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Enhancing Maritime Safety Through Gender- Inclusive Technological Design

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ABSTRACT

Maritime safety is critically influenced by human factors, with studies showing that human error contributes to roughly 80–85% of marine accidents [1,2]. One often overlooked aspect of the human element is the impact of gender on the usability of maritime technology and equipment. Women comprise only about 1.2% of the global seafarer workforce [1], yet most ships and safety systems have been historically designed around a predominantly male workforce. This paper examines how gender-inclusive technological design can improve safety and operational efficiency in the maritime sector. An interdisciplinary research approach was adopted, integrating policy analysis, technical design review, and socio-cultural insights. The research finds that many current maritime technologies – from personal protective equipment and safety gear to bridge controls and training simulators – do not adequately accommodate the needs of a diverse user group. Case studies reveal design flaws such as ill-fitting safety equipment and lack of female-specific facilities on ships, which can compromise safety and deter women's participation. In response, the research proposes guidelines for gender-inclusive design, aligned with international maritime policies (including IMO initiatives on gender equality), and provide evidence-based recommendations. Data visualizations and tables are included to summarize ergonomic mismatches and highlight gaps. The findings underscore that improving design inclusivity is not just a matter of equity but a practical strategy to enhance maritime safety and efficiency for all seafarers.

Keywords: Maritime Safety, See Safety, Maritime Organization, Gender

Introduction

Maritime transportation remains the backbone of global trade, carrying over 90% of world commercemdpi.com. Ensuring the safety of maritime operations is paramount. Human error accounts for around 80% of marine accidents [2]. The underrepresentation of women (about 1.2% of seafarers) has led to equipment and ship systems often being designed with only male users in mind. Significant progress has been made over the decades in ship design, engineering, and regulations to improve safety [1]. However, the "human factor" continues to dominate incident causation. Research consistently finds that human error accounts for most marine accidents (around 80% or more) [2]. This has led maritime authorities and organizations to focus on human factors engineering and the human–machine interaction as critical areas for safety improvementsmdpi.com.

Human factors in maritime contexts encompass ergonomics, user interface design, crew training, fatigue management, communication, and other elements that affect how people perform tasks onboard. While much attention has been given to training and procedural aspects, ergonomic and design factors are equally important. Poorly designed equipment or work environments can induce errors or accidents even among well-trained crew. For example, if a critical control on the bridge is hard to reach or a safety device is cumbersome to use, the risk of mishandling in an emergency increases. Human-centered design principles thus play a vital role in maritime safety.

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A largely underexplored dimension of human-centered design is gender inclusivity. The maritime workforce has traditionally been overwhelmingly male. Women represent today only about 1.2% of the global seafarer workforce [1], reflecting a long-standing gender imbalance. This underrepresentation has multiple causes, including cultural barriers and workplace challenges. However, one contributing factor is that ships and maritime technologies have been designed with the male majority in mind, often unintentionally neglecting the needs of the few women at sea. Anthropometric data (body dimensions) used in design, for instance, have typically been based on male averages. As a result, female seafarers often face equipment, tools, and living facilities that are not optimally suited to their physiology or comfort [3,4]. This misalignment can lead to reduced operational efficiency and even safety risks for women on board, further discouraging their participation in seafaring.

The push for greater diversity and inclusion in maritime is gaining momentum. The International Maritime Organization (IMO) has, since the late 1980s, run programs to promote women in the industry. In 2019, "Empowering Women in the Maritime Community" was the World Maritime Theme, and the IMO Assembly adopted a resolution urging action to achieve a "barrier-free" working environment for women in the maritime sectorimo.org. This aligns with the United Nations Sustainable Development Goal 5 on gender equalitywwwcdn.imo.org. These policy developments recognize that attracting and retaining more women in maritime is not only an equity goal but also beneficial for the sector's resilience and talent pool. Empirical evidence from other industries suggests diverse teams can enhance problem-solving and innovation, which in maritime could translate to safer and more effective operations.

This paper investigates how inclusive technological design – considering gender-specific needs – can enhance maritime safety and efficiency. The research examines current maritime technologies (such as safety equipment, vessel controls, and training simulators) through a gender lens to identify design gaps. The research also explores human-factor incidents and case studies to see where a lack of inclusivity may have been a contributing factor. Importantly, the research integrates socio-cultural perspectives: the experiences of women seafarers in a male-dominated environment, which often include feelings of exclusion or even harassment [3]. These factors can indirectly impact safety (for instance, a crew member who feels isolated or unsafe may be less able to perform optimally).

By combining policy review, technical analysis, and human-centered insights, the research aims to provide a comprehensive understanding of the issue. The structure of this paper follows a typical academic approach:

The Methodology section outlines how data and evidence were gathered; Results present findings on current workforce composition, examples of design shortcomings, and their consequences; Discussion interprets these findings, connecting them back to broader safety outcomes and policy objectives; and finally, the Conclusion offers recommendations for moving towards more gender-inclusive design in maritime, benefiting safety for all.

Methodology

This study used a literature review and policy analysis approach. Surveys indicate over 80% of women seafarer's face issues with standard PPE [3,5]. Case studies and incident reports were used to identify equipment and design gaps that affect women. And employed in interdisciplinary research methodology comprising literature review, case study analysis, and policy analysis. First, a review of existing literature was conducted, focusing on three key areas: (1) maritime human factors and accident causation, (2) gender disparities and experiences in the maritime workforce, and (3) ergonomic design standards for maritime equipment and workspaces. Sources reviewed included peer-reviewed journals (for human factors and ergonomics studies), industry reports (such as the BIMCO/ICS Seafarer Workforce Report and safety bulletins), and publications by international bodies (IMO, ILO, and others). This provided quantitative data (e.g. workforce statistics, accident percentages) and qualitative insights (e.g. anecdotal evidence of design issues).

Next, the research gathered case studies and firsthand reports to identify documented instances of design flaws affecting women on board. This involved examining incident reports, safety newsletters, and seafarer surveys. For example, reports from organizations like CHIRP (Confidential Hazardous Incident Reporting Program) and the Seafarers International Research Centre were reviewed to find any safety incidents or near- misses where equipment design was a factor. The research also drew on recent survey research such as the All-Aboard Alliance's "15 Key Pain Points for Women at Sea" report, which compiled interviews with women seafarers to pinpoint common.

Such qualitative data helped identify recurring themes (e.g. ill-fitting PPE, lack of facilities, task allocation issues) that inform our analysis. On the technical side, the research reviewed maritime design and ergonomics guidelines to understand current standards. Notably, documents like the ABS Guidance Notes on Ergonomic Design of Navigation Bridges and human engineering standards (ISO and ASTM standards for anthropometry) were consulted. These standards typically recommend designing for a range of body sizes (often from the 5th percentile female to the 95th percentile male) to accommodate the majority of usersmaritimesafetyinnovationlab.org. The research assessed whether and how such guidelines are being implemented in practice on ships, by comparing them to reports on on-board conditions.

The study also includes a policy analysis component. The research examined international conventions and regulations for any mandates or guidelines related to gender inclusivity. For instance, the Maritime Labor Convention (MLC) 2006 was checked for provisions on accommodation and equipment, especially after recent updates. Indeed, the research noted that in 2022, new amendments to the MLC were adopted requiring that all seafarers have access to personal protective equipment appropriate in size by no later than December 2024 [3]. Similarly, IMO resolutions and strategic documents on diversity (such as the IMO Assembly resolution A.1147(31) on removing barriers for womenimo.org) were reviewed to align our recommendations with ongoing global initiatives.

Finally, the research compiled evidence-based findings,

including quantitative data and examples, which are presented in the Results. Where appropriate, the research created data visualizations (charts/tables) to summarize key points – for example, a table of ergonomic mismatches and their impacts on women's safety. The analysis in the Discussion then synthesizes these findings, drawing connections between technical design issues and human/safety outcomes, and framing them in the context of maritime organizational culture and policy.

This mixed-methods approach (combining statistical data, narrative reports, and standards review) is suitable for the topic because it touches on engineering, sociology, and policy domains. It allowed us to triangulate information: for instance, if women seafarers report a particular difficulty (say, climbing ladders due to their design), The research could check design standards for ladder dimensions and see if they account for a shorter stature. In summary, our methodology is essentially a holistic literature-based investigation, appropriate for an academic conference paper aiming to bridge gaps between technical design and its real-world human impact in the maritime sector.

Results

Human Factors and Maritime Safety Incidents

Our review reaffirms that human factors are a dominant cause of maritime accidents, highlighting the importance of designing technology with the end-user in mind. Multiple studies and accident investigations have attributed around 80% or more of maritime accidents to human. These human errors include operational mistakes, lapses in judgment, miscommunication, and ergonomic misuse of equipment. For example, analysis of 135 accident reports by showed that the most frequent causal factors were decision errors and poor resource management, often rooted in how humans interact with ship systemsmdpi.commdpi.com [2]. Such findings underscore that improving the human–machine interface can directly reduce incidents. Indeed, the maritime industry has recognized this through frameworks like IMO's "Human Element" agenda and the adaptation of aviation's HFACS (Human Factors Analysis and Classification System) for marine accidents.

A recurring theme in incident analysis is that technology can be a double-edged sword: while it generally improves safety, it can introduce new human factor issues if not designed ergonomically. Modern bridges with advanced electronic navigation systems, for instance, demand careful layout planning. If instruments are poorly arranged or alerts overwhelm operators, situational awareness drops. In one case (a collision of a Ro-Ro ferry reported in a safety bulletin), investigators noted that "ergonomics in the way instrumentation was deployed… meant the helmsman couldn't hear orders easily or reach controls efficiently", contributing to the accident. This exemplifies how design flaws (layout, reach, information design) can precipitate human errors.

Importantly, anthropometric mismatches – differences between design assumptions about user body dimensions and the actual user – have safety implications. If a control panel is positioned assuming the operator is of average male height, a shorter person might struggle to reach or see it clearly. Applied anthropometric design principles state that designing to accommodate from the 5th percentile female to the 95th percentile male can cover about 94% of the populationmaritimesafetyinnovationlab.org. However, many older vessels and even some new designs have not fully implemented this range. This can leave out a portion of the crew (often women, who statistically tend to be smaller in certain dimensions like height and reach) from comfortably or safely using some equipment. For instance, a female officer on the bridge might need a footstool to attain the same field of view or reach overhead instruments that a taller male colleague accesses easily – a workaround indicating the design didn't fit all users.

Another human factor is fatigue and physical strain, which ties into design. Equipment requiring excessive physical strength or awkward postures can lead to quicker fatigue and errors. If a valve requires a strong force to turn and is placed in a hard-to-reach spot, a crew member with lower upper-body strength might struggle, possibly leading to it being improperly secured. Over time, such design-induced strain contributes to accidents or injuries (a concept known as "design-induced error"). Our research identified several such scenarios reported anecdotally, though not always formally in accident stats, since they often manifest as near-misses or ergonomic injuries rather than headline collisions or spills.

In summary, the human factors analysis confirms that safety is closely tied to design. Technologies that are not adapted to the user increase the chance of error. Therefore, addressing human factors is a dual effort: training and procedural improvements on one hand, and better ergonomic and inclusive design of work systems on the other. This sets the stage for considering gender as a specific variable in human factors – since women are part of the seafaring workforce, albeit a small part, are there safety incidents or issues arising from designs not suited to them? To answer that, the research first quantifies and characterize the presence of women in maritime and then examine how current technology serves (or fails) this minority group.

Gender Composition of the Maritime Workforce

The maritime industry remains one of the most gender-imbalanced sectors in the world. According to the BIMCO/ICS 2021 Seafarer Workforce Report, women seafarers represent roughly 1–2% of seagoing personnel [3,1]. The IMO has reported the figure of 1.2% of the global seafarer workforce being female, underlining the extreme minority that women constitute at sea [1]. For context, across all industries globally, women make up about 40% of the workforce on average, and even within the broader "maritime sector" (including onshore roles, cruise hospitality, etc.), the share of women is higher (an average of 16% by some estimates) [1]. But in the core roles on cargo and passenger ships, female representation remains very low.

It is noteworthy that women seafarers are not evenly distributed across maritime roles. The cruise industry and passenger vessels employ a relatively higher proportion of women, often in the hospitality or service departments, and in some cases on the bridge (e.g., there have been cruise ships with female captains and all- female bridge teams). A 2023 industry article noted that while women are ~2% of the overall crewing workforce, they are predominantly found in the cruise sector, whereas on cargo

ships their presence is minimal [3]. In ship owning companies (including office roles), women make up about 34% of the workforce, but those on actual voyages remain few [3]. This disparity means that on many cargo vessels, a woman officer or engineer may be the only female on board among dozens of crews.

The low numbers have a reinforcing effect on design: historically, ship designers and equipment manufacturers had little incentive to consider female-specific requirements if virtually all users were male. However, this is slowly changing as the number of women, while small, is growing (the 1.2% represents a 45% increase since 2015 in absolute termstheseafarerscharity.org). Furthermore, the maritime community is recognizing that attracting more women is important for alleviating crew shortages and fostering innovation. For example, major shipping companies and organizations like WISTA (Women's International Shipping & Trading Association) are actively encouraging diversity. The presence of women in the workforce, albeit limited, has started to expose areas where legacy ship designs and policies fall short. Through surveys and research, women seafarers have voiced challenges that were perhaps invisible to their male counterparts or to management, simply because they hadn't been experienced before.

A qualitative study by Sampson and Acejo– "The Port-Based Welfare Needs of Women Seafarers" – gathered testimonies from 30 female seafarers on cargo ships [6]. The research vividly documents that women often feel excluded by the design and culture of shipboard life, citing "a multitude of ways that women are made to feel excluded… causing them to feel isolated and vulnerable onboard" theseafarerscharity.org. Key issues identified include concerns about personal safety, feelings of fear and isolation, and a fundamental lack of practical facilities to support women (such as for menstruation) [3]. While some of these concerns are cultural (e.g. harassment by crewmates, which will be discussed later), many are directly tied to physical provisions and equipment on ships – or lack thereof – for women.

To better illustrate the current state, the research compiled representative examples of design gaps that particularly affect women. Table 1 summarizes several such ergonomic and design mismatches identified through our research, along with their impacts:

Table 1: Summarization of Ergonomic and Design mismatches identifications

Design Gap	Impact on Women	Examples / Consequences
fitting Personal Protective Equipment (PPE): e.g. safety shoes, gloves, coveralls designed to male sizes	**Reduced protection and comfort; higher risk of injury or non-compliance (not wearing gear)**	Standard issue gear is often too large for female crew. E.g., a typical woman's foot is shorter/narrower, so even the smallest male- size safety boots can be loose, undermining grip [3]. Women report gloves that don't fit and harnesses that don't secure properly, leading to slips/falls risk [3]. Over 80% of women seafarers in one survey reported PPE fit problems related to their gender [3,5]. Some resort to buying their own PPE, or wear ill-fitting gear, which can increase injury likelihood [3].
Safety and survival gear not adapted: lifejackets, immersion suits historically unisex (male-focused)	Lower safety and effectiveness in emergencies; hindered mobility	Traditional survival suits and lifejackets were not shaped for the female body, causing issues like poor sealing and discomfort. One maritime safety company recently introduced the first immersion suit specifically engineered for women, with a shorter torso, wider hips, and adjusted chest area for an optimal [7]. This design "reduces snag risks and enhances mobility" for women, addressing issues they had with unisex suits. The need for such a product highlights the previous gap: women's survival suits often fit poorly, potentially compromising thermal protection and escape performance.
Bridge and control station ergonomics: consoles, instrument layout, seat design based on average male anthropometry	Difficulty in reach and visibility; increased fatigue; slower reaction in critical moments	Many ships' bridges were built to standards assuming a certain range of height and reach. A **5th-percentile female** (significantly shorter than avg. male) might struggle with overhead controls or have a limited view over consoles. Design guides recommend adjustable consoles and chairs to accommodate this, but older vessels may lack such adjustability. In practice, female officers have reported needing adjustments like cushions or stools to achieve proper lookout posture [8]. In emergency scenarios, even a few seconds delay reaching a button or levers due to physical mismatch can be critical. Although hard to quantify, this represents a latent safety risk and added strain on shorter crew.

Onboard facilities & accommodations: lack of separate or suitably designed sanitary and living facilities for women	Discomfort, hygiene issues, stress; can affect morale and concentration on duties	Legacy ship designs often did not include dedicated female bathrooms or changing rooms. Women on older ships sometimes have no choice but to use male-designated facilities or forego certain amenities. E.g., a female engineer noted only new ships had women's toilets in the accommodation area; older ships did not, forcing difficult adjustments [4]. Privacy for changing is another concern: female crew may have to change in their cabin if no separate space is provided, and sometimes those spaces get misused for storage by others [4]. Moreover, basic needs like sanitary product disposal or availability have been overlooked: one officer recounted lacking access to sanitary pads on board and called for companies to stock women's hygiene products in the medical locker [4]. Such facility inadequacies not only cause inconvenience and embarrassment, but also create health and safety issues (e.g., improper disposal can clog systems, stress can impair job performance).

As shown in Table 1, issues range from personal equipment to large-scale ship infrastructure. Many of these have direct safety implications. For instance, if a woman cannot find properly fitting safety gear, she may be less likely to always wear it – indeed, it's noted that discomfort with PPE leads to reduced usage, increasing risk exposure [3]. In an emergency like a fire or evacuation, an ill-fitting suit or lifejacket could hamper a female seafarer's ability to survive or help others. These design oversights also subtly undermine everyday operational efficiency. A crew member preoccupied with physical discomfort or improvising solutions (like modifying gear or workspace) is not performing at peak efficiency. It should be stressed that these design gaps do not only affect women. Small-statured men or older crew with less strength also face some of the same issues. In that sense, many of the improvements for "gender-inclusive" design benefit a wide range of users, embodying principles of universal design. However, because women are the most extreme outliers in the current maritime workforce in terms of being underserved by design, their experiences shine a light on these problems.

Case Studies of Design Flaws Affecting Women Onboard

To further illustrate the real-world impact, the research highlights a few case anecdotes and initiatives that have emerged in recent years:

Personal Protective Equipment (PPE) for Women

In 2019, the maritime safety community began openly discussing PPE issues specific to female seafarers. CHIRP (a maritime incident reporting program) published observations noting how standard PPE was failing women – for example, women reported that standard hard hats would slip down over their eyes, and safety harnesses and coveralls were so oversized they impeded movement [3]. By 2020, a Solent University study found "more than 80% of female participants had problems with PPE relating to their gender" [3]. This led to industry responses: in 2023, Synergy Marine (a large ship manager) rolled out tailor-made PPE for women on over 60 vessels [3]. The new gear, designed with textile engineers and female seafarers, provided properly proportioned boiler suits, smaller boots, etc., directly addressing safety and comfort. This case shows how identifying a design flaw (ill-fitting PPE) and correcting it can immediately improve the safety of a minority group, and likely the overall crew's safety culture as well. It also prompted regulatory action – the Maritime Labor Convention revision mentioned earlier, requiring appropriate PPE for all, is a direct outcome of such evidence being brought forward [3].

Ship Accommodation Retrofits

Some shipping companies have begun refitting older ships or specifying new builds with improved accommodation for mixed-gender crews. One cited pain point was the lack of designated female bathrooms or changing rooms on ships. A third engineer in the Diversity Sea interviews noted that only the newest ships she'd seen had a women's toilet in the accommodation area; older ships had none, meaning a long walk to find a private space, or using male heads at off-hoursassets.ctfassets.net. In another instance, a female cadet described having to go back to her cabin to change into work gear because no female changing room was available – this is inefficient and can delay response times for on-deck dutiesassets.ctfassets.net. Shipping companies addressing this have added locks or set aside one bathroom for women only and ensured that signage and policies keep those facilities exclusively for women's use (preventing them from being co-opted for storage or by male crew). While these might seem like minor quality-of-life improvements, they have a bearing on safety and performance: crew who are at ease and can attend to personal needs readily are less stressed and more alert on the job.

Bridge Design and Equipment Adjustability

There have been informal reports (e.g., via seafarer forums and conferences) of female mariners encountering difficulties with bridge equipment. One example often mentioned is the weight and leverage needed for manual wheel steering on older vessels, or reaching emergency shutoffs placed high on bulkheads. Modern integrated bridges largely mitigate these issues with adjustable chairs and console heights, but not all ships have those features. The Nautical Institute's Alert! bulletins (from the 2000s) described a scenario labeled an "ergonomic nightmare" where a short officer could not reach a console emergency stop button while strapped into the pilot chair, because the console was built for a taller operatormaritimesafetyinnovationlab.orgmaritimesafetyinnovationlab.org. Such scenarios are being addressed by classification societies that now offer ergonomic notation and inspections (ABS, for example, has a notation for

crew habitability and ergonomics). While The research did not find a published accident directly caused by this, it is exactly the kind of latent hazard that inclusive design aims to eliminate.

Training Simulators and Tools

Training simulators are a technology not physically on a voyage but crucial in preparing crew. While no overt gender-based design issues were reported in simulators (most software allows configuring avatars of any gender, for example), there is an angle of inclusivity in training content. Mentorship and scenario training are being adapted to encourage women's participation. For instance, IMO's recent "Women in Maritime" initiatives emphasize mentorship programs and leadership training for female seafarers [3]. A panel of experts noted that having women role-players and mentors in simulations and drills can build confidence and normalize mixed crews [3]. This is more a cultural inclusion aspect than a hardware design issue. However, one could argue that if bridge simulator workstations and gear (like virtual reality headsets, survival craft simulators) are not adjustable for smaller body frames, that could disadvantage female trainees.

Manufacturers have started to consider this by offering a range of seat and console adjustments even in simulators, recognizing that one size doesn't fit at all. In summary, while no simulator-specific ergonomic flaw was identified, training benefits from inclusive thinking – ensuring everyone can fully participate and learn in realistic conditions.

Collectively, these case studies and examples show that gender-related design flaws have tangible effects but can be addressed with targeted solutions. Importantly, solving them tends to have positive side-effects for others too. For example, better PPE sizing will help smaller-built male seafarers and even improve comfort for the average user by offering more size options. Separate bathrooms benefit privacy for all and can improve hygiene standards on board. Ergonomic bridge designs reduce fatigue for all operators. Thus, inclusive design is essentially an extension of good human-centered design. It aims to ensure that the full spectrum of users – which in modern times does include women – can operate safely and efficiently.

Discussion

Our findings highlight a crucial link between inclusive design and maritime safety. In a high-risk, high- reliability environment like a ship, even small design-induced impediments can have outsized consequences. When examining these through the lens of gender inclusivity, it becomes evident that what might have been historically dismissed as "minor inconveniences" for a tiny minority are systemic design oversights that contradict best practices in human factors engineering. By addressing these, the maritime industry can make significant strides in safety and efficiency, in line with both operational goals and international policy expectations.

Technical Perspective

Ill-fitting PPE reduces safety, as reported by Safety4Sea [3]. VIKING introduced a female-specific immersion suit in 2025 [9]. Bridge ergonomics often exclude shorter users, affecting accessibility and visibility [10]. From a technical standpoint, many of the issues identified (PPE sizing, equipment reaches, etc.) have relatively straightforward engineering solutions. The technology exists – for example, adjustable consoles, variable-sized gear, modular accommodation units – to accommodate diverse user groups. The challenge is largely one of implementation and standards. Maritime design codes and procurement specifications need updating to include requirements for inclusiveness. This is already happening to some extent. As noted, class societies like ABS and LR have developed ergonomic notations and guidelines; the IMO's MSC (Maritime Safety Committee) has guidelines for bridge layout and arrangement that emphasize the human element (e.g., MSC/Circ.982 on bridge design). Ensuring these guidelines explicitly account for gender differences would be a logical next step. The principle of designing for the 5th percentile female and 95th percentile malemaritimesafetyinnovationlab.org should be uniformly applied for critical equipment. In practice, this might mean, for instance, that a ladder rung spacing or a hatch door force requirement is tested against a small-framed person to verify usability. The cost of such design adjustments is usually marginal at the newbuild stage (or during major retrofits), but the benefit is devices and spaces that are safer for everyone.

Safety and Operational Efficiency: The discussion of operational efficiency ties closely with safety. When equipment fits the user, tasks can be done faster and with fewer errors. A crew member who doesn't have to waste time finding workarounds or struggling physically can focus on the task at hand. For example, a well-fitting harness means a worker can move freely and confidently at heights, maintaining productivity and safety. Conversely, if 1–2 crew on a ship (the women) are unable to perform certain tasks without assistance purely due to design mismatches, this effectively reduces the available manpower and puts extra load on others. Over a long voyage, this dynamic can affect schedules and stress levels. Inclusive design therefore can subtly improve team efficiency and morale. Additionally, from a maintenance perspective, having equipment that is user-friendly for all means inspections and checks are more likely to be done correctly and on time (no one avoids a task because it's too hard for them physically, for instance).

A noteworthy point is that inclusive design can help attract and retain more women in maritime, which in turn addresses workforce shortages and builds a more robust safety culture. The evidence from the Seafarers' Charity report was that women often feel like they "don't belong" on ships due to the very fact the environment isn't designed for them [11,3]. This feeling of alienation can drive them to leave the career prematurely, as indicated by many respondents who said they plan to quit seafaring because of compounded challengesassets.ctfassets.net. If The research reverse this by making the environment visibly more accommodating – offering properly tailored gear, having separate facilities, showing representation in training materials – it sends a signal that women are welcome and valued. Over time, this can increase the percentage of women seafarers. Why is that good for safety? Research in organizational safety finds that diverse teams can be more vigilant and innovative in problem-solving, reducing groupthink. In bridge resource management, for example, diversity (including gender diversity) might improve communication dynamics and decision-making, as different viewpoints are considered. While hard data on this in maritime is still emerging, analogous findings in aviation and

corporate settings show positive correlations between diversity and performance outcomes.

Socio-Cultural Factors: Not all problems can be fixed by design alone; some are cultural or require policy enforcement. Sexual harassment and bullying of women on board, unfortunately, is a documented issue [3]. Even the best-designed ship will not retain women if they face hostile behavior. That said, design can contribute to a safer social environment – for instance, having locks on cabin doors, well-lit corridors, perhaps CCTV in passages, and clear privacy demarcation can deter misconduct and give women a greater sense of security. The IMO and various NGOs are promoting a culture of equality and respect (through campaigns like "Safe at Sea: it takes all of us!") [11]. Such socio-cultural initiatives complement technical fixes. A holistic approach is needed: train crews on diversity and inclusion (so male seafarers become allies in making the environment welcoming), establish reporting mechanisms for any harassment (so issues don't stay hidden), and simultaneously remove the practical irritants (so women aren't, say, stressed about something as basic as finding a bathroom or PPE).

The research should acknowledge a potential counterargument or concern from industry: given women are only ~1% of crew, is it worth investing in major design changes? This view, while perhaps pragmatic in the

short term, misses the larger picture. First, as argued, changes that help women generally help others (universal benefit). Second, the percentage may be low now, but the aim (per IMO and others) is to increase it – one cannot increase if the environment remains unfriendly. Third, even with 1%, in absolute numbers that's on the order of 24,000 women at sea globallytheseafarerscharity.org, whose safety and rights are important; accidents or injuries affecting them are just as unacceptable. And finally, certain improvements like better ergonomics contribute to compliance with existing regulations (for example, MLC mandates on living conditions, SOLAS requirements for life-saving appliances to be usable by all persons on board, etc.). In many cases, it's not a completely new requirement but enforcing standards that should have been met.

Alignment with International Policy: Our discussion would be incomplete without circling back to the international policy perspective. The IMO's stance as of the last few years is clearly in favor of gender equality in maritime. The Women in Maritime program (since 1988) and the 2019 Assembly Resolution A.1147(31) urge stakeholders to create a "barrier-free working environment" [12]. This essentially means identifying and removing barriers that prevent women from full and safe participation. The barriers are not just social biases; they include the tangible design and equipment-related ones The research have identified. By implementing gender-inclusive design practices, shipping companies and shipbuilders directly contribute to this goal. It shows compliance not only with the letter of regulations (like the MLC amendment on PPE) but the spirit of IMO's drive for inclusivity. There is also a resonance with the United Nations Sustainable Development Goals (SDGs) – particularly SDG 5 (Gender Equality) and SDG 8 (Decent Work and Economic Growth). A gender-inclusive maritime industry is part of achieving decent work for all and tapping into a broader talent pool for economic growth.

On the labor side, the International Labor Organization (ILO) via the MLC and related conventions (e.g., those on occupational safety) is increasingly explicit about non-discrimination [1]. Ensuring that women have equal access to safe working conditions is a matter of compliance with those principles. The research saw that companies are already responding; by the 2024 deadline, the research expects virtually all responsible operators to supply female crew with proper PPE as required [3]. The research also foresees class societies possibly making ergonomic inclusivity part of their survey checks – for example, verifying the availability of at least one sanitation facility per ship for female crew if women are employed, etc. These policies and regulatory reinforcements will push laggards to improve and will standardize what progressive companies have started doing proactively.

In essence, the discussion affirms that enhancing maritime safety via gender-inclusive design is both a practical necessity and an ethical mandate. It is practical because it addresses real safety issues (reducing error and injury) and improves efficiency and retention. It is ethical because it ensures no group is left at a disadvantage by design, aligning with contemporary values of equality. Moreover, as the maritime industry modernizes with automation and digitalization, there is an opportunity to embed inclusivity from the ground up – not to perpetuate biases into the next generation of ships. For instance, the design of autonomous ship control interfaces or new offshore platforms can proactively include diverse user testing.

Addressing gender-specific design gaps can improve safety and morale. IMO initiatives advocate for inclusive maritime environments [3]. Improved ergonomics benefit all crew members, not just women. Culture and onboard safety perception are also improved [6,0…].

Finally, it should be noted that inclusive design is an ongoing process. It requires feedback loops: as more women join and share their experiences, the designs should continuously evolve. The All-Aboard Alliance's approach of co-designing solutions with both men and women seafarers is an excellent modelassets.ctfassets.netassets.ctfassets.net. By involving end-users of all demographics in the design and testing phase, the industry can preempt many issues. This participatory design ethos will likely drive the next wave of safety improvements.

Conclusion

This research supports the implementation of gender-inclusive design. Adoption of proper PPE, ergonomic bridges, and policy alignment with IMO and ILO standards will enhance safety across the maritime sector and sets out to explore how gender-inclusive design can enhance maritime safety and operational efficiency [3,9,10,13]. Through analysis of human factors in maritime incidents, workforce demographics, current technology use, and case studies, the research found compelling evidence that many maritime systems have historically been designed without adequately considering the needs of women, and that this has safety and performance repercussions. Key problem

areas identified include personal protective equipment sizing, shipboard accommodation, and certain equipment ergonomics that do not fit smaller or differently shaped personnel. By addressing these gaps, the maritime industry can not only improve the safety and well-being of female seafarers but also achieve broader benefits for all crew and align with international mandates on equality [14-16].

Recommendations

Based on our findings, the research proposes the following recommendations and guidelines for stakeholders (ship designers, equipment manufacturers, shipping companies, and regulators):

- **Adopt Gender-Inclusive Design Standards:** Integrate requirements into ship design specifications that account for the 5th percentile female dimensions for reach, strength, and accommodation. Regulatory bodies and classification societies should update bridge design guidelines, machinery layout standards, and accommodation rules to ensure usability by both women and menmaritimesafetyinnovationlab.org. This includes adjustable height consoles, ergonomic seat designs, and placement of critical controls within reach of a smaller individual.
- **Personal Protective Equipment (PPE) Provisioning:** Ensure that PPE in appropriate sizes and fits is available on all vessels. Ship operators must stock women's sizes for safety shoes, harnesses, gloves, immersion suits, etc., in line with the amended MLC 2006 mandate [3]. Manufacturers should continue to develop and offer female-tailored safety gear (as some are now doing with immersion suitsviking-life.com), and companies should preferentially procure such gear. Regular feedback from female users should be solicited to improve PPE design continuously.
- **Shipboard Facility Improvements:** Retrofit older ships where feasible to provide separate sanitary facilities and privacy for women. At minimum, designate one restroom for female crew and equip it with necessary amenities (sanitary bins, etc.), ensuring compliance with health and sanitation standards [3]. Provide locks or swipe-card access to certain facilities if needed to enhance personal security. New ships should be built with unassigned bathrooms that can be allocated to women if they are part of the crew, avoiding the need for ad-hoc arrangements.
- **Inclusive Emergency Equipment:** Review life-saving appliances (LSA) and arrangements with an inclusive lens. Conduct drills with mixed-gender crews to observe if any group faces difficulty – for instance, can all crew, regardless of gender, launch lifeboats, handle fire hoses, don breathing apparatus, etc. If not, implement technical aids (like powered davits, lighter nozzles) or additional training to compensate. Ensure that emergency instructions and signage are easily understandable and consider any potential differences in PPE (for example, diagrams that show long hair to remind of tucking in for breathing masks, etc., can be small inclusion cues).
- **Training and Awareness:** Incorporate modules on human elements and diversity in maritime training curricula. This includes educating all seafarers on unconscious bias, teamwork in diverse groups, and the proper use of adjustable equipment. Senior officers should be trained to manage and mentor mixed crews effectively, fostering an inclusive safety culture. Mentoring programs (such as those by WISTA or company initiatives) can help women seafarers navigate challenges and advance to leadership, which in turn will normalize female presence and influence design needs being heard.
- **Policy and Leadership Commitment:** Companies should adopt diversity charters and action plans (as recommended by ICS and others) that explicitly cover workplace design and safety. This means leadership allocates budget and resources to make physical modifications or purchase specialized equipment when a need is identified [3]. It should become standard practice that whenever a female seafarer joins a vessel, a review is done by the safety officer to ensure she has all necessary equipment and accommodations to work safely – essentially a personalized risk assessment – and any gaps are promptly filled. Over time, these practices will become routine and anticipated rather than reactive.
- **Monitoring and Research:** Lastly, the research recommends ongoing data collection on the impact of these changes. Industry associations and researchers should monitor injury rates, near-miss reports, and retention rates of female seafarers as inclusive design measures are implemented. If our hypothesis holds, the research expects to see a reduction in PPE-related injuries, higher reported comfort and morale among women, and perhaps an uptick in women pursuing seafaring careers knowing that conditions are improving. Publishing these metrics will help maintain momentum and share best practices.

In conclusion, enhancing maritime safety through gender-inclusive design is both feasible and advantageous. It requires a concerted effort that spans engineering adjustments, procurement choices, policy enforcement, and cultural change. The maritime sector has always evolved by learning from accidents and near-misses – here, it must also learn from the voices that have long been in the minority. As one female 2nd engineer succinctly put it, "overalls never fit; they need to be designed for different kinds of bodies" assets.ctfassets.net. By heeding such feedback and acting on it, the research makes the industry safer for her and for everyone. This aligns perfectly with the IMO's vision of a "barrier-free working environment" for womenimo.org, and indeed for all seafarers regardless of gender. Ultimately, a ship that is designed for everyone's safety is a ship that sails more smoothly, with a more effective and confident crew – a goal that benefits the entire maritime community.

Declaration

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- "The author has no competing interests to declare."
- "The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials."

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