other times, they use a drop-down alarm list on the ECDIS, which is available from some manufacturers. Reading them as they appear in the alarm line is possible at different times (13.3B).

The lack of defined responses for the various bridge alerts was an interesting observation. Some alerts, like the warning of lost sensor(s), would not even inform the bridge officer which sensor(s) were lost or degraded. Instead, it asked the user to user to visit an entirely different menu (Figure 46).

1.22.4.5 Question 14: How often do you look through the alarm list display during a large fault, trip, or demanding operation?

Notably, ~44% of the engineering officers state they observe the alarm list display *Several times a minute*, while ~27% said *Once every couple of minutes*. Furthermore, ~18% answered *Once every 10 minutes*, and ~12% answered *Less than once every 10 minutes*.

For the bridge officers, ~58% answered that they look through the alarm list *Less than once every 10 minutes*, ~10% *Once every 10 minutes*., ~13% *Once every couple of minutes*, and ~19% *Several times a minute*.

The answers from the engineering officers depend on whether the ship was built and operated according to an unmanned machinery spaces (UMS) notation. All non-passenger ships had been certified with UMS notation or equivalent. For all passenger ships, the ECR/machinery spaces were continuously manned. Here, the watchkeeping engineer could not leave the ECR and, therefore looked more closely at the alarm list displays.

For the engineering officers, some used the information on the alarm list (in need of better sources) to assess the overall plant state. Although the ability to stream text on a screen is virtually unlimited, at the receiver's end—for the human— it is limited indeed. Certain engineering officers reported that they would

continuously monitor the situation (the alarm list screen) for an extended period before deciding on a response (14.1E).

Other engineers had a different strategy of looking through the alarm list and restoring services one by one (14.3E). Some believed this would be *Once every 10 minutes*, while others on the same ship said *Less than once every 10 minutes*. In summary, these differences in strategies hint at an absence of response procedures and the training of the engineering officers on how to find the shortest path for system recovery.

During the interviews, a majority of the bridge officers mentioned not using the alarm display during demanding operations, as they looked out the window instead (necessary to manoeuvre the ship to a safe anchorage). First then, they would examine the alarm list. Those bridge officers who answered *Several times a minute* or *Once every couple of minutes* were generally 3rd mates or 2nd mates. As likewise described in the narratives in response to question 12.e, these were the "Colleagues" who took care of the alarms as they would annunciate. More often than not, these were not the ranks that manoeuvre the ship during demanding operations; those are often chief mates or captains. Some 3rd mates and 2nd mates mentioned that the alarm list did not bring them any value. They just acknowledged the alarms to keep the bridge silent for the officer in charge of manoeuvring (12.e.7B, 12.e.15B, 12.e.17B, 12.e.19B, 12.e.20B). Similar narratives are heard from the engineering officers (12.e.7E, 4.6E).

1.22.4.6 Question 15. How often during a large fault, trip or demanding operation do the alarms come too fast to take them in?

Always

15.4E - "There's no way to take all the alarms in during a blackout".

15.5E - "We get 200-400 alarms in a few seconds when a blackout occurs."

15.6E - "Everything around you is going off." - "A total challenge of your ability to do your thing."

15.7E - "If you had total blackout, get 4-5 pages of alarms almost immediately."

Mostly

15.3E - "When a lot of alarms come, all you can do is mute them all, and then start to take them in one by one."

Sometimes

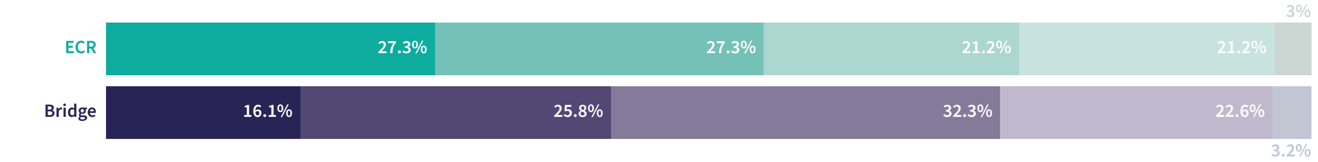
15.2E - "It depends if it's a total blackout or only a trip of the individual equipment."

Rarely

15.1E - The system is built with a CAM system, which separates non-critical alarms in a non-annunciated folder during alarm floods.

Never

No contextual answer



Always

15.6B - "We had a period where the officers would go to bed at night after a four-hour shift with alarm fatigue and still hearing alarms ringing for their ears." The officer reported that this was attributed to all the machinery alarms being routed to the bridge, for half a year after the vessel's delivery from the shipyard.

Mostly

15.5B - "We need filtering of alarms, so we don't get the unimportant ones."

Sometimes

15.3B - It depends if they experience a lot of alarms from the ECR at the same time.

15.4B - "Usually, it's bearable, but of course, sometimes there comes a lot of alarms."

Rarely

15.1B - With many of the same alarms, they can quickly see which alarm it is and know what to do.

15.2B - "During ROV operations, we had to keep the exact same position, but because of the bad weather, the DP system goes crazy." When asked under which circumstances the DP system is really important, officer answers, "I guess it's actually during bad weather," followed by a pause for reflection.

Never

No contextual answer

In general, the engineering officers were divided, with ~27% answering *Always* and also ~27% stating *Mostly*. This is followed by ~21% responding *Sometimes* and *Rarely*. Only a single officer 3% answered *Never*.

For the bridge officers, ~3% answered *Never*, ~23% *Rarely*, ~32% *Sometimes*, ~26% *Mostly*, and ~16% *Always*.

Looking at each ship's responses (Appendix A), it can initially seem like certain engineers can handle considerably different alarm loads. However, the interviewers noted that there were different perceptions of the context of this question. Some engineers mentioned they read every single alarm in the instance of annunciation. Others did not consider the alarms outside their mental model of the alarm system. These engineers were less sensitive (more numb) to high alarm loads (15.3E). This has affected the distribution of the answers.

For the engineers, the most common scenario was blackouts. Some engineers stated that there is no possibility of taking in the 200-400 alarms in a few seconds during such a foreseeable abnormal event (15.4E, 15.5E, 15.7E). In these situations, they would abandon using the alarm system altogether (15.6E). During one interview on a ship with four diesel generators as the main power supply, a trip occurred on

one of the running generators. This resulted in 19 alarms in under four minutes. None of these were identified as pointing to a root cause or potential remedy.

For one lead ship (the first one in a series of technical sister ships), bridge officers who had served on board since the yard delivery reported narratives of alarm fatigue to the point of continuous ringing in the ears after a four-hour watch (15.6B). Many of the bridge officers on that ship likewise stated that they had felt incapable of navigating the ship safely during that period. A period when all machinery alarms from the ECR were also annunciated on the bridge for the first six months.

A final note to consider is how well the alarm systems support the officers when the going gets tough. Noticeably, a dynamic positioning system is most needed during adverse weather conditions. Not while the water is calm and skies are blue. In such ideal conditions, experienced officers can maintain the ship's position perfectly. Yet, it seems as if these alarm systems are sometimes engineered under the assumption of uniform relevance across the operational spectrum (15.2B).

1.22.4.7 Question 16. How often in a large system fault, trip or demanding operation are you forced to accept alarms without having time to read and understand them?

Always

16.5E - "We have to acknowledge them all to be able to think because of the high alarm sound."

16.6E - "Young officers don't know better; they think this is how it's supposed to be."

Mostly

16.4E - As explained by the engineer: "Sometimes spa pool alarms come in every millisecond for minutes; operators take turns sitting and muting them."

Sometimes

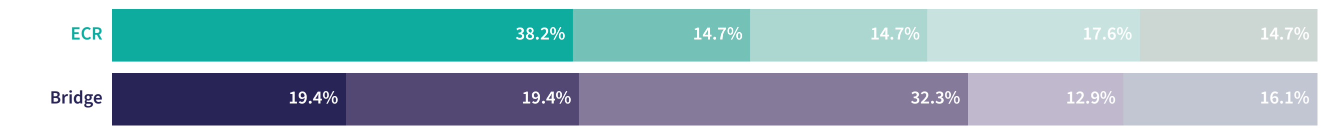
16.3E - It is brought up that it is very dependent on the trip and situation on board.

Rarely

16.2E - It is pointed out that the engineers can mute the alarms and then acknowledge them later.

Never

16.1E - "I always read and understand the alarm before I acknowledge it."



Always

16.5B - "You can only do so much; you get to a point where you just acknowledge alarms without reading it."

Mostly

16.4B - "There is a dedicated person to acknowledge alarms during arrival."

Sometimes

16.3B - "In certain situations, the captain tells us just to mute alarms to get rid of all the noise, without reading them."

Rarely

16.2B - The officer explained that they usually mute and then acknowledge afterwards.

Never

16.1B - "I never acknowledge them. I mute the alarms and read through the list when I have time."

For the engineering officers, ~15% answered that they are *Never* forced to acknowledge alarms without having time to read and understand them, ~18% answered *Rarely*, ~15% *Sometimes*, ~15% *Quite often*, and ~38% *Always*.

That more than half of the engineers stated *Quite often* and *Always* is concerning. One factor is alarms that chatter relentlessly (16.4E). Another aspect is that this delays the engineer's response and recovery of the affected system because they feel they must acknowledge the alarms before doing anything about the situation (16.5E).

Considering an abnormal event in which the root cause alarm is buried among multiple other alarms. Some engineers explained that this problem was the most stressful part of watchkeeping duty. They feared the day they would merely accept a critical alarm without reading and understanding it. Some more senior chief engineers expressed concerns that younger engineering officers believed that this was just ordinary (16.6E).

Interestingly, some of the passenger ships were observed to be in such a state constantly. Even when safely alongside in port. It was simply impossible for the engineers to keep up with the incoming rate of alarms. On one passenger ship, the IAS could decompose the stream using various lists nested within different mimic sections (Figure 47). Grouped by function, it helped the engineering officers get an overview of the alarms specific to, e.g. machinery or the propulsion without conferring to a flooded alarm list.

For the bridge officers, ~19% answered *Always*, and ~19% *Quite often* that they are forced to acknowledge alarms without having time to read and understand them, while ~32% answered *Sometimes*, ~13% *Rarely*, and ~16% *Never*.

Similarly to the engineering officers, the bridge officers report alarm rates in which reading and understanding each alarm is left to be desired (16.5B). During operational modes such as arrival, some ships need to position a dedicated person on the bridge to deal with the alarms (16.4B). This is ordered with full intent by the most senior management representative on board—the captain (16.3B).

For some bridge systems, it is possible to prevent certain alarms for re-annunciation if left silenced but not acknowledged. For reasons reported in response to question seven.

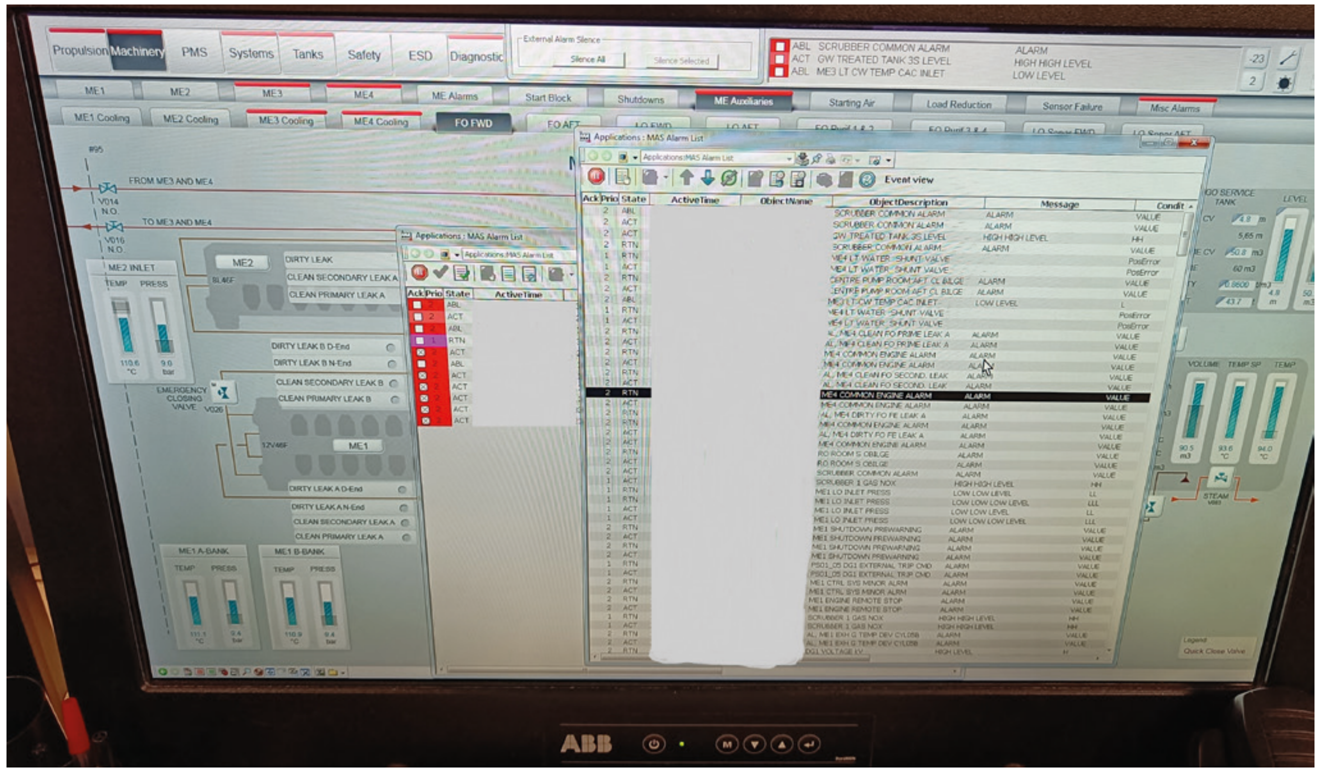


FIGURE 47.
Integrated automation system (machinery view) with various alarm lists: Three rows at the top right where alarms from all systems always arrive. At the centre right is the incoming stack of machinery alarms, and at the centre left is a filtered list of priority 2 and 1 alarms from this centre stack. Multiple other views than "Machinery" have active alarms. The ship was safely moored alongside with one generator running

1.22.4.8 Question 17. Does the alarm system help you to pick out key safety related events during a large system fault, trip, or demanding operation?

17.1E - Multiple engineers mentioned that magenta-coloured alarms are very critical.

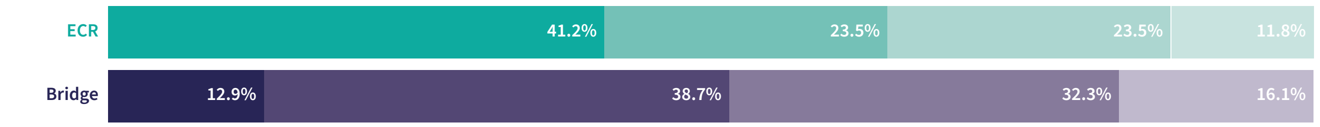
17.2E - There are colours flashing on the mimic pages where there are critical alarms, which helps pick out the alarms.

17.3E - There is minimal prioritisation, and some engineers explain that during a trip or blackout, they receive hundreds of alarms with minimal prioritisation. This frightens some engineers because they can miss one very important safety-related alarm.

17.4E - "Our system has the capability, but it's implemented with all the same priorities anyhow."

17.5E - No prioritisation is observed, and the alarm log gets flooded with alarms during trips or blackouts, according to some engineers.

Very well | Some help | Little help | A nuisance



Very well | Some help | Little help | A nuisance

17.1B - There is a prioritisation in yellow and red, where red is the most critical and needs immediate action.

17.2B - A prioritisation is found, but there are still a lot of unimportant alarms going off at the same time, which can sometimes be a challenge.

17.3B - There is no intelligence behind the engineering of the alarm system. "Many systems have that fault."

17.4B - All the alarms get annunciated the same way, whether they are critical alarms or not.

For the engineering officers, ~41% answered *Very well*, ~24% answered *Some help*, ~24% *Little help*, and ~12% answered *A nuisance*. This distribution shows that almost half of the engineers consider that the alarm system helps them to a great extent in picking out key safety-related events.

Responses from the bridge officers were distributed as follows: ~13% reported *Very well*, ~39% said *Some help*, ~32% stated *Little help*, and ~16% reported it as *A nuisance*.

Generally, the answers of the same ships vary between the bridge officers (Appendix A). This shows some disagreement on how well an alarm system supports the individual watchkeeper. A bridge officer mentioned that the systems engineering behind the alarm systems is not executed intelligently and has had that experience on numerous ships throughout his/her career (17.3B). One example involved the telephone line dangerously mingling with the track pilot controls whenever an officer needed to pass the phone to the assisting officer (typically the captain) at the opposite side of the central bridge console (Figure 48).

FIGURE 48.
Bridge centre console telephone cable mingling with the track pilot joystick

Given that the systems on the bridge are typically not integrated (stand-alone), each system or console has its individual alarms. It becomes challenging to identify a key safety-related event when each system announces its own alarms during situations where these are not sufficiently independent of the root causes (17.4B).

Officers on bridges which were fully integrated and had a well-functioning setup of the general priority types from the CAI found that consistent colouring helped (17.1B)

Some engineering officers showed high regard for the feature of pointing (and moving) directly to the mimic (process view) page for important alarms via the alarm list. This enabled a much faster diagnostic overview since specific markings pointed at the fault (Figure 49) (17.2E).

Other engineering officers appreciated a specific colour prioritisation for critical safety-related alarms, using a magenta colour (17.1E). In addition, certain manufacturers implemented features allowing seamless navigation between trending process variables, the alarm list, the process mimics, and the affected machinery. The engineering officer felt it eased the mental load during diagnosis. It was further facilitated by allowing the user to split one screen into multiple views (Figure 50).

Looking back at responses to questions 15 and 8, certain engineers have already conveyed that the overwhelming influx of alarms poses a challenge for them to process. In such instances, having no real prioritisation makes it impossible for them to pick out the key safety-related event. It is further emphasised by 17.3E and 17.4E, stating that only a *little help* is offered when the system employs only minimal prioritisation.

This minimal prioritisation is confined to the "abstract" priority categories or types in the CAI: *emergency alarm, alarm, warning*, and *caution*. It is a design philosophy which does not consider the priority of alerts within the same priority category. It lacks any consideration of the urgency and consequences of inaction for each specific alarm, nor does it take into account the necessary sequences of response actions needed. Instead, these are propagated to the human watchkeeper.

Despite priority limitations, it is still important to keep in mind that engineers on board ships with low levels of integrated automation, did not find an architecture of stand-alone systems to be of much help either (5.b.3E). The benefit of a chronological view of the annunciated alarms is still highly desired. As such, it appears that full system integration is needed to achieve complete levels of information. Yet, such levels of information seem to be observable only when effectively distilled and decomposed with the end-receiver in mind.

1.22.4.9 Story No. 05 – "Hack my ship, please."

This story describes a major incident witnessed during one ship visit. It is reported as one example of how an alarm system is used in practice during such times of adversity and how it can be more of a burden than assistance.

A passenger ship encountered adverse weather conditions. Although these conditions were foreseeable, there was considerable commercial pressure to maintain business continuity and reach the destination on time. It is important to remember that captains are human, too. And humans may experience fear losing their jobs, missing out on promotions, or facing similar consequences whenever they need to challenge decisions that upper management may not want to hear. For unknown reasons, the captain did not use the overriding authority to keep the ship safely in the harbour until the weather had improved.

During normal steady operations (good weather), a perpetual pre-warning alarm had been annunciated on the ship's main propulsion system. The second stage alarm would activate an instrumented safety function and limit the power of the propulsion. The pre-warning alarm was caused by the natural water ingress through sealing systems around the propulsion units' moving parts, causing the water level to rise above the pre-warning setpoint (example of the "hole in the ground" analogy, Figure 4). The level sensors were sensitive to the

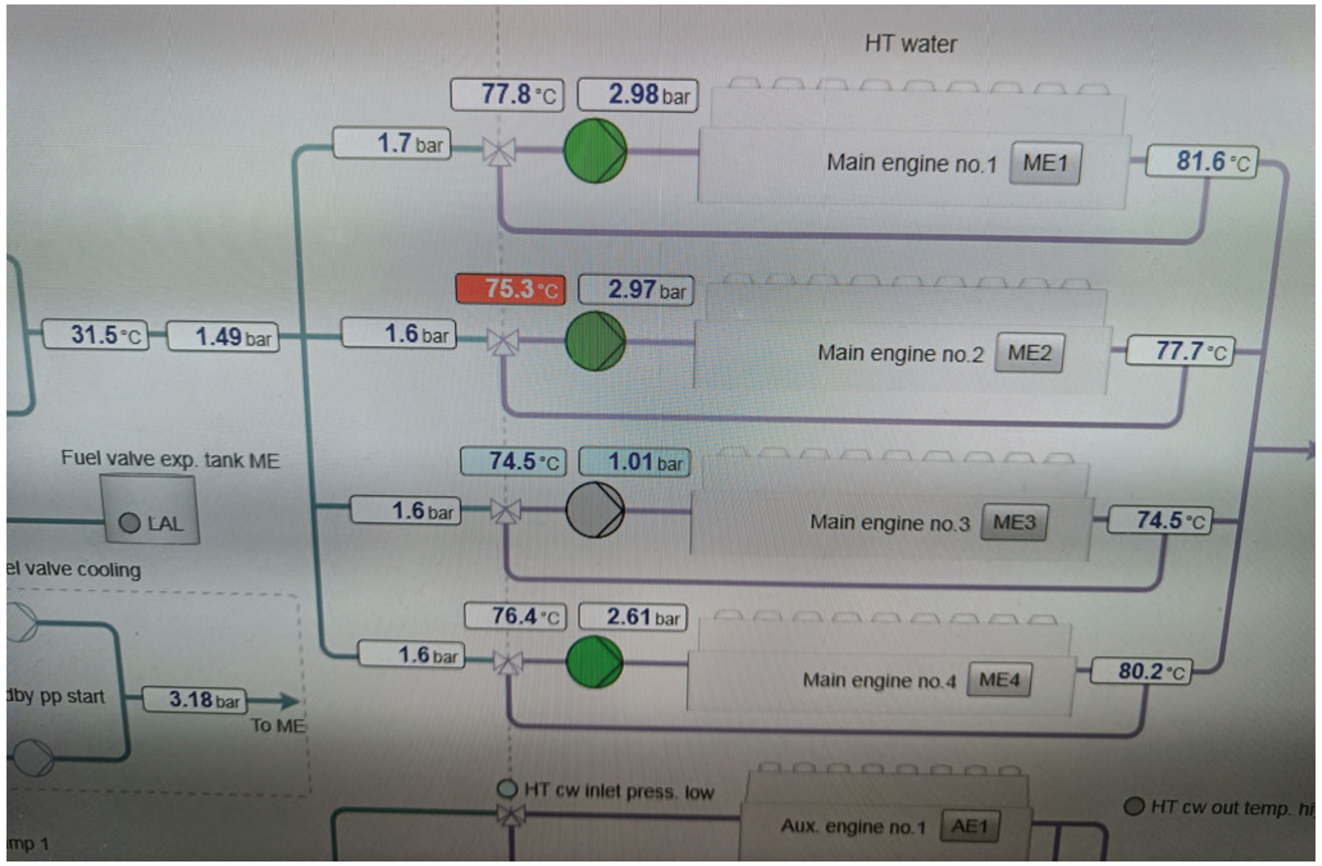


FIGURE 49.
Process view (mimic) of the HT cooling water system for the Main Engines. The red background on the cooling supply temperature indicates the alarm condition to the user

FIGURE 50.
Split view of the alarm list from the IAS and the power management view, the icon next to the "Status" column takes the watchkeeper directly to the process or mimic view of the relevant alarm

slightest splash of water. To contain the ingress of water, two bilge pumps had to be running constantly, which was designed to be necessary only in actual flooding conditions. Normally, one pump should be sufficient and activate only rarely.

It would have required a drydock (taking the ship out of service) to amend the sealing and likely the re-engineering of the sensor mechanism to make this perpetual alarm disappear. Taking a passenger ship out of service comes at a high cost. Therefore, it was to be postponed to the following five-year docking. Until then, the watchkeepers had learned (and been told to) simply to ignore it.

As the story unfolded, the bad weather and high waves increased the ingress rate of seawater and caused a series of pre-waring alarms as the sensor reacted to spray droplets. At one point, the ship tilted so much that the propellers of the propulsion units lifted out of the waterline, causing a brief but intermittent loss of load. This resulted in a safety shutdown due to over-speeding. The shutdown of the propulsion system triggered an alarm flood, both in the ECR and on the bridge, which promptly startled the engineer on watch. Within a few minutes, the vessel was dead in the water and slowly turning with its side towards the incoming waves. At this point, a large wave hit the ship, throwing furniture and people from one side to the other on all decks, prompting all the engineers to rush to the ECR to assist.

The engineers divided into two groups, one gathering an overview of the situation in the ECR and the other rushing to the propulsion units' local motor control panels (MCP). Besides a simple reset of the overspeed shutdown alarm, the engineers encountered a more complex problem. The second-stage water sensor had activated an inflatable emergency sealing to prevent more water from entering the propulsion unit space. That emergency sealing functioned as a safety interlock to get the propulsion running at full power. The power need to manoeuvre safely in that weather. During their attempt to find a solution to get the propulsion fully functioning and the vessel safe, the engineers and bridge officers were constantly inundated with alarms, struggling to think clearly.

With no solution available on board, the engineers had to contact the systems provider (OEM) of the propulsion system to help "hack away" the safety interlocks, alarms, and associated shutdowns. Over an hour after the call, support from shore was ready to connect to the ship's propulsion control system. The OEM took control remotely, leaving the engineers, passengers, and crew on board at the mercy of someone located elsewhere in the world, suppressing the alarms to avoid the emergency shutdown and emergency seals being re-inflated. This went on for quite a while. Throughout this time, the engineers were constantly silencing alarms in the ECR, and the bridge was overloaded with the same propulsion alarms, which reduced their focus and concentration on manoeuvring the vessel as safely as possible.

In summary, this story highlights both the future and present situation of opaqueness concerning what alarms and their associated safety functions entail in adverse circumstances. And that the technical management decisions can have a much more profound (negative) impact on the ship's safety than what is manageable by the watchkeepers on board. This example also brings new perspectives to the upcoming requirements on cyber resilience (IACS UR E26/27).

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1.22.5 General procedures and management's resolve

This section examines the watchkeepers' general opinion of the set procedures and the management´s proactive resolve to manage the alarm system well (Table 16). That conversation takes place after the watchkeeping officer has spent some time reflecting on their experiences. The questions are presented by asking the watchkeepers to reflect on the procedures and interest in the alarm system from the management's point of view (onshore). Their perception is contrasted with actual examples from the crew on board selected ships.

TABLE 16.
Questions related to general procedures and shipping management's proactive approach to alarm management

Question	Question No.	Theme
What do you think about the procedures for getting changes made to alarm settings etc.?	18.a	General procedures and possibilities regarding alarm management.
Are you aware of a procedure that is used when alarms are modified?	18.b	
Compared with the other things your management does to improve your operations, such as adding additional technology, do they put enough effort into improving the alarm systems?	19	

1.22.5.1 Question 18: What do you think about the procedures for getting changes made to alarm settings etc.?

Over-restricted and cumbersome

18.1E - An engineer described that the ETO was not helpful in correcting stale alarms. They had a list with 40 alarms which has been standing since more than half a year (6-7 months).

Strict but safe

18.2E - When talking about alarm settings:

- "The alarms are what they are; we just deal with them".

18.3E - "Strict. Rightly so. Should not be able to change major alarm settings, but (that) would be useful for certain things like sludge tanks as (it) would allow better monitoring."

Easy to use - but you have to be careful what you do

18.4E - The setpoints can be changed without further notice, but the engineers must inform the next engineer on watch.

Sloppy and uncontrolled

No respondents

Over-restricted and cumbersome

18.1B - The bridge officers cannot do it themselves; only the engineers can make changes.

Strict but safe

18.2B - They must type a password to make changes, and only the bridge officers and the engineer responsible know the password.

Easy to use - but you have to be careful what you do

18.3B - Anyone with access to the control panel can make changes and have to remember to change them back before the next person on watch.

18.4B - "If the navigational settings are customised specifically to what I prefer, then I have to spend time setting all these back to default at the end of my watch."

Sloppy and uncontrolled

18.5B - Everyone can make changes; there is no password on the ECDIS.

The answer distribution given by the engineering officers was *Strict but safe* (~50%), *Easy to use – but you have to be careful what you do* (~41%), while only a few answered *Over-restricted and cumbersome* (~9%).

For the bridge officers, the distribution varied considerably from the engineering officers, with the responses: *Easy to use – but you have to be careful what you do* (~73%), *Over-restricted and cumbersome* (~13%), *Strict but safe* (~10%), and *Sloppy and uncontrolled* (~3%).

The majority of the engineers who responded *Over-restricted and cumbersome* and *Strict but safe* were located on ships where the watchkeepers did not have the ETO license. Here, only the ETO adjusted the settings in the IAS, which some engineers found unnecessarily complicated (18.1E, 18.2E). This reveals a big difference in delegated trust levels between engineers with the ETO license and engineers without the ETO license (18.3E).

During the field studies, it was observed that ships with more "united" departments tended to have better insight into each other's work tasks. This fostered a deeper understanding of the different systems' requirements and appreciation of the work of their colleagues. A few visited ships had clear procedures for filling out a form, and then changes would continuously be implemented by the engineer in charge or in conjunction with system providers visiting the ship.

On the ships where most of the engineers answered *Easy to use – but you have to be careful what you do* were seniors (with ETO license). Unlocking the settings in these systems did not need a password. Sometimes the password appeared to be a software version of a two-stage action; a way asking confirmation of user intent. Since alterations were easy, it meant that these engineers relied on a system of trust to inform each other about changes in the settings, usually on a dedicated whiteboard shared within the departments (18.4E).

This question tended to drift onto the ECDIS or radar when interviewing the bridge officers. It was observed

that accessing the system to make changes was usually very easy (18.3B, 18.5B), however, it still took substantial time and effort (18.4B). Therefore, the officers had to be careful, remembering to let the next watch know the settings. On some ships, a whiteboard was used as well.

For safety reasons, some officers believed that this was too sloppy and uncontrolled for the safety of the ship, crew, and passengers. It was also noted during the interviews that the bridge officers answering *Over-restricted and cumbersome* and *Strict but safe* did so due to strict orders for settings from either the company or master. At times, they also relied on the ETO (18.1B, 18.2B). A few of the visited vessels used personal profile settings, so each bridge officer would log into his/her profile and have the settings used at the end of the last watch.

1.22.5.2 Question 18.b: Are you aware of a procedure that is used when alarms are modified?

Yes

18.b.1E - The engineer explains how they apply for changes to the Chief ETO.

No

18.b.2E - Chief Engineer: "Not really, but (now that) I think about it, we should have that."

18.b.3E - Chief Engineer on the topic of retrofitted systems: "New stuff just gets thrown on board."

Yes

18.b.1B - "We do it ourselves and reset or mention it in the handover for the next watch."

18.b.2B - "Yes, when it has to go wrong before the management does anything."

No

18.b.3B - The settings are modified by the officer on watch without any set procedure for handover or reset of settings.

For the bridge officers, this question was generally experienced as an operational question similar to the previous one. However, it was intended to be a question related to maintenance and modifications. Regardless, ~77% stated *Yes*, while ~23% said *No*. For the engineering officers, ~88% said *Yes*, while ~12% said *No*.

On board ships with engineers with and without the ETO license, there was a clear division with the ETO-licensed engineers making these modifications (18.b.1E). Usually, modifying an alarm had to be approved by the chief engineer first. On the contrary, ships on which the engineers had the ETO license would do it themselves while having a set procedure for filing the changes made.

Some engineers were unaware that there was not a procedure in place. One chief engineer concluded during the interview that they should get a set a procedure for making changes (18.b.2E).

For modifications, one chief engineer reported that the dedicated project team ashore tended to believe that their retrofit project was the centre of the universe (18.b.3E). They had little understanding that their system was a tiny part of overall ship operations. As soon as the retrofitted system it "hit the water" (was installed onboard), it would have undergone class approval, and any improvement points or inputs from the crew would not be considered.

The majority of the bridge officers had clear handover procedures between the watches (18.b.1B), while the rest of the officers on the visited ships just modified the alarms without being aware of any set procedures for it (18.b.3B). Some bridge officers used sarcasm to express their criticism of the management's reactive approach to managing modifications (18.b.2B).

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1.22.5.2 Story No. 05. The crawl space and the navigational fallout.

On board one visited ship, the chief mate told a story in which they experienced a complete loss of the dual navigational systems, including the satellite compass. It also caused the autopilot and automatic identification system (AIS) to be unavailable. During diagnostics, it was discovered that the two upstream uninterruptable power supplies (UPS) feeding these systems had fully discharged, without any annunciated warning on the bridge or ECR (Figure 51).

A loose connection had caused the discharge. The electrical connection upstream of the UPS was discovered to have been drawn from another cable using T-branch connectors (not done according to rules and regulations) and some electrical tape (Figure 52). When the T-connection was moved officers could hear sparks.

Both uninterruptable power supplies were located at the farthest corner of the technical crawl space under the bridge. At the time the ship was built, paper charts were in use, and most navigational systems had been retrofitted in the meantime. It is important to highlight that even the experienced officers on board, who had been familiar with the ship for over a decade, were unaware of the poor quality of the installation. They all agreed it should never have passed a quality control inspection.

Despite this, the officers expressed understanding and empathy as to why the electrician had given up back in the day it was installed and commissioned. The space was almost impossible to enter, one could not move about freely and everyone described the space as causing a strong feeling of claustrophobia. Following the event, the UPS have been relocated to two accessible lockers on the bridge.

The officers were thankful the loss of navigation systems occurred while safely alongside in port. According to the bridge officers, had the ship been underway in coastal waters at night, the situation would have been different.

The story exemplifies why the potential low quality of modifications may not immediately be apparent if tested only for functionality. Further, it was evident that many legacy systems had not been fully decommissioned or removed from the crawl space, which was visible from the extensive number of cables for such a type of ship. Over time, the crawl space had become narrower.

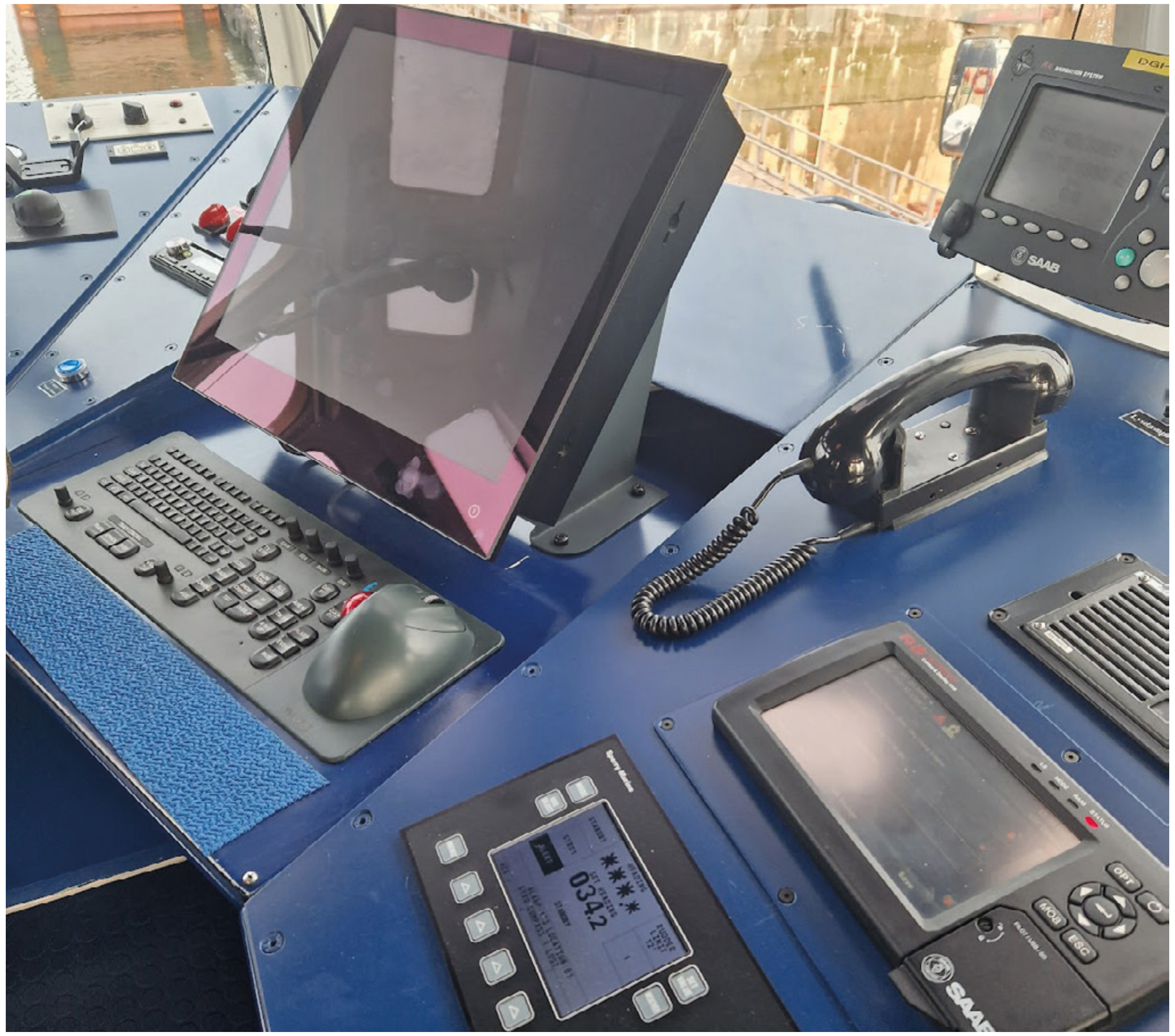


FIGURE 51.
Picture of the blacked-out ECDIS display caused by discharged UPS. The AIS (SAAB panel) indicates red in its "status" lamp, while the autopilot (Sperry Marine) displays a set of stars, indicating a lack of heading control. Both are caused by losing the satellite compass signal. A signal which needed power supply and was supplied by the discharged UPS

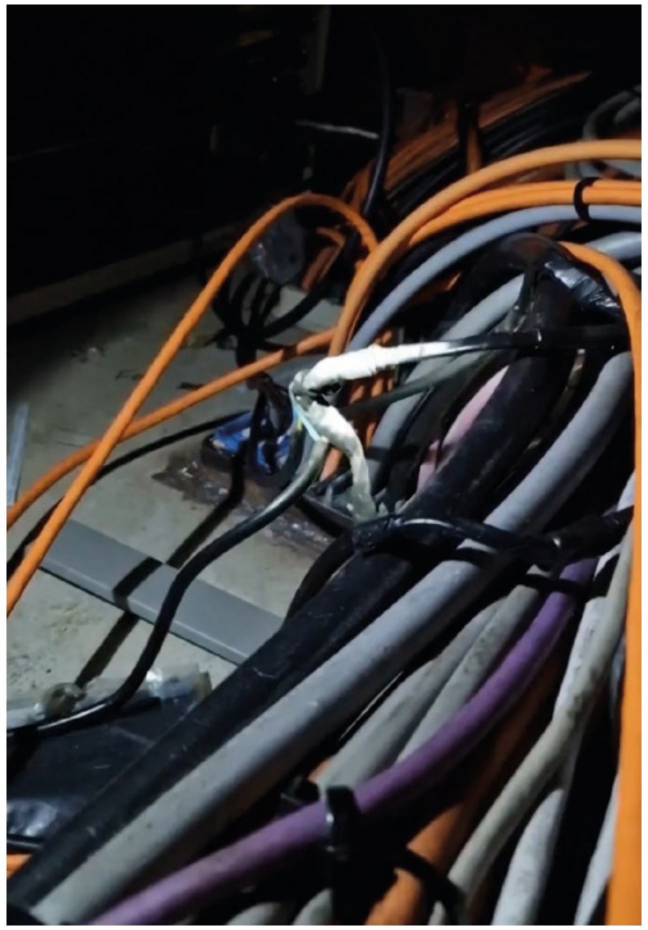


FIGURE 52.
The T-connection or "power thief" upstream of the UPS supplying the navigational systems

1.22.5.4 Question 19. Compared with the other things your management does to improve your operations, such as adding additional technology, do they put enough effort into improving the alarm systems?

Too much

19.1E - "It has to go all the way to class for approval, which takes forever!"

About right

19.2E - When the chief engineer requests changes, management are open to listening and doing something about it.

19.3E - The engineer explained that they can tweak the system with the system provider without management's involvement at the annual visit.

Too little

19.4E - The engineer would like them to do more and stated, "Zero effort into improving alarm systems from management."

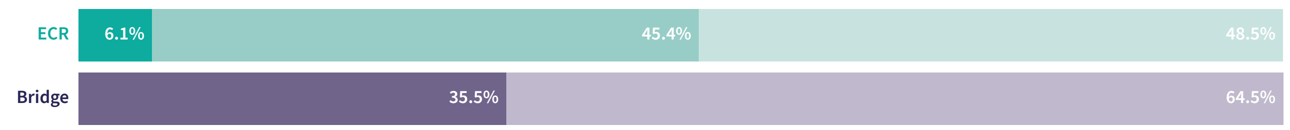
19.5E - "You guys are the first ones to ask us about how we see the system."

19.6E - "'The alarm system provider' didn't make up on warranty claims after production."

19.7E - "Should aim to be reducing the alarm list—not allowing it to mount up. Other ships have a competition to drive down or reduce to nothing. We may not achieve that but we could certainly put in a push to reduce. You'd be surprised how many we could remove. That we don't is because of the standard of the watchkeepers and department at the moment."

19.8E - "The totally red alarm screen with all the standing and unacknowledged alarms is pathetic."

19.9E - "Some never clear. We have 'sensors in fault' which are standing alarms where we have no spares. On this ship we cannot mask alarms and maintain a 'masked alarms list', so this is a real problem."



Too much

No respondents

About right

19.1B - "If we reach out, yes. Otherwise, no."

Too little

19.2B - "They don't do anything for us regarding the alarms! They just don't, so they can blame us when it goes wrong!"

19.3B - "We need people ashore that know how the ship works and what things help and (which) don't!"

19.4B - The officer stated that he/she would like the management from the shipping company to ask the operators about their experience with the alarm systems.

19.5B - "If the management care(d) about the safety of the ship, they have to do improvements to the alarm system."

19.6B - The officers have the reoccurring nuisance alarms "DPTH Failure" and "VDR Missing", that has been occurring since vessel delivery, several years ago.

The engineering officers answered as follows: *Too much* (~6%), *About right* (~45%), and *Too little* (~49%). For the bridge officers, these were *About right* (~36%), while ~64% said *Too little* , with no one stating *Too Much*.

Certain segments, such as advanced chemical tankers, mandated class reviews of improvement suggestions from the engineering officers for minor elements such as delay times, setpoint alterations, or similar factors normally covered by standard management of change (MoC) procedures. The engineers found that this hindered improvement efforts (19.1E).

The answer *About right* from some engineers explained that they did not want the management to get involved in the assessment of the alarm system, since they did not see value in their interference with the system; it was better that the issue was "forgotten" by management and dealt with "under the radar" by the engineers (19.3E).

One of the biggest concerns was that management involvement in the alarm assessment would produce more paperwork. This explains why management's inaction was regarded by the engineers as positive. A tendency of resistance towards the onshore management was observed on ships exhibiting such response distributions. At the other end of the spectrum, some engineers were satisfied with the number of improvements identified by the engineers and approved by the management (19.2E).

Still, on most of the visited ships, the management did not proactively try to improve the alarm systems (19.4E, 19.5E). Most engineers stating *Too little* were frustrated that their management would implement new technologies on board without the involvement of the engineers. As a result, additional equipment was added, thereby causing alarms that needed (undue) attention.

In general, the sampled companies did not perform self-assessments regarding the performance of the alarm systems. This often resulted in the poor integration of retrofitted systems, which in turn generated a cascade of issues within the overall operation. Several engineers stated that they wished the management would commit to improving the alarm systems (19.8E, 19.9E).

A simple feedback system on board one vessel (19.2E) was very successful—anyone could add ideas or improvement points to a binder. The analogue method of using a sheet of paper and a handwritten explanation made this easy. The collection would be reviewed prior to the service visits by the system provider. This meant that the system was continuously improved and that issues could be addressed at designated times in the future.

The bridge officers generally felt there was a lot left to be desired as compared to the engineering officers (19.3B, 19.4B, and 19.5B). One officer accused the management of not making any improvements to the alarm systems, only for the management to be able to blame the officers for human error if one officer did not notice a specific alarm that would inform of a danger before an incident. This indicates the frustration felt by at least one bridge officer: in the mind(s) of the officer(s) the employer did not care sufficiently about the quality of officers' work environment and, by extension, did not prioritise the safety of the ship (19.2B).

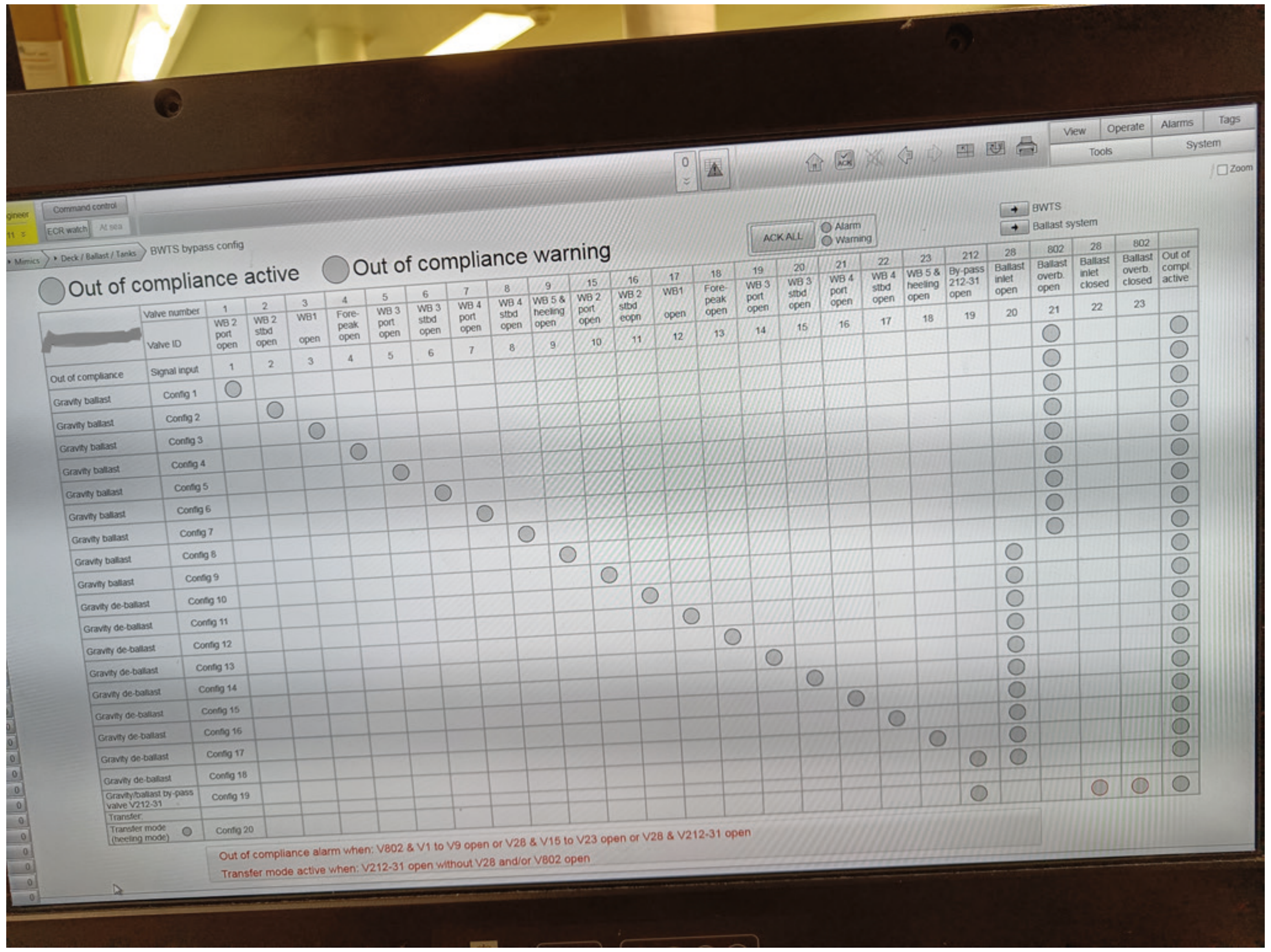


FIGURE 53.
Matrix table of ballast valves and BWTS modes.

1.22.5.5 Story No. 06. Bottom up empowerment

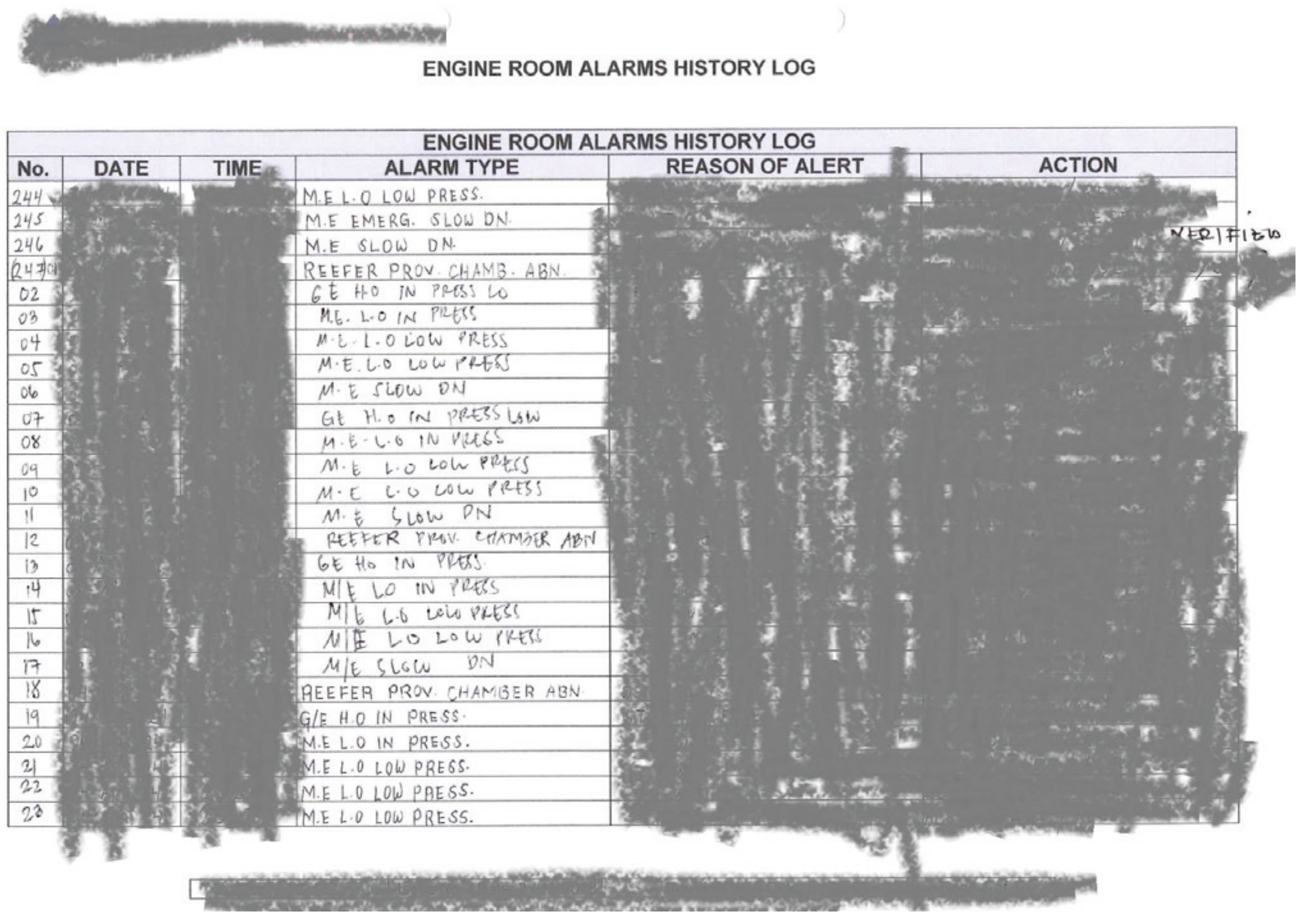
High crew capabilities, accountability, and a strong sense of technical ownership were observed on visited ships. This was especially true for ships managed by the owners, who employed their own crew and technical management. Most distinctively, these companies had crew on back-to-back contracts.

One example of such observed practice took place on a visited passenger ship. Here, the 2nd engineer did extensive user-centred and systems engineering to ensure the proper usability of retrofitted equipment in connection with a recently refitted ballast water treatment system. The engineer presented this recent concept: a matrix view of ballast valves. During the last periodic service visit, the system integrator implemented it as a mimic within the IAS (Figure 53). The resulting table allows all watchkeepers to assess at a glance if ballast water is discharging or loading and if it is done in compliance.

Not only did the 2nd engineer exhibit an unparalleled understanding of the ship's systems, but the technical management enabled a path to transfer this knowledge to the other colleagues on board, and not to forget, other ships in the fleet.

1.22.5.6 Story No. 07. Management resolve and risk-ownership

On one visited ship (SIGTTO segment), the technical management required a handwritten explanation from the chief engineer for each alarm that had been announced within a given month. This was not because the shore management lacked digital access to the logs. Instead, it was used as a method of keeping the number of alarms very low by keeping the engineers engaged with and reflective about the alarm system. The results were self-explanatory; the ship experienced an average of 150-250 engine room alarms per month, roughly less than 10 per day, a performance far exceeding the IEC 62682 metrics. The handwritten explanation included clarification on why an alarm had occurred and what action was needed to prevent it from annunciating again (Figure 54). The chief engineer, with over 30 years of seagoing experience, reported that staying on top of maintenance was the primary strategy for preventing alarms, including having a finely tuned system.


[redacted]

ENGINE ROOM ALARMS HISTORY LOG

ENGINE ROOM ALARMS HISTORY LOG					
No.	DATE	TIME	ALARM TYPE	REASON OF ALERT	ACTION
244	[redacted]	[redacted]	M.E L.O LOW PRESS.	[redacted]	[redacted]
245			M.E EMERG. SLOW DN.		
246			M.E SLOW DN.		
(247)01			REEFER PROV. CHAMB. ABN.		
02			GE HO IN PRESS LO		
03			M.E. L.O IN PRESS		
04			M.E. L.O LOW PRESS		
05			M.E. L.O LOW PRESS		
06			M.E SLOW DN		
07			GE H.O IN PRESS LOW		
08			M.E. L.O IN PRESS		
09			M.E L.O LOW PRESS		
10			M.E L.O LOW PRESS		
11			M.E SLOW DN		
12			REEFER PROV. CHAMBER ABN		
13			GE HO IN PRESS.		
14			M/E LO IN PRESS		
15			M/E L.O LOW PRESS		
16			M/E LO LOW PRESS		
17			M/E SLOW DN		
18			REEFER PROV. CHAMBER ABN.		
19			G/E H.O IN PRESS.		
20			M.E L.O IN PRESS.		
21			M.E L.O LOW PRESS.		
22			M.E L.O LOW PRESS.		
23			M.E L.O LOW PRESS.		

[redacted]

FIGURE 54.
Chief engineer's handwritten alarm report to the technical management ashore

1.22.6 Open questions

This section presents the narratives and quotes from the remaining open questions in the questionnaire.

TABLE 17.
Questions related to general procedures and shipping management's proactive approach to alarm management

Question	Question No.	Theme
If you could change any part of the alarm system(s), what features would you add to better run the system?	22	General procedures and possibilities regarding alarm management.
What features would you remove because they do not help or you do not like them?	23	
Can you add any other comments which might help us improve alarm systems?	24	
How many IOs are interfacing your system? (see section Research Site)	25	
Considering the questions you already answered in this survey, is there a question you feel we have forgotten to ask? If so, what would the question be, and what would be its answer?	26	

1.22.6.1 Question 22

Question 22: If you could change any part of the alarm system(s), what features would you add to better run the system?

HMI & Ergonomics:

- 22.1E – "A replay function could be the best recommendation."
- 22.2E – "Get information about where the alarm is and what to do to fix it."
- 22.3E – "I would like to change the colours for the system, so that it suits a colour blind (person)."
- 22.4E – "Incorporate all equipment in the alarm system so that all heaters and heat exchangers are shown in the alarm system."
- 22.5E – "Change of basic layout colours in the main menu in integrated alarm system."
- 22.6E – "I would change the entire system for a more stable one."
- 22.7E – "More automated actions through the alarm system. Integrated control system in alarm system. All subsystems integrated in control system."
- 22.8E – "That local panels are connected to the main system, so that the timestamps are identical."
- 22.9E – "An integration of all the subsystems into the integrated alarm and control system."
- 22.10E – "More details to common alarms. Different sounds for different alarms such as critical alarms. Different colours for different alarms such as critical alarms."
- 22.11E – "A pop-up that could show trends automatically within the last period."
- 22.12E – "The colours should change to be better prioritized, on a trip the system should help filtering."
- 22.13E – "Change the sound. Make better colour prioritization."
- 22.14E – "Have a list of inhibited/suppressed alarms. CAM system to help prioritize during a trip."
- 22.15E – "Temporary/secondary setpoints for temporary situations or tests to avoid keeping an eye on it all the time. CAM system."
- 22.16E – "Easier (to) make trends."
- 22.1B – "Volume level should be possible to adjust."
- 22.2B – "Softer sound on some alarms."

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- 22.3B – "In emergency situations having one single screen where all the alarm systems are put in together so you only have to look at one alarm screen/panel."
- 22.4B – "Central alarm console."
- 22.5B – "Make it easier to figure out on which panel the alarm is."
- 22.6B – "To get a modern up-to-date alarm system."
- 22.7B – "Make a light panel for the alarms instead of only acoustic notifications. ECR alarms should be delayed for a couple of minutes before it gets to the bridge."
- 22.8B – "Having one integrated screen where you can acknowledge all alarms from and keep it centralised."
- 22.9B – "One fully integrated alarm system without any local panels where there are alarms on both the central alarm display and the local panels."
- 22.10B – "Variable alarm volume, different sounds for different priority alarms."
- 22.11B – "A timed mute function for when doing critical and demanding operations."
- 22.12B – "Dimmer for light panels, a complete integration of the different systems so that you only get alarms one place."
- 22.13B – "Better hardware and quicker software so it's not that slow. It can cause the system to shut down, so we have to mitigate the planning to keep routes out of the system."

Prioritisation capability:

- 22.17E – "Priority and integration."
- 22.18E – "Blackout settings that suppress alarms the first 15 minutes in accordance with the chief."
- 22.19E – "The sound announcement for the priority of the alarms."
- 22.20E – "More prioritised alarm list with more categories. More descriptions of alarms and the lack of intended response or action plan."
- 22.14B – "Prioritized alarm list in the IAS."
- 22.15B – "More system integration of alarms with the control system. A prioritised alarm list."
- 22.16B – "One integrated alarm system that contains alarms from all the subsystems but still keeps ECDIS and radar separated. The system should be properly prioritised relative to each other."
- 22.17B – "Better priority of alarms and better integration of different control systems in the IAS."
- 22.18B – "More brainpower imbedded in the system, that would help the operator prioritise. Make it 'smart' with an awareness of the situation so the alarms wouldn't be repeated within such a short time frame. Five seconds is a nuisance. Five minutes could be ok."
- 22.19B – "Filtering regarding ECDIS and radar during different operations like arrival and departure so it doesn't distract."
- 22.20B – "Keep radar and ECDIS separated from the rest of the systems. Add different sounds for the different categories. Add the old nubs to adjust the light on the screens instead of touch and buttons."
- 22.21B – "Colour coding different categories of alarms."

Alarm Quality:

- 22.21E – "Less alarm points, and more specified alarms, and remove the common alarm."
- 22.22E – "Scrubber system. I could add some more details regarding the alarms."
- 22.23E – "Have suggested corrective actions to alarms."
- 22.24E – "Blinking priority alarms and better colour coding of the priority of the alarms."

- 22.25E – "No, it works properly and according to the design criteria."
- 22.26E – "Would like trending similar to the newer [manufacturer] on [other ship name]. Also, graphics are better."
- 22.22B – "Better communication, better prioritisation."
- 22.23B – "Differentiate different waters, settings for open waters or confined waters, for example."
- 22.24B – "Detailed descriptions of why you get alarms. Course of actions."
- 22.25B – "More information."
- 22.26B – "Incorporate an algorithm that could filter the alarms so the bridge only gets the relevant bridge alarms and ECR gets their relevant alarms. Have different sound(s) for the alarms and make one fully integrated system!!"

Spatial adaptability:

- 22.27E – "Having the IAS screen in my cabin so I don't have to go to the ECR to check if it is an important alarm or not during night hours. There is a refrigeration plant for the morgue room where there are no alarm points connected to, which means I have to go check continuously to make sure it is running correctly."
- 22.27B – "One integrated panel for all the systems. A function where you could permanently silence alarms, but still get the visuals."

Of the 27 extracted narratives from both the bridge and the engineering officers, the question regarding improvement points gathered on the alarm system highlights several key suggestions. From a Human-Machine Interface (HMI) and ergonomics perspective, users express a desire for enhanced features such as a replay function (22.1E), detailed information about alarm locations and resolutions (22.2E), and customisable colour options to accommodate colour blindness (22.3E). Suggestions include incorporating all equipment into the alarm system for comprehensive monitoring (22.4E) and modifying the primary layout colours in the integrated alarm system's main menu (22.5E). Users call for a more stable system (22.6E) and advocate for increased automation and integration of subsystems within the control system (22.7E, 22.9E). Further, there is a demand for unified time stamps on local panels (22.8E). Recommendations extend to improvements in common alarms, including additional details, distinct sounds for different priorities, and better colour prioritisation (22.10E to 22.13E). Users also propose features, such as a pop-up for displaying trends (22.11E), adaptive colour changes for improved prioritisation (22.12E), and a timed mute function for critical operations (22.13E).

In terms of prioritisation capability, suggestions involve enhancing prioritised alarm lists (22.14B), greater integration with the control system (22.15B), and the development of a fully integrated alarm system incorporating alarms from all subsystems while maintaining separation for specific systems like ECDIS and radar (22.16B). Users emphasise the need for better priority management, increased system intelligence, and effective filtering to avoid repeated nuisance alarms (22.17B to 22.19B). Additionally, there are calls for improvements in filtering, separation of radar and ECDIS, and better controls for screen adjustments (22.19B to 22.21B).

Concerning alarm quality, users express a desire for fewer, more specified alarms (22.21E), additional details for scrubber system alarms (22.22E), suggested corrective actions for alarms (22.23E), and enhanced visual cues for priority alarms (22.24E). While some users find the existing system satisfactory (22.25E), others wish for trending features similar to those in other systems (22.26E). From the bridge, feedback calls for better communication and prioritisation (22.22B and 22.23B), detailed descriptions of alarms (22.24B), and the incorporation of algorithms for intelligent filtering (22.26B).

Spatial adaptability suggestions involve having the Integrated Alarm System (IAS) screen in individual cabins (22.27E), advocating for a single integrated panel for all systems (22.27B), and emphasising the need for user-friendly visuals even in silent modes (22.27B).

1.22.6.2 Question 23

Question 23: What features would you remove because they do not help, or you do not like them?

HMI & Ergonomics:

- 23.1E – "Same sound for all alarms."
- 23.2E – "Change to a new system"
- 23.3E – "Change the way dead man switch works when shifting 'the watch'."
- 23.4E – "The same background colour of the screens (should be different from the different systems)."
- 23.5E – "The window in the mimics only close(s) when you click 'X'. It should close when clicking another place on the mimics outside of the small pop-up window."
- 23.1B- "The way that the features are built together are not working. They work individually but not together."
- 23.2B – "Simplify the system maybe with one fully integrated system."
- 23.3B – "The duplicated alarms (there are 9 screens that get the same alarms and you have to acknowledge the alarm on all 9 individual screens)."
- 23.4B – "Remove the TCP (touch control panel)."
- 23.5B – "TCP screens, touch screens (make hard buttons)."
- 23.6B – "The inability to control the alarm volume (loudness) and frequency (number of alarms) parameters."

Alarm Quality:

- 23.7E – "Remove the common alarm that do(es)n't tell you anything else then that there is an alarm on something."
- 23.8E – "This common alarms."
- 23.9E – "When critical alarms triggered together at the same time received also common alarm."
- 23.10E – "The messaging system should be simplified so that the alarms give you better information."
- 23.11E – "The nuisance alarms."
- 23.12E – "Unnecessary alarms which are stressing the operator."
- 23.7B – "Communication errors (we don't use them for anything)."
- 23.8B – "GMDSS alarms."
- 23.9B – "Doubled alarms for lanterns."
- 23.10B – "'Ready signal on the bridge' gives alarm twice because you're ready, which is really annoying, but it was probably installed because some(one) at some point forgot to give a signal when ready."
- 23.11B – "Some alarms on ECDIS—irrelevant alarms when off track, collision warning, safety contour."
- 23.12B – "Most of ECDIS and radar alarms."
- 23.13B – "On the DP system the alarm tells you when it has switched from one GPS to another."
- 23.14B – "All the unnecessary alarms (e.g. when the kitchen is doing steam cleaning, it would be nice to be able to cut out the fire alarm while they're cleaning and someone is obviously in the room."
- 23.15B – "Nuisance alarms, repeated alarms."
- 23.16B – "The repeated alarms from the systems that are talking/communicating together."

Spatial adaptability:

- 23.18B – "Regarding the radio alarm communication if there is an alarm you have to acknowledge it both on the radio and on the control console (It should be possible to only have to acknowledge on one device)."
- 23.19B – "The systems should be close to the operator. Alarm system that generates alarms at the same time, should be operated from the same place."
- 23.13E – "Unrelated alarms, should be sent to the people that use them instead of the ECR (HVAC for example)."

Of the 19 extracted narratives from the bridge and 13 from the engineering officers, a common theme regarding the Human-Machine Interface (HMI) & Ergonomics, the users expressed a desire to eliminate features that hinder efficiency or user experience. These include having the same sound for all alarms (23.1E), proposing a shift to a new system (23.2E), and suggesting changes to the dead man switch mechanism during watch shifts (23.3E). Users also highlight concerns about the uniform background colour of screens, recommending differentiation based on systems (23.4E). Additionally, there are requests to improve the functionality of closing windows in mimics (23.5E).

From the perspective of bridge officers (B), some users find issues with integrating features, stating that they work individually but not collectively (23.1B). Recommendations also involve simplifying the system with a fully integrated approach (23.2B) and addressing challenges related to duplicated alarms on multiple screens (23.3B). Users suggest removing the touch control panel (TCP) and opting for hard buttons (23.4B and 23.5B). Concerns are raised about the inability to control alarm volume and frequency parameters (23.6B).

Regarding alarm quality, users express a need to remove common alarms that lack informative value (23.7E and 23.8E). There are concerns about the simultaneous triggering of critical and common alarms (23.9E) as well as a desire for a simplified messaging system that provides better information (23.10E). Users also highlight the need to address nuisance alarms and stress-inducing unnecessary alarms (23.11E and 23.12E).

Bridge officers point out communication errors as features that could be eliminated (23.7B), along with the annoyance of GMDSS alarms (23.8B) and duplicate alarms related to lanterns (23.9B). Specific challenges related to repeated alarms from various systems, including ECDIS and radar, are also mentioned (23.10B to 23.12B). Users express frustrations with repeated alarms from systems communicating with each other (23.15B) and stress the importance of reducing unnecessary alarms during specific activities, such as kitchen steam cleaning (23.14B).

Regarding spatial adaptability, suggestions include streamlining the acknowledgement process for radio alarms (23.18B) and emphasising the need for systems generating alarms simultaneously to be operable from a centralised location (23.19B). Additionally, users prefer sending unrelated alarms directly to the relevant personnel instead of the ECR (23.13E).

1.22.6.3 Question 24

Question 24: Can you add any other comments which might help us improve alarm systems?

HMI & Ergonomics:

- 24.1E – "Alarm panels to state the alarms in a better way than they do today. Keep the bottoms to push and not all this touch screens."
- 24.2E – "System fully automated and I could not think of any improvement for the moment."
- 24.3E – "If it's possible when we have an update, setpoints and alarm location should not go back to yard set up."
- 24.4E – "Make a 'colour blind' switch as a setting."
- 24.5E – "Easier to integrate new systems to the main alarm system."
- 24.6E – "Full integration of systems so that you can

control everything from one monitor and see all alarms, wireless alarm indicator that you can bring to the rest of the ship."

- 24.7E – "Having all the systems compatible and integrated into one system that is properly integrated."
- 24.8E – "Having things in 'boxes' in the IAS so that it's easier for unfamiliar users that don't have the IT-knowledge behind the system."
- 24.9E – "One fully integrated alarms system (integration of all sub-systems). Improve the automation—make all systems run in auto (for example, not operating valves manually)."
- 24.10E – "On older ships have one fully integrated system."
- 24.11E – "Having multiple screens for proper monitoring."
- 24.12E – "Full system integration."
- 24.13E – "Timestamps on local panel."
- 24.1B – "Would be nice to have a system for all alarms that, for instance, on the bridge and a central system, that would collect all equipment into one common central where one can read out. It would manage the working environment better."
- 24.2B – "One alarm system for all bridge equipment that manages all the alarms from the different equipment."
- 24.3B – "A menu where you can set different modes, so some alarms are off in some specific operations, e.g. in cargo operations."
- 24.4B – "Minimize the amount of screens."
- 24.5B – "Having the systems on the bridge more compact and built together in a fully integrated system, have a lower pitch alarm tone, having a decibel instrument and that can make sure the alarm is not too loud in the moment."
- 24.6B – "The sounds need to be 'not so horrible'."

Prioritisation Capability:

- 24.14E – "Proper colour prioritization in the system."
- 24.15E – "Prioritization of alarms, very important preferably by colours. Alarms from morgue room plant."
- 24.7B – "Have a filter to manage the incoming alarms or a prioritized alarm list or Central alarm management system."
- 24.8B – "Condensing the number of alarms to the minimum, so you can actually concentrate on what you have to do instead of acknowledging the same alarm multiple times on different displays."
- 24.9B – "The alarms have to be more logically prioritized so that you get the right alarms at the correct time."

Alarm Quality:

- 24.16E – "Each alarm must be identified—not common alarms."
- 24.17E – "More detailed alarms tell me what the failure is, not that it has failed."
- 24.18E – "In an ideal world, we would only have the machinery space alarms for equipment under direct control (so not the incinerators, garbage equipment, pools, mooring deck) but these are useful for overall situational awareness of plant."
- 24.19E – "Don't have common alarms. Integrate alarm descriptions properly."
- 24.10B – "Make sure to do something that can help avoid nuisance alarms."
- 24.11B – "If the same alarm is sounding all the time it should be stale until acknowledgment, so you don't get 1000 alarms a day because of a faulty sensor."
- 24.12B – "Cut down on all alarms on ships. In general, there are too many.

Spatial adaptability:

- 24.20E – "There should be an alarm system in the dayroom on board."

Management of Change:

- 24.13B – "Lower requirements from IMO about the alarm system, so that it is easier to adjust the settings of different alarms."
- 24.14B – "Integrating all the systems into one system, so that all the systems are not stand alone. A more logical acknowledgement of the alarms."
- 24.15B – "Simplify the rules of the UMS. It would be a good idea with ship type specific alarm systems so that the alarms system fits the vessel properly and we get the alarms we need in the right context. An agreement between classification societies in regard to the regulation and rules, so that the shipping companies won't just pick ABS or another classification society if Lloyd's won't approve their system or vice versa."
- 24.16B – "Have someone go the ship and ask the operators more often, just like LR are doing instead of sitting in the head office ashore."

Of the 35 extracted narratives, the following can be summarised:

With regard to Human-Machine Interface (HMI) & Ergonomics, officers provide insights and recommendations for improving alarm systems. They emphasise the need for advanced alarm panels that articulate alarms more effectively, preferring tactile buttons over touch screens (24.1E). Suggestions include maintaining setpoints and alarm locations during updates and avoiding a reset to yard setup (24.3E). Proposals for features like a 'colour blind' switch, easier integration of new systems, and full system integration for centralised control are highlighted (24.4E, 24.5E, 24.6E).

Officers weigh the importance of having all systems compatible and integrated into one cohesive system for efficient operation (24.7E). They advocate for user friendly organisation with features presented in 'boxes' for ease of understanding (24.8E). The desire for a fully integrated alarms system, running all systems in auto mode, is emphasised (24.9E). The necessity for timestamping on local panels is also noted (24.13E).

In terms of Prioritisation Capability, officers stress the significance of proper colour prioritisation within the system and the need for logical prioritisation of alarms (24.14E, 24.15E). Bridge officers propose tools like a filter for managing incoming alarms and a prioritised alarm list or Central Alarm Management system (24.7B, 24.8B, 24.9B).

Alarm Quality is a focal point, with officers highlighting the need for each alarm to be individually identified, more detailed alarm information, and the integration of alarm descriptions to avoid common alarms (24.16E, 24.17E, 24.19E). Bridge Officers advocate for measures to avoid nuisance alarms, suggesting that repetitive alarms should become stale until acknowledgement (24.10B, 24.11B).

Spatial adaptability concerns prompt the suggestion of having an alarm system in the dayroom on board (24.20E).

In the area of Change Management, officers express the need for lower requirements from IMO, integrating all ship systems into one cohesive unit, simplifying UMS rules, and exploring ship type-specific alarm systems (24.13B, 24.14B, 24.15B, 24.16B). The suggestion to conduct regular ship visits collecting anonymous operator feedback at scale is emphasised (24.16B).

1.22.6.4 Question 26

Question 26: Considering the questions you already answered in this survey, is there a question you feel we have forgotten to ask? If so, what would the question be, and what would be its answer?

Engineering officers:

- 25.1E – "How many alarms do you typically get during your duty time? A good night would be zero, and a bad one could be 4-5 alarms. And how many hours are you on duty? Twelve hours from 2000H to 0800H next day."
- 25.2E – "Questions about how the psychological health of the operator is affected by non-essential alarms. And how the psychological health affects the way you respond to alarms."
- 25.3E – "Ask about how the psychological aspects are in regard to the alarm systems. How are we affected by the alarm system, and how is our psychological state affecting our handling of the system? How can alarms affect sleeping patterns."
- 25.4E – "What is the cost-effect of human operators vs. AI? When AI is more developed, it will be."
- 25.5E – "Should make a questionnaire that is more directed towards the operator's position on the ship. The operator works mainly in the engine room and operates local panels."
- 25.6E – "Have the operators been trained before operating the system? No."
- 25.7E – "You should ask how well we were trained for the system. I would like training in the [Manufacture] system to understand it better. Operators need time to understand the system when they first start."
- 25.8E – "It's about management; we need to have proper emergency procedures and (to) drill them."

Bridge officers:

- 26.1B – "A lot of the questions asked in the interview are based on context, which doesn't make much sense."
- 26.2B – "What should be improved? Decibel level requirement from SOLAS for alarms. It's way too loud for some systems and for others it's too quiet."
- 26.3B – "Do you try to disconnect alarms that are necessary or required by law? (Sometimes!)."
- 26.4B – "Ask about stressed situations, plan B's, how do you prepare for it."
- 26.5B – "How would you change alarms? (Some alarms would be enough with a red light, no sound)."
- 26.6B – "How are the alarms affecting you? Answer: Psychologically speaking, I'm getting tired/exhausted by all the alarms."
- 26.7B – "How are the alarms affecting you psychologically? Raising awareness all the time which can make you feel stressed all the time."
- 26.8B – "How often do the alarm(s) distract you/do you lose time? A lot."
- 26.9B – "How health is affected? The operator says he is tired—tired because of the alarms and stressed out."
- 26.10B – "What is the actual volume (loudness) of your top three most frequent alarms in decibels? It is easy to measure one meter away from the alarm buzzer/speaker with a sound meter app on your phone. I have tested this with a calibrated decibel reader and it was spot on."

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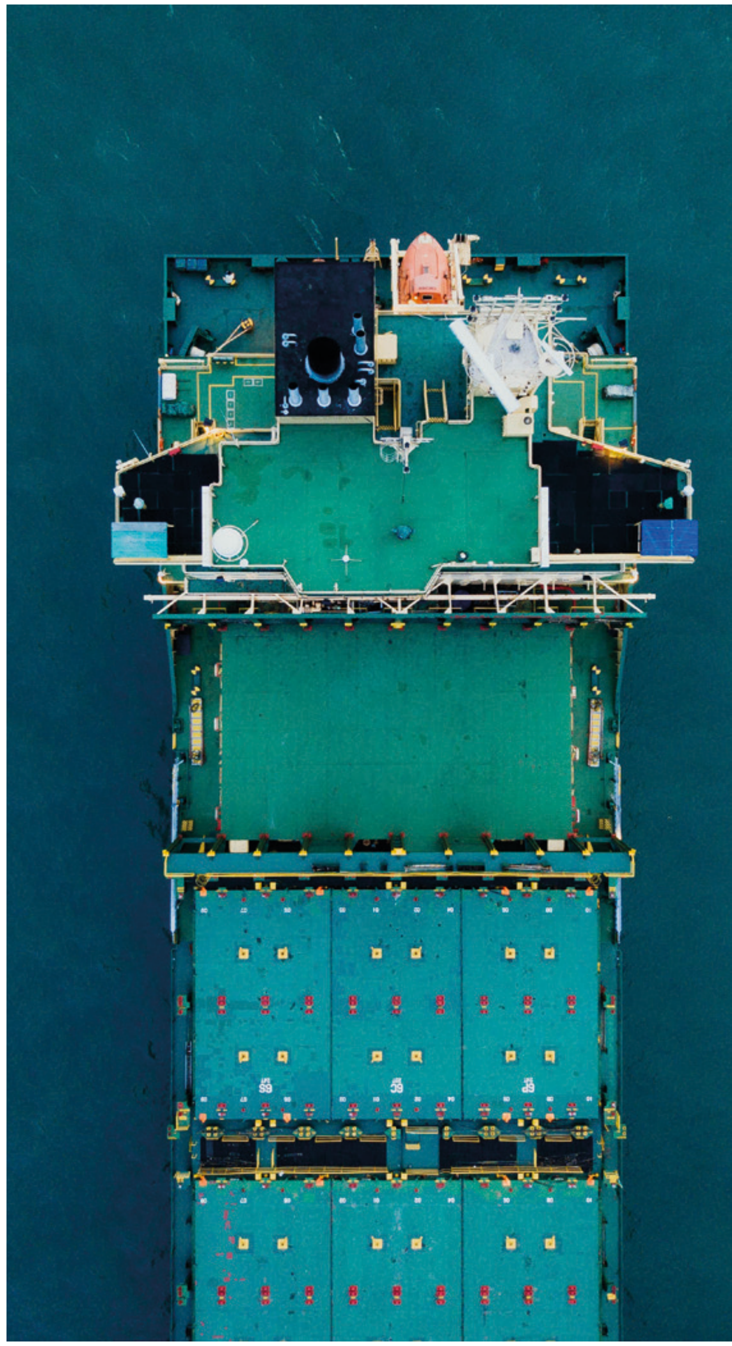
Results and Discussion

In reflections provided by engineering officers, some additional questions have been proposed for a more comprehensive understanding of the alarm system's impact. These include probing the frequency of alarms during duty hours and the duration of shifts (25.1E). Psychological aspects, such as the influence of non-essential alarms on operator well-being and their subsequent response to alarms, are highlighted (25.2E, 25.3E). Suggestions involve delving into the cost-effectiveness of human operators compared to AI as technology advances (25.4E). A call for tailored questionnaires catering to an operator's position and training history is emphasised, with an expressed desire for training in specific systems like [Manufacturer] (25.5E, 25.6E, 25.7E). The importance of proper management and emergency procedure training is also underscored (25.8E).

On the bridge officers' side, additional questions touch upon contextual relevance in the interview questions (26.1B). Recommendations include revisiting the decibel level requirements for alarms according to SOLAS regulations and considering variations in system loudness (26.2B).

Operational insights reveal instances of disconnecting necessary alarms, even safety ones. In addition, needs are highlighted for preparedness in stressed situations (26.3B, 26.4B). Proposals for altering alarm characteristics, such as introducing visual-only alarms, are suggested (26.5B). Psychological impacts are detailed, with concerns about exhaustion and stress due to alarm frequency and volume (26.6B, 26.7B, 26.8B). Operational distractions and health effects are raised, emphasising the need for addressing these issues (26.9B, 26.10B).



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Synthesis and evaluation of the results

In this section, an evaluation of the collective results is presented with a perspective on answering the first question presented in the introduction:

> ***"To what extent does the overall maritime alarm philosophy consider human limitations?"***

The content is synthesised from the results of this entire report: the objective alarm load observations, the subjective narratives and questionnaire results from the watchkeepers, and the preceding findings of related work and best practices of adjacent industries. This is conducted by answering a series of questions used to assess the performance of alarm management systems. The questions below are derived mainly from the HSE information sheet, *Better alarm handling*. The sheet was an actionable output of the *Texaco Milford Haven* incident and the *HSE Contract Research Report No. 166*, and is further discussed in the review of related work. Similar to the approach used in this report, the information sheet advises that multiple sources of evidence are consulted. In addition, possible improvements are suggested, followed by references to existing maritime rules and regulations, which can help address identified challenges here and now.

Selected questions as inspired by the HSE information sheet, *Better alarm handling* [30]:

A. What are the users' (watchkeepers) opinions and observed experiences on the quality of the ship's provisioned alarms?

1. Are they all necessary, requiring user action?

The short answer is no. The longer answer is that:

(1) The observed alarm rates on both the bridge and within the ECR entail that a majority of alarms require no user action at the time of annunciation (section 1.21). With observed rates at times exceeding one alarm per minute, it is impossible to argue that a ship would be sufficiently resourced in terms of qualified manning to action such rates.

(2) On average, less than one third of the 10 most typical alarms (which the 65 different officers brought up) were reported to require them to take positive action (Table 10). This indicates missing steps within the alarm management lifecycle, especially rationalisation. The latter dramatically contributes to the number of provisioned alarms that should not have been implemented as alarms at all. As reviewed in the section on related work, this is substantiated by comparing these results to generally accepted good engineering practices, e.g. EEMUA 191 states: "Every alarm should have a defined purpose" and "Every alarm should have a defined response".

(3) The review of related maritime work identified an empirical study from 2006 reporting that 42% of all observed alarms in the ECR required no operator intervention [43]. The situation does not appear to have improved much since.

Possible improvement: Alarm rationalisation and alarm system integrity assessment.

Existing rule "hooks" available in the maritime industry:

a. *"4.18 The number of alerts and indicators which are not required to be presented on the navigation bridge should be minimized." – [35]*

b. *"2.3.3 Where the facility to provide messages in association with alarms and warnings exists, messages accompanying alarms and warnings are to describe the condition and indicate the intended response required by the crew." – [77, p. part 6 ch. 1 sec. 2]*

c. *"9.7 The alert messages should be completed with aids for decision-making, as far as practicable. An explanation or justification of an alert should be available on request." – [37]*

2. Are they timely, do the users have enough time to respond?

The short answer is that we do not know. The longer answer is that:

(1) Instances like the recounted story of the inland ferry's battery thermal runaway, at which time the warning was given after the safety function had already been enacted (Figure 38), does not support a positive answer to this question. Nor do brief examinations of incident reports, which outline expectations of manual safety actions of engineering officers confronted with bilge system alarms (flooding), as evidenced by just two examples:

- *"Several valves were located under bolted-down floor grates, which made it challenging to operate them manually…"* – NSIA – From the *Helge Ingstad* incident report [78, p. 172]

- *"When operating the handwheel, a steel pin broke and the handwheel could not be used. The engineer then crawled under the floor plates and used a wrench to open the valve while standing on the tank top in water to the knees."* – DMAIB – From the *Emma Maersk* incident report [12, p. 27].

It is difficult to justify that engineering officers have time to deal with these kinds of issues at such times.

(2) As presented in the introduction, engineering sufficient *Allowable operator response time* is an interdisciplinary effort (Figure 3). Discussions with expert alarm management practitioners from the process industries, including the technical executives at EEMUA, made it plain that *timeliness* is the most difficult variable to quantify during alarm rationalisation.

(3) The review of related work identified that other adjacent industries (nuclear and aviation) have extensive requirements for considering time design criteria for safety-related operator actions. The nuclear sector applies a site-specific TCA[24] programme (ANSI/ANS 58.8(2019) [29, p. 11]. The aviation industry requires consideration of time-critical warnings [32, p. part 6 b.], which includes requirements to "show" that the flight crew can recover from the failures in a timely manner [79, p. part 5.5].

Similarly, EEMUA 191 specifies proof testing by operator scenario testing of safety-related alarms when claimed as a barrier of protection against IEC 61511-1 [8, p. 23]. Moreover, it proposes to *measure time* when assessing *Operator response time* as a performance metric [8, p. 94 Table 13].

(4) To the best of the authors' knowledge, the alarm quality attribute of timeliness is considered only to a very limited degree in the maritime rules and regulations. The same goes for other types of time-critical operator actions in general. When time requirements were found, they were explicit in their formulations, such as evacuation times found in the LSA . While adjacent industries have given extensive consideration on the subject of manual operator time criteria, only two very high-level clauses are generally apparent within rules and regulations (shown right). Neither are accompanied by any performance criteria or validation requirements.

(5) The above points raise the question of the "practicality" of the many prescriptive first-stage high/low alarms or pre-warnings required within existing rules and regulations. Such alarms are intended to alert the crew in due time prior to tripping essential machinery or prevent incidents from happening. One concern may be that the actual situation is one in which it may already be too late for the crew to intervene. Such a reality would mean that the availability of the equipment or system is lost or degraded despite the crew's manual interventions.

Possible improvement: An investigation into the time delays between pre-warnings/alarms and their associated shutdowns should be conducted with regard to the *Allowable response time*. Such future work should investigate whether the ANSI/ANS 58.8 process could be transferable to the maritime context and if similar objective time design criteria for safety-related operator actions can be defined using a similar approach. The merit of such objective approaches is that assessing current numbers of provisioned alarms subjectively for *timeliness* is impractical. Prescriptive tables or formulas comparable to those found within the ANSI/ANS 58.8-versions would ensure that systems engineers, C&I engineers, and naval architects, allow sufficient time for the human operator. While enough time is only one of many human performance-shaping factors, it should not be the dominant one.

Existing rule "hooks" available in the maritime industry:

a. *"2.13.9 Control, alarm and safety related information is to be displayed in a clear, unambiguous and **timely** manner, and, where applicable, is to be given visual prominence over other information on the display" – [77, p. part 6 ch. 1 sec. 2]*

b. *"3.6.1 The displays and indicators are to present the operator with clear, **timely** and relevant information." [77, p. part 6 ch. 1 sec. 3]*

c. *"2.6.8 Automation systems are to be designed in a manner such that a threshold warning of impending or imminent slow-down or shutdown of the propulsion system is given to the officer in charge of the navigational watch **in time** to assess navigational circumstances in an emergency. In particular, the systems are to control, monitor, report, alert and take safety action to slow down or stop propulsion while providing the officer in charge of the navigational watch an opportunity to intervene manually, except for those cases where manual intervention will result in total failure of the engine and/or propulsion equipment within a short time, for example, in the case of overspeed." [77, p. part 6 ch. 1 sec. 2]*

24 Time-Critical Actions

3. Are they realistic, do they take into account human performance envelopes?

The short answer is that we do not know. The longer answer is that:

(1) To the best of the authors' knowledge, the reliability of the human operator is not considered widely within current rules and regulations—not for alarms, nor for other types of time-critical operator actions. While the general spirit of maritime safety philosophy is to prevent any single failure from causing a loss of essential services, reliability appears unconsidered for humans. Human reliability was only found to be addressed within IMO guidelines for rule-making processes: *formal safety assessments, MSC-MEPC.2/Circ.12/Rev.2 – Annex 1.*

(2) Examples of designs expecting outstanding human performances were evident from incident reports and observed SRtP actions (see Figure 41 and Figure 42). The SRtP example was on a passenger ships with thousands of people on board.

(3) The review of related work identified that adjacent industries, nuclear in particular, require that the operator's necessary sequence of discrete safety actions be considered against a single operator error [29, p. 4]. Similar considerations were found to be required within aviation for crew errors [79, p. part 5.6.2].

Possible improvement: Consider the reliability on an individual human to correct a single error within the necessary sequence of discrete safety actions for alarm response procedures. Confirmatory information is likely needed to inform the operator of errors after executing safety actions. Consider what compensating measures are implemented to control risks when humans fail to do so.

Existing rule "hooks" available in the maritime industry:

a. *"3.5.1 Operator inputs are to be checked for errors, for example, out of range data or incorrect actions, and the operator is to be alerted when they occur." – [77, p. part 6 ch. 1 sec. 3]*

b. *"3.5.3 Assistance is to be provided to the operator to recover from operator errors, for example, through advisory screens where the automation system has this facility." – [77, p. part 6 ch. 1 sec. 3]*

c. *"3.5.12 Controls that affect the safe operation of the ship should be arranged so as to minimise the possibility of inadvertent operation." – [77, p. part 6 ch. 1 sec. 3]*

B. What is the user's opinion on the usability of the overall provisioned alarm system, including the management practices surrounding it?

1. Are they ever overwhelmed by alarm floods?

The short answer is yes. The long answer is that:

(1) Even for foreseeable abnormal or demanding conditions such as losing electrical power or navigating through traffic separations, numerous watchkeepers reported being flooded with alarms, with statements below prevalent on most ships:

- *"Too many to count."*

- *"At traffic separations like yesterday, I feel like I am doing nothing else but hitting this acknowledge button".*

At such times, only ~25% of all officers report that alarms *never* or *rarely* "come in too fast for them to take them in" (Table 10).

(2) The objective alarm load observations so far support these narratives. For a highly modern and sophisticated bridge system, alarm rates were observed to exceed one per minute (74 per hour) while passing through the Strait of Gibraltar at nighttime (Figure 25). Moreover, on the majority of larger passenger ships, the engine room alarm system was observed to be constantly in an alarm flood condition (Figure 30, Figure 47), with one case showing a peak of ~22500 machinery alarms on a single day (Figure 29). Another analysis of a RORO ship showed 218 alarm floods a year when computed against IEC 62682:2014 (Figure 31).

(3) Comparing the alarm recordings stated above with what was found during the review of related literature for similar studies on alarm loads on ship bridges shows that the peak rate of bridge alarms has not changed much (Figure 28). On the contrary, a 6% increase was found for the most demanding scenarios. This is even though the International Maritime Organization introduced both a revised code on alerts and indicators in 2009, and the bridge alert management standard (BAM) in 2010. For the engine room alarms, a related empirical study from 2006 reported that a partial blackout test generated 206 alarms in the first 115 seconds on a shuttle tanker [43]. It appears that burst alarm rates for even foreseeable abnormal or demanding conditions have not improved since.

(4) Only one of the 15 visited ships (a passenger ship) applied advanced alarming techniques in its central alarm management system to ensure that only critical alarms were presented in the case of a blackout. The engineering officers on board reported that this was immensely helpful. The substantial ship-specific experience of the engineering officers was used during the rationalisation process to suppress non-relevant alarms in that foreseeable event. The review of related work identified an article in which a chief engineer appealed to the industry to adopt similar approaches [45, p. 115].

Possible improvement: The maritime industry should investigate the applicability of advanced alarming techniques to address alarm floods. This should start with techniques already widely recognised and proven effective in adjacent industries. Examples can be found within ISA 18.2, IEC 62682 and the EEMUA 191.

Existing rule "hooks" available in the maritime industry:

a. *"5.2 If practicable, there should be not more than one alert for one situation that requires attention" – [37]*

b. *"6.1.2 Number of alerts for one situation: … Unless required by IMO, if there is a situation that requires attention, a functional alert…shall be raised, while the underlying causes (e.g. technical situations or symptoms) shall not provide (additional) audible alerts(s)." – IEC 62923-1:2018 [36]*

2. Are there nuisance alarms, are large numbers of alarms acknowledged or silenced without subsequent operator actions?

The short answer is yes. The longer answer is that:

(1) Multiple watchkeepers report being exposed to irrelevant alarms that chatter, are fleeting or happen for no rational reason. This usually occurs when the watchkeepers are already under a lot of mental pressure, such as during arrival. In such circumstances, less than a third of all watchkeepers reported that they *never* or *rarely* felt forced to accept alarms without having time to read and understand them. Narratives like the ones below were common across the majority of visited ships:

- *"…officers take turns to sit and mute them."*

- *"There is a dedicated person to acknowledge alarms during arrival."*

- *"You can only do so much; you get to a point where you just acknowledge alarms without reading it."*

- *"You have to decide between the alarm list and keeping the ship safe."*

(2) In normal operations, the watchkeepers report being subject to nuisance alarms. Notably, more than half (~58%) of the engineering officers report being *Often* or *Sometimes* subject to two or more alarms occurring at the same time, meaning the same. In addition, ~52% of these engineering officers reported nuisance for alarms of shut down machinery, cluttering the alarm list (Table 10). Besides, more than half (~61%) of the bridge officers reported that *40-70%* or *70-100%* of alarms were a repeat of one already seen in the last 5 minutes. Overall, these indicate high rates of nuisance alarms.

(3) The review of related work found similar narratives of needing an additional dedicated bridge officer just for silencing alerts [43]. A more recent and far more extensive industry investigation on ECDIS usability reports similar challenges on nuisance alarms from navigational systems [48]. Furthermore, the HSE CR 166 report identified a study and paraphrased it as follows:

"Experiments using a mental decision-making task showed that as the probability of an alarm being false increased, subjects waited longer before starting a troubleshooting process and that they invested less mental effort into the task. Under increasing time pressures, subjects did not choose their intervention strategies to optimise the outcome. Instead, they requested confirmatory information." [9, p. 117] [34].

Similarly, the aviation industry was found to have adopted requirements for integrity assessment of crew alert systems with the rationale:

"The integrity of the alerting system should be examined because it affects the flight crew's trust and response when assessing an alert. Since the individual assessment of a False or Nuisance alert for a given system may lead to a specific consequence, the impact of frequent False or Nuisance alerts increases the flight crew's workload, reduces the flight crew's confidence in the alerting system, and affects their reaction in case of a real alert. For example, if False or Nuisance alerts are presented the flight crew may ignore a real alert when it is presented." [32, p. part 7 e]

The review of related work further identified that the process industry does not objectively measure "relevance" as such. Although its source literature does contain a method to quantity the nuisance rate [9, p. 177]. However, it does employ objective performance metrics for the two other characteristics that can define a nuisance alarm: *chattering* or *fleeting* behaviour. Its performance criterion is zero, with action plans to correct any that occur [18, p. 73].

(4) Stories like the thermal runaway on the inland ferry highlight the potential risks of alarm systems lacking integrity (Figure 38).

(5) To the best of the authors' knowledge, the integrity of maritime alarm (alert) systems is not currently required to be assessed and is not widely considered within current rules and regulations.

Possible improvement: Establish assessment criteria for maritime alarm (alert) system integrity.

Existing rule "hooks" available in the maritime industry:

a. *"4.17 Means should be provided to prevent normal operating conditions from causing false alerts, e.g., provision of time delays because of normal transients." – [35]*

b. *"Alerts shall be defined such that they are only raised when relevant to the operational context." - IEC 60092-504:2016 - [38]*

3. Are persistent audible alarms turned off?

The short answer is yes. The longer answer is that:

(1) The watchkeepers report the need to suppress alarms required by rules and regulations, such as safety alarms, because they cause a high level of distraction, with quotes and narratives such as:

- *"We have to acknowledge them all to be able to think because of the high alarm sound."*

- *"We had a period when the officers would go to bed at night after a four-hour shift with alarm fatigue and still hearing alarms ringing for their ears."*

Throughout this investigation, sound appears to be an urgent matter needing regulatory revision on its validation and rationale. The multiple accounts found in the questionnaire under open question 21 should make that sufficiently evident. For this report, the highest number was observed on a visited ship with 70 manually suppressed alarms (Figure 55).

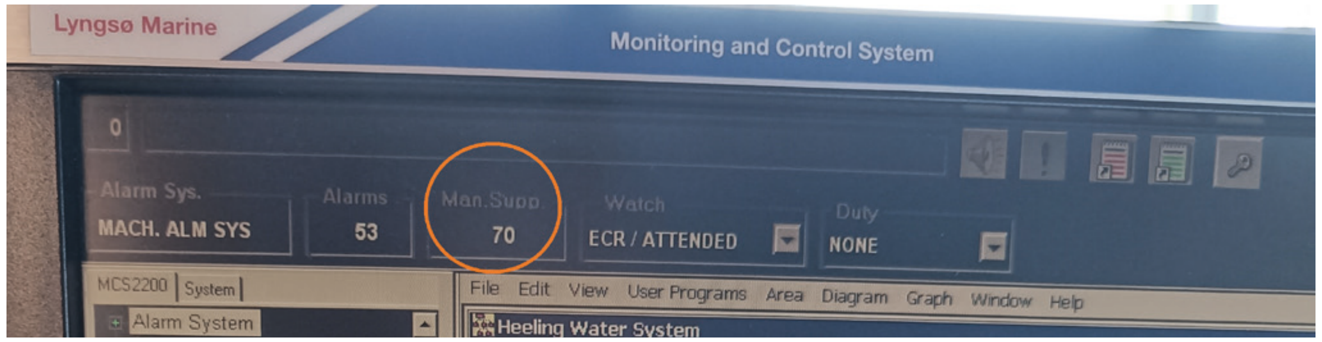

FIGURE 55.
Visited ship with 70 manually suppressed "cut-out" alarms.

FIGURE 56.
Examples of muffled alarm buzzers from three of the sampled ships.

(2) A common observation is that the majority of officers identified the sound as a frequent reason for disregarding the alarm system. Some officers described the sound as "ear deafening" or "like a bomb goes off". This startled and distracted the officers, preventing them from performing their job. All visited ships had implemented some form of noise damping (made more difficult on newer systems) on the buzzers. Some were sophisticated, others more primitive (Figure 56).

(3) Captains reported sound as being a safety issue because of the helmsman's inability to hear the orders (e.g., see *Captain's letter* – Table 9). When different alarm panel annunciations are not synchronised, they reportedly produce a "cacophony" that amplifies the overall sound level.

(4) It was highly doubtful that the alarm sound pressure levels on most visited ships collectively performed according to Res. MSC.337(91) (which excludes alarms, as stated in it its clause 1.3.10). Regardless, the startle response induced by such sound noise levels has been shown to degrade the performance of operators in adjacent industries [80] [81].

Possible improvement: Remove the absolute dB(A) values from the CAI clause 5.13 (below). A much better goal is to achieve the relative value of 10 dB(A) above ambient noise level. Establish objective sound validation criteria for audible alarms (field measurements). Verify adequate sound diversity across systems and defined priority levels. Do so for a combinatorial collection of alarms, not just one by one. It entails that system suppliers need to do a systematic tune-in, rather than simply setting it at 85 dB(A) "*ab fabrik*".

Existing rule "hooks" available in the maritime industry:

a. *"5.13 For the audible presentation of navigational alerts on the bridge the sound pressure should be at least 75 dB(A) but not greater than 85 dB(A) at a distance of one metre from the systems. Alternatively, it may be allowed to adjust the sound pressure to at least 10 dB(A) above the ambient noise level instead, if the ambient sound pressure on the bridge can be determined. The upper noise level should not exceed 85 dB(A)." – [35]*

4. Is alarm prioritisation helpful?

The short answer is no. The longer answer is that:

(1) In summary, the reason why people want prioritised alarms is because they get a lot of them. In an ideal world, all alarms are normally actioned straight away. Prioritising alarms is intended to assist decision making during alarm overload. An overload occurring due to an unforeseen event or disturbance.

(2) Despite this intent, watchkeepers report limited assistance from the implemented priority levels defined by the Code on Alerts and Indicators. Several watchkeepers describe that prioritisation within individual alert categories is needed at the current rate of alarms. Narratives like those below were common across all visited ships:

- *"Our system has the capability, but it's implemented with all the same priorities anyhow."*

- *"I can't say how often I get wrong prioritised alarms. There (is) only one priority."*

- *"Even though the IAS has prioritisation of alarms, it is not applicable. We don't have alarm prioritisation."*

- *"The audio and volume of the alarms don't fit the severity of the alarm. Insignificant alarms are loud. Fire alarms are low."*

(3) Review of related work in adjacent industries found bespoke requirements for prioritisation taking into account timeliness. For instance, the review of EASA CS-24.1322 found that it requires alerts to be prioritised within each priority category, while also considering not only time-critical warnings, as well as a necessary sequence of crew responses. This is likely only possible in combination with a proper rationalisation process, something that regulation requires as well.

Similarly, EEMUA 191 defines a criterion for provisioned priority distributions during design (Table 18), while IEC 62682 defines one objective performance metric as the annunciated prioritisation closely following these distributions (Table 19). EEMUA 191, advice that inversed distributions in operation indicate that the rationalisation unsuccessfully assigned the correct priorities, or that the system is operating very unsafely [8, p. 216].

(4) The reported lack of useful prioritisation is indicative that the maritime regulations do not mandate a rationalisation step to justify and minimise initially proposed alarms. Nor is it mandated to establish the timeliness; a step necessary to compute the urgency. This is an essential component for basic prioritisation, because any basic priority heuristics depend on at least the two variables; (1) the time left to respond and (2) the consequence of not responding.

Possible improvement: Implement similar requirements, such as EASA CS-25 13.1322, for alerts to be prioritised within each priority category. In addition, adopt objective performance criteria for both provisioned and annunciated priority distributions similar to IEC 62682 and EEMUA 191.

Existing rule "hooks" available in the maritime industry:

a. For ships with Integrated navigational systems (INS): *"…the means for the bridge team and pilot to assess the urgency of different abnormal situations in cases where more than one abnormal situation has to be handled…" – [82].*

5. Do they know what to do for each alarm?

The short answer is yes, but only for alarms which they have experienced or practiced personally. The longer answer is that:

(1) Since modern ships are provisioned with thousands of alarms (Figure 14), and most of which are without written procedures, it is unrealistic to expect watchkeepers to fully understand each alarm message and know what to do about it.

(2) Officers generally felt comfortable dealing with alarms they had already experienced. This is attributed to the result of ~71% stating *Mostly* when asked.

(3) However, watchkeepers both report and demonstrate a limited understanding of the significance of alarm messages and the anticipated responses to alarms which they had not personally experienced or dealt with (even if they had acknowledged it while on watch). Vessels experiencing frequent turnover among their officers, whether employed or contracted through agencies, seem particularly susceptible to the potential failure of effective crew responses to alarms.

(4) Watchkeepers on back-to-back contracts were more likely to know what to do for alarms than those who were not on back-to-back contracts.

Possible improvement: Ensure that watchkeepers (and crew) are trained before being made responsible for responding to alarms.

Existing rule "hooks" available in the maritime industry:

a. *"4.13 Provision should be made for functionally testing required alerts and indicators. The Administration should ensure, e.g., by training and drills, that the crew is familiar with all alerts." – [35]*

TABLE 18.
(EEMUA 191 3rd edition. Table 27.) Priority distribution during system configuration [8, p. 129].

Priority band	Alarms configured during system design
Critical	About 20 altogether
High	5% of total
Medium	15% of total
Low	80% of total

TABLE 19.
(IEC 62682:2014. Table 6, Annunciated priority distribution - Section 16 - Alarm system performance metrics) [18, p. 72]. Copyright © 2022 IEC Geneva, Switzerland. www.iec.ch

Priority designation	Percentage distribution
3 priorities: low, medium, high	~80 % low, ~15 % medium, ~5 % high
4 priorities: low, medium, high, highest	~80 % low, ~15 % medium, ~5 % high, ~<1 % highest

Conclusion

This study provides an initial exploration into the best practices and challenges of alarm systems on ships and is presented in the light of the experiences of the watchkeepers. Its findings enhance the understanding of alarm system usefulness and performance, including the watchkeepers' ability to respond appropriately and in a timely manner to alarms—an aspect crucial for overall ship safety in routine, and especially, in abnormal conditions. The study draws upon 65 questionnaire responses from 15 ships, with 60 responses gathered via semi-structured interviews and five via an online survey. Additionally, over 33 hours were spent observing alarm loads on ship bridges. Preliminary analysis of event logs of machinery spaces offers further context and insights into collected narratives. The study finds positive aspects of alarm systems supporting watchkeepers during normal operations and in demanding situations. It likewise identifies that these coexist with significant points of criticism related to the management of alarm systems within the maritime industry. It is important to emphasise that no watchkeepers advocate for a return to continuously manned machinery spaces or similar legacy-based operational structures. Instead, the takeaway is that the utility gained from the provisioning of alarms reached the point of saturation a long time ago. And like any prescribed and administered "remedy", there is a danger of overdose—a risk which ought to be controlled far better than current practices.

In essence, the questions presented in the introduction are concluded as follows:

1. To what extent does the overall maritime alarm philosophy consider human limitations?

The reported narratives and experiences of the seafaring watchkeepers advocate substantial room for improvement with regard to considering human limitations in the maritime alarm philosophy (1.22). The alarm data analysed so far reinforce this too (1.21). The review of related maritime work found examples from academic and joint industry projects suggesting similar views (Table 2). The questionnaire results indicate a strong correlation between the views of watchkeeping seafarers and the historical experiences of control room operators in the chemical (process) and power industries over 25 years ago—a time when these industries had not yet adopted alarm management as good practice (Table 10). Evaluating these results in line with the modern day recognised and generally accepted good practices, stresses an insufficient consideration of human limitations in alarm system design, implementation and operation (Synthesis and evaluation of the results). In summary, the commonality of the watchkeepers' accounts and narratives found across the sampled ships of such variety suggests that this alarm problem is systematic—a problem which has also taken hold in the maritime industry. Even among the best of the best (see Research Site).

On a positive note, some aspects of control system ergonomics were found to be considered in current rules and regulations (Table 1). However, examining these from the perspective of relevant maritime literature, good practices and regulations of adjacent industries reveals regulatory gaps. These gaps centre on the absence of processes and objective performance variables. These elements were identified by adjacent industries as being necessary for an alarm system to satisfy the usability criteria for human operators. Most notably, these gaps were:

- **a.** A lack of consideration for the assessment of alarm system integrity.
- **b.** No explicit attention to the quality attributes of provisioned alarms.
- **c.** A complete absence of quantitative (objective) performance criteria for the collective sum of provisioned alarms (alerts). Both at the design stage and during operations.
- **d.** In general, *timeliness* for time-critical actions is not contemplated, despite the fact that the engineered design choices may easily dominate the *Allowable operator response time* (Figure 3).

The results make it evident that the design of provisioned alarms define the operability and usability of the alarm system once operationalised. Since alarms need people to work, that design must take account of human limitations. Maritime policymakers must urgently address this matter to ensure that it does.

2. How can it be determined whether an alarm system's performance is acceptable for the maritime setting, and what discernible indicators do high performers exhibit in this regard?

Numerous discernible indicators were identified for organisations exhibiting high performance in managing their alarm systems (being high performers). The most important ones were managerial in nature. However, some were system-specific as well. The managerial indicators can be summarised as follows:

(1) Crew resourcing: Generally, watchkeeping officers who had gained a high degree of familiarity by maintaining a *back-to-back* schedule were more positive in their opinion about the alarm systems. The familiarisation and ship-specific experience gained with this approach assisted these watchkeepers in understanding the meaning of the alarm messages and what to do about them. They had a decent mental model of the system and its time constants. This assists them in prioritising the relevance and urgency of alarms.

(2) Competence aligned with system complexity: With the degree of automation, electronics and electrification on board modern ships, the watchkeeping engineering officers with a valid STCW III/6 certificate exhibited more profound knowledge regarding the alarm systems (Figure 43). The latter made certain intended response procedures more "believable". The contrary was found on ships on which engineering watchkeepers did not have these competencies, especially for SRtP[25] actions needing physical tampering with safety-related control systems (Figure 41).

(3) User empowerment: Watchkeepers involved in the decisions around the alarm system exhibited more favourable opinions of the alarm systems. A particularly effective approach was observed on board a ship using a straightforward pen and a paper booklet. Here, the watchkeepers would suggest improvements/changes in writing. Suggestions would be reviewed at regular intervals (Figure 53). The agreed changes would be implemented on board by the alarm system provider in consultation with the watchkeepers. Successful changes would also be transferred to other similar ships.

(4) Validated response procedures: Alarm procedures were written for the most critical alarms and validated to work in practice. The most positive responses on alarm system usability were from watchkeepers who had co-authored, reviewed, and validated these response procedures—and had done so on board.

(5) Management risk ownership: A dominant characteristic of good performers was that they were entirely operated, managed, and resourced by their owners. In these cases, the management understood and valued the information on risks to business continuity that the alarm system performance indicates. For one visited ship, the technical management required a hand-written explanation from the chief engineer on each alarm, which had to be announced within a given month (Figure 54).

It is essential to highlight that some of these managerial strategies compensate in places where alarm integrity and systems engineering are lacking. The firster indicator (1) builds on the notion that people need to be sufficiently familiar and experienced to gauge the relevance of an alarm, including its degree of urgency in the given situation. On the contrary, adjacent industries (notably aviation), have deemed it dangerous for the crew to form personal opinions on whether an alarm is relevant or not (1.12.8).

Specific alarm system indicators found among the highest performing companies were:

(1) Manageable alarm rates in normal operation conditions: Rates were managed by the watchkeepers, and they could concentrate on their daily work.

(2) Manageable alarm rates during foreseeable abnormal or demanding conditions: Examples were the use of advanced alarming techniques, such as state-based alarm suppression during, e.g., blackouts or harbour manoeuvres. This was found on a single ship only.

(3) Alarms were implemented with clear, understandable and actionable messages.

(4) "Common alarms" were reserved for non-essential equipment and never for safety-related alarms.

(5) Stale or standing alarms: No stale alarms cluttering the alarm list screen (this is as much a management decision, aka. a zero tolerance of building up stale alarms).

(6) Distilled integration: While only full integration can provide full awareness, it changes the problem of too little information to one of too much information for humans. Officers appreciated "old-fashioned" indicators (and physical buttons) in conjunction with a centralised alarm list display and process view HMI. When abnormal events flood the alarm list display, the watchkeepers rely on these independent indicators to quickly gauge the health state of the essential systems, which means that the critical alarms are always on view.

(7) Good HMI: Besides basic functionality of adjusting setpoints, shelving[26] alarms for equipment under maintenance and so forth, the watchkeepers report the following:

a. Swift user navigation between alarm list to the relevant mimic process screens.

b. Trending functionality of process variables in the same picture.

c. The ability to revisit the recorded state of the system at a given moment in the past was reported to assist the users in diagnosing why something happened and thereby preventing it from happening again.

d. Separate indicators and physical buttons (not touch) for important alarms and safety controls. Summed up, not touch screens.

e. Not losing tuned parameters such as delays and setpoints when updating the system.

In conclusion, significant and continuous effort was put into the alarm management system by the company's management, with demonstrable impact.

25 Safe Return to Port

26 Temporarily taking alarms out of service.

Suggestions for further work

This project has raised many unanswered questions about alarm systems and identified lines of research and development that might be worthy of further consideration. These are described as follows.

1. An investigation into the time delays between pre-warnings/alarms and their associated shutdowns should be conducted with regard to *Allowable response time*. Future work should investigate whether the ANSI/ANS 58.8 process could be transferable to the maritime context and if similar scalable and objective time response design criteria for safety-related operator actions can be defined using a similar approach.

2. Establish the differences in quantifying alarm system performance metrics according to IEC 62682:2014, between (1) *continuous time* versus a set of (2) *discrete generalisable modes of operation*. This will aid the maritime industry in informing the appropriate approach to objective performance assessments.

3. Quantify the nuisance rate (HSE approach – *How many alarms are useful*) or similar alarm system integrity metric imposed on the bridge and engineering officers. Do this by applying a sampling criteria similar to the one used in this study.

4. A key requirement for the effective management of alarm system is investment in its continuous improvements. Since alarms are never a root cause on their own, establishing the monetary value needed to convince senior management can be challenging without any recognised methodology. Thus, a better understanding of the “cost” of poor alarm performance in terms of financial losses and avoidable hazards is highly desirable.

1.23 Final remarks

An analogy can be made to a ship venturing out into open seas with intact stability less than that prescribed by the International Code on Intact Stability 2008. Such a condition would not necessarily entail 100% certainty of a loss, nor would the opposite guarantee a 100% safe voyage. The poor stability may cause the crew to become seasick and fatigued. Yet, they may still be able to manage and operate the ships’ systems and equipment to some degree. The same is true for alarm systems, which in steady operations (clear skies and moderate seas) may at first glance seem to work well enough or at least be bearable to the operators. However, when the storm arrives the story becomes another. And storms do happen.

However, unlike intact stability, which is ensured in part by the merits of the officers, such is not the case for the alarm systems provided for the watchkeepers. In fact, it is seldom given any deeper attention, nor are its users commonly consulted on how these systems should be best designed and implemented. This is despite the fact that these systems are installed with the primary purpose of supporting the crew in keeping the vessel safe and operational at all times. This must change for the maritime industry to achieve its dreams of tomorrow. Alas, risks are high that they will remain just that—dreams.

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Appendix A – Operator questionnaire results

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6)						
		Question 1.b How long have you worked with the present alarm control system?		**Question 2** About your primary alarm system - how old is it?	**Question 2.b** About your primary alarm system - when was the last update?	**Question 2.c** How old is the ship?	**Question 2.d** Is the primary alarm system part of the control system (can you perform actions with it)?	
		Total years	**Avg. years**	**Years**	**Years**	**Years**	**Yes**	**No**
1	-	Non-disclosed See box & whisker plots	Non-disclosed See box & whisker plots	Non-disclosed See box & whisker plots	Non-disclosed See box & whisker plots	Non-disclosed See box & whisker plots		
2	10						10	
3	5						5	
4	1						1	
5	2						2	
6	5						5	
7	1						1	
8	3						3	
9	1						1	
10	2						2	
11	2						2	
12	-							
13	1						1	
14	1						1	
15	-							
Total	34	110	3.2				34	0
%	100						100	0

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6)							
		Question 3 How well does the alarm system support you in normal steady operation?				**Question 4** How well does the alarm system support you during system faults, trips, or demanding operations?			
		Very good	**OK**	**Poor**	**Very poor**	**Very good**	**OK**	**Poor**	**Very poor**
1	-								
2	10	5	4	1		3	5	1	1
3	5	4	1			3	1	1	
4	1		1					1	
5	2	1	1			1	1		
6	5	3	2				4		1
7	1		1						1
8	3	1	1	1			2	1	
9	1	1				1			
10	2	2				1	1		
11	2	1	1				1	1	
12	-								
13	1		1				1		
14	1	1				1			
15	-								
Total	34	19	13	2	0	10	16	5	3
%	100	55.9	38.2	5.9	0	29.4	47.1	14.7	8.8

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6)							
		Question 5 What about the number of alarms in the system?					**Question 5.b** Can you distinguish between alarms generated from different parts of the system?		
		Too many	**Many but necessary**	**Few but adequate**	**Too few**	**No. of operators**	**Yes**	**Partly**	**Not at all**
1	-					-			
2	10	3	7			10	3	5	2
3	5	2	1	1	1	5	3	2	
4	1	1				-			
5	2		2			2	1	1	
6	5	1	4			5		4	1
7	1		1			1	1		
8	3		2	1		3			3
9	1		1			-			
10	2		1	1		2	1	1	
11	2		2			2		1	1
12	-					-			
13	1		1			1	1		
14	1		1			1	1		
15	-					-			
Total	34	7	23	3	1	32	11	14	7
%	100	20.6	67.6	8.8	2.9	100	34.4	43.7	21.9

Ship no.	No. of operators	ECR Question 6 How many alarms do you get per hour in normal steady operations? Total per hour	Average per hour
1	-		
2	10	217	22
3	5	3	1
4	1	70	70
5	2	17	9
6	5	52	10
7	1	0	0
8	3	0	0
9	-		
10	2	7	4
11	2	19	10
12	-		
13	1	3	3
14	1	1	1
15	-		
Total	33	389	11.8
%	100		

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6) Question 7 How often do you find that an alarm that comes up is a repeat of an alarm you have already seen in the last 5 minutes? 70-100% of alarms	40-70% of alarms	20-40% of alarms	<20% of alarms
1	-				
2	10		1	3	6
3	5			1	4
4	1				1
5	2			2	
6	5	1		1	3
7	1				1
8	3			1	2
9	1				1
10	2				2
11	2			1	1
12	-				
13	1			1	
14	1				1
15	-				
Total	34	1	1	10	22
%	100	2.9	2.9	29.4	64.7

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6) Question 8 Do you suffer from the following 'nuisance' alarms? Alarms which are wrongly prioritised			Alarms from equipment that is shut down			Two or more alarms occurring at the same time that mean the same			Alarms occurring in a trip that is only relevant in steady operations and vice versa		
		Often	Sometimes	Rarely	Often	Sometimes	Rarely	Often	Sometimes	Rarely	Often	Sometimes	Rarely
1	-												
2	10	3	1	6		7	3	3	4	3		1	9
3	5		3	2	1		4		2	3			5
4	1		1				1		1		1		
5	2			2		1	1		1	1		1	1
6	5	4	1		1	2	2	2	2	1		1	4
7	1			1	1					1	1		
8	3			3			3		1	2			3
9	-												
10	2			2			2		1	1			2
11	2	1	1		1	1			1	1	1	1	
12	-												
13	1			1	1				1				1
14	1			1		1				1			1
15	-												
Total	33	8	7	18	5	12	16	5	14	14	3	4	26
%	100	24.2	21.2	54.5	15.2	36.4	48.5	15.2	42.4	42.4	9.1	12.1	78.8

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Appendix A

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6) Question 9 What proportion of alarms are really useful to you when operating the ship? All are essential	Most are useful	Few, but useful	Very few useful	Question 10 Do you fully understand each alarm message and know what to do about it? Always	Mostly	Sometimes	Question 11 Consider a normal operating situation and 10 typical alarms. How many of the 10 alarms: SUM	Require you to take positive action?	Cause you to bring up a screen and monitor something closely?	Are noted as useful information?	Are read and quickly forgotten?
1	-								-				
2	10	4	5	1		3	5	2	100	33	27	26	14
3	5	4	1			2	3		50	20	11	13	6
4	1		1				1		10	1	2	3	4
5	2	2					2		20	7	5	6	2
6	5	2	3				5		50	17	10	14	9
7	1		1				1		10	4	2	2	2
8	3		3				3		30	11	5	10	4
9	1	1					1		-				
10	2		1	1		1	1		20	4	7	5	4
11	2		1	1		1	1		20	3	5	5	7
12	-								-				
13	1		1				1		10	3	2	5	
14	1	1				1			-				
15	-								-				
Total	34	14	17	3	0	8	24	2	320	103	76	89	52
%	100	41.2	50	8.8	0	23.5	70.6	5.9	100	32.2	23.7	27.8	16.3

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6) Question 12 How many alarms would you get during a large system fault, trip or demanding operation? In the 1st min?	In the next 10 mins?	In the next hour?	Question 13 Do you bring up an additional alarm list display during a large system fault, trip or a demanding operation? No. of operators	Yes	No	No. of operators	Question 14 How often do you look through the alarm list display during a large fault, trip or demanding operation? Several times a min.	Once every couple of min.	Once every 10 min.	Less than once every 10 min.
1	-				-			-				
2	9	739	172	169	10	6	4	10	4	2	2	2
3	4	322	37	15	5	3	2	5	4		1	
4	1	8	2	1	1	1		1		1		
5	2	105	10	19	2		2	2		1	1	
6	5	347	55	66	5	2	3	5	3	1	1	
7	1	170	2	6	1	1		1	1			
8	3	80	63	52	3	1	2	3		1	1	1
9	-				1	1		1	1			
10	1	200	50	0	2	2		2		1		1
11	2	150	15	25	2		2	2	1	1		
12	-				-			-				
13	1	20	10	5	1		1	1		1		
14	1	10	30	30	1	1		1	1			
15	-				-			-				
Total	30	2151	446	388	34	18	16	34	15	9	6	4
%	Avg.	71.7	14.9	13	100	52.9	47.1	100	44.1	26.5	17.6	11.8

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6) – Question 15: How often during a large fault, trip or demanding operation do the alarms come too fast to take them in?					No. of operators	Question 16: How often in a large system fault, trip or demanding operation are you forced to to accept alarms without having time to read and understand them?				
		Always	Mostly	Sometimes	Rarely	Never		Always	Quite often	Sometimes	Rarely	Never
1	-						-					
2	10	4		2	3	1	10	2	1	1	3	3
3	5		3	2			5	1		1	1	2
4	-						1			1		
5	2		1		1		2	1	1			
6	5	4	1				5	5				
7	1		1				1	1				
8	3	1			2		3	2			1	
9	1		1				1		1			
10	2			1	1		2			1	1	
11	2		1	1			2	1	1			
12	-						-					
13	1		1				1		1			
14	1			1			1			1		
15	-						-					
Total	33	9	9	7	7	1	34	13	5	5	6	5
%	100	27.3	27.3	21.2	21.2	3	100	38.2	14.7	14.7	17.6	14.7

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6) – Question 17: Does the alarm system help you to pick out key safety related events during a large system fault, trip or demanding operation?				
		Always	Mostly	Sometimes	Rarely	Never
1	-					
2	10	6	2	2		1
3	5	4	1			
4	1		1			
5	2		2			
6	5			3	2	
7	1				1	
8	3		1	1	1	
9	1			1		
10	2	1		1		
11	2	1	1			
12	-					
13	1	1				
14	1	1				
15	-					
Total	34	14	8	8	4	1
%	100	41.2	23.5	23.5	11.8	3

Ship no.	No. of operators	Engineering Officers (In addition to STCW III/1,…,3 also includes III/6) – Question 18: What do you think about the procedures for getting changes made to alarm settings etc.?				Question 18.b: Are you aware of a procedure that is used when alarms are modified?		No. of operators	Question 19: Compared with the other things your management does to improve your operations, such as adding additional technology, do they put enough effort into improving the alarm systems?		
		Over-restricted	Strict but safe	Easy to use - but you have to be careful what you do	Sloppy & uncontrolled	Yes	No		Too much	About right	Too little
1	-							1			1
2	10	1	6	3		9	1	6		1	5
3	5	1	3	1		5		2		1	1
4	1	1				1		-			
5	2			2		2		2		1	1
6	5		5			5		8		2	6
7	1			1		1		3		2	1
8	3		1	2		1	2	4		3	1
9	1		1			1		1		1	
10	2		1	1		1	1	-			
11	2			2		2		2			2
12	-							1			1
13	1			1		1		-			
14	1			1		1		-			
15	-							1			1
Total	34	3	17	14	0	30	4	31	0	11	20
%	100	8.8	50	41.2	0	88.2	11.8	100	0	35.48	64.52

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 1.b: How long have you worked with the present alarm control system?		Question 2: About your primary alarm system - how old is it?	Question 2.b: About your primary alarm system - when was the last update?	Question 2.c: How old is the ship?	Question 2.d: Is the primary alarm system part of the control system (can you perform actions with it)?		
		Total years	Avg. years	Years	Years	Years	No. of operators	Yes	No
1	1	Non-disclosed See box & whisker plots	Non-disclosed See box & whisker plots	Non-disclosed See box & whisker plots	Non-disclosed See box & whisker plots	Non-disclosed See box & whisker plots	1	1	
2	6						6	6	
3	2						2	2	
4	-						-		
5	2						2	1	1
6	8						8	8	
7	3						3	3	
8	4						4	4	
9	1						-		
10	-						-		
11	2						2	1	1
12	1						1	1	
13	-						-		
14	-						-		
15	1						1	1	
Total	31	51	1.8				30	28	2
%	100						100	93.3	6.7

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 2.f Do you use personal settings on the ECDIS?		Question 2.g Do you add alarms or suppress alarms? (Those who answered yes to 2.f)				
		Yes	No	No. of operators	I add alarms	I suppress alarms	I do both	I do neither, I leave it as it was when I took over the watch
1	1	1		1			1	
2	6	4	2	4			3	1
3	2	1	1	1				1
4	-			-				
5	2		2	-				
6	8	1	7	1			1	
7	-			-				
8	4	1	3	1			1	
9	-			-				
10	-			-				
11	2		2	-				
12	1		1	-				
13	-			-				
14	-			-				
15	1	1		1			1	
Total	27	9	18	9	0	0	7	2
%	100	33.3	66.7	100	0	0	77.8	22.2

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 3 How well does the alarm system support you in normal steady operation?				Question 4 How well does the alarm system support you during system faults, trips, or demanding operations?			
		Very good	OK	Poor	Very poor	Very good	OK	Poor	Very poor
1	1	1					1		
2	6		5	1			5	1	
3	2	1	1				1	1	
4	-								
5	2		2				1	1	
6	8	3	5			1	2	5	
7	3	2		1			1	2	
8	4	1	3				3	1	
9	1			1			1		
10	-								
11	2		1	1				1	1
12	1		1				1		
13	-								
14	-								
15	1		1					1	
Total	31	8	19	4	0	1	16	13	1
%	100	25.8	61.3	12.9	0	3.2	51.6	41.9	3.2

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 5 What about the number of alarms in the system?				No. of operators	Question 5.b Can you distinguish between alarms generated from different parts of the system?		
		Too many	Many but necessary	Few but adequate	Too few		Yes	Partly	Not at all
1	1	1				1		1	
2	6	5		1		6		6	
3	2	1	1			2	2		
4	-					-			
5	2	2				2		1	1
6	8	5	2	1		8	1	7	
7	3		2	1		3	1	1	1
8	4	1	3			4	4		
9	1	1				-			
10	-					-			
11	2	2				2		2	
12	1			1		1	1		
13	-					-			
14	-					-			
15	1	1				1		1	
Total	31	19	8	4	0	30	9	19	2
%	100	61.3	25.8	12.9	0	100	30	63.3	6.7

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 6 How many alarms do you get per hour in normal steady operations?	
		Total per hour	Average per hour
1	1	8	8
2	6	136	22.7
3	2	14	7
4	-		
5	2	60	30
6	8	101	12.6
7	3	27	9
8	4	43	10.8
9	1	50	50
10	-		
11	2	15	7.5
12	1	1	1
13	-		
14	-		
15	1	11	11
Total	31	466	15
%	100		

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 7 How often do you find that an alarm that comes up is a repeat of an alarm you have already seen in the last 5 minutes?			
		70-100% of alarms	40-70% of alarms	20-40% of alarms	<20% of alarms
1	1		1		
2	6	1	3	2	
3	2		1	1	
4	-				
5	2	1	1		
6	8	1	4	1	2
7	3	1		2	
8	4	2	1		1
9	1			1	
10	-				
11	2		1	1	
12	1			1	
13	-				
14	-				
15	1		1		
Total	31	6	13	9	3
%	100	19.4	41.9	29	9.7

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 8: Do you suffer from the following 'nuisance' alarms? Alarms which are wrongly prioritised			Alarms from equipment that is shut down			Two or more alarms occurring at the same time that mean the same			Alarms occurring in a trip that is only relevant in steady operations and vice versa		
		Often	Sometimes	Rarely	Often	Sometimes	Rarely	Often	Sometimes	Rarely	Often	Sometimes	Rarely
1	1	1					1	1					1
2	6	2	4		5		1	4	2		2	2	2
3	2	2				2			2		1	1	
4	-												
5	2	1	1				2		1	1	1	1	
6	8	4	3	1	1	4	3	5	3		1	1	6
7	3		2	1			3	2		1		1	2
8	4		2	2		2	2		2	2	1	2	1
9	1		1				1		1			1	
10	-												
11	2		1	1	1		1			2			2
12	1			1			1			1			1
13	-												
14	-												
15	1	1				1				1		1	
Total	31	11	14	6	7	9	15	12	11	8	6	10	15
%	100	35.5	45.2	19.4	22.6	29	48.4	38.7	35.5	25.8	19.4	32.3	48.4

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 9: What proportion of alarms are really useful to you when operating the ship?				Question 10: Do you fully understand each alarm message and know what to do about it?			Question 11: Consider a normal operating situation and 10 typical alarms. How many of the 10 alarms:				
		All are essential	Most are useful	Few, but useful	Very few useful	Always	Mostly	Sometimes	SUM	Require you to take positive action?	Cause you to bring up a screen and monitor something closely?	Are noted as useful information?	Are read and quickly forgotten?
1	1		1				1		10	2	2	5	1
2	6		5	1			4	2	60	16	15	16	13
3	2		1	1		1	1		20	5	5	5	5
4	-								-				
5	2		2				2		20	6	3	3	8
6	8		6	2			7	1	70	19	13	21	17
7	3		1	2		2		1	30	8	7	6	9
8	4		3	1			4		40	9	5	11	15
9	1		1				1		-				
10	-								-				
11	2		2				1	1	20	4	1	1	14
12	1		1			1			10	4	1	4	1
13	-								-				
14	-								-				
15	1				1		1		10	1	1	1	7
Total	31	0	23	7	1	4	22	5	290	74	53	73	90
%		0	74.2	22.6	3.2	12.9	71	16.1	100	25.5	18.3	25.2	31

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 12: How many alarms would you get during a large system fault, trip or demanding operation?			Question 13: Do you bring up an additional alarm list display during a large system fault, trip or a demanding operation?			No. of operators	Question 14: How often do you look through the alarm list display during a large fault, trip or demanding operation?			
		In the 1st min?	In the next 10 mins?	In the next hour?	No. of operators	Yes	No		Several times a min.	Once every couple of min.	Once every 10 min.	Less than once every 10 min.
1	1	8	3	1	1	1		1		1		
2	6	53	62	156	6	1	5	6	1	2		3
3	2	15	15	6	2	1	1	2	2			
4	-				-			-				
5	2	8	7	4	2	1	1	2	1		1	
6	8	39	102	191	8	3	5	8				8
7	3	10	12	16	3		3	3		1		2
8	4	275	61	51	4	2	2	4	1			3
9	-				1	1		1	1			
10	-				-			-				
11	2	15	7	6	2		2	2			1	1
12	1	4	0	0	1	1		1				1
13	-				-			-				
14	-				-			-				
15	1	4	10	25	1	1		1			1	
Total	30	431	279	456	31	12	19	31	6	4	3	18
%	Avg.	14	9.3	15.2	100	38.7	61.3	100	19.4	12.9	9.7	58.1

Ship no.	No. of operators	Bridge Officers (Including Captains) – Question 15: How often during a large fault, trip or demanding operation do the alarms come too fast to take them in?					No. of operators	Question 16: How often in a large system fault, trip or demanding operation are you forced to to accept alarms without having time to read and understand them?				
		Always	Mostly	Sometimes	Rarely	Never		Always	Quite often	Sometimes	Rarely	Never
1	1		1				1					
2	6	1	2	3			1	2	2	1		3
3	2	1	1					2				2
4	-											
5	2			1		1		1	1			
6	8	1		4	3		2		3	2	1	
7	3		2		1		1		2			
8	4	2			2		1			1	2	
9	1			1					1			
10	-											
11	2		1		1			1			1	
12	1		1								1	
13	-											
14	-											
15	1			1					1			
Total	31	5	8	10	7	1	6	6	10	4	5	5
%	100	16.1	25.8	32.3	22.6	3.2	19.4	19.4	32.3	12.9	16.1	14.7

Ship no.	No. of operators	Bridge Officers (Including Captains) Question 17 Does the alarm system help you to pick out key safety related events during a large system fault, trip or demanding operation?				
		Always	Mostly	Sometimes	Rarely	Never
1				1		
2		3	3			1
3		1	1			
4						
5	1	1				
6		3	3	2	2	
7		2	1		1	
8	2	1	1		1	
9				1		
10						
11		1		1		
12	1					
13						
14						
15			1			
Total	4	12	10	5	4	1
%	12.9	38.7	32.3	16.1	11.8	3

Ship no.	No. of operators	Bridge Officers (Including Captains) Question 18 What do you think about the procedures for getting changes made to alarm settings etc.?				Question 18.b Are you aware of a procedure that is used when alarms are modified?		No. of operators	Question 19 Compared with the other things your management does to improve your operations, such as adding additional technology, do they put enough effort into improving the alarm systems?		
		Over-restricted	Strict but safe	Easy to use - but you have to be careful what you do	Sloppy & uncontrolled	Yes	No		Too much	About right	Too little
1	1		1				1	1			1
2	6		1	5		6		6		1	5
3	2	1		1		2		2		1	1
4	-							-			
5	2			1	1	2		2		1	1
6	8	2	1	5		8		8		2	6
7	3			3		2	1	3		2	1
8	4			4		1	3	4		3	1
9	-							1		1	
10	-							-			
11	2			2		1	1	2			2
12	1			1			1	1			1
13	-							-			
14	-							-			
15	1	1				1		1			1
Total	30	4	3	22	1	23	7	31	0	11	20
%	100	13.3	10	73.3	3.3	76.7	23.3	100	0	35.48	64.52

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