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Assessing Noise Exposure on Offshore Support Vessels: Implications for Crew Health and Safety

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ABSTRACT

This study examines the impact of noise exposure on crew members aboard an offshore vessel supporting wind farm operations in the North Sea. Noise measurements were conducted during both navigation and dynamic positioning modes. The study focuses on noise levels in various compartments and their impact on crew health, especially the risk of hearing loss, sleep disturbances and fatigue. The results show that despite compliance with international standards (e.g., IMO MSC.337(91)), some crew members, especially those working in the Engine Department, are exposed to noise levels exceeding EU Directive 2003/10/EC limits. Voluntary notation classes focus primarily on accommodation spaces and fail to enforce the recommended 40 dB(A) limit for restful sleep. The study underscores the importance of addressing noise levels to improve safety and crew well-being, especially in areas such as cabins and workspaces.

1. Introduction.

In recent years, the International Maritime Organization (IMO) has increasingly focused on the human factor and its influence on maritime transport. Nearly two million seafarers worldwide are responsible for transporting 80% of international trade (UNCTAD, 2023). Therefore, the health and well-being of seafarers are crucial to global commerce (Oluseye and Ogunseye, 2016; Tetemadze et al., 2021; Sánchez-González et al., 2024). Regulations such as the ILO MLC 2006 Convention have significantly improved living conditions on board (García, Castaños and Irastorza, 2011; NORMLEX, 2013); however, there are still areas that can be further enhanced (Al-Balushi et al., 2022). Specifically, in terms of occupational health and safety, harmful noise exposure remains a concern for seafarers (Costa et al., 2020; Borelli et al., 2021; Cui et al., 2022).

While regulations have improved over time, a significant portion of onboard workers still experiences the physiological effects of noise overexposure. Permanent and temporary threshold shifts, along with fatigue and sleep disorders, are the most common conditions resulting from such overexposure.

Permanent Threshold Shift (PTS), commonly referred to as hearing loss or *hypoacusis*, is a condition wherein an individual experiences diminished auditory perception compared to a person with normal hearing, characterized by an auditory threshold of 20 dB or lower across various frequencies (typically between 125 Hz and 8,000 Hz) (Mehrotra et al., 2024). PTS often begins to develop in early adulthood and tends to worsen over time. Its severity is associated with factors such as noise exposure levels, prior auditory infections, hereditary influences, and ototoxic agents (Liu et al., 2024).

Once hearing loss begins, it typically follows a recognizable audiometric pattern. The frequency of the noise to which an individual is exposed is significant, as initial changes often manifest as a loss of perception at 4,000 Hz. However, it is not uncommon for the peak impairment to occur between 3,000 and 6,000 Hz (Frederiksen et al., 2017).

Temporary Threshold Shift (TTS) refers to a transient loss of hearing or *tinnitus*. It constitutes a temporary change in auditory threshold resulting from exposure to extreme episodes of loud noise, which can displace the tiny hair cells in the ear.

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Even after the noise subsides, these cells may take time to return to their normal position, leading to a muffled hearing sensation and, in some cases, *tinnitus*. Although TTS is a temporary condition, repeated occurrences signal that the ear is regularly exposed to hazardous noise levels, potentially resulting in permanent hearing loss. It manifests as whistles, buzzes, or hisses, with volume ranging from subtle noises to high-intensity sounds that can be extremely bothersome, potentially leading to stress if perceived continuously (Langguth, 2015).

A third disorder is known as auditory fatigue, which refers to a reduction in hearing capacity caused by exposure to high-intensity noise. Symptoms may include a lack of understanding or intelligibility, as well as mental fatigue, which can diminish motivation to perform work tasks and hinder communication with colleagues. This decline is not irreversible, as normal hearing can typically be restored within 2 to 16 hours after noise exposure. However, if noise exposure persists without adequate recovery, it may lead to chronic injury, resulting in hearing loss (Yadav et al., 2021).

During their time on board, seafarers sleep amidst constant noise sourced from the engine room and propellers, among others. Noise during sleep hours significantly alters normal sleep patterns. Generally, optimal resting conditions should not exceed an equivalent background noise level of 40 dB(A), while levels above 55 dB(A) can lead to increased sleep latency and a reduction in the duration of deep sleep phases, which are essential for restorative sleep. Consequently, individuals often awaken feeling fatigued. Furthermore, poor sleep quality leads to decreased intellectual performance, fatigue, and reduced attention levels, which pose risks in specific activities such as machinery operation or maintenance (European Commission, 2002; WHO, 2009). This is particularly relevant in the maritime environment, as fatigue is recognized as one of the leading causes of maritime accidents attributed to human error (Jakob and Holmen, 2011; Febriyanto, Rahman and Guedes, 2023).

In addition to the previously mentioned issues, noise aboard a vessel also affects communication among the crew, which can negatively affect ship safety as well. Such communication challenges increase the likelihood of misunderstandings, as orders may be partially understood or misinterpreted, posing a risk to operational safety. Therefore, it is crucial to adopt communication protocols among the crew and implement technology to reduce onboard noise. Moreover, many crews are international and multicultural, requiring a common language, typically English, which complicates communication as it is often not the native language of most crew members (Kumar and Subhashini, 2019; Pauksztat, 2021).

The remainder of the text is structured as follows: Section 2 describes the case study vessel, applicable regulations and noise measurement methods employed on board, along with the subsequent calculation of the exposure levels for the studied crew. Section 3 presents the results obtained, accompanied by a corresponding discussion. Section 4 is dedicated to presenting the conclusions derived from the analysis.

2. Materials and Methods.

In this section, materials used are described, including both the case study vessel and the instrumentation for noise measurement, as well as the methods for point measurement of sound pressure levels at each compartment and the calculation of the equivalent noise exposure for seafarers.

2.1. Case Study Vessel.

The case study vessel is an offshore type with dynamic positioning (DP) system, designed to provide technical support in wind farms located in the North Sea. In addition to transporting materials, it has the capability to accommodate technicians for extended periods, functioning as a flotel. Since it carries external personnel, the vessel underwent certification for the DNV COMF V-2 class notation (DNV, 2021). Main particulars of the ship are presented in Table 1.

Table 1: Main particulars of the case study vessel.

Length	88 m
Beam	20 m
Gross Tonnage	7,093 tons
Main Engines power	5,310 kW
DP Propulsion	3 x 1,300 kW Bow thrusters

Source: Authors.

2.2. Regulatory Framework.

In this subsection, the regulatory framework applied to the case study vessel is presented. Operating primarily in offshore wind fields in the North Sea, the vessel is subject to compliance with both international and European regulations.

2.2.1. International Maritime Organization.

The primary regulation on noise levels onboard ships is established by IMO. The first relevant guideline was introduced in 1981 through Resolution A.468(XII), and followed by an updated version in 2012 under Resolution MSC.337(91), *Code on Noise Levels on Board Ships*, which is currently in force (International Maritime Organization (IMO), 1981, 2012). These resolutions specify permissible air-borne noise levels across work and accommodation spaces. The noise limits apply to commercial vessels over 1,600 GT, and is further categorized by size into vessels under and over 10,000 GT. Although the Code is legally binding, certain provisions, such as those outlined in Chapter 5 regarding noise exposure limits, are of a recommendatory nature. The specific noise limits established by the Code are provided in Table 2.

Table 2: Noise limits according to Resolution MSC.337(91).

Spaces	Noise limit [dB(A)]	
	1,600 to 10,000 GT	≥10,000 GT
Work Spaces		
Machinery spaces	110	110
Machinery control rooms	75	75
Workshops other than those forming part of machinery spaces	85	85
Non–specified work spaces (other work areas)	85	85
Navigation Spaces		
Navigating bridge and chartrooms	65	65
Look-out posts, incl. navigating bridge wings	70	70
Radio rooms (with radio equipment operating but not producing audio signals)	60	60
Radar rooms	65	65
Accomodation Spaces		
Cabin and hospitals	60	55
Messrooms	65	60
Recreation rooms	65	60
Open recreation areas (external recreation areas)	75	75
Offices	65	60

Source: International Maritime Organization (IMO), 2012.

2.2.2. European Union.

In Europe, noise exposure limits in the workplace are governed by EU Directive 2003/10/EC, which seeks to safeguard workers from the risks posed by hazardous noise levels. This directive establishes minimum standards for protecting workers from noise-induced risks, with a particular focus on preventing hearing damage (European Commission, 2003). Key provisions of the directive include:

- Exposure Limit Values: Daily exposure must not exceed 87 dB(A), taking into account the attenuation provided by personal protective equipment (PPE).
- Lower Action Value: Daily noise exposure of 80 dB(A). At this level, employers must provide information, training, and make hearing protection available to workers.
- Upper Action Value: Daily noise exposure of 85 dB(A). At this level, employers must implement noise-reduction measures, ensure the use of hearing protection, and carry out health surveillance.

It is important to note that, although both IMO and EU regulations aim to protect seafarers' health, their approaches differ. In the case of IMO Resolution MSC.337(91), noise limits are defined by the sound pressure level measured in each compartment of the vessel. In contrast, the EU focuses on worker hearing protection from the perspective of noise exposure. While European regulations do not set noise limits for individual spaces, they do regulate equivalent exposure levels both for the 8-hour work period and the full 24-hour day. This distinction is significant because, in order to meet or exceed IMO requirements, actions must be taken in the ship's construction and materials, such as improved acoustic insulation. On the other hand, improving the exposure levels required by the EU can be achieved by modifying crew behavior, restructuring their routines, or reducing the time spent in the noisiest areas.

2.2.3. Market-Based Measurements.

Although vessels like the one in this case study must comply with both specific maritime regulations and general European standards, both sets of regulations were established in the early 2000s. Today, advances in shipbuilding technologies and the availability of more effective insulating materials have made it easier to meet the required noise limits, suggesting that stricter standards may now be feasible (Kurt et al., 2016). Acknowledging this, various organizations within the International Association of Classification Societies (IACS) have introduced their own regulations, often with more stringent limits.

In the case of the classification society DNV, a voluntary class notation was established to classify noise and vibration levels on board into three categories. The class notation is COMF-V(crn), where "crn" stands for "comfort rating number" and can take the values 1, 2, or 3, with crn 1 being the most stringent. At level 3, compliance with MSC 337(91) for noise and ISO 6954 for vibration is ensured. Table 3 presents the noise values specified for each crn level.

Table 3: DNV COMF-V (crn) noise level limits.

Location	V-1		V-2		V-3	
	< 10,000 GT	≥ 10,000 GT	< 10,000 GT	≥ 10,000 GT	< 10,000 GT	≥ 10,000 GT
Wheelhouse	60	60	60	60	65	65
Radio room	55	55	55	55	60	60
Cabins	50	50	55	53	60	55
Public spaces	55	55	60	58	65	60
Gym	65	60	65	60	65	60
Hospital	55	55	58	55	60	55
Offices	60	55	60	58	65	60
Engine Control Room	65	65	70	70	75	75
Open recreation decks	70	70	73	73	75	75
Workshops	85	85	85	85	85	85

Source: DNV, 2021.

Although the creation of class notations such as the one presented represents a step forward, they remain voluntary measures. It is up to the shipowner to assess whether the additional investment required to adapt the vessel to these standards is economically viable. In the case of passenger ships and vessels like the one in this study, which accommodates offshore technicians in addition to the crew, complying with these measures can be economically attractive, as they add value to the vessel.

2.3. Noise Measurement.

2.3.1. Noise Measurement Procedure.

Noise levels in various spaces of the vessel were certified during sea trials, in accordance with Resolution MSC.337(91). Measurements were taken with the microphone positioned at a height between 1.2 m and 1.6 m above the deck. A minimum distance of 2 m between measurement points was maintained. Additionally, care was taken to ensure that measurements were not conducted within 0.5 m of the boundaries of each space, in order to achieve a more accurate assessment of the compartment and to minimize reverberations and potential errors in the results.

The DNV COMF-V notation specifies that noise levels during transit conditions (normal navigation) must be measured under the vessel's normal operating conditions, with the propeller shaft operating at no less than 80% power. For measurements taken in DP mode, a minimum of 40% power must be maintained at the bow thrusters. Additionally, all other equipment not specifically mentioned must be functioning normally during all measurements.

2.3.2. Sound Level Meter.

A Norsonic sound level meter manufactured according IEC 61672-1, specifically model Nor140, was utilized (International Electrotechnical Commission, 2013). Both before and after conducting the measurement, a field calibrator was employed to ensure accuracy, as mandated by Resolution MSC.337(91). During this verification, the microphone of the sound level meter was inserted into a field calibrator, which emits a 1 kHz sound at 94 dB.

2.4. Noise Exposure Levels.

2.4.1. Crew Members' Routines.

For this study, the vessel's crew is categorized into five groups: Bridge Officers, Deck Ratings, Engine Officers, Engine Ratings, and Hotel Staff. Each group has distinct functions and routines that influence their designated workspaces aboard the vessel. Additionally, due to the vessel's role in transporting and accommodating technical personnel involved in offshore wind facility operations and maintenance, a sixth group of Technicians is included. This group is considered to act as passengers, with no sporadic visits to the wheelhouse or engine room accounted for.

2.4.2. Noise Exposure Calculation.

This research addresses noise exposure over a 24-hour period. This is because both the crew and the technicians on board do not have the option to go ashore, unlike other types of vessels. Additionally, it is pertinent to examine how noise exposure in the vessel's accommodation areas affects the total exposure levels for each crew group. For the calculation of these exposure levels, it is estimated that each crew member spends 10 hours in their work area and 14 hours in the accommodation zones of the vessel. In the case of the technicians, their 24 hours are spent in various accommodation areas. To calculate the equivalent noise exposure level over a 24-hour period, Equation 1 is used:

$$L_{EX,24h} = 10 \cdot \log \frac{1}{T} \sum_{i}^{n} t_i \cdot 10^{L_i/10} \tag{1}$$

Where T represents the overall duration of exposure, 24 h, t denotes the time of exposure in each individual compartment, and L corresponds to the sound pressure level, in dB(A), within the respective compartment.

During the calculation process, two scenarios were considered: the vessel in navigation and the vessel operating in DP. This approach provides a clearer understanding of the noise levels to which workers are exposed during various operations of the vessel. In positions where it is required, the noise exposure level has also been calculated without any hearing protection, followed by an assessment assuming the use of hearing protection in areas where it is necessary. Attenuation of head protection was evaluated in accordance with OSHAS standards for occupational noise exposure, with the assumption that standard headsets provide a noise reduction rating of 30 dB(A) (Occupational Safety and Health Administration, 2020).

3. Results and Discussion.

3.1. Onboard Noise Measurements.

The noise levels measured during the experimental phase are presented in Table 4.

The results of the onboard noise measurements indicate that during the navigation phase, the vessel complies with the point noise levels in each space according to the COMF V-2 class notation. In the case of DP operations, some measurements exceeded the requirements of the class notation, although most of them remained in compliance with the mandatory IMO standard, Regulation MSC.337(91).

If Decks 3 and 4 are observed, it becomes evident that the noise trends are very similar. The influence of the bow thrusters can be seen, as hotel cabins are quieter during navigation, when only the aft propulsion is in use, compared to the crew cabins. This trend changes once the vessel switches to DP mode. In this mode, noise mitigation is more closely related to horizontal location, with the quietest cabins situated in the aft area, while those with higher noise levels are found in the bow section.

3.2. Noise Exposure Levels.

This subsection presents the daily noise exposure levels for the various crew members of the vessel, as well as the technicians, under both operational conditions: navigation and DP. For the Engine Department, who are exposed to sound pressure levels above 85 dB(A), the exposure has been calculated both with and without the use of hearing protection. Table 5 displays the calculated noise exposure values.

Table 4: Results of onboard noise measurements.

Space	Navigation	DP	COMF V-2
Deck1		dB(A)	
Engine Room Aft	108	109	110
Engine Room Fwd	106	106	110
Deck2			
Main Engines Room	96	92	110
Aux. Machinery Room	83	82	110
Workshop	65	65	85
Bow Thrusters Room	61	101	110
Main Switchboard Room	73	74	85
Deck3 Forward			
Crew Cabin 3	52	50	55
Crew Cabin 4	52	48	55
Crew Cabin 5	51	50	55
Crew Cabin 7	54	53	55
Crew Cabin 8	56	54	55
Crew Cabin 10	54	53	55
Crew Cabin 11	53	53	55
Crew Cabin 12	52	50	55
Crew Cabin 13	54	56	55
Gym	60	57	60
Hotel Cabin 20	48	52	55
Hotel Cabin 22	45	52	55
Hotel Cabin 24	47	55	55
Hotel Cabin 25	48	56	55
Hotel Cabin 26	46	58	55
Hotel Cabin 27	48	58	55
Hotel Cabin 28	47	60	55
Hotel Cabin 30	44	60	55
Hotel Cabin 31	46	60	55
Hotel Cabin 33	42	60	55
Hotel Cabin 34	47	64	55
Hotel Cabin 35	44	62	55
Hotel Cabin 36	46	61	55
Hotel Cabin 38	47	59	55
Hotel Cabin 40	47	57	55
Hotel Cabin 42	44	55	55
Hotel Cabin 44	49	52	55
Deck4			
Crew Cabin 3	47	49	55
Crew Cabin 4	45	51	55
Hotel Cabin 6	47	52	55
Hotel Cabin 7	40	53	55
Hotel Cabin 9	40	55	55
Hotel Cabin 10	37	55	55
Hotel Cabin 14	39	57	55
Hotel Cabin 15	44	60	55
Hotel Cabin 16	41	60	55
Hotel Cabin 17	39	61	55
Hotel Cabin 19	42	62	55
Laundry	60	64	85
Deck5			
Office 1	52	54	60
Office 2	52	53	60
Hospital	51	51	58
Conference Room	50	59	60
Mess (port)	45	60	60
Mess (center)	50	63	60
Mess starboard	55	62	60
Galley	57	61	75
TV Room (port)	42	55	60
TV Room (center)	44	59	60
TV Room (starboard)	43	56	60
Deck6			
Captain Cabin	43	45	55
Chief Mate Cabin	46	47	55
Chief Engineer Cabin	41	46	55
Wheelhouse			
Wheelhouse center	49	49	60
Port Wing	47	45	60
Starboard Wing	49	51	60

Source: Authors.

Table 5: Daily noise exposure levels.

Crew role	Navigation [dB(A)]		DP [dB(A)]	
Deck Officer	56.11		60.42	
Deck Rating	95.20		95.76	
Engine Officer	99.51[1]	88.01[2]	100.47[1]	88.97[2]
Engine Rating	102.78[1]	91.28[2]	103.78[1]	92.28[2]
Hotel Crew	61.43		65.41	
Technicians	57.71		67.49	

Source: Authors.

1 – Noise exposure level without hearing protection.

2 – Noise exposure level with hearing protection.

The results presented in Table 5 show that in the case of Deck Officers, Hotel Crew, and Technicians, daily noise exposure levels are significantly lower than those established by the EU Directive 2003/10/EC and even the recommendations of Resolution MSC.337(91) in its Chapter 5, which states that the noise level limits set out in Chapter 4 are designed so that if complied with, seafarers will not be exposed to an L_{EX}(24h) exceeding 80 dB(A). However, for Deck Ratings, Engine Officers, and Engine Ratings, the daily exposure values are exceeded. Although in all cases the noise exposure levels decrease with the use of hearing protection, the noise levels to which Engine Department crew members are daily exposed still exceed the established limits, even though compartment-level sound pressure measurements do not exceed permissible levels. For these crew members, solutions could include increasing acoustic insulation in the machinery spaces, although this would incur additional costs, or changing crew behavior by designing work routines that minimize time spent in the noisiest areas. In the case of Deck Ratings, the high level of noise exposure is due to the time spent during safety rounds, in which they inspect areas of the vessel that may present risks such as fire or flooding. Due to the short time needed to visually inspect each space, it is common for Deck Ratings to avoid the use of hearing protection, which results in overexposure to noise. In this case, raising crew awareness is recommended, as if the Deck Rating were to use hearing protection similar to that used by the Engine Department, noise exposure would decrease to 84 dB(A), thus meeting the requirements of the EU Directive 2003/10/EC.

Conclusions.

This research presents a study on noise levels aboard an offshore vessel primarily engaged in supporting offshore wind farms and accommodating their technicians, functioning as a flotel. Due to this latter function, the shipowner decided to construct the vessel with superior acoustic insulation, aiming to certify it under the DNV COMF V-2 notation class. By adopting this voluntary regulation measure, the shipowner expects to achieve greater returns from the vessel, as the charter rate can be increased due to the higher quality of accommodations for the technicians.

Noise measurements were taken during the vessel's two main operational modes: navigation and dynamic positioning. Although the results of the measurements mostly fall below the thresholds required by the voluntary notation class, the work routines of some crew members lead to noise exposure levels that exceed the limits established by regulations based on exposure time, such as the EU Directive 2003/10/EC, even when hearing protection is used. This indicates that these seafarers are at risk of experiencing hearing degradation, which could affect both their professional and personal lives.

In general, two measures can be considered to reduce these noise exposure levels. First, constructive measures can be implemented on the vessel, such as increasing acoustic insulation. While this can be an effective solution, it comes with associated costs. Second, behavioral measures can be proposed, in which seafarers' routines are designed to minimize time spent in the vessel's noisiest areas, and emphasis is placed on using hearing protection in spaces where noise levels exceed 85 dB(A), even if the time spent in those spaces is minimal.

Finally, it is important to note that international health authorities recommend that rest areas maintain noise levels of 40 dB(A) or lower to ensure proper rest. In the case study vessel, the crew cabins register an average of 51.82 dB(A), and the cabins designated for technicians record an average of 44.38 dB(A), both measured during navigation. Although these sound pressure levels are not significantly above the recommended levels, they do exceed the suggested limits.

Moreover, the noise limits established by voluntary standards, such as notation class, primarily focus on accommodation spaces without imposing restrictions on work areas. Therefore, to improve the quality of life and well-being of the crew and passengers on board, it would be advisable for voluntary notation classes to raise their standards by lowering noise limits in rest areas and establishing restrictions for noise levels in work areas.

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