Mitigating Alarm Fatigue in Ship Bridge Operations: The Role of Speech Alarm in Enhancing Navigational Safety

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المستخلص

تُصبح مشاكل إرهاق الإنذارات مصدر قلق على السفن الحديثة. الإنذارات المستمرة التي لا يتم وصف دلالتها بشكل صحيح تكفي فقط لتشتيت انتباه ضباط الملاحة عن مهامهم الملاحية. هذه التحذيرات، عندما يتم عدم الاستجابة اليها أو تجاهلها، تزيد من خطر تعريض السلامة للخطر. ومن هنا يأتي الإرهاق الذهني. تدرس هذه الورقة البديل الممكن: إنذارات صوتية تقدم رسائل واضحة وطبيعية باللغة كما تفعل خرائط جوجل مع السائقين. خلال سيناريو المحاكاة، تم تقسيم ١٢ ضابط ملاحة مرخص إلى مجموعتين تقومان بإجراء اختبارات المحاكاة. أجرى أحد المجموعتين الاختبارات عند تلقي إنذارات صفير عادية، بينما سمعت المجموعة الأخرى إنذارات صوتية مع تعليمات من المدرب. تم قياس العبء العقلي، وأوقات الاستجابة، والاستجابات الصحيحة للإنذارات من خلال استبيان NASA-TLX.

انتهت الدراسة ببعض النتائج الحاسمة: كانت إنذارات الصوت أكثر قابلية للتنبؤ بها من قبل ضباط الملاحة (٢٢٪ مقابل ٧,١٪)، وتفاعلوا بشكل أسرع (٤,٢ ثانية مقابل ٦,٩). كما بدا أن هناك علاقة سلبية بين الإحباط والأداء: كلما انخفض التوتر، زاد الأداء ($r = -0.979, p < 0.01$) ذكر العديد من المشاركين أن إنذارات الصوت كانت أسهل في الفهم، وتقلل من الطلب العقلي، والطلب الجسدي، والطلب الزمني، والجهد. تُظهر نتائج هذا البحث أن إنذارات الصوت تتمتع بإمكانات هائلة في تخفيف إرهاق الإنذارات وتعزيز سلامة الملاحة في البحر. يجب النظر في دمج مثل هذا النهج في صناعة البحرية لإجراء تعديلات مستقبلية على معايير إنذار المنظمة البحرية الدولية.

Abstract

Alarm-fatigue issues become a safety concern on modern ship bridges. Continuous alarms whose connotation is not properly described are just enough to distract navigation officers from their navigational tasks. These warnings, when delayed or neglected, track the risk of compromising safety. Hence the mental exhaustion. This paper studies one such feasible alternative: speech alarms giving clear and natural language messages in the way Google Maps instructs drivers. During the simulation scenario, 12 licensed navigation officers were divided into two groups performing simulator tests. One group undertook tests when being given regular beep alarms, while another group heard speech alarms with pertinent instructions and context from instructor. Mental workload, reaction times, and correct responses to alarms were measured through the NASA-TLX questionnaire. The research ended with some definite findings: speech alarms were more often predictable by navigation officers (22% vs. 7.1%), they reacted faster (4.2 seconds versus 6.9). There also appeared to be a negative correlation between frustration and performance: the lower stress, the higher performance (r = -0.979, p < 0.01). Several participants stated that the speech alarms were easier to comprehend, and reduce mental demand, physical demand, temporal demand and effort. This research results show that speech alarms suffer a huge potential in alleviating alarm fatigue and in the enhancement of navigation safety at sea. Integration of such an approach into maritime industry should be considered for future amendments into the IMO alarm standards.

Keywords: Alarm fatigue, bridge operations, speech alarm, human factors, maritime safety, Google Maps voice, navigational alert systems

1- Introduction

The safety of modern ship bridge operations requires that navigation officers continuously monitor and interpret information from a range of systems such as Electronic Chart Display and Information Systems (ECDIS), radar, Automatic Identification Systems (AIS), central alarm management, engine room monitors, and communication equipment. Alarm systems are intended to be an important component of maritime safety by alerting bridge crews to navigational hazards, equipment failure, besides other hazardous conditions (Xi, 2024). However, with the huge amount of information being processed and the potential for false alarms, it is essential that navigation officers are properly trained to effectively manage and prioritize alarm notifications. Effective communication and coordination among bridge team members is likewise critical in ensuring alarms are being responded to in a timely fashion and that appropriate actions are being undertaken to address any risks. Lastly, the effectiveness of alarm systems in ensuring maritime safety depends on the vigilance, skills, and collaboration of the navigation officers on board (Liu and Guo, 2023).

Alarm fatigue, a condition where too many or poorly prioritized alarms overload operators to the point where they react slowly, become situation-aware, and, in severe situations, ignore important notifications, is a problem that shipping is increasingly experiencing (Koppaka and Valsan, 2024). Human cognitive capacity is limited, as research indicates; persons are capable of processing five to nine pieces of information at a time. An excess of auditory alerts within high-stress operating conditions, such as those found on ship bridges, may cause tunnel vision, as operators fail to perceive key cues due to disjointed or overly focused attention (Boppudi et al., 2024).

Human cognitive capacity is limited in how many stimuli can be effectively processed at once. Nikkinen (2018) points out that most people can manage about five to nine items at a time, and when attention is focused too narrowly, important signals can be missed because of this tunnel vision. In this situation, too many or poorly prioritized alarms disrupt situational awareness, slow down reactions, and may cause navigation officers to override or ignore critical alarms that can affect the safety of navigation. Alarm fatigue can lead to frustration, loss in awareness, slower decision-making, and precipitate silencing of alarms, all of which threaten bridge safety (Kane-Gill et al., 2017). However, the usage of speech alarms, which substitute intelligible, natural-language messages for conventional beep tones, is one possible approach. Speech alarms can transmit precise information and directions, much like voice navigation systems like Google Maps (Xi, 2024). This could improve comprehension, lessen cognitive burden, and enable quicker and more precise operator replies. Speech alarms have the ability to enhance general situational awareness and decision-making in high-stress situations by offering context and real-time guidance. This technology has the potential to completely change how alerts are interpreted and handled across a range of industries, resulting in safer and more effective operations (Koppaka and Valsan, 2024).

To assess this problem, this research explores a new approach: replacing traditional beep alarms with speech alarms. These speeph alarms provide clear, natural-language instructions, similar to intelligent speech assistants like Google Maps. The goal is to make alarms more informative and easier to act on, reduce mental demand, physical demand, temporal demand and help navigation officers respond more quickly and accurately.

2- Research Background

2-1 Alarm Fatigue in Maritime Operations

Alarm supervision remains an actual problem in effective operation of navigation equipment. Low priority or overload alarms may put an important burden on the navigation officers, generating potential distraction and mental overload. Maglić (2020) authored that in a single typical watch, a navigation officers spend approximately 22.4 minutes managing 64 different actions triggered by 16 alarms. These repeated alarms not only demand much attention but also possibly divert attention away from important navigational tasks. Surprisingly, research indicated that 45% of these alarms were considered to be annoying and over-emphasized, even leading to alarm fatigue and reduced responsiveness to actually critical alerts. Such evidence emphasizes the need to improve alarm design and prioritization mechanisms to enhance situational awareness and overall navigational safety. (Maglić L, 2020). Alarm fatigue in maritime circumstances is a widely discussed safety concern. Lloyd's Register (2024a) found a 197% increase in audible alarms on ship bridge since the year 2000. Alarms are typically non-emergency or spurious and tend to be ignored or silenced by navigation officers. In 2017 bulk carrier grounded in Malacca Strait due to the disregard of depth warnings (MAIB, 2020).

According to InterManager (2019), 89% of navigation Officers often faced frequent distractions from alarms, and 66% felt that these alarms were not easy to identify or not important. Recent study demonstrated in figure 1 based on Lloyd’s Register (2025) viewed more than 40 million alarm-related events over 2,000 operational days from integrated automation systems of 11 commercial vessels. This huge dataset was compared with internationally recognized performance criteria as per IEC 62682:2014 and EEMUA 191, showing that the majority of alarms are far from the prescribed limits and, hence, there is a system inefficiency in bridge alarm configuration and prioritization (Lloyd’s Register, 2025). The findings support the necessity for context- dependent and human-centered alarm design, which, in turn, justify alternate developments such as speech alarms.

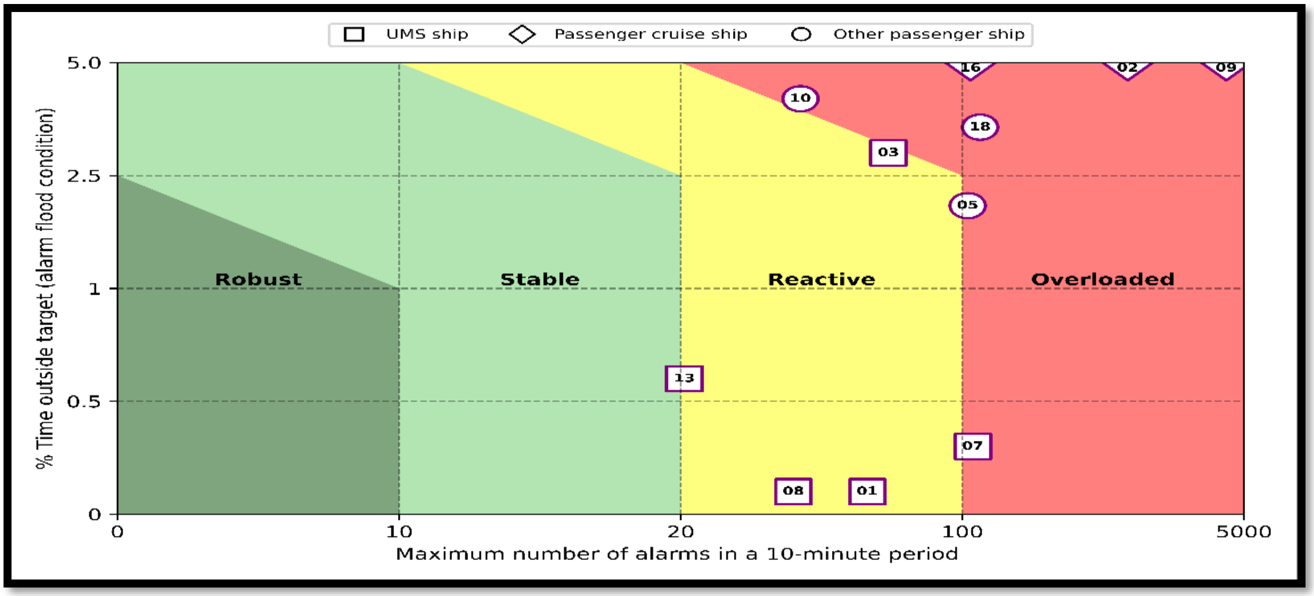


Figure 1: Alarm system performance in upset states for participating ship types
Source: (Lloyd's Register, 2025)

2-2 Alarm Fatigue in Other Sectors

Alarm fatigue is reported across various safety and critical sectors, where the accumulation of alarm leads operator to confusion, delayed responses or neglect alarm system. In healthcare, mainly in intensive care units (ICUs), research found that clinicians are often received plenty alarms per shift many of which are either false or non-important. Recent research by Cvach et al. (2022) demonstrate that such alarm overload has been directly linked to missed or delayed responses to critical events, eventually exposing patient care and medical outcomes. The aviation sector has challenged similar, mostly during important tasks such as takeoff or landing. Wu et al. (2024) assess several types of aviation alerts and found that numerous of ambiguous alarms lower the pilot performance and situational awareness. Their findings show how poorly designed alarm systems can lead to human error, especially when auditory participates with time-critical decision-making.

In recent years, much attention has been given to advances in alert management applied to reduce alarm fatigue in aviation and health care sectors. A hierarchical filtering of alarms, contextualized alerting, and a voice interface were all shown to reduce physical overload and improve an operator's decision-making ability (Wen et al., 2025; AHRQ, 2024). These techniques apply with much relevance to the maritime industry, where navigation officers face similar challenges while using bridge equipment during navigational watch, especially in coastal waters alarms increase that act negatively to erode the officers' situational awareness and ability to respond efficiently. Lloyd's Register (2024) suggests Learn from aviation, the time is ripe for the evolution of ECDIS alarms into more intelligent and user-focused systems. Latest update from IMO's S-100 framework and the structured integration of historical casualty data pave the way for smarter, context-aware alerts generated against a background of real-time environmental and navigational conditions (IHO, 2024; Lee et al., 2025).

2-3 Human Cognitive Response to Speech

Recent research by Wu et al. (2024) examined the impact of different alarm types ear cons, auditory icons, and speech alarms on pilot performance in aviation simulations. Their findings verified that speech alarms reliably produced lower cognitive workload, mental demand, physical demand and temporal demand as measured by NASA-TLX, and faster reaction times, the efficiency of speech alarm in working environments where timely decision-making is critical. In addition, Wickens' Theory which suggests that distributing tasks across separate cognitive channels such as speech instructions reduces information processing overload in maritime bridge operations, where navigation officers manage instantaneous tasks from radar, ECDIS, AIS, and VHF, speech alarms can consequently improve cognitive stress and enhance situational awareness (Shehata et al., 2023 ; Wickens et al., 2020). Also, the idea that speech alarm enhances task performance by reducing visual confirmation and allowing faster responses. This idea strengthens the case for integrating speech alarm systems in navigation environments to mitigate alarm fatigue and optimize human system interaction (Wu et al. 2024).

2-4 Google Maps as a Model for Speech Alarms

Google Maps delivers a familiar implemented model for real time speech navigational alarm, which can propose perceptions for bridge alert systems. Key features of Google Maps' voice interface include: Anticipatory phrasing for enhancing the probability of timely and accurate responses. Progressive prompting Instructions intensify as the decision point nears to ensure urgency is appropriately conveyed. Conversational tone for reduces user stress and avoids startling the driver, thereby improving user receptiveness and confidence (Google Design, 2024). These techniques can directly update the design of maritime speech alarm systems, especially within complex interfaces such as ECDIS. For example, instead of beep or visual indication, a speech alarm might announce: "Caution: crossing safety contour." Recent design principles by Google Design (2024) support natural voice language communications that prioritize user cognition and minimize mental and physical demand. These include voice recurrence options, customizable urgency sceneries, and human natural phrasing, all theoretically can be transferable to maritime alarming systems. Adopting such strategies would allow alarm systems to become more instinctive, less disturbing, and more actionable, thereby reducing alarm fatigue and enhancing situational awareness on the bridge team.

3- Literature Review

Previous research shows an overall congruence on the importance of developing speech alarm systems in high-risk industry such as the maritime sector, with a particular focus on the mental and physical impact of these systems on individual performance and operational safety. (Kim, J. and Song, H., 2024) established the efficiency of user-generated speech alarm in enhancing awareness and accomplishing successfully daily tasks. These outcomes are consistent with what was shown by (Deschamps et al., 2024) that showed that sounds designed in a qualitative and specific manner improve response and reduce mistake in identifying an occurrence compared to beep alerts or traditional alerts. These results support the findings of (ASALOMIA et al., 2025) that used artificial intelligence to evaluate and classify maritime alerts, as it demonstrated that precise classification and intelligent alerting improve situational awareness, which contributes to supporting effective decision-making.

On the other hand, the most prominent (Kuparinen-Koho 2020, Dewi 2025), such as the importance of taking into account human factors and complex digital environments, showed that poor system design and increased complexity lead to a deterioration in situational awareness and increased mental stress and technical fatigue among users, which intersects with the results of (Öcal 2025) where it was found that excessive reliance on digital systems without sufficient arrangement leads to unsafe behaviors and a decline in the efficiency of maritime surveillance. Although the study does not directly address the navigational context, the communications emphasizes the importance of self-awareness and methodology in conducting field awareness in a sensitive environment, which is an aspect that can be used methodologically to understand the psychological and mental contexts of navigational officers when exposed to a high density of alerts. Therefore, there is agreement among furthermost research that designing speech alert systems in a clear, directed manner that considers human factors can increase awareness, reduce incidents, and improve safety. Furthermost likewise approve that poor training, excessive confidence on technology, and poor interface design epitomize extreme challenges that must be addressed. After the researches focused on alert systems in healthcare, while others focused on the maritime sector, but taken together they provide a solid scientific framework to support the importance of targeted speech alerts as a means of improving decision making, situational awareness and safety in the maritime industry.

Researches illustrate cumulative concentration in the problem of alert fatigue and mental load linked with critical work environments, especially in intensive care units and vessel navigation bridges, where conditions are considered by dense information, restricted time, and quick decision-making. (Shanmugham et al., 2018, Seok et al., 202, Salameh et al., 2024, Guo et al., 2021) agree that frequent alerts that are not designed according to human factors principles contribute directly to increased cognitive load, which negatively affects employee performance and increases the probability of human error.

In addition, (Shanmugham et al., 2018) demonstrate that regulating clinical alert settings based on the patient's condition directed to a decrease in mental load and an improve decision making, which meets with the outcomes presented (Guo et al., 2021) on the importance of informal and resilient design in vessel navigation bridges to reduce mental load and improve response in emergency situations.

Despite the diversity of researches that have addressed the topic of alert fatigue, mental load, and the impact of alert interface design on human performance, there are several aspects that still need in-depth study. First, most of the literature focuses on medical environments such as intensive care units, while navigational environments, especially the navigational bridge environment, are almost absent from the study in terms of experimental analysis of the effect of alert density on navigational officers while performing tasks in realistic or simulated scenarios. Second, there is a deficiency of researches that demonstrate the efficiency of speech alerts compared to traditional beep alerts in relations of their impact on quick decision making, high level of situational awareness. The literature also demonstrates the lack of navigation officers in perceive and process different types of alerts under conditions of time and information pressure. Third, most studies do not adopt an integrated methodology that combines self-assessments of mental impairment, such as the NASA-TLX scales, and behavioral indicators such as response time. Psychological indicators such as stress and mental fatigue in the contexts of field work or realistic simulation, especially in maritime environments. Fourth, theoretical frameworks think of comprehensive models that link alert systems, human factors, mental and behavioral performance, and the level of operational safety. There is also a deficiency in integrating these concepts within training and operational policies specific to the field of maritime navigation, which limits the effectiveness of applying human-centered design concepts in improving the efficiency and safety of navigation operations.

This study addresses an important gap in the existing literature through an empirical examination of the effectiveness of speech alert system in a vessel marine bridge setting, to date a topic not fully researched. It presents experimental evidence that shows speech alerts alleviate mental demand and improve physical demand, temporal demand, improve situation awareness and decision making compared to beep alerts. It also emphasizes the importance of including human factors in alarm system design and provides working guidance to advise and support maritime training.

4- Methodology: Evaluating Speech Alarms in ship Bridge Operations

This experiment uses a multimethod experimental design consisting of performance based quantitative measures with objective data and e-based qualitative measures to determine the effectiveness of speech alarms for ship bridge operations. Twelve navigation officers with sea experience were randomly assigned to control and experimental groups to which they were subjected to traditional beep alarms and to speech alarms, respectively. Solo simulation scenario was conducted by each subject on a full-mission bridge simulator at AASTMT, configured to simulate real-world maritime conditions. Objective metrics response times and number of accepted alerts were collected through simulator logs. Subjective cognitive workload was measured after scenario completion by the NASA Task Load Index (NASA-TLX), a subjective measure of perceived workload across six dimensions. Performance was further analyzed by assessing the association of frustration ratings with task performance using the Pearson’s correlation coefficient. This methodical approach allowed for the collective assessment of the impact of different alarm modalities on daily performance and mental workload in the ship bridge operations.

4-1 Participant Profile and Scenario Development

Twelve navigation officers who had attended Bridge resource management course trainings at AASTMT participated in the research, all participants had sea experience. participants were randomly assigned into two equal groups: Control Group (exposed to traditional beep alarms) and Experimental Group (exposed to contextual speech alarms). A simulation of a bridge navigation was performed by each of the navigation officers individually to reduce the effect of groupthink on decision making. Two scenarios were generated and executed using AASTMT full-mission bridge simulator: one of them representing normal sea conditions that might typically be encountered during maritime operations and the other representing poor sea conditions with: Moderate traffic, Complexity of environmental conditions, and the Common ECDIS, radar and engine alarms. The simulation was controlled by two instructors to maintain identical timing and content of critical alerts across both groups. In the beep group, alerts were communicated with traditional beeps. In the speech group, the instructor delivered real-time speech alerts via intercom using natural, context-rich phrases.

4-2 Data Collection Tools

To assess both objective performance the following tools were used:

- Simulator logs to record: Reaction times to alerts and Number of acknowledged responses
- (NASA-TLX) questionnaire, was applied in the end of simulation scenario to evaluate six dimensions of perceived: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration to assess the subjective cognitive workload experienced by participants, the research applied the (NASA-TLX) a widely validated tool in human factors research. After finishing each simulation scenario, participants rated each dimension on a scale from 0 (low) to 100 (high), providing a complete profile of their perceived workload. This method allows to comprehend how different alarm impact mental stress and decision-making effort. NASA-TLX is generally appropriate in maritime studies, where high-stress industry and complex multitasking are communal. Its presence in this research enhances the strength of the findings by relating objective performance data with subjective human experience.

4-3 Performance Metrics

The following dependent variables were used to compare two groups performance:

Table 1: Performance Metrics

Metric	Description
Reaction Time	Time (in seconds) from alarm onset to corrective action initiation
Acknowledged Responses	Count of alarms that were responded to correctly within a reasonable timeframe
Subjective Workload (NASA-TLX)	Scores from 0–100 for each cognitive demand dimension, self-reported by officers' post-task

Metric	Description
Frustration-Performance Correlation	Pearson correlation used to explore the relationship between perceived frustration and performance outcomes

This structured approach allowed for a strong comparison between beep and speech alarms, evaluating both task efficiency and cognitive impact under operational conditions.

5- Analysis and Results

The simulator experiment intended to compare the effectiveness and cognitive impact of beep alarms against speech alarms during bridge operations. total of 12 licensed navigation officers participated in the research, with 6 officers randomly assigned to each group (beep alarms vs speech alarms). Navigation officers in the research, consistently divided between (beep alarm group) and (speech alarm group). Independent samples t-tests were conducted to determine the significance of differences in reaction times and Acknowledged Responses between the two groups.

Table 2: Independent Samples t-Test: Reaction Time and Acknowledged Responses

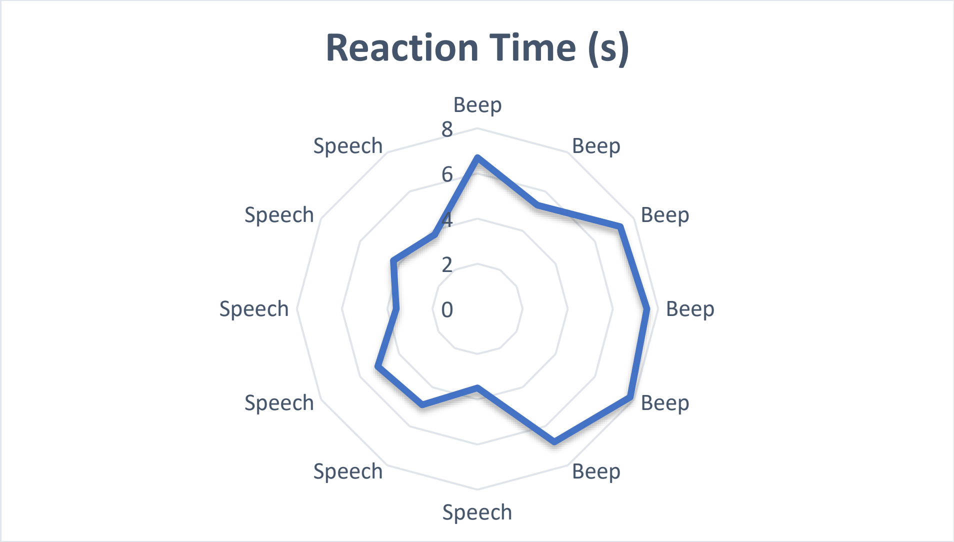
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Reaction Time Beep	19.040	5	.000	6.90000	5.9684	7.8316
Reaction Time Speech	15.103	5	.000	4.20000	3.4852	4.9148
Acknowledged Responses Beep	5.736	5	.002	7.16667	3.9549	10.3785
Acknowledged Responses Speech	35.383	5	.000	22.03333	20.4326	23.6341

5-1 Reaction Time

Reaction time, defined as the interval between alarm activation and the officer's initiation of corrective action, was expressively lower in the speech alarm group. The mean reaction time is higher for the Beep group (6.90 s) compared to the Speech group (4.20 s). The standard deviation is higher for the Beep group (0.89 s) compared to the Speech group (0.68 s). This reduction shows that speech alarms provided clearer and more instantly actionable information and earlier responses.

Table 3: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Reaction Time Beep	6	5.30	7.80	6.9000	.88769
Reaction Time Speech	6	3.50	5.10	4.2000	.68118
Valid N (listwise)	6				



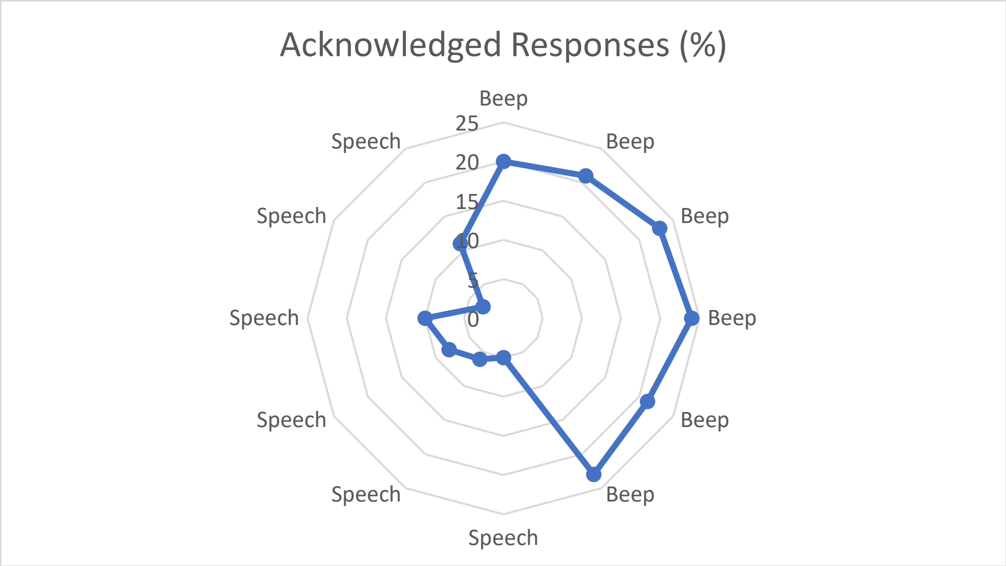
Graph 1: Reaction Time

5-2 Acknowledged Responses

Navigation officers Participate in the speech alarm group effectively acknowledged more critical alarms compared to navigation officers participate in the beep alarm group. On average, navigation officers using speech alarms responded to 22.03 alarms, while those using beep alarms responded to only 7.17 alarms during the simulation scenario. This result indicates a considerable enhancement in attentiveness and responsiveness under speech guidance. The standard deviation was lower in the speech group (1.53) than in the beep group (3.06), suggesting more consistent performance among navigation officers using speech alarms. This difference suggests that speech alarms mitigate the desensitization associated with alarm fatigue by enhancing message clarity and urgency. Also help reduce cognitive overload and alarm fatigue by delivering clearer, more actionable messages.

Table 4: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Acknowledged Responses Beep	6	3.00	11.00	7.1667	3.06050
Acknowledged Responses Speech	6	20.00	24.00	22.0333	1.52534
Valid N (listwise)	6				



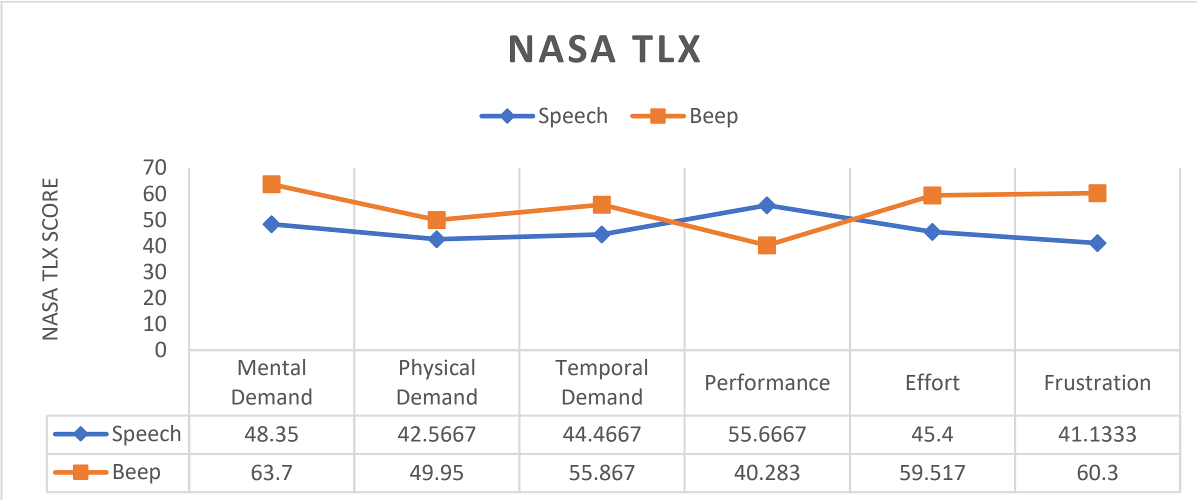
Graph 2: Acknowledged Responses (%)

5-3 Subjective Workload (NASA-TLX)

The NASA Task Load Index (NASA-TLX) was administered to assess perceived cognitive workload across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration.

Table 5: Descriptive Statistics

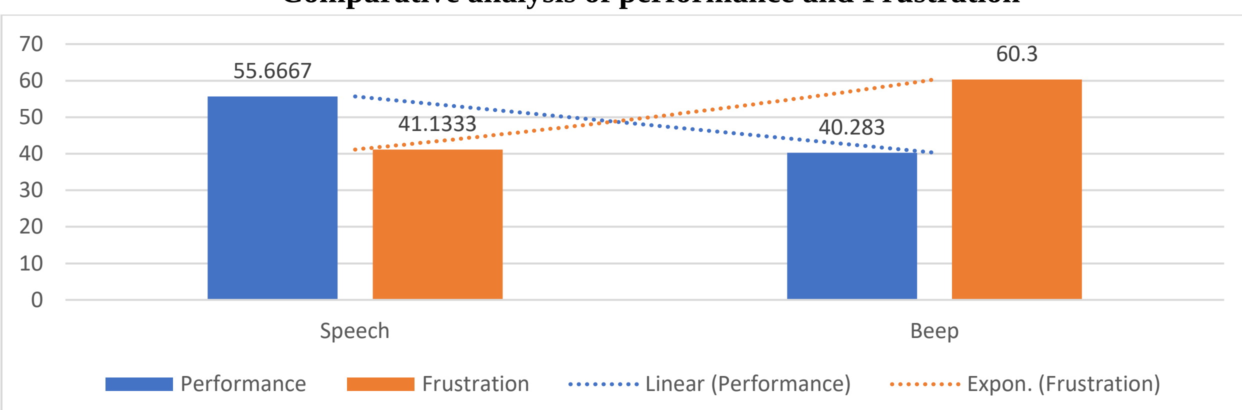
	N	Minimum	Maximum	Mean	Std. Deviation
Mental Demand Speech	6	46.80	50.10	48.3500	1.18110
Mental Demand Beep	6	60.3	66.4	63.700	2.1679
Physical Demand Speech	6	40.30	44.00	42.5667	1.33816
Physical Demand Beep	6	47.9	52.3	49.950	1.6171
Temporal Demand Speech	6	42.50	46.10	44.4667	1.22746
Temporal Demand Beep	6	53.1	58.6	55.867	1.9796
Performance Speech	6	53.60	57.40	55.6667	1.36039
Performance Beep	6	38.4	42.5	40.283	1.4386
Effort Speech	6	43.90	46.90	45.4000	1.09179
Effort Beep	6	57.6	61.0	59.517	1.3977
Frustration Speech	6	39.40	42.30	41.1333	1.07269
Frustration Beep	6	58.9	62.1	60.300	1.2665
Valid N (listwise)	6				



Graph 3: NASA TLX

Regarding graph 3 demonstrated that, the Beep group generally experienced higher levels of workload, as indicated by higher means in Mental Demand, Physical Demand, Temporal Demand, Effort, and Frustration. Regarding Performance Differences, the Speech group revealed better Performance and a higher percentage of Missed/Delayed Responses compared to the Beep group. Regarding Reaction Time, participants in the Beep group had a slower Reaction Time compared to those in the Speech group.

Comparative analysis of performance and Frustration



Graph 4: a comparative analysis of performance and Frustration

Graph 4 presents a comparative analysis of performance and Frustration between participants exposed to traditional beep alarms and those exposed to speech alarms during bridge simulator exercises.

Interpretation of Correlation: Negative Correlation is evident between Performance and Frustration. The correlation coefficient of −0.97 indicates a very strong negative linear correlation between Performance and Frustration. As frustration decreases, performance improves. This supports the hypothesis that replacing beep alarms with speech alarms can reduce cognitive load and improve operational effectiveness on ship bridges.

Table 6: Correlations Analysis

		Performance	Frustration
Performance	Pearson Correlation	1	-.979**
	Sig. (2-tailed)		.000
	N	12	12
Frustration	Pearson Correlation	-.979**	1
	Sig. (2-tailed)	.000	
	N	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

1. Reaction Time (seconds): Participants using speech alarms responded earlier (4.2 seconds) compared to those using beep alarms (6.9 seconds), suggesting that speech alarms provide clearer and more actionable information.
2. Missed or Delayed Responses (%): The beep group missed or delayed 22% of critical alarms, while the speech group had a much lower rate at 9%, indicating improved attention and response consistency with speech alerts.
3. Mental Demand (NASA-TLX Score): Navigation officers using beep alarms reported a mental demand score of 63.7**,** whereas those using speech alarms reported 48.3, showing that speech alarms reduce cognitive strain.
4. Effort: navigation officers in the beep group reported expending more effort (59.8) than those in the speech group (45.5), indicating a smoother workload in the latter condition.
5. Frustration: Frustration levels were substantially higher for the beep group (60.1) compared to the speech group (41.2), suggesting that traditional alarms contribute more to stress and confusion.

5-4 Qualitative Feedback

The speech group’s navigation officers felt more familiar with speech alarm. Improved alert specificity and clarity, less reliance on visual confirmation, increased confidence in situational awareness, and less discomfort than with a loud beep alert. The beep group, on the other hand, reported having trouble interpreting the significance of alarms without checking radar or ECDIS systems, experiencing alarm overload, and becoming confused during simultaneous alerts.

5-5 Observational Insights

Simulator logs shows that navigation officers in the speech group made fewer course corrections due to quicker decisions and increase accuracy in traffic avoidance maneuvers. Their bridge team management also improved, as speech alerts allowed better coordination and reduced redundant verbal communication between bridge team members. The simulator-based experiment provides strong evidence that speech alarms improve navigational performance and reduce cognitive load. The observed benefits include: faster and more accurate responses to incidents, fewer missed alerts, lower subjective workload, and higher operator satisfaction. These findings strongly support the integration of speech-based alerts into modern bridge systems, especially in industry with high-frequency alerts.

6- Discussion

The Operational Benefits of Speech Alarms that provide immediate contextual understanding, improve bridge team confidence in alert systems, and reduce cognitive strain and decision-making delay time. The speech alarm could particularly decrease incidents involving underestimated vessel maneuverability, ignored ECDIS or RADAR alerts, or misread engine warnings. Regarding design considerations, effective implementation of using IMO-standard Maritime English, modular alert severity, tone, context, and configurability language, voice gender, and frequency. For example, “Warning: crossing safety contour.

There are a few lessons to be learned from some of the most prevalent voice technologies such as Google Maps and other AI assistant platforms. They service a measured and informative tone with modulation intended to impart expressive data without imparting anxiety or distraction. In being in maritime settings, having a similar approach will assist one in remaining calm and level-headed in possibly high-stress circumstances. Key principles are maintaining a consistent and not startling tone, issuing segmented warnings that incrementally build up to critical warnings, and incorporating options for users to replay or request repetition of messages when needed. These features ensure that speech alarms not only alert but also improve decision-making, just as the friendly and reassuring attributes have contributed to voice assistants' popularity elsewhere.

7- Recommendations

Based on the findings of this study, several recommendations are proposed to enhance navigational safety through the adoption of speech alarm utilization. Initially, it is recommended that the International Maritime Organization (IMO) consider revising existing regulation, particularly MSC.302(87), to expansively incorporate speech alarm utilization provisions in the conduct of bridge operations. At the same time, bridge system original equipment manufacturers (OEMs) need to be encouraged to incorporate speech alert modules into their equipment packages to encourage universal adoption. Second, implementing a standardized protocol for maritime speech-based alarms based on ISO/IEC standards would encourage consistency and compatibility with diverse vessels and systems. Training schools must also incorporate speech alarm systems into simulator-based training courses and the respective modules of the Standards of Training, Certification and Watchkeeping (STCW) to familiarize navigation officers with this technology and its implications for use. Last but not least, further human factors research is required, including longitudinal studies to further evolve speech interaction patterns, assess their long-term efficiency, and identify cultural and linguistic compatibility across the globally diverse maritime workforce. These collective measures could mitigate alarm fatigue and enhance safety in modern ship bridge operations.

Alarm fatigue is prevalent, with a majority reporting frequent exposure and negative impacts on awareness. Auditory overload leads to ignored alarms, reducing the effectiveness of bridge monitoring systems. Beep alarms lack clarity, especially under high-stress or complex navigational conditions. Officers show a strong preference for speech-based alerts, associating them with improved clarity and prioritization. Recommendation include Pilot studies using speech-based alarms in bridge simulators or training ships may validate these findings before fleet-wide implementation.

8- Conclusion

Alarm fatigue is increasing the risk factor in bridge navigation, undermining safety by dulling the human response to critical signals. Drawing from successful speech assistance platforms like Google Maps, this study demonstrates the potential for speech-based alarms to alleviate cognitive burden, increase clarity, and improve timely decision-making. The maritime industry stands at the cusp of a new era in alert design one that should prioritize context, clarity, and human-centered communication.

References

-AHRQ (2024) *Alert Fatigue*. Patient Safety Network. Available at: https://psnet.ahrq.gov/primer/alert-fatigue.

- ASALOMIA, L.B., SAMOILESCU, G. and MIHĂILESCU, M.I., 2025. AN ADVANCED AI-BASED SYSTEM FOR INTELLIGENT BRIDGE ALARM MONITORING ON MARITIME VESSELS. *REVUE ROUMAINE DES SCIENCES TECHNIQUES—SÉRIE ÉLECTROTECHNIQUE ET ÉNERGÉTIQUE*, *70*(2), pp.223-228.

- Boppudi, R., Doddapaneni, S., Dasari, K., Burri, B., & Kancharla, V., 2024. IoT-Driven Boat Health Surveillance and Sinking Alert System. 2024 IEEE Students Conference on Engineering and Systems (SCES), pp. 1-4. https://doi.org/10.1109/SCES61914.2024.10652329.

- Cvach, M., Rothwell, K.J., Smith, A.H. and Bonafide, C.P., 2022. *Alarm fatigue: evidence, trends, and best practices for reducing clinical alarm burden*. *Critical Care Medicine*, 50(3), pp.298–306. [online] Available at: https://pubmed.ncbi.nlm.nih.gov/35100248 .

- Deschamps, M.L., Sanderson, P., Waxenegger, H., Mohamed, I. and Loeb, R.G., 2024. Auditory sequences presented with spearcons support better multiple patient monitoring than single-patient alarms: a preclinical simulation. *Human Factors*, *66*(3), pp.872-890.

- Dewi, A.A.S., 2025. The impact of digitalization on environment and maritime safety within the shipping industry.

- Google Design, 2024. *Speaking the same language: Designing intuitive voice user interfaces (VUIs)*.https://design.google/library/speaking-the-same-language-vui/ .

- Guo, F.B., Yang, Z., Davis, E.B., Khalique, A. and Bury, A., 2021, July. Does Being Human Cause Human Errors? Consideration of Human-Centred Design in Ship Bridge Design. In *International Conference on Applied Human Factors and Ergonomics* (pp. 302-309). Cham: Springer International Publishing.

- IHO (2024) *Proposal for a new output to realize the full potential of the S-100 ECDIS*. International Hydrographic Organization. Available at: https://iho.int/uploads/user/About%20IHO/Council/council8/MSC%20109-19-3.pdf.

- InterManager. (2019). Constant Bridge warnings create 'alarm fatigue' survey reveals. *InterManager*. Available at: https://www.intermanager.org/2019/07/constant-bridge-warnings-create-alarm-fatigue-survey-reveals/

- Kane-Gill, S.L., O'Connor, M.F., Rothschild, J.M., Campbell, W. and Santell, J.P., 2017. Technologic Distractions (Part 2): A Summary of Approaches to Manage Alarm Fatigue in the Clinical Setting. Critical Care Medicine, 45(1), pp.117–123.

- Kim, J. and Song, H., 2024, May. My voice as a daily reminder: self-voice alarm for daily goal achievement. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (pp. 1-16).

- Koppaka, A., P, A., & Valsan, V., 2024. Navigating the Waves: IoT Border Alert System for Maritime Safety. 2024 International Conference on Advances in Computing Research on Science Engineering and Technology (ACROSET), pp. 1-8. https://doi.org/10.1109/ACROSET62108.2024.10743867.

- Koundal, N., Abdalhadi, A., Al-Quraishi, M.S., Elamvazuthi, I., Moosavi, M.S., Guillet, C., Merienne, F. and Saad, N.M., 2024. Effect of interruptions and cognitive demand on mental workload: A critical review. *IEEE Access*, *12*, pp.54405-54425.

- Kuparinen-Koho, T., 2020. Risks in the user interaction of alarm functionality in situation awareness systems.

- Lawson, L., 2018. An Analysis of the factors inhibiting ECDIS from effectually achieving its intended primary function of contributing to safe navigation.

- Lee, H., Park, J. and Kim, S. (2025) 'Structuring historical marine casualty data within S-100 ECDIS framework for intelligent alerting', *Applied Sciences*, 15(12), p.6432. Available at: https://www.mdpi.com/2076-3417/15/12/6432.

- Liu, Y. and Guo, X., 2023. Study on risk of ship collision in bridge life-cycle based on synergetic theory. Ocean Engineering, 289, p.116148.

- Lloyd's Register (2024) *Alarms on ships must be rationalized to support crew welfare and avoid the safety risks associated with alarm fatigue*. Available at: https://www.lr.org/en/knowledge/press-room/press-release/2024/alarms-on-ships.

- Lloyd's Register, 2025. *Alarm Management in the Maritime Industry – Volume 2*. [online] London: Lloyd's Register. Available at: https://www.lr.org/en/knowledge/research-reports/2025/alarm-management-volume-2/ [Accessed 4 Jul. 2025].

- Maglić, L. and Zec, D., 2020. The impact of bridge alerts on navigating officers. *Journal of Navigation*, 73(2), pp.421–432. https://doi.org/10.1017/S0373463319000687

- MAIB. (2020). Report on the investigation of grounding due to ignored alarms. *UK Maritime Accident Investigation Branch.*

- Muhaimin, A.M.M., Zhang, L., Dhakal, S., Lv, X., Pradhananga, N., Kalasapudi, V.S. and Azizinamini, A., 2021. Identification and analysis of factors affecting the future of bridge design, construction, and operation. *Journal of Management in Engineering*, *37*(5), p.04021049.

- Nikkinen, M., 2018. Cognitive load and attention in safety-critical environments: Human limitations in information processing. Journal of Human Factors and Ergonomics, 60(2), pp.145–158.

- Öcal, D.K., 2025. Studying state violence through an embodied approach: methodological reflections. *Geographica Helvetica*, *80*(2), pp.123-134.

- Salameh, B., Abdallah, J., Alkubati, S.A. and ALBashtawy, M., 2024. Alarm fatigue and perceived stress among critical care nurses in the intensive care units: Palestinian perspectives. *BMC nursing*, *23*(1), p.261.

- Seok, Y., Cho, Y., Kim, N. and Suh, E.E., 2023. Degree of alarm fatigue and mental workload of hospital nurses in intensive care units. *Nursing Reports*, *13*(3), pp.946-955.

- Shanmugham, M., Strawderman, L., Babski-Reeves, K. and Bian, L., 2018. Alarm-related workload in default and modified alarm settings and the relationship between alarm workload, alarm response rate, and care provider experience: quantification and comparison study. *JMIR human factors*, *5*(4), p.e11704.

- Shehata, M. S., Aly, S., & Ibrahim, A. M. (2023). A Decade of ECDIS: Analytical Review of the ECDIS Effect towards the Safety of Maritime Shipping. *AIN Journal*, (46). https://doi.org/10.59660/46731

- Wen, S., Akgun, C., Cho, H. and Dorneich, M. (2025) 'AdaptiveCoPilot: Design and Testing of a NeuroAdaptive LLM Cockpit Guidance System', *arXiv preprint*, arXiv:2501.04156. Available at: https://arxiv.org/abs/2501.04156 (Accessed: 7 July 2025).

- Wickens, C.D., Hollands, J.G., Banbury, S. and Parasuraman, R., 2020. Engineering Psychology and Human Performance. 5th ed. New York: Routledge

- Wu, J., Thorne-Large, J. and Zhang, P., 2022. Safety first: The risk of over-reliance on technology in navigation. *Journal of Transportation Safety & Security*, *14*(7), pp.1220-1246.

- Wu, M., Li, Y., Wang, Y., Tian, J., Yang, W. and Niu, Y., 2024. The effectiveness of audible alarm types and presentation rates on pilot performance in beyond visual range combat scenarios. Nanjing: Southeast University, School of Mechanical Engineering. [online] Available at: https://www.researchgate.net/publication/377208142.

- Xi, R., 2024. Design of Ship Power System Monitoring and Alarm Software Based on PLC and Touch Screen. 2024 8th International Conference on Electrical, Mechanical and Computer Engineering (ICEMCE), pp. 143-148. https://doi.org/10.1109/ICEMCE64157.2024.10862225.