2025 I 224

Alarm Management in the Maritime Industry. A field investigation into the watchkeepers' experiences

Controls, Automation, Measurement, Monitoring & Predictive Maintenance

Asger Schliemann-Haug, Lloyds Register

Nanna Thit Hemmingsen, Aarhus University
Kristoffer Kloch, Aalborg University

This paper has been presented and published at the 31st CIMAC World Congress 2025 in Zürich, Switzerland. The CIMAC Congress is held every three years, each time in a different member country. The Congress program centres around the presentation of Technical Papers on engine research and development, application engineering on the original equipment side and engine operation and maintenance on the end-user side. The themes of the 2025 event included Digitalization & Connectivity for different applications, System Integration & Hybridization, Electrification & Fuel Cells Development, Emission Reduction Technologies, Conventional and New Fuels, Dual Fuel Engines, Lubricants, Product Development of Gas and Diesel Engines, Components & Tribology, Turbochargers, Controls & Automation, Engine Thermondynamis, Simulation Technologies as well as Basic Research & Advanced Engineering. The copyright of this paper is with CIMAC. For further information please visit https://www.cimac.com.

ABSTRACT

On the high seas, 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 maritime industry first began to govern its practices on such matters. While technological advances have evolved considerably to control the spectrum of risks associated with maritime operations, so have the practicalities of watchfulness. Today's watchkeeping officers have become highly reliant on human-machine interaction. The human-machine systems 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.

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 fails to consider the overall alarm burden. Experts within the maritime safety community have previously advocated 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. This view was likewise shared by safety experts in adjacent industries, such as the process and power industries, several years ago. 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. Some events even attribute incidents to alarms (and their associated safety shutdowns) activating inadvertently. Other incidents testify to seagoing personnel deliberately deactivating safety alarms.

Since alarms need people to work, this study investigates current best practices and challenges regarding alarm management on ships. It presents the experiences of 65 watchkeeping officers from 15 ships managed by ten distinct companies. 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. Additionally, the initial analysis of machinery space event logs, combined with 33 hours of observed alarm loads on ship bridges, offers further context and insights into the collected narratives. Overall, the study finds positive aspects of alarm systems supporting watchkeepers during normal operations. It likewise identifies that these coexist with significant points of criticism related to the management of alarm systems within the maritime industry—something which the maritime industry must urgently address to achieve its ambitions of digitalisation and decarbonisation safely.

1 INTRODUCTION

On modern ships, alarm response is not merely an automated process involving deterministic machines; rather, it is a human cognitive and physical process that requires thought, analysis, and action. While computer display and data processing technologies have rapidly evolved, human abilities have remained relatively unchanged. As a result, human capacities now limit or govern the number of alarms that can be managed successfully at any time—particularly in the maritime context. While human design constraints may seem like common sense, numerous incident investigations highlight ongoing concerns about the contrary [1] [2] [3] [4, p. 8] [5, p. 14] [6] [7] [8, p. 18] [9, p. 42] [10, p. 39] [11, p. 6]. This urged us to better understand and report:

1. How well current alarm systems measure up to the expectations of seafaring watchkeepers—the very people expected, entrusted, and ultimately held accountable for responding to the vast spectrum of provisioned alarms aboard today's modern ships? As well as

2. What learnings we can draw from the good practices of adjacent industries in making design and operational decisions that account for end-users' usability? (After all, if alarms are not for the end-users, then who are they for?)

In this paper, we present the key results from this information collection and conclude with suggestions on how to incorporate these learnings into shipborne alarm management practices today. Additionally, we highlight areas for future research to address unresolved aspects of incorporating certain valuable learnings.

2 APPROACH

To stay true to the spirit of Gemba (a Japanese term meaning "where work happens"), we embraced a "Go, Look, See" approach, immersing ourselves in the operational environment to capture the rich narratives and experiences of the watchkeeping seafarers onboard modern ships—a research design decision influenced by an initial literature review, which revealed that similar approaches had proven successful in the process and power industries decades ago.

To foster a psychologically safe environment that encouraged open sharing, we gathered insights from 65 seafarers aboard 15 ships operated by 10 distinct companies. At the same time, we collected more than 2000 hours of operational alarm data from the machinery spaces from 11 of these same vessels, amounting to over 40 million logged events. In addition, bridge alarm data was also collected. This was conducted on two sophisticated technical sister ships (cruise), both in compliance with the IMO's Bridge Alert Management performance standard and assured by an IACS member for enhanced navigational awareness.

A critical sampling criteria was carefully designed to select ships with the best safety performance and overall excess factor. This was based on the proposition that learning what works well is more valuable than focusing on what doesn't. After all, one could spend a lifetime pointing out destinations to avoid, but that wouldn't necessarily guide anyone on where to go. Simultaneously, we believed that challenges identified among the best of the best would likely also be present among those less capable—but not necessarily the other way around.

2.1 Researched site

The visited ships consisted of the following types and segments:

- 1 RO-RO (roll-on/roll-off)
- 4 ROPAX (roll-on/roll-off with passengers as well): Operated and managed by three different companies. Two were fully electric. Another was a hybrid vessel with battery storage as an alternative power source. Another could be powered with a novel fuel type.
- 3 Tankers (Chemical, LPG, Product): Each were owned, operated and managed by their beneficial owners.
- 1 Multi-purpose offshore vessel: Redundant dynamic positioning and fully diesel-electric.
- 1 Tug. Owner operated.
- 5 Passenger cruise ships: Four different companies operated these. Some were among the biggest cruise ships in the world. Others operated smaller and more specialised ships. These ships varied from 6000+ passengers to fewer than 1000 passengers (excluding the crew). Two of these five ships were technical sisters and did not vary in terms of their internal systems.

A common characteristic of the sampled ships; their owners primarily operated multinational companies with annual turnovers exceeding billions of USD. In part of this paper, the ships are labelled as numbers and do not correspond to the order given in the above list.

2.1.1 Sampled ship ages

At the time of sampling, the age of the ships spanned from less than two years after delivery to upwards of 33 years of operation (Figure 1).

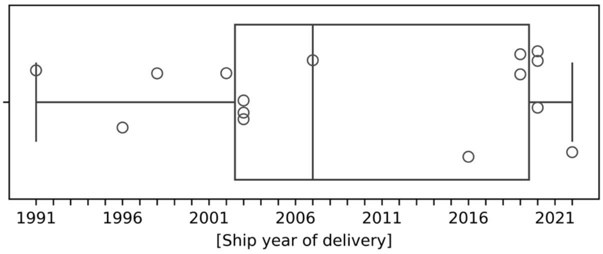

Figure 1. Box and whisker plot of the sampled ship´s ages. Each dot represents a sampled ship.

2.1.2 Sampled seafarers

From the 15 ships, 65 seafarers completed a questionnaire, 34 of whom were engineering officers and 31 of whom were navigational officers (Figure 2). System-specific experience spanned from a few months to 18 years.

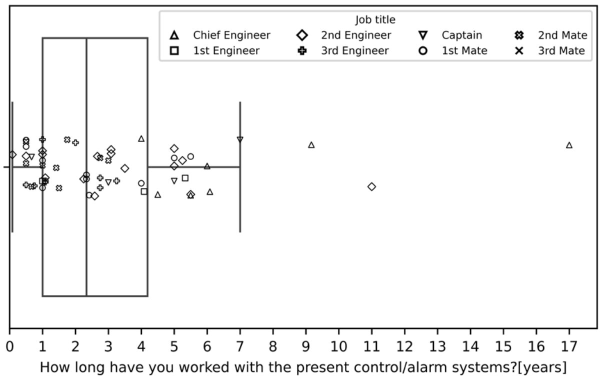

Figure 2. Box and whisker plot of distributions of rank and experience with the alarm/control systems on board.

2.1.3 Configured alarms onboard

Assessing the number of configured alarms onboard the sampled ships was impossible. Instead, we counted the alarms for a range of similar ships recently built to LR class, showing an average of ~32% of the IO budget allocated to alarms (Figure 3).

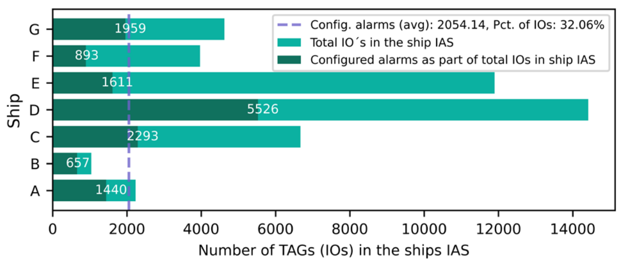

Figure 3. Configured alarms within the integrated automation system (IAS) for seven ships recently built to LR class (NB: not listed in the researched site).

3 RESULTS AND DISCUSSION

In this section, we have emphasised what we believe to be the most pertinent findings. Additionally, we have provided a peek into the quantitative analysis of the engine room alarm performance against internationally recognised practices such as IEC 62682 and EEMUA 191. Over 40 million logged events from the 11 ships' integrated automation system (IAS) were analysed. The sampled ships spanned various segments (Table 1) but did not succeed in sampling the container, bulk, tugs, and naval segments. The Canadian Department of National Defence (DND) made a similar investigation within their fleet, and readers in that sphere should contact the DND Canada for information of their findings.

Table 1. Ships analysed in this work for machinery alarms for engine room alarm performance.

Segment	Ship No[1]
ROPAX	01
Cruise ship	02
Chemical Tanker	03
ROPAX	05
RORO	07
Multi-purpose-offshore supply	08
Cruise ship	09
ROPAX	10
Product Tanker	13
Cruise ship	16
ROPAX	18

[1] Sampled ships assigned randomly between 1 and 20.

3.1 Objective bridge alarm load

The first observation was on a 160-nautical-mile journey from Minorca to Mallorca (Spain), lasting 16 hours from afternoon to the following morning, with calm seas and good visibility (Figure 4).

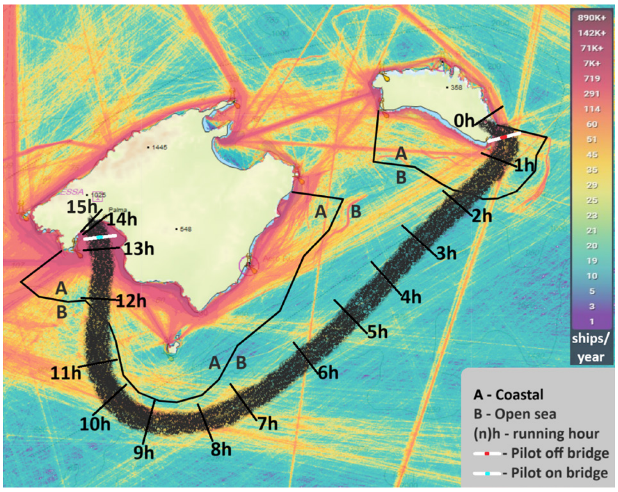

Figure 4. Route 1 sketched on a traffic density map with timestamps and sea areas.

A total of 352 alarms were observed on the bridge, of which 66 came from the ECDIS and 60 from the radar. Another 50 more were either the ECDIS or radar, but the researchers could not tell because the officers acknowledged them so quickly. At the same time, the engine control room (ECR) received 728 alarms, with a peak rate of 111 alarms per hour (Figure 5).

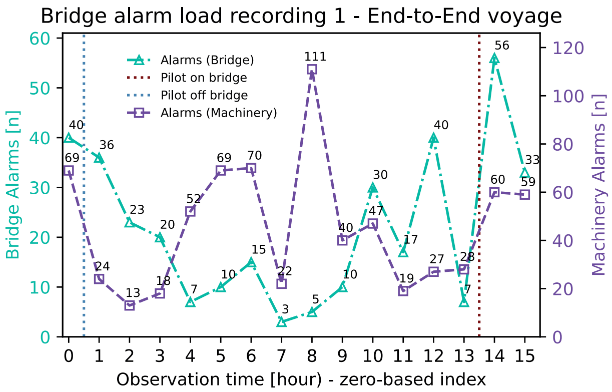

Figure 5. Time series of annunciated alarms respectively from the bridge and ECR during Bridge alarm load recording 1.

In a hunt for peak alarm rates on the bridge, the researchers observed the alarm rates during a voyage from the Mediterranean Sea into the Atlantic Ocean, through the Strait of Gibraltar. A distance of around 55 nautical miles, taking 2 hours and 41 minutes (Figure 6).

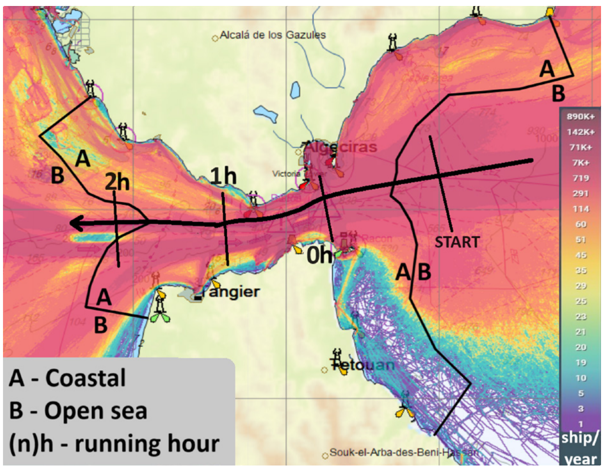

Figure 6. Route 3 sketched on a traffic density map with timestamps and sea areas.

A total of 163 alarms were observed on the bridge, mainly from ECDIS and radar, with a peak rate of 74 per hour (Figure 7). The officers relied primarily on looking out the windows to navigate, rather than using the radar and ECDIS displays.

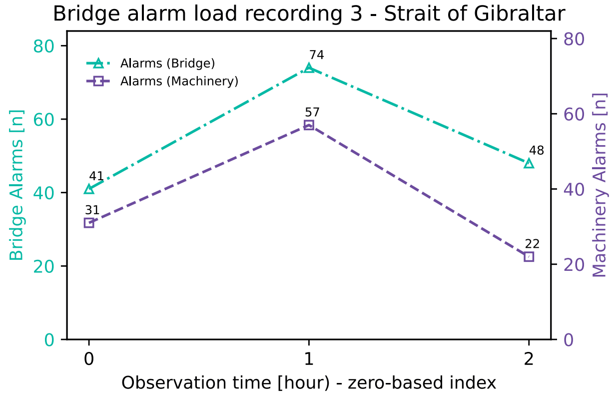

Figure 7. Time series of annunciated alarms from the bridge and ECR during Bridge alarm load recording 3.

3.2 Objective engine room alarm loads

For the engine control room (ECR), historical data from the same vessel of the bridge recordings showed average daily rates of ~2500 alarms per day, with peak rates of upwards of 22,500 (Figure 8). According to the data, a high number of these alarms are never accepted or acknowledged. Instead, they are silenced by the watchkeepers, which effectively renders them “inhibited” from re-annunciation (Figure 9).

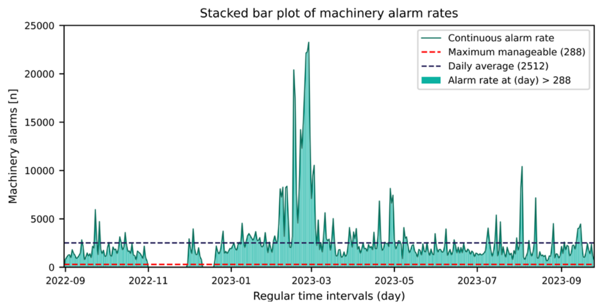

Figure 8. Daily alarm rates – Machinery alarms – the zero values for specific dates indicate missing data, not zero alarms (same vessel as bridge alarm load observations).

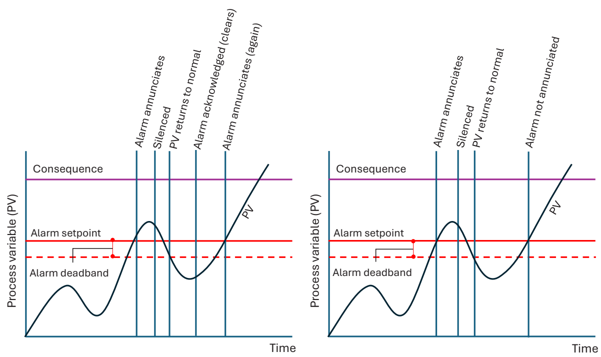

Figure 9. Left (the alarm is annunciated the second time it passes the alarm setpoint), Right (The alarm is not annunciated the second time it passes the alarm setpoint).

Analysis of alarm data from LR's internal records of a passenger cruise ship more than a decade older than the one mentioned above revealed daily alarm rates averaging 1,854, with peak rates nearing 16,000 (Figure 10). These figures fall short of the recommended performance values of adjacent industries, e.g., IEC 62682 or ISO 11064-5.

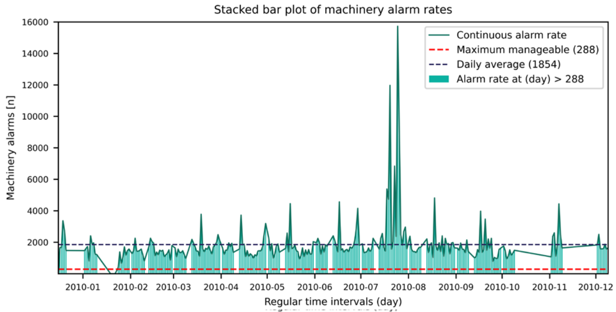

Figure 10. Daily alarm rates – machinery alarms in the ECR for a passenger cruise ship built to LR class in the 2000´s – the zero values for specific dates indicate missing data, not zero alarms.

A third cruise ship constructed in mid-2010 shows very similar average alarm rates of ~1850 per day (Figure 11). It is important to note that the three cruise ships presented were built at different shipyards, nearly a decade apart. This suggests a systemic trend, rather than a few isolated cases.

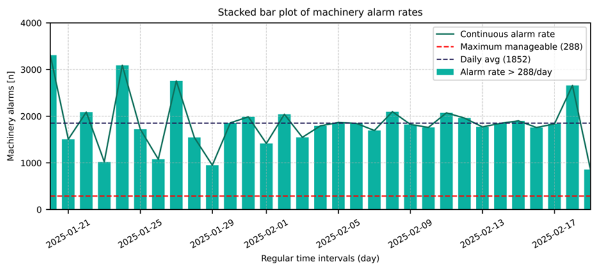

Figure 11. Daily alarm rates – machinery alarms sounded in the ECR for a passenger cruise ship for 30 days of provided data.

Other passenger ship segments (ROPAX) exhibit lower alarm rates, although peak rates can be considerably higher than the averages (Figure 12). Still, two of these ships managed to meet the recommendation for average alarm rates.

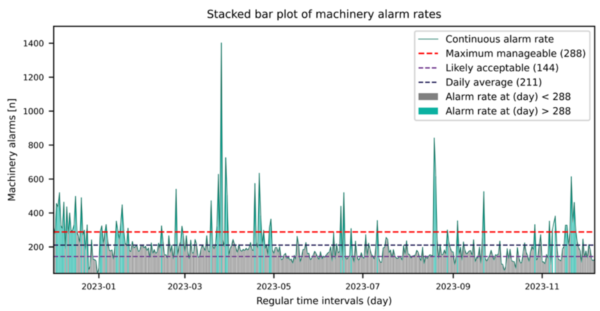

Figure 12. Daily alarm rates – machinery alarms sounded in the ECR for a ROPAX ship built to LR class in the 2000´s.

The limited variability of ROPAX ships' operational patterns opened the opportunity to understand better when and where alarms occur. Here, the temporospatial analysis of the machinery alarms was found to be more heavily concentrated closer to shore and in the port than in the open sea mode of operation (Figure 13).

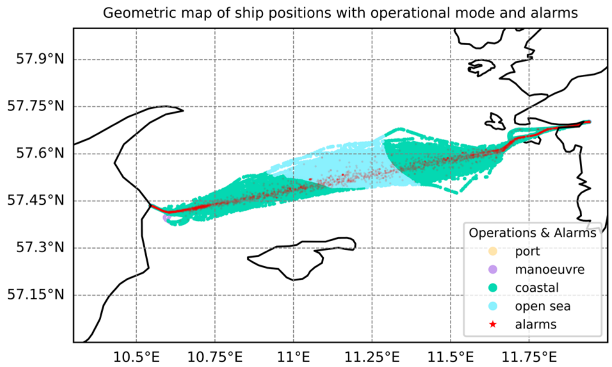

Figure 13. Geometric map of ship positions with operational mode and alarms. On the plot, 10% of the alarm data from one year of operations is randomly sampled without replacement and depicted. Courtesy of Stena Line.

While evaluating the long-term average alarm rate results, one must keep in mind that the IEC 62682 performance recommendations were, at large, envisioned for continuously supervised control rooms. However, on many modern ships, engineers may not always be present in the ECR (unmanned machinery spaces (UMS)).

Many participating ships have such a UMS notation (01, 03, 07, 08, 13) or equivalent. It is important to emphasise that sea trials for UMS operation require the unattended mode to be demonstrated during sea trials over 4-6 hours. This is undertaken while observing alarms and crew intervention in machinery space during the operation [12, pp. Part 6, ch. 1 sec 7]. A long-term average interpretation of the UMS performance criteria could be that 95% of the 4–6-hour regular intervals be alarm-free.

Instead, it was found that between 38-84% of all the 4-6 hourly intervals have at least one alarm. Initially, many of these alarms were expected to occur during daytime hours (regular work periods). However, we found it a high proportion (avg. ~63%) of typical rest periods between 10 PM and 6 AM were disrupted by at least one alarm (Table 2).

Table 2. Ships analysed in this work for machinery alarms for engine room alarm performance.

Ship No.	01	03	07	08	13
Percentage of zero alarms between 22PM to 06 AM	9	6	17	70	62

3.2.1 Alarm distribution

According to the IEC 62682 performance recommendation, the top 10 most frequent alarms should account for no more than 5% of the overall alarm load. Seeing a few alarms impose a significant alarm load is not unusual (Table 3).

Table 3. Percentage contribution of top 10 alarms to overall alarm load.

Percentage contribution of top 10 alarms to overall alarm load (%)	Ship No[1]
90	01
64	02
33	03
28	05
17	07
36	08
12	09
54	10
36	13
30	16
27	18

[1]Sampled ships assigned randomly between 1 and 20.

None of the ships managed to meet this recommended performance. While this may initially seem like a bitter pill to swallow, it does have a sweet aftertaste: considerable improvements can be made with comparable little effort by simply addressing the top 10 most frequent alarms first. Remarkably, every analysed ship provides this opportunity (Figure 14).

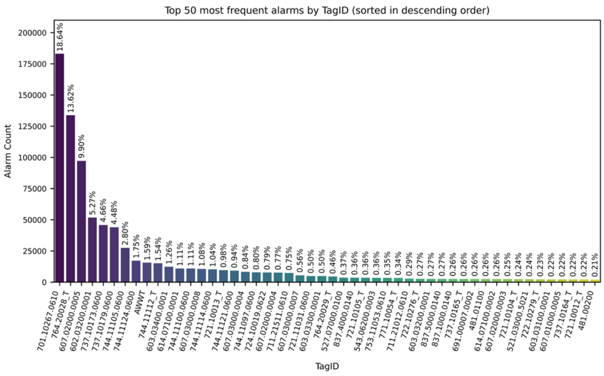

Figure 14. Alarm Count per unique TAG-id. Sorted in descending order; albeit alarm counts vary, all analysed ships exhibit a similar pattern.

It is worth highlighting that, on passenger ships, hotel systems appear to contribute a lot to the alarm load in the ECR. For instance, on Ship 02 (Table 4), the spa pool treatment plant and the technical water chemical dosing system were responsible for approximately 148,000 alarms over the analysed period, with the bioreactor and advanced water treatment plant adding another 149,000 alarms. A crewmember underscores this observation:

’16.4E - As explained by the engineer: "Sometimes spa pool alarms come in every millisecond for minutes; operators take turns sitting and muting them."’ [13]

Table 4. Top 10 most frequent alarms on ship 02.

Alarm Description (Unique)	Alarm counts[1]
POD 1 SB LT	183294
BIOREACTOR 1 10BP	133809
SPA POOL TREATMENT PLANT	97215
TW CHEM DOSING + PH ADJ.	51756
HOT WELL 2 ALARM	45931
HOT WELL 1 ALARM	44414
HFO SETTL. TK 12	27464
HFO STOR. TK 07/08	17232
ADVANCED WASTEWATER TR	15640
HFO OVERFLOW TK 11	15121

[1]Aggregated over a 12-month period of data (2023).

3.2.2 Peak alarm rates

Adjacent industries define peak alarm rates as the maximum number of alarms in any 10-minute period. The IEC 62682 recommendation is that this figure be less than or equal to 10. Regretfully, none of the analysed ships meet this recommendation, with rates significantly exceeding the recommended threshold (Table 5).

Table 5. Maximum number of alarms in a 10-minute period.

Maximum alarm rate within a regular 10-minute interval (n)	Ship No
73	01
2976	02
79	03
191	05
282	07
52	08
4691	09
54	10
21	13
240[1]	16
408	18

[1] Alarm system buffer was limited; the maximum number in an alarm flood was found to be 2823 alarms.

3.3 Watchkeepers' experiences and opinions

A ship-adapted version of the EEMUA 191 operator opinion questionnaire (originally introduced in the HSE Contract Research Report No. 166), was used to capture watchkeepers' feedback. The findings closely mirror the insights of the 96 control room operators surveyed across 15 sites in the late 1990s by Dr. M.L. Bransby [14].

One of the most notable parallels lies in the perception of alarm relevance. When discussing the 10 most typical alarms operators could recall, only 29% were reported as requiring positive action (Table 6). For the HSE survey, the reported figure was 26%—back in 1997.

Table 6. Response distributions when asking the watchkeepers which proportion of the 10 most typical alarms require a positive operator's response.

Q. How many of the top 10 most typical alarms:	ECR [%]	Bridge [%]
Require you to take positive action	32.2	25.5
Cause you to bring up an additional screen an monitor something closely?	23.7	18.3
Are noted as useful information	27.8	25.2
Are read and quickly forgotten	16.3	32

Further, the watchkeepers report that they often find themselves forced to accept alarms without having time to read and understand them, with only 15% of the combined respondents stating this to *Never* be the case (Table 7).

Table 7. Response distribution when asking watchkeepers if they feel forced to accept alarms without time to read and understand them during large upsets.

Q. 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?	ECR [%]	Bridge [%]
Always	38.2	19.4
Mostly	14.7	19.4
Sometimes	14.7	32.3
Rarely	17.6	12.9
Never	14.7	16.1

A point of concern is that while the correct operation of protection systems (safety trips) triggers a flood of alarms, it will be difficult, if not impossible, for the watchkeepers to observe what has failed to trip as required. During a severe alarm flood, the alarm system was reported by the watchkeepers to hinder or distract, leading them to either abandon it as a decision support system or waste a lot of allowable response time trying to silence the highly audible noise of multiple alarms going off at the same time:

´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]

´13.2B – "You have to decide between the alarm list and keeping the ship safe."´ [13]

'16.5E – *"We have to acknowledge them all to be able to think because of the high alarm sound." '* [13]

'16.5B – *"You can only do so much; you get to a point where you just acknowledge alarms without reading it."'* [13]

It must be emphasised that such behaviour is a sensible and expected human coping mechanism. The objective data reinforces these anecdotal testimonies, highlighting the watchkeepers' experiences of being overwhelmed by an excessive number of alarms during critical situations—alarm rates that are undeniably beyond the limits of human capacities.

3.4 Detrimental effects of nuisance alarms

A letter received by the captain of one of the world's largest passenger ships left a profound impression. The captain holds responsibility for the safety of over 6,000 passengers and crew aboard an asset valued at more than one billion USD. The letter expressed deep frustrations with the navigational alarm system and a sense of powerlessness in resolving the alarm fatigue issues (Figure 15).

In discussions about alarm fatigue, we frequently encountered the argument that the crew is already on board anyway and that attending alarms is merely part of a watchkeeping officer's job description. However, the safety implications of this perspective are far more subtle—and far more dangerous.

Every false alarm works to systematically "break" the watchkeepers, reshaping how they think about and respond to alarms—leading to a dangerous normalisation of the abnormal.

The tale of the *Boy Who Cried Wolf* is not merely a cautionary fable; it is a phenomenon repeatedly validated by research and industry, not to mention our observations on the sampled ships [13, pp. 104, 108, 130]. In a maritime safety context saturated with administrative risk controls, the erosion of trust in alarm systems can have catastrophic consequences. A zero-tolerance against nuisance (false) alarms appears essential not only for ensuring reliability but also for maintaining the integrity and trustworthiness of the alarm system.

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

Figure 15. Captains letter [13, p. 75]

3.5 What we can learn from adjacent industries

Comparing good practices of adjacent industries with the Maritime Industry's Code on Alerts and Indicators, it was found that adjacent industries have acknowledged human limitations as the fundamental design constraint for alarm systems. This contrast is most apparent in the following systemic gaps:

1 No explicit attention to the quality attributes of provisioned alarms.

2 A lack of consideration for the assessment of alarm system integrity.

3 A complete absence of quantitative (objective) performance metrics for the collective sum of provisioned alarms (alerts). Both at the design stage and during operations.

4 In general, timeliness for time-critical actions is not contemplated.

In addition, adjacent industries adopt a bottom-up approach called Rationalisation, aimed at ensuring that the initially (many) proposed alarms for a given asset meet specific quality criteria. If system design issues are propagated into the operational stage (using alarms), designers are sent back to the drawing board.

Anecdotes from large research programmes in abnormal situation management indicate the effectiveness of this design process [15]. For example, two pairs of similar manufacturing units were compared for alarm system performance at a specific site. The newer units had approximately 40% more tags than the older units but were fully rationalised, while the older units had little to no rationalisation. During a three-month data collection period, the older units operated steadily, while the newer units experienced a plant trip in the first month. Comparing the units:

1 There the newer units maintained an average alarm rate of about 1 alarm per 10-minute period during steady operations.

2 The older units had alarm rates up to 7 times higher per minute, even without trips.

3 Excluding the month with the plant trip, the older units had alarm rates up to 20 times higher than the newer ones

4 The older units also experienced 2-3 times the number of alarm bursts (defined as more than 10 alarms in 10 minutes) compared to the newer units, despite the newer units experiencing trips.

3.6 Pilot results of alarm load reductions

As part of the research, it was investigated how much the alarm load could be reduced on a complex platform (cruise ship) following the life cycle practice outlined IEC 62682 (entering the lifecycle at step H *Performance monitoring and assessment*).

One of the authors of this paper was invited by the owners of ship 02 to test the practicalities of improving the alarm system performance based on their initial performance results. Over a seven-day period, an onboard alarm improvement campaign was conducted in collaboration with the ship's engineering crew to eliminate the top 10 most frequent alarms. It was noted that these had changed (Table 4 vs Table 8), which underscored the need for continuously monitoring performance.

Table 8. Top 10 most frequent alarms on ship 02.

Alarm Description (Unique)	Alarm counts[1]
BWTS HEARTBEAT ALARM	56058
TW CHEM DOSING + PH ADJ	41691
MGO EDG TK LVL (level low)	28134
POD 1 SB LT (low pressure)	22613
AWWT Non-Critical	15581
HFO SETTL. TK 12 (Temp. high)	15551
HOT WELL 1 ALARM (Temp. low/high)	13669
HOT WELL 2 ALARM (Temp. low/high)	13477
HFO STOR. TK 11/12S (Temp. high)	8511
BIOREACTOR 1 10PB (Level high high)	8336

[1]Aggregated over a 6-month period of data (2024-2025).

During the seven days onboard, it was possible to address 6 of the top 10 most frequent alarms. Retrospectively, these six TAGs accounted for 101,925 alarms in the 6 months (~21%). For the remaining four, significant information about their causes and remedies was obtained. The shipowner subsequently addressed these, yielding a further retrospective reduction of 121,600 alarms (~27%).

The underlying causes of the top 10 alarms varied significantly. Some had simple fixes, such as topping up a tank, while others required days of investigation and resolution. In nearly every case, the alarms stemmed from insufficient commissioning and process tuning. For example, the low-temperature alarms for Hot Wells 1 and 2 (part of the ship's steam plant) were caused by two 3-way valves being incorrectly mounted, resulting in their PID controllers operating inverse of intent.

Thus, ensuring correct tuning of physical processes and field instrumentation appears vital—fixing the process first. Without this first step, removing alarms or adjusting the alarm settings could have obscured underlying issues.

4 CONCLUSION

We set out to answer the following:

1. How well current alarm systems measure up to the expectations of seafaring watchkeepers—the very people expected, entrusted, and ultimately held accountable for responding to the vast spectrum of provisioned alarms aboard today's modern ships? As well as

2. What learnings we can draw from the good practices of adjacent industries in making design and operational decisions that account for end-users' usability? (After all, if alarms are not for the end-users, then who are they for?)

To accomplish this, we gathered insights from 65 watchkeeping officers from both the bridge and the engine control room, covering a wide range of ship segments. Additionally, we analysed +40M events from alarm system event logs, extracted from 11 ships, comparing them with performance metrics from IEC 62682:2014. We contextualised these objective results with the anecdotal experiences shared by the watchkeeping officers.

4.1 Does the alarm system measure up to expectations?

With respect to the first question, the objective performance results generally align with the subjective experiences shared by the watchkeepers, indicating that they are relevant to the maritime industry. We also confirm that some ships are already achieving some of the recommendations for alarm system performance in relation to widely recognised accepted good (engineering) practices (IEC 62682, EEMUA 191), with some caveats.

Based on the seafarers' narratives, many of the visited ships suffered to a major degree from the same two common complaints:

1. there were too many alarms during upsets, and

2. too high a proportion of them were nuisance alarms of little operational relevance.

It is important to recollect that these ships were sampled from the best performing segments using a rigorous set of sampling criteria. The challenges revealed herein may well be just the tip of an iceberg.

In particular, it appears that cruise ships may experience notable challenges related to alarm overload. Analysis from three independent cruise ships, each built nearly a decade apart (at different yards), show alarm rates ranging from approximately 1600 to 2600 per day (Figure 8, Figure 10, Figure 11). These figures are further supported by a letter received from the captain of a different cruise vessel, which reported 2100 per day in the Engine Control Room (ECR) averaged over the course of a week [13, p. 75 Table 9]. These ranges likewise appear to be in line with the accounts provided by seafarers. For instance, in our previous work, ship number 4 reported an average of 70 alarms per hour [13, p. 101 Table 13]. This would aggregate to around 1600 alarms per day, although specific data was not provided for analysis from that ship.

At the same time, peak rates on the cruise ships were found to reach 2900 to 4600 alarms within 10 minutes—and within the integrated automation system (IAS) alone (Table 5). These numbers align with findings of incident investigations such as the Viking Sky:

"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." [11, p. 6].

In summary, the objective data shows significant room for improvement—for all vessel types. Many ships with UMS notation had more than one alarm every four to six hours.

4.2 What learnings can be drawn?

Good alarm system performance is within reach. To get there, a holistic approach combining qualitative and quantitative methods charts this critical path. The quantitative (data-driven) method of using objective performance monitoring helps ensure the alarm system stays in Shipshape Bristol Fashion. At the same time, the qualitative top-down approach of alarm rationalisation can help validate the quality of the qualitative engineering effort invested in each alarm signal—and the human expectations at the other end.

We encourage owners with existing ships to get a head start by first addressing the top 10 most frequent alarms with an average alarm load reduction potential of ~39% on average (Table 3). Our first pilot study on reducing the alarm load onboard ship 02 showed that this was achievable with justifiable means. Further it shows that we do not need refined measures of human performance techniques to address identified problems and set targets for improving them, supporting similar conclusions drawn in earlier work [14, p. 18].

4.3 Final remarks

Given the apparent scale of alarms on modern ships and the number of incidents attributed to human error, it appears that challenges at the interface between technological systems and human operators are becoming more apparent. It would only seem productive to identify and address the factors that lead humans to fall short of our expectations. Yet, to overcome that issue in our industry, the limitations, strengths and weaknesses of both partners, human and machine, must be recognised. The strengths of both must be leveraged. The weaknesses minimised.

Think if drivers were expected to maintain a safe distance from the car ahead using only a forward collision warning—or to stay in their lane relying solely on lane departure alerts. Imagine if cars were deliberately designed this way, with no windshield or windows, based on the argument that "driving" the operator's actions through alarms alone achieves adequate safe control. Indeed, few would agree with that approach. The analogy highlights that a clear view or window into the situational context is what users really need to operate a highly complex platform. And do so safely and efficiently. Good situational awareness goes a long way in preventing alarm scenarios in the first place. After all, (most) people have managed to keep their cars in the lane for decades without lane departure warnings. In summary, counting on a watchkeeping officer to wait for an alarm before engaging with the system is a rather poor use of a human. Rather than over-optimising alarms for the sake of alarms, it is perhaps worth asking: Can this information be made available by better means?

5 ACKNOWLEDGMENTS

We thank LR and the participating parties for allowing us to present this information in an open forum. We would further like to thank Magnus Selvejer, Mark Munch-Jacobsen, and Nicklas Schaldemose Jensen, who worked with this subject in collaboration with LR while undertaking their final thesis.

6 REFERENCES

[1] Danish Maritime Accident Investigation Board, "Stena Scandica - Maine accident report on fire," DMAIB, DK-4220 Korsoer, 2023.

[2] Marine Accident Investigation Board - UK, "Report on the investigation of the catastrophic failure of a capacitor in the aft harmonic filter room on board RMS Queen Mary 2 while approaching Barcelona," MAIB, Southampton, UK, 2011.

[3] Danish Maritime Accident Investigation Board, "EMMA MÆRSK - Flooding of engine room on 1 February 2013," DMAIB, DK-2500 Valby, 2013.

[4] Accident Investigation Board Norway (AIBN), "INTERIM REPORT 12 NOVEMBER 2019 ON THE INVESTIGATION INTO THE LOSS OF PROPULSION AND NEAR GROUNDING OF VIKING SKY, 23 MARCH 2019," AIBN, 2001 Lillestrøm, NO, 2019.

[5] National Transportation Safety Board, "Collision between Cargo Ship Damgracht and AP Revelin," NTSB, 2023.

[6] Maersk Line, "Maersk Eindhoven-103N encounters harsh weather Transpacific 6 service," Maersk, 19 February 2021. [Online]. Available: https://www.maersk.com/news/articles/2021/02/18/maersk-eindhoven-103n-encounters-harsh-weather-transpacific-6-service. [Accessed 23 February 2023].

[7] Marine Accident Investigation Board (UK), "Collision between general cargo vessel Scot Explorer and gas carrier Happy Falcon," Marine Accident Investigation Branch (UK), 5 March 2024. [Online]. Available: https://www.gov.uk/maib-reports/collision-between-general-cargo-vessel-scot-explorer-and-gas-carrier-happy-falcon. [Accessed 14 March 2024].

[8] Maritime Safety Investigation Unit (Malta), "Safety investigation into the grounding of the Maltese registered container ship Kea Trader," Maritime Safety Investigation Unit, MRS 1917, 2018.

[9] Danish Maritime Accident Investigation Board (DMAIB), "UMOE VENTUS Fire on 23 December 2015," DMAIB, Copenhagen, 2016.

[10] Australian Transport Safety Bureau (ASTB), "Engine room fire onboard MPV Everest - Southern Ocean on 5 april 2021," ASTB, Canberra, 2023.

[11] Norwegian Safety Investigation Authority (NSIA), "Report on loss of propulsion and near grounding of Viking Sky, Hustadvika, Norway 23 March 2019," NSIA, NO-2001 Lillestrøm, 2024.

[12] Lloyds Register, "Lloyd's Register Rules and Regulations," in Rules and Regulations for the Classification of Ships, London, Lloyd's Register Group Limited, 2023.

[13] Lloyds Register, "Lloyd's Register Alarm Management in the Maritime Industry - Volume 1 - A field investigation into the watchkeepers´ experiences on watchfulness in a connected world," Lloyd's Register, London, 2024.

[14] Bransby, M. L.; Jenkinson, J., "The management of alarm systems - A review of current practice in the procurement, design and management of alarm systems in the chemical and power industries," UK Health and Safety Executive, London, 1998.

[15] Dal, Vernon and Reising, "Achieving Effective Alarm System Performance: Results of ASM Consortium Benchmarking against the EEMUA Guide for Alarm Systems," The ASM consortium (Abnormal Situation Management) - Honeywell, Atlanta, 2005.