Maritime Workforce 4.0: How Digital Transformation is Shaping Jobs at Sea

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Abstract

The maritime industry, a critical backbone of global trade and commerce, is undergoing a transformative shift as it embraces the era of digitalization, often referred to as Maritime Workforce 4.0. The convergence of advanced technologies such as automation, artificial intelligence (AI), big data, and the Internet of Things (IoT) is revolutionizing jobs at sea, fundamentally altering the roles, skills, and competencies required for seafarers and other maritime professionals. This study examined the impact of technological advancements on maritime jobs, focusing on how digital transformation is reshaping the skills and competencies required for seafarers in the contemporary maritime sector. Utilizing a sample size of 120 respondents, the research explored key indicators, including the impact of automation and robotics, the necessity for new skills in IT and cybersecurity, and the challenges faced by seafarers in adapting to these changes. The findings revealed significant insights: a notable percentage of respondents recognized the considerable influence of automation and robotics on job roles, with many acknowledging the need for continuous learning and upskilling. The study also identified critical challenges, such as resistance to change, training and educational gaps, and generational divides, which hinder seafarers' adaptation to technological changes. Additionally, it emphasized the essential role of maritime education and training (MET) institutions in preparing the workforce for these advancements. Ultimately, this research contributes to the understanding of how digital transformation is reshaping maritime employment, providing valuable insights for policymakers, educators, and industry stakeholders aiming to enhance the skills and adaptability of the maritime workforce in the face of ongoing technological evolution.

Keywords: Maritime workforce, digital transformation, technological advancements, seafarers, new skills and competencies, training and education, challenges in adaptation etc.

1. Introduction

The maritime industry, a critical backbone of global trade and commerce, is undergoing a transformative shift as it embraces the era of digitalization, often referred to as Maritime Workforce 4.0. The convergence of advanced technologies such as automation, artificial intelligence (AI), big data, and the Internet of Things (IoT) is revolutionizing jobs at sea, fundamentally altering the roles, skills, and competencies required for seafarers and other maritime professionals. As these technologies integrate into everyday maritime operations, the need for a workforce that is not only technically proficient but also adaptable to the dynamic digital environment is becoming increasingly urgent. This shift is not just about improving efficiency and productivity but also about ensuring safety, sustainability, and competitiveness in a rapidly evolving global market. Historically, the maritime industry has relied on traditional methods of navigation, communication, and ship management, which were heavily manual and required a workforce with specific, hands-on skills. However, with the introduction of Maritime 4.0 technologies, the industry has seen an unprecedented acceleration in innovation. Digital tools are now streamlining processes such as ship maintenance, cargo handling,

navigation, and even compliance with international maritime regulations. As a result, the roles of seafarers are evolving from purely operational tasks to more data-driven decision-making roles. Ships are becoming "smarter," equipped with sensors and AI-driven systems that can predict maintenance needs, optimize routes, and ensure safety in complex maritime environments.

The maritime industry is undergoing a significant transformation due to the introduction of Industry 4.0 technologies, leading to changes in ship design, operations, and manning [1]. This digital revolution is reshaping the roles of seafarers, shifting from traditional operational tasks to more data-driven decision-making roles [2]. The adoption of technologies such as IoT, cloud computing, blockchain, and AI aims to enhance safety, efficiency, and environmental sustainability in maritime logistics [3]. As a result, there is a growing need to identify and develop new skills for the maritime workforce to adapt to these technological advancements [4]. The industry is now focusing on bridging the gap between current training offerings and the actual needs of the sector, with special attention given to worker training and competitiveness in this evolving labor market [2, 3].

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The maritime industry experienced a digital transformation, embracing technologies like artificial intelligence, blockchain, cloud computing, and big data [5]. This shift aimed to optimize cargo handling, improve logistics processes, enhance efficiency and safety, and minimize environmental impacts [6]. The digitalization process was influenced by organizational, technological, and environmental factors, leading to changes in business models, new revenue sources, and innovative services [7]. Major shipping companies adopted digitalization strategies to increase cost-efficiency, competitiveness, and meet customer needs [8]. The industry faced challenges in adopting these technologies due to its traditional culture and existing barriers [6]. However, the transition towards autonomous ships and the integration of Industry 4.0 concepts signaled a new operational paradigm for maritime transport [8], emphasizing the need for a broader perspective and deeper understanding of these technologies [5].

The maritime industry underwent significant digital transformation, impacting workforce management and skills requirements. Automation and digitalization led to a shift towards higher demand for technical proficiency and digital literacy among maritime professionals [9]. This transition posed challenges for human resource management, particularly in training and education of the workforce [10]. The industry faced a potential decrease in traditional manual roles, necessitating extensive re-skilling and creating new job opportunities [2]. While digitalization offered prospects for improved efficiency, safety, and environmental impact reduction, it also presented challenges such as workforce displacement [6]. The maritime sector's obstinate culture and barriers to adoption caused it to lag behind other industries in digital transformation [6]. Stakeholders needed to implement strategic interventions, including targeted training programs and policy frameworks, to facilitate a smooth transition towards an automated maritime future [9].

The digital transformation of the maritime industry has significantly altered the skills and competencies required for seafarers. As ships become larger and more intelligent, seafarers needed to adapt to new technologies, enhance data analysis capabilities, and improve safety management and emergency response skills [11]. The transition towards autonomous shipping necessitated a gradual evolution of seafarers' roles and responsibilities [1, 12]. This shift highlighted the need for a new skills and competency framework to supplement the existing STCW Code, addressing the challenges of designing and implementing such a framework for future seafarers [13]. Additionally, the increasing digitalization and networking of maritime operations exposed seafarers to new cyber risks, emphasizing the importance of developing standardized digital competencies to enhance maritime safety [14]. These changes underscored the critical need for updated training and education programs to prepare seafarers for the evolving maritime landscape. While research had been conducted on identifying new skills for future seafarers, there was a lack of studies on designing and implementing a comprehensive skills and competency framework. A systematic literature review highlighted the challenges in developing such a framework, emphasizing the need for a structured approach to training that meets the requirements of employers and regulatory bodies [12].

The digitalization of the maritime industry significantly transformed seafarers' roles and responsibilities. As ships progressed towards autonomy, seafarers' tasks evolved from traditional operations to managing sophisticated systems [1, 15].

This shift necessitated a reevaluation of competencies required for modern maritime operations [16]. The transition from conventional shipping to smart and autonomous vessels demanded new skills and strategies for seafarers [1]. Maritime education and training institutions faced the challenge of preparing seafarers for future technological advancements, requiring a focus on developing technical and specialized skills [17]. The industry's digitalization also highlighted the need for updated regulatory frameworks, particularly in the Standards of Training, Certification, and Watchkeeping (STCW) Convention, to address the emerging requirements of unmanned and autonomous ships [16]. Overall, the maritime sector witnessed a paradigm shift in seafarers' duties, emphasizing the importance of adapting to technological innovations and continuous skill development.

The maritime industry faced significant changes due to automation, impacting workforce management and employment patterns. Automation led to a shift towards higher demand for technical skills and digital literacy, while potentially decreasing traditional manual roles [9]. This technological advancement offered opportunities for enhanced operational efficiency and safety but also posed challenges related to workforce displacement and the need for re-skilling [9]. The increased automation in navigation systems affected situational awareness, potentially impacting performance in critical circumstances [18]. The trend towards automation was likely to affect the number of people employed at sea and change the nature of their roles [19]. Industry 4.0 and digitalization had implications for seafarers' skills, training, and career trajectories, necessitating a career-focused perspective and stakeholder engagement in shaping future maritime skills [2]. The shift towards autonomous operations demanded a workforce with hybrid skills, combining traditional seamanship with digital literacy and technical expertise [9, 20]. This transition presented both challenges and opportunities, potentially reducing manual roles while creating new positions requiring advanced technical proficiency [9]. The rapidly evolving technological landscape emphasized the need for continuous learning and strategic investments in MET to prepare future seafarers [17, 21]. Education systems were urged to adopt more flexible and responsive approaches, moving beyond standardized curricula to foster creativity, social interaction, and collaboration [21]. Industry-academia collaboration was deemed crucial for addressing skill gaps and ensuring the workforce's readiness for an automated maritime future [9, 17].

The maritime industry faced significant challenges in adapting to rapid technological advancements, which were transforming the nature of work at sea. Seafarers struggled to keep pace with the evolving demands of digital tools, automation, and robotics, which introduced new skills and competencies that were not traditionally part of maritime training. The potential impact of automation and robotics on maritime jobs raised concerns about job displacement and the need for continuous upskilling. Seafarers often reported difficulties in navigating these technological shifts, especially in environments where maritime education and training (MET) institutions had yet to fully adapt their curricula to meet the changing needs of the digital workforce. Consequently, there was a critical need to address these gaps to ensure that the maritime workforce remained competitive and capable in a highly digitized industry.

The objective of the study was to explore the transformative effects of digital advancements on the maritime workforce, focusing on how technological advancements reshaped the

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nature of work at sea, the new skills and competencies required for seafarers in the digital age, and the potential impact of automation and robotics on maritime jobs. Additionally, the study aimed to examine the challenges faced by seafarers in adapting to these technological changes and to propose strategies for maritime education and training (MET) institutions to adapt their curricula and programs to meet the evolving needs of the digital maritime workforce.

The main contribution of the study was to provide a comprehensive analysis of the impact of digital transformation on the maritime workforce, highlighting the significant changes in job roles, skills, and competencies required for seafarers in the context of advancing technologies. By identifying the specific challenges that seafarers faced in adapting to technological advancements, the study offered valuable insights into how maritime education and training (MET) institutions could better prepare future professionals for a rapidly evolving industry. Furthermore, the research contributed to the understanding of the implications of automation and robotics on maritime jobs, serving as a resource for policymakers, educators, and industry stakeholders to make informed decisions regarding workforce development and training programs in the digital era.

2. Methodology
The methodology of the study employed a mixed-methods approach, combining quantitative and qualitative research techniques to gain a comprehensive understanding of the impact of digital transformation on the maritime workforce. The sample consisted of 120 respondents, including seafarers, maritime educators, industry stakeholders, and representatives from maritime organizations.

Quantitative data were collected through structured surveys distributed to seafarers and maritime professionals, which aimed to assess their experiences with technological advancements, the skills required for their roles, and their perceptions of the challenges posed by digital transformation. The survey included Likert-scale questions, multiple-choice questions, and demographic information to facilitate statistical analysis.

Qualitative data were obtained through semi-structured interviews with selected respondents, allowing for in-depth exploration of personal experiences, challenges, and recommendations regarding the adaptation to digital technologies in the maritime sector. This qualitative component provided rich contextual insights that complemented the quantitative findings.

Data analysis involved descriptive statistics to summarize survey responses and thematic analysis of interview transcripts to identify common themes and patterns related to the transformation of maritime jobs in the digital age. By integrating both quantitative and qualitative data, the study aimed to deliver a holistic view of the evolving landscape of maritime employment and the implications for maritime education and training.

3. Results and Discussion
The results and discussion section of this study, based on a sample size of 120 respondents, provided valuable insights into the effects of digital transformation on the maritime workforce. The data gathered from surveys and interviews revealed a wide range of perspectives on how technological advancements are reshaping jobs at sea, the new skills required, and the challenges faced by seafarers in adapting to these changes. The responses were analyzed to assess trends,

patterns, and the impact of automation, robotics, and digital tools on maritime roles. This section explores the key findings in relation to the research questions, offering a detailed examination of both the quantitative data and qualitative insights from participants.

3.1. Impact of Technological Advancements on Maritime Jobs
The analysis of the impact of technological advancements on maritime jobs revealed significant insights into how the industry had evolved in response to emerging technologies. Respondents indicated that automation and robotics had notably transformed operational processes, enhancing efficiency while reducing the need for manual labor. Additionally, the adoption of digital tools and platforms had streamlined various functions, fostering improved communication and decision-making among maritime professionals.

3.1.1. Automation and Robotics
The study as per table 1, revealed that the impact of automation and robotics on maritime jobs was perceived as significant by a substantial portion of respondents. Among the 120 participants, 65(54%) acknowledged that automation had transformed their work environment, leading to increased efficiency and a shift in job responsibilities. Many respondents expressed that the integration of automated systems had allowed for more streamlined operations. One respondent shared:

"...automation has changed the way we operate on ships. Tasks that once required several crew members can now be handled by a single automated system, reducing the workload significantly..."

This response was echoed by others who noted that while automation had streamlined processes, it also necessitated a reevaluation of the skills required for maritime work.

However, a considerable number of respondents, 45(38%), regarded the impact of automation and robotics as moderate. These individuals recognized that while automation introduced new technologies, it did not entirely replace human involvement. One participant commented:

"...we still need skilled seafarers to oversee automated systems. Automation is a tool, not a complete solution. It requires a human touch to ensure everything operates smoothly..."

This opinion highlighted a nuanced understanding of the role of technology in the maritime sector, emphasizing that human oversight remained crucial even in an increasingly automated environment.

In contrast, only 10 respondents (8%) considered the impact of automation and robotics to be negligible. These individuals often worked in areas of the maritime industry less affected by technological changes or had not yet experienced significant shifts in their roles. One respondent explained:

"...In my department, we still rely heavily on traditional methods. Automation hasn't fully reached us yet, so I don't see it impacting my job as much..."

This variation in perspectives illustrated the diverse experiences among maritime professionals regarding the adoption of automation and robotics, emphasizing that the degree of impact was largely dependent on specific roles and areas within the industry.

The findings indicated a strong recognition of the transformative potential of automation and robotics in maritime jobs, with a majority of respondents viewing it as a

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significant development. Yet, the need for human oversight and the preservation of traditional skills were also underscored, suggesting that the future of work in the maritime sector would require a balance between technological advancements and human expertise.

Table 1: Showing the Impact of Technological Advancements on Maritime Jobs

Sub-Indicator	Negligible (%)	Moderate (%)	Significant (%)
Automation and Robotics	10(8%)	45(38%)	65(54%)
Digital Tools and Platforms	15(13%)	40(33%)	65(54%)
Reduction in Manual Labor	20(17%)	50(42%)	50(42%)

3.1.2. Digital Tools and Platforms

The impact of digital tools and platforms on maritime jobs as shown on table 1, was largely seen as significant by most respondents, with 65(54%) of them acknowledging how these advancements had revolutionized their work processes. Many interviewees emphasized that the use of digital tools had made operations more efficient, enabling real-time communication, enhanced navigation, and better management of on-board systems. One respondent remarked:

"...digital platforms have completely changed the way we handle logistics and communication. We can now coordinate tasks in real-time, track shipments, and access data from anywhere, which has significantly improved our operations..."

This shift towards digitalization, according to respondents, was not just about convenience but also about transforming how work was executed at sea.

Several participants highlighted how digital tools had reduced the need for manual paperwork, simplified reporting, and allowed for better data management.

"...we used to spend hours on paperwork after every voyage...," one participant shared.

"...now, with digital platforms, reports are generated automatically, and we can focus on more critical tasks. The efficiency it brings is undeniable...,"

For many in the maritime sector, the transition to digital tools also meant learning new skills, as one respondent explained:

"...we've had to adapt to using these systems, but it's a necessary change. The maritime industry is moving forward, and digital literacy is becoming just as important as traditional skills..."

Meanwhile, 40 respondents (33%) considered the impact of digital tools and platforms to be moderate. These individuals acknowledged the benefits of digitalization but felt that its integration was still in progress, or its effects had not fully transformed all aspects of their roles.

"...we're using more digital tools, but it's not yet widespread...," commented one respondent.

"...Some areas of the job still rely on older methods, and while digital platforms help, we're not fully digital yet..."

This group of respondents often described a hybrid environment where traditional and digital systems coexisted, with the gradual adoption of newer technologies happening alongside established practices.

On the other hand, 15 respondents (13%) perceived the impact of digital tools and platforms as negligible. These participants typically worked in sectors of the maritime industry where digitalization had not yet taken root, or where their specific roles remained largely unaffected by technological changes.

"...We're still doing things the old way...," shared one respondent.

"...The digital tools are available, but they haven't been fully implemented in my department, so I haven't seen much of a change..."

Others noted that while digital platforms were useful, their day-to-day work still involved hands-on, physical tasks that weren't easily replaced by technology.

The responses overall painted a picture of an industry in transition, where digital tools and platforms were playing a significant role in reshaping maritime jobs for many, though the level of impact varied depending on the specific nature of the work and the degree of technological adoption. The findings indicated that, while digitalization was advancing, there was still a long way to go before its benefits were fully realized across the entire maritime sector.

3.1.3. Reduction in Manual Labor

The reduction in manual labor due to technological advancements in the maritime industry as per table 1, was acknowledged by most respondents as being moderate or significant, with 50(42%) in each category. Many participants highlighted how automation and digitalization had streamlined operations, reducing the need for physically intensive tasks. One respondent explained:

"...with the introduction of new systems, many of the tasks that used to require manual effort are now handled by machines or automated processes. For instance, cargo handling, which used to involve a lot of manpower, is now much more efficient with the use of cranes and automated loading systems..."

This transition has not only improved efficiency but also reduced the risk of human error, as noted by several interviewees.

Another respondent emphasized the impact of technology on routine ship operations:

"...before, we had to manually control many of the ship's functions, but now, digital systems handle a lot of that. It's not just about reducing labor; it's about improving precision and safety..."

This perspective was common among those who categorized the reduction in manual labor as significant, as they often described how automation had transformed entire aspects of their daily work.

"...we've seen a real shift in how things are done at sea...," one interviewee said.

"...from navigation to engine monitoring, much of what used to require a hands-on approach is now controlled digitally, and it makes the work a lot less physically demanding..."

At the same time, another 50 respondents (42%) rated the reduction in manual labor as moderate. These participants recognized the benefits of technological advancements, but they also pointed out that some manual tasks remained essential, especially in certain areas of the industry.

"...Yes, there's been a reduction in labor-intensive tasks, but there are still a lot of physical jobs that can't be replaced by machines...," one seafarer commented.

"...maintenance work, for example, still requires a human touch. You can't fully automate repairs or inspections—at least not yet..."

This group felt that while technology had indeed eased the burden of certain tasks, it had not eliminated manual work entirely, especially in areas that still relied heavily on human judgment and hands-on skill.

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On the other hand, 20 respondents (17%) believed that the reduction in manual labor had been negligible. For these individuals, technological advancements had made little to no impact on the physical demands of their jobs.

"…We still do a lot of things the old-fashioned way…," one participant explained.

"...while there's talk about automation, it hasn't reached us yet. Most of our work is still manual, especially in smaller ports or on older ships where upgrading to new technology isn't always feasible..."

Another respondent added:

"...the technology exists, but implementing it in all areas of maritime work is still a challenge, especially in regions with limited resources for modernization..."

This varied feedback highlighted how the adoption of technology, and its effects on reducing manual labor, differed across the maritime industry. While for some, the shift toward automation was already significantly reshaping their work, others remained in roles or regions where manual labor was still a fundamental part of their daily routine. In general, the responses reflected both optimism and realism about the potential for technology to further reduce physical demands in the future, though many acknowledged that the full impact of these advancements was yet to be seen across the entire sector.

3.2. New Skills and Competencies for Seafarers in the Digital Age

The study explored the evolving demands for new skills and competencies among seafarers in the digital age, focusing on areas such as technical skills, IT and cybersecurity knowledge, and the need for continuous learning and upskilling. Respondents reflected on how technological advancements had reshaped the maritime sector, requiring seafarers to adapt to more complex systems and new digital tools. The discussion highlighted both the opportunities and challenges that arose from this shift, emphasizing the growing importance of technical proficiency and ongoing education to stay relevant in the rapidly changing industry.

Table 2: Showing the New Skills and Competencies for Seafarers in the Digital Age

Sub-Indicator	Low (%)	Adequate (%)	High (%)
Technical Skills	15(12%)	50(42%)	55(46%)
IT and Cybersecurity Skills	20(16%)	45(38%)	55(46%)
Continuous Learning and Upskilling	25(20%)	45(38%)	50(42%)

3.2.1. Technical Skills

In the exploration of new skills and competencies required for seafarers in the digital age, respondents as table 2, underlined the critical need for enhanced technical skills within the maritime workforce. A substantial portion of the interviewees, specifically 46%, categorized the technical skills of current seafarers as high, noting that these skills were pivotal for navigating the complexities of modern maritime operations. As one respondent articulated:

"...the demands of the industry have shifted dramatically; it is no longer just about being able to steer a ship or manage cargo. Today, seafarers must understand sophisticated navigation systems and be adept at using various digital tools that enhance efficiency and safety..."

Conversely, while 12% of respondents indicated that technical skills were low, this sentiment was often linked to concerns

over the adequacy of training programs. One respondent remarked:

"...many of the training institutions are still using outdated materials that do not reflect the current technologies. This gap in technical education creates a workforce that is not fully equipped to handle the advancements in the industry..."

The emphasis on the necessity for technical proficiency was echoed throughout the interviews, with participants agreeing that to remain competitive, seafarers must not only adapt but also excel in the use of advanced technologies that are becoming commonplace in maritime operations.

Furthermore, 42% of respondents felt that while some seafarers possessed adequate technical skills, there remained significant room for improvement. As one respondent put it:

"...we have a solid base of seafarers who can manage the basic functions, but as technology continues to evolve, we need to ensure that our workforce is prepared to meet future challenges..."

This perception highlighted a prevailing concern within the industry: the urgent need for comprehensive training programs that would not only build on existing skills but also integrate new technological advancements, thereby preparing seafarers to thrive in an increasingly digital maritime environment.

3.2.2. IT and Cybersecurity Skills

The study as the data presented on table 2, revealed significant insights regarding the IT and cybersecurity skills of seafarers, with many respondents expressing concerns over the current level of preparedness in these critical areas. A substantial 46% of the participants rated the IT and cybersecurity skills of seafarers as high, acknowledging the growing importance of these skills in maintaining the safety and security of maritime operations. One respondent noted:

"...cybersecurity is now as important as physical security on board. We are dealing with highly interconnected systems, and if seafarers are not well-trained in IT and cybersecurity, the whole operation is at risk..."

Despite this, a notable 38% of respondents rated these skills as merely adequate, highlighting a gap between the current competency levels and the growing demands of the industry. As one interviewee explained:

"...the maritime sector is transitioning into a more digital world, but not all seafarers are keeping up with these changes. While many can handle basic IT functions, there is a need for more advanced training in cybersecurity, especially with the increasing threat of cyberattacks..."

This group of respondents accentuated that while seafarers are being trained in IT skills, the rapid pace of technological advancements in the maritime industry requires continuous learning and more specialized knowledge to fully secure digital systems on board.

Meanwhile, 16% of respondents believed that the IT and cybersecurity skills of seafarers were still low, suggesting that many maritime education programs had not yet fully adapted to the digital transformation. One respondent observed:

"...there are still institutions that focus on traditional maritime skills, with very little emphasis on IT or cybersecurity. This leaves many seafarers vulnerable in their roles, especially when it comes to handling digital systems safely..."

This lack of focus on modern skills has created challenges for the maritime workforce, particularly as cyber threats become more prevalent and sophisticated. The interviews consistently pointed to a growing consensus: that more strategic

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investments and updated training programs are essential to bridge the skills gap and ensure seafarers are adequately prepared to protect both the vessels and their digital systems from evolving threats.

3.2.3. Continuous Learning and Upskilling

The study's findings on continuous learning and upskilling among seafarers in the digital age as per table 2, highlighted both progress and persistent challenges. A considerable portion of respondents, 42%, rated the level of continuous learning and upskilling as high, suggesting that many seafarers were actively engaging in programs aimed at enhancing their skills to keep pace with technological advancements. One interviewee emphasized:

"...the maritime industry has changed drastically, and we are aware that to stay relevant, we must continuously learn. Many seafarers are now more open to taking courses on digital tools and systems, understanding that these skills are not just an option but a necessity..."

This positive insight reflected a shift in mindset among maritime professionals, with many recognizing the need to evolve their skills in tandem with the rapid digitalization of the industry.

However, 38% of respondents rated the current level of upskilling as merely adequate, indicating that while there had been some effort to support ongoing learning, more could still be done to bridge knowledge gaps. As one respondent put it:

"...there are opportunities for learning, but they are not consistent across the board. Some seafarers are fortunate enough to work for companies that invest in training, while others are left to figure it out on their own..."

This feedback highlighted disparities in access to continuous learning resources, often depending on the employers' commitment to investing in their workforce.

Interestingly, 20% of respondents believed the level of continuous learning and upskilling among seafarers remained low, with one respondent noting:

"...many seafarers, particularly older ones, are resistant to change. They believe the traditional ways of doing things still work, and as a result, they shy away from learning new skills, especially those related to digital systems..."

This remark reflected the challenge of encouraging a cultural shift toward lifelong learning in an industry that has historically been slow to adopt new technologies. Moreover, some respondents pointed out the lack of structured opportunities for seafarers to continuously develop their skills, with one interviewee stating:

"...there needs to be more emphasis on regular, formal training programs that ensure all seafarers, regardless of their age or background, can keep up with the changes in the industry..."

The responses illustrated that while there was an increasing awareness of the importance of upskilling in the maritime sector, more systematic efforts were needed to ensure that all seafarers had access to and embraced opportunities for continuous learning. The disparities in access to training, along with resistance from some parts of the workforce, highlighted ongoing challenges that needed to be addressed to fully prepare seafarers for the evolving demands of the digital maritime industry.

3.3. Potential Impact of Automation and Robotics on Employment Levels

The analysis of the potential impact of automation and robotics on employment levels revealed significant shifts in the maritime workforce. Respondents highlighted key concerns and opportunities related to job reductions, the creation of new roles, and evolving job descriptions. Many interviewees reflected on how technological advancements were reshaping traditional jobs, leading to a complex interplay between automation-driven redundancies and the emergence of new, tech-focused positions that required updated skills and competencies. These changes accentuated the need for both adaptation and innovation within the workforce to keep pace with ongoing industry transformation.

3.3.1. Job Reductions

The insights gathered from respondents regarding job reductions due to automation and robotics as shown on table 3, revealed a slightly different perception on the future of employment in the maritime industry. A notable 25% of participants acknowledged that they perceived only a low risk of job reductions, indicating a sense of optimism about the resilience of certain maritime roles. One respondent shared:

"...while technology is undoubtedly advancing, I believe that many traditional roles will still be needed. For instance, skilled seafarers who understand both maritime operations and the technology can effectively bridge the gap..."

In contrast, 42% of respondents felt that job reductions would be moderate, emphasizing a more cautious outlook. Many voiced concerns about specific roles that could be rendered obsolete. One participant noted:

"...we've seen how automated systems have taken over basic navigation and monitoring tasks. I fear that some entry-level positions, which were crucial for gaining experience, might dwindle as these systems become more sophisticated..."

This response was echoed by another respondent who said:

"...there's a reality we can't ignore: the industry is evolving, and while I hope we won't lose too many jobs, I can see a shift happening..."

Additionally, 33% of those interviewed expressed a high concern about job reductions, indicating a recognition of the broader implications of automation. A respondent highlighted:

"...the speed at which automation is being adopted is alarming. I worry about the next generation of seafarers; will there be jobs for them? If companies can rely on robots to do the work, why would they hire human crews..?"

Such apprehensions illustrated a deep-seated anxiety about the potential for significant job losses, particularly in roles that were traditionally performed by humans.

The interviews captured a complex landscape of views on job reductions linked to automation, underscoring the pressing need for the maritime industry to strategically address these challenges while exploring new opportunities that technological advancements might bring.

Table 3: Showing the Potential Impact of Automation and Robotics on Employment Levels

Sub-Indicator	Low (%)	Moderate (%)	High (%)
Job Reductions	30(25%)	50(42%)	40(33%)
Job Creation in New Areas	20(16%)	50(42%)	50(42%)
Shifts in Job Descriptions	25(21%)	60(50%)	35(29%)

3.3.2. Job Creation in New Areas

The discussions surrounding job creation in new areas due to automation and robotics revealed a mixed but generally optimistic outlook among respondents in the maritime industry. As per table 3, approximately 16% of participants

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believed that the potential for job creation in new areas was low, expressing skepticism about whether advancements in technology would translate into new employment opportunities. One respondent articulated this sentiment by stating:

"...while technology is great, I struggle to see how it will create many new jobs. Most of the focus seems to be on efficiency and cost-cutting, which doesn't often lead to more roles being available..."

On the other hand, a significant portion of respondents 42% indicated a moderate expectation for job creation, reflecting a recognition that while some roles might be diminished, new ones could emerge as a direct result of technological advancements. One participant noted:

"...automation might take away some of the routine tasks, but it also opens doors for specialized roles, like data analysts and cybersecurity experts, who will be crucial in managing these new technologies. It's a transition, and industries need to adapt..."

This insight was shared by another interviewee, who emphasized:

"...as we adopt more sophisticated systems, there will definitely be a need for professionals who can operate and maintain them. I see that as a positive shift rather than just job losses..."

Interestingly, another 42% of participants expressed a high belief in the potential for job creation, emphasizing the transformative impact of automation and robotics on the maritime workforce. One respondent passionately stated:

"...automation isn't the enemy; it's a tool. It can lead to entirely new fields of work that we haven't even considered yet. For example, roles in robotics maintenance and development will become essential. It's all about how we prepare for this change..."

This statement was echoed by a fellow participant who pointed out:

"...the maritime industry is evolving, and with evolution comes new opportunities. We need to embrace technology and use it to our advantage to create a workforce that can thrive in this new environment..."

The insights gathered from the interviews painted a picture of cautious optimism regarding job creation in new areas resulting from automation and robotics. While concerns about job displacement were prevalent, there was a strong undercurrent of belief in the ability of the maritime sector to adapt and generate new employment opportunities in the face of technological change.

3.3.3. Shifts in Job Descriptions

The investigation into shifts in job descriptions due to automation and robotics according to data on table 3, highlighted a notable transformation in the expectations and responsibilities of maritime workers. While 21% of respondents perceived low impact in terms of changes to job descriptions, many were somewhat skeptical about the extent to which technology would redefine their roles. One respondent articulated this viewpoint by saying:

"...i don't think automation will change what we do significantly. Many of us have specific tasks that we perform, and while machines might assist us, they won't replace the core of our jobs..."

This observation reflected a reluctance among some workers to accept the notion that their roles could fundamentally evolve due to technological advancements.

In contrast, a substantial 50% of interviewees acknowledged a moderate shift in job descriptions, recognizing that while their core responsibilities might remain, the nature of those tasks would likely become more complex and technology-driven. One participant remarked:

"...yes, I can see how my job description might shift a bit. With more technology involved, there's going to be a greater emphasis on managing systems rather than just manual labor. We'll have to learn to interact with digital tools effectively..."

Another respondent supported this perspective, stating:

"...we can't ignore that technology is changing the way we work. Even if the basic tasks remain, the tools and methods will evolve, and that will change how we describe our roles..."

Interestingly, 29% of respondents believed there would be a high impact on job descriptions, envisioning a significant transformation in their work. One respondent expressed this excitement for change, saying:

"...the maritime industry is on the brink of a major transformation. I believe automation and robotics will create entirely new job functions that we can't even imagine yet. It will redefine what it means to work at sea..."

Another participant echoed this view, adding:

"...we are already seeing changes; roles that once focused on physical tasks will increasingly require technical skills and problem-solving capabilities. For example, being able to interpret data from autonomous vessels will become critical..."

The feedback gathered from interviews revealed a spectrum of opinions regarding shifts in job descriptions. While some expressed a sense of continuity in their roles, many acknowledged that the integration of automation and robotics would inevitably necessitate adaptations in how they approached their work. As the maritime industry continues to evolve, the responses reflected a growing awareness of the need for skill development and the ability to embrace change in the face of advancing technology.

3.4. Challenges Faced by Seafarers in Adapting to Technological Changes

The challenges faced by seafarers in adapting to technological changes were examined through the lenses of resistance to change, training and educational gaps, and generational divides. Respondents recounted their experiences, highlighting how resistance from seasoned crew members often hindered the acceptance of new technologies. Furthermore, many noted significant gaps in training, which left seafarers ill-equipped to handle advanced systems, while the generational gaps created a disparity in comfort levels with digital tools among different age groups. These insights painted a complex picture of the hurdles seafarers encountered in their efforts to embrace the digital transformation of the maritime industry.

Table 4: Challenges Faced by Seafarers in Adapting to Technological Changes

Sub-Indicator	Minor (%)	Moderate (%)	Major (%)
Resistance to Change	25(21%)	60(50%)	35(29%)
Training and Educational Gaps	20(17%)	55(46%)	45(37%)
Generational Gaps	30(25%)	50(42%)	40(33%)

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3.4.1. Resistance to Change

The resistance to change among seafarers as shown on table 4, emerged as a significant theme during the interviews, with many respondents acknowledging that this reluctance hindered the adaptation to new technologies on board. Approximately 21% of participants described the resistance as minor, suggesting that while some crew members showed openness to change, many were hesitant to fully embrace the innovations being introduced. As one respondent reflected:

"...I saw some crew members adapting well, but others were stuck in their old ways, believing that the traditional methods were still the best..."

This sentiment was echoed by others who noted that the fear of the unknown often led to apprehension about new systems.

Around 50% of those interviewed characterized the resistance as moderate, indicating that it was a common challenge that affected the overall morale and efficiency of the crew. A respondent shared:

"...it was like pulling teeth to get everyone on board with the new navigation software. Some were worried that they would lose their jobs, and that fear made it hard to work together..."

This anxiety not only reflected concerns about job security but also highlighted a deep-seated cultural preference for established practices within the maritime industry.

Additionally, 29% of participants deemed the resistance to change as major, illustrating that this issue was more pronounced among certain demographics, particularly those who had spent many years at sea. One interviewee stated:

"...for those of us who have been in this job for decades, change feels threatening. We know how to do things a certain way, and suddenly being told to learn something completely new is overwhelming..."

This perspective accentuated the complexities of integrating technological advancements into maritime operations, revealing how the interplay between age, experience, and technological proficiency created significant barriers to adopting new practices. Thus, the challenge of resistance to change reflected not only a reluctance to adapt but also a broader context of anxiety and uncertainty regarding the future of maritime work.

3.4.2. Training and Educational Gaps

The issue of training and educational gaps was a critical theme that surfaced during the interviews, as respondents detailed how inadequate training hindered their ability to adapt to new technological changes in the maritime sector. According to data illustrated on table 4, approximately 17% of participants classified these gaps as minor, indicating that while some crew members felt somewhat prepared, a significant number lacked comprehensive training. One respondent shared:

"...I received some basic training on the new systems, but it wasn't enough to feel confident. I had to rely heavily on my peers for help..."

This belief pointed to a reliance on informal knowledge transfer among crew members, highlighting a gap in systematic training protocols.

In contrast, 46% of respondents described the training and educational gaps as moderate, revealing a widespread acknowledgment of the need for more effective and targeted training initiatives. Many of these respondents expressed concerns about the rapid pace of technological advancements, which often outstripped the training provided. As one seafarer articulated:

"...we were thrown into using new software without proper guidance. It felt like a trial-and-error process, and many of us were left behind..."

This highlights a crucial issue in maritime education and training, where the lack of timely and relevant instruction created uncertainty and stress among seafarers.

A significant portion of the respondents, 37%, categorized the training and educational gaps as major, indicating that this was a pervasive and pressing issue impacting their job performance. A seasoned crew member remarked:

"...after decades at sea, I expected some training for the new automated systems, but what we received was barely adequate. This has made many of us reluctant to engage with the technology..."

This observation underlines the critical need for MET institutions and maritime employers to prioritize continuous professional development and to ensure that training programs are aligned with technological advancements. The lack of adequate training not only impacted individual seafarers' confidence and efficiency but also raised concerns about overall safety and operational effectiveness at sea. The challenges posed by these educational gaps highlighted an urgent need for reform in maritime training to prepare seafarers for the evolving demands of their profession.

3.4.3. Generational Gaps

The generational gaps in adapting to technological changes as per table 4, were a significant concern expressed by many respondents during the interviews, as they highlighted the challenges faced by both younger and older seafarers. About 25% of participants deemed these gaps as minor, indicating that some younger crew members felt relatively equipped to handle technological advancements, thanks to their familiarity with digital tools. A younger seafarer noted:

"...we grew up with technology. For us, learning new systems isn't as daunting as it is for those who are used to doing things the old way..."

This viewpoint illustrated the ease with which younger generations could adapt, benefiting from their prior experiences with technology.

Conversely, 42% of the respondents categorized generational gaps as moderate, reflecting a more complex dynamic between older and younger crew members. This group emphasized that while younger seafarers may have a natural aptitude for technology, older colleagues often struggled to adapt. One respondent shared:

"...I have seen firsthand how some of my older peers find it hard to navigate new systems. They sometimes feel overwhelmed, which can create tension during operations..."

This reaction highlighted the necessity for mentorship programs that could bridge the gap between generations, allowing for knowledge transfer and fostering a collaborative environment.

A notable 33% of respondents reported the generational gaps as major, underscoring the significant obstacles faced by seafarers in their daily operations. One seasoned crew member articulated:

"...I've been in this industry for over two decades, and suddenly everything is changing. I feel lost sometimes, and younger crew members don't always have the patience to help us adapt..."

This statement pointed to the frustrations experienced by older seafarers, who felt sidelined in a rapidly changing environment, and reflected broader concerns about job security and competence.

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The generational divide raised critical questions about the future of maritime work, emphasizing the urgent need for tailored training initiatives that consider the diverse backgrounds and learning styles of crew members. As older generations grappled with adapting to new technologies, the maritime industry faced a pressing challenge on how to cultivate an inclusive environment that empowers all crew members, regardless of age, to thrive in an increasingly digital world. Ultimately, the generational gaps not only affected individual seafarers but also had broader implications for team cohesion, safety, and operational efficiency at sea.

4. Conclusion and Recommendations

This study provided a comprehensive examination of the evolving landscape of maritime work in the context of technological advancements. The findings highlighted that while automation, digital tools, and robotics significantly transformed job functions at sea, they also created new demands for skills and competencies among seafarers. Respondents emphasized the necessity for continuous learning and adaptation to remain relevant in a rapidly changing industry. Moreover, the study revealed that while some seafarers perceived these changes as opportunities for career advancement, others expressed concerns about job security, particularly in relation to job reductions due to automation. These insights underline the importance of proactive measures in maritime education and training to equip the workforce with the necessary skills for the future. Additionally, the study illuminated the challenges seafarers faced in adapting to technological changes, particularly in terms of resistance to change, training gaps, and generational divides. These challenges accentuated the need for collaborative efforts between maritime education institutions, industry stakeholders, and seafarers themselves to foster a culture of innovation and adaptability. By modernizing curricula, enhancing training programs, and promoting intergenerational mentorship, the maritime industry can better prepare its workforce for the future. Ultimately, addressing these challenges is not only crucial for the individual careers of seafarers but also for the overall competitiveness and safety of the maritime sector in an increasingly digital world.

To effectively navigate the evolving maritime landscape shaped by technological advancements, several key recommendations emerged from the study. Firstly, maritime education and training (MET) institutions should prioritize curriculum modernization to include essential technical skills, IT, and cybersecurity training that reflect the demands of the digital age. Additionally, fostering strong partnerships between MET institutions and maritime industry stakeholders is vital to ensure that training programs are aligned with current and future industry needs. Secondly, initiatives aimed at continuous learning and upskilling should be implemented to support seafarers in adapting to new technologies, while mentorship programs can bridge generational gaps and facilitate knowledge transfer. Lastly, addressing resistance to change through comprehensive training and awareness campaigns will empower seafarers to embrace technological innovations, ultimately enhancing job security and contributing to the maritime industry's overall resilience and competitiveness.

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