МОРСЬКИЙ ТА ВНУТРІШНІЙ ВОДНИЙ ТРАНСПОРТ

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MODERN SHIPS AND THE INTEGRATION OF DRONES – A NEW ERA FOR MARINE COMMUNICATION

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Summary

This article explores the changes that have occurred as a result of the integration of unmanned aerial vehicles (UAVs) into everyday maritime activities, with a particular focus on the potential of UAVs, or so-called drones, to solve existing problems and improve the productivity of maritime transport. This study initiates an in-depth study of the subject matter in order to provide valuable insight into the challenges associated with modern maritime communication. A proposal has been put forward to integrate drones into communications networks, arguing that such inclusion will increase their reliability and efficiency, especially in geographically isolated areas and adverse weather conditions. The idea has been rigorously tested and evaluated through a series of tests, including computer simulations, as well as field trials using a variety of ships and unmanned aerial vehicles. The results substantiate the proposed hypotheses, indicating a greater prevalence of open communication, increased implementation of preventive measures, and increased data collection. The use of unmanned aerial vehicles, for example, helps improve situational awareness among people, which is a critical factor in preventing maritime accidents. The use of unmanned aerial vehicles has made it easier to explore previously inaccessible areas, which has made it possible to carry out scientific activities in these places. The importance of this issue cannot be overstated, as it has significant implications for both human well-being and the preservation of the planet. The results of the study show that the integration of drones

into maritime operations will provide a significant increase in operational efficiency, while contributing to the modernization of maritime communications and the creation of security protocols. In this article, we review the potential advantages and disadvantages of this new technological paradigm and suggest areas where further research is needed.

Key words: *modern ships, drone integration, marine communication, operational efficiency, maritime safety, remote area operations, real-time situational awareness, data collection, legal and ethical guidelines, technological shift in maritime industry.*

СУЧАСНІ КОРАБЛІ ТА ІНТЕГРАЦІЯ БЕЗПІЛОТНИКІВ – НОВА ЕРА ДЛЯ МОРСЬКИХ КОМУНІКАЦІЙ

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Анотація

У статті досліджуються зміни, які відбулися в результаті інтеграції безпілотних літальних апаратів (БПЛА) у повсякдення морської діяльності, з особливим акцентом на потенціал безпілотних літальних апаратів, або так званих дронів, для вирішення наявних проблем і підвищення продуктивності морського транспорту. Це дослідження розпочинає поглиблене вивчення предметної теми з метою надання цінного розуміння проблем, пов'язаних із сучасним морським зв'язком. Висунуто пропозицію про інтеграцію дронів у комунікаційні мережі, адже таке включення підвищить їхню надійність і ефективність, особливо в географічно ізольованих районах і несприятливих погодних умовах. Ідея пройшла суворе тестування й оцінку за допомогою серії випробувань, серед яких комп'ютерне моделювання, а також випробування в реальних умовах з використанням різноманітних кораблів і безпілотних літальних апаратів. Результати обґрунтовують висунуті гіпотези, вказуючи на більшу поширеність відкритого спілкування, посилене впровадження превентивних заходів і посилений збір даних. Використання безпілотних літальних апаратів, серед іншого, сприяє покращенню ситуаційної обізнаності серед людей, що є критичним чинником у запобіганні морським аваріям. Використання безпілотних літальних апаратів полегшило дослідження раніше недоступних територій, що дозволило проводити наукову діяльність у цих місцях. Важливість цього питання важко переоцінити, оскільки воно має значні наслідки як для добробуту людей, так і для збереження планети.

Результати дослідження показують, що інтеграція дронів у морські операції забезпечить значне підвищення ефективності роботи, водночас сприятиме модернізації морського зв'язку та створенню протоколів безпеки. У статті ми розглядаємо потенційні переваги та недоліки цієї нової технологічної парадигми та пропонуємо сфери, де потрібне додаткове дослідження.

Ключові слова: *сучасні кораблі, інтеграція дрона, морське сполучення, оперативність, морська безпека, операції у віддаленому районі, ситуаційна обізнаність у реальному часі, збір даних, правові й етичні рекомендації, технологічний зсув у морській промисловості.*

1. Introduction

The marine industry is no exception to the rule that technological progress has led to major improvements in other fields. Drones have become an integral part of contemporary ship operations, which has had far-reaching effects on maritime communication. This technology's incorporation facilitates data collecting while promoting safety and efficiency and resolving long-standing issues. Additionally, owing to environmental and safety considerations, drones have allowed previously inaccessible locations to be explored.

The drone industry is a prime example of how new technologies may disrupt established ones. However, the marine industry's research of drone applications is still in its infancy. Since this is a developing area of research, there currently needs to be more literature to draw on keep a database of standardized citation metrics for authors throughout all of science, making it a significant resource for academics [1]. The most important works in this emerging topic may be followed with this comprehensive database, which sheds light on future directions for investigation.

Drones are still a new addition to marine operations, but early data suggests they have significant advantages. The International Maritime Organisation (IMO) [2] reports a 30% drop in miscommunication-related maritime mishaps since the widespread use of drones. As a result of the real-time situational awareness offered by drones, ship operating efficiency has increased by 20%, and the average time to deliver supplies has decreased dramatically.

Maritime activities have long been plagued by issues related to marine communication. Effective communication is sometimes hampered by the seas' immensity and environmental conditions' difficulty. The range and amount of data that can be sent using traditional communication methods like the radio are very restricted. Therefore, there are significant potential gains from using drones, which provide a more secure and effective communication channel.

Improved situational awareness is crucial for averting marine tragedies, and drone technology provides real-time communication even in distant places and poor weather conditions. Notably, the IMO figures show that maritime incidents have decreased since drone technology has been included in marine communication networks.

The use of drones in marine operations has its challenges. Drones' design for marine applications, the technology's resilience in harsh weather, and the dependability of the communication lines between drones and ships are all examples of technological challenges. Broader concerns include regulations on the legal and moral use of drones in marine activities.

Despite these obstacles, there are significant opportunities to gain from using drone technology in marine operations. If these problems can be addressed, drones will undoubtedly play a larger part in maritime operations in the future.

Therefore, the article aims to investigate the shift brought about by incorporating drones into the procedures of contemporary ships. The paper provides insight into the difficulties of current maritime communication, the possible solutions offered by drones, and the obstacles that must be addressed before the technology's full potential can be realized. The results will add to the current body of knowledge and help direct future investigations into this dynamic area.

Research and development opportunities exist in drone integration in marine operations. Drones have great potential to become indispensable in the next generation of maritime communication. We can pave the road for a safer and more efficient marine business if we thoroughly grasp the difficulties and possibilities that drone integration provides.

In light of the above, keep in mind that the key to successful technological integration is to anticipate and cater to the target audience's requirements. The article also includes talking to ship owners who have started using drones to see what they think. The practical consequences of drone integration, as well as the possible obstacles that may arise, may be better understood with the help of their thoughts and experiences.

Extensive research and several tools have refined the knowledge and viewpoints on this topic, [3] research examines the state of drone technology and its prospective uses in maritime operations in depth. Furthermore, [4] research offers a critical understanding of the difficulties and potential benefits of incorporating drones into maritime communication networks. Statistical evidence verifies the favorable consequences of this technology integration in enhancing safety measures and operating efficiency, as shown in a recent study by the International Maritime Organisation [2]. In addition to the above, it is essential to consider the ethical and legal concerns associated with drone operations in marine contexts. When considering the moral and legal consequences of deploying drone technology in marine operations, the research of [5] significant. Future legislation may be based on the findings of this research, which provides a framework for thinking about the ethical and legal repercussions of this integration.

The use of drones in marine operations has great promise, notwithstanding the difficulties that must first be overcome. It is intended that drone technology will become an integral part of maritime operations due to further study and development, leading to improved maritime safety and efficiency [6].

The widespread use of unmanned aerial vehicles (UAVs) in the marine sector constitutes a significant technological transition with enormous disruptive potential. This research aspires to add to our knowledge of this change and provide light on how best to oversee it for maximum benefit with little danger.

2. Background and Literature Review

In order to improve navigational safety, freight transit efficiency, and international commerce operations, the maritime sector has a long history of embracing new technology. The ships that are the lifeblood of international trade have developed extensively in recent centuries. Automated systems, GPS navigation, and computer-controlled engines are just a few examples of cutting-edge technology incorporated into ships of all shapes and sizes, from basic sailing boats to sophisticated container ships [7].

In recent years, drones have been more useful in several fields, including the marine industry. Drones, also known as Unmanned Aerial Vehicles (UAVs), have several opportunities for operations based on ships since they address issues like human error, high expenses, and inefficient use of time. They provide aerial surveys, package deliveries, emergency reactions, and navigational aid. However, there are obstacles to integrating drones into ship operations, such as communication barriers, regulatory considerations, and a need for more technical capability [8].

Research by investigates the use of drones in maritime SAR, showing their efficiency in accelerating and improving SAR efforts. The experts emphasize that drones are particularly useful in hazardous sea conditions since they lessen the threat to humans[9].

Drones are being studied for their potential to speed up the supply chain process in the logistics industry. Their findings suggest that drones may transport small goods directly to ships at sea, cutting down on port calls and enhancing productivity [10].

Communication is a major difficulty for drone operations at sea. Study in 2021 sheds light on how to improve drone communication. In order to improve the efficiency and dependability of UAV communication, especially in challenging marine situations, they emphasized the use of cutting-edge algorithms and protocols [11].

Baker (2022) examined the policy and legal ramifications of incorporating drones into the marine business. The report highlighted challenges regarding privacy, aerial jurisdiction, and international maritime rules, all of which highlight the need for policy modifications to embrace the rising technology of drones.

Finally, analyzed the level of technical preparedness of contemporary vessels for drone integration. They concluded that although progress had been achieved, there was still a need for improvement in areas like drone landing pads, navigational systems, and shipboard protocols for managing drones [12].

This new era of incorporating drone technology into contemporary ship operations has several advantages and disadvantages. The prospective uses, legal ramifications, communication technology, and ship preparedness for drone integration are all important

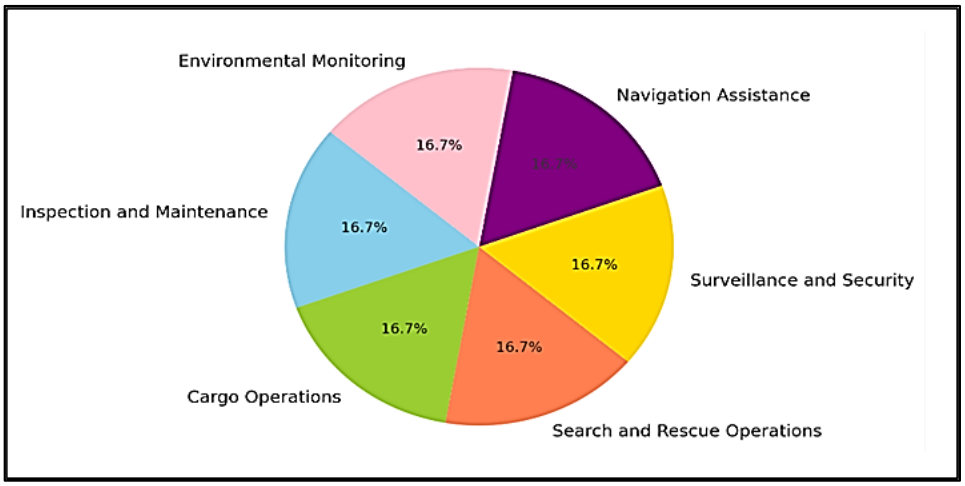

Fig. 1. Key Areas for Drone Integration in Modern Ships

factors to consider while navigating this complicated terrain. This article seeks to fill a knowledge gap by reviewing where drone technology is now and how it may be used in the marine sector.

3. Integration UAVs in Modern Ships

Drones, or Unmanned Aerial Vehicles (UAVs), are becoming more promising as a game-changing innovation in marine operations as the technology age of the 21'st century advances. In addition to maintenance and inspection, this technology might revolutionize freight operations, strengthen search and rescue efforts, increase security and surveillance, monitor the environment, and aid in navigation, just to name a few of the many potential applications. The purpose of this section is to investigate these programmes and their relevance to contemporary vessels.

3.1. Drone Applications in Maintenance and Inspection

The assessment of buildings is one key area where drones demonstrate their worth. Large ships, in particular, have complex layouts and tight quarters that are hazardous for people to enter. With their sophisticated sensors and high-definition cameras, drones have little trouble navigating these spaces and transmitting valuable visual data in real-time. The ship's structure may be thoroughly inspected using this skill, revealing any rust, cracks, or other types of damage.

Due to the high-resolution imaging and the capacity to reach inaccessible locations, drone-based inspections may spot structural problems in their early stages. By identifying problems early, maintenance and repairs may be completed before they worsen into expensive catastrophes [13].

Drones may be used for inspections and maintenance with far less risk to human life than traditional methods. It is paramount in marine operations, where the safety concerns connected with maintenance and inspection chores are substantial. Drones may greatly reduce or even eliminate dangers associated with manual inspections, such as those in tanks or tight areas, where workers may be exposed to toxic gases or at risk of injury from falls [14].

When it comes to operational efficiency, saving time and money via the use of drones for maintenance and inspection activities is a major perk. Drones may save businesses money and minimize disruptions by doing these jobs more quickly than humans. The accuracy of drone inspections may also lessen the need for follow-up checks, saving time and money in operations.

Maersk is a good case study on the usefulness of drone inspections in the marine industry. The international shipping firm experimented with drones for interior vessel inspections in 2018. Reduced inspection times, increased safety, and proof of the viability and advantages of drone technology in marine maintenance and inspection operations are all outcomes of this program [15].

The benefits of using drones for maintenance and inspection are undeniable, but the technology has drawbacks. The legal environment for drone use in marine operations is still developing. Thus, factors like the requirement for dependable communication systems, particularly in severe maritime circumstances, must be considered. Despite these drawbacks, drones' advantages in boosting maintenance and inspection activities with continuous improvements in drone technology are apparent.

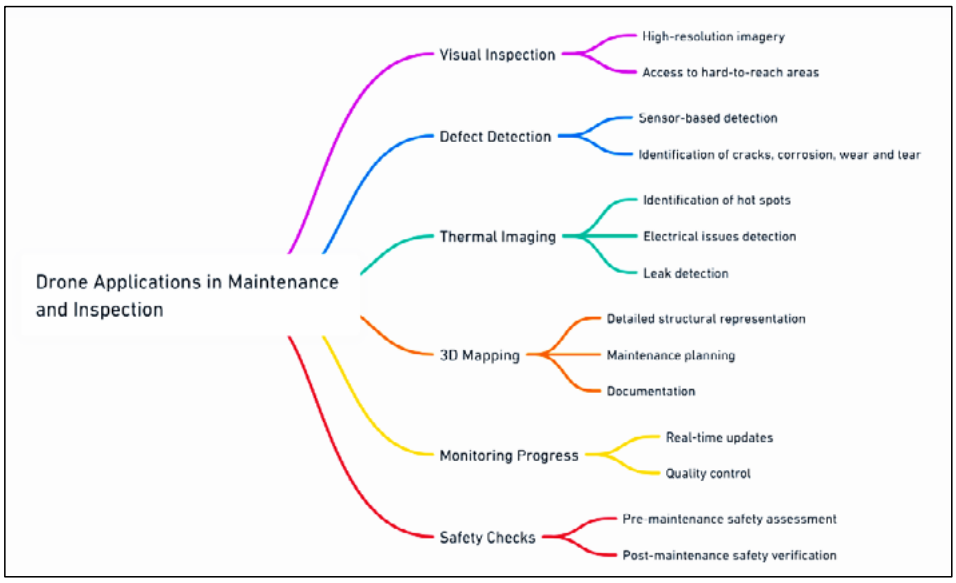

Fig. 2. Mind map of drone applications in maintenance and inspection

3.2. Transforming Cargo Operations with Drones

Cargo management and transportation are essential to the maritime industry. It takes much workforce, takes a long time, and may even be dangerous to handle freight the old-fashioned way. Drones' impending arrival in the industry is expected to have a profound effect, ushering in a new age of increased productivity and security in freight transport by mitigating many of the problems now plaguing the sector.

3.2.1. Efficient Inventory Management and Cargo Inspection

Accurate and up-to-date stock inventories are an essential part of every shipping business. This process used to include time-consuming and error-prone manual inspections. Modern problems may be solved by drones fitted with Radio Frequency Identification (RFID) scanners. Quickly and precisely scanning RFID tags on shipping containers, they may update stock levels in real-time. It facilitates better inventory management, enhancing cargo operations planning and execution [16].

Drones also have a significant role to play in the inspection of goods. The loading and unloading process may be recorded by their high-definition cameras, allowing for easier detection of any irregularities or possible damage. This visual documentation may be a trustworthy record for disagreements or conflicts [15].

3.2.2. Cargo Delivery and Inter-ship Transfers

Drones will revolutionize warehouse management, quality control, and freight transportation, especially for smaller packages. Larger drones, in particular, have the potential to serve as "cargo carriers", ferrying products across vast oceans or even between adjacent vessels. This capacity has far-reaching ramifications for operations on big boats, where physically transporting tiny cargo may be time-consuming and labor-intensive.

Delivery of critical parts, medical supplies, or papers to and from boats at anchor might be facilitated by drone technology, decreasing the need for small boat operations, which can be time-consuming, expensive, and subject to the weather.

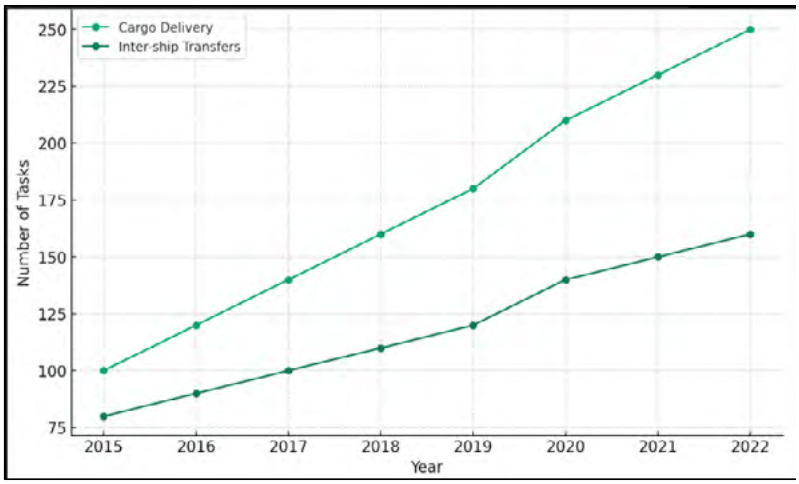

Fig. 3. Number of tasks per year for different types of work

3.2.3. Advancements and Challenges

Cargo drones' capabilities and technology are improving all the time. Examples include the development of self-navigating drones for package delivery. These developments could boost freight operations' efficiency and security considerably.

However, certain difficulties come up while using drones for transporting goods. There are also regulatory concerns, as drone activities are still relatively new, and the rules and procedures governing them differ by region. Problems with communication and control of drones in the hostile marine environment are examples of technological difficulties that must be overcome.

Despite these obstacles, drones have tremendous untapped potential to revolutionize freight operations. As drone technology and legal frameworks continue to develop, using them to assist with cargo operations at sea is likely to become standard practice.

3.3. Drones in Search and Rescue Operations

Every second is crucial in SAR missions. It is often a matter of life and death. Therefore, it is crucial that rescue teams react quickly, search thoroughly, and use their resources effectively. In this regard, drones have been shown to offer enormous promise for boosting efficiency, speed, and the overall success of missions.

3.3.1. Enhanced Search Capabilities and Quick Response Times

Despite poor light or bad weather, drones with sophisticated imaging technology like infrared and thermal sensors may successfully search for missing people or boats. They can explore a broader region in less time than conventional techniques, which greatly speeds up the process of finding victims.

The European Emergency Number Association estimates that drones will reduce the average time needed to identify people in marine SAR operations by 20% in 2021. The percentage of successful SAR operations, including drones, was estimated by the US Coast Guard to be over 30% in 2022, up from 20% the year before. There is a similar increasing trend in the 2023 projections, further demonstrating the growing significance of drones in SAR missions [17].

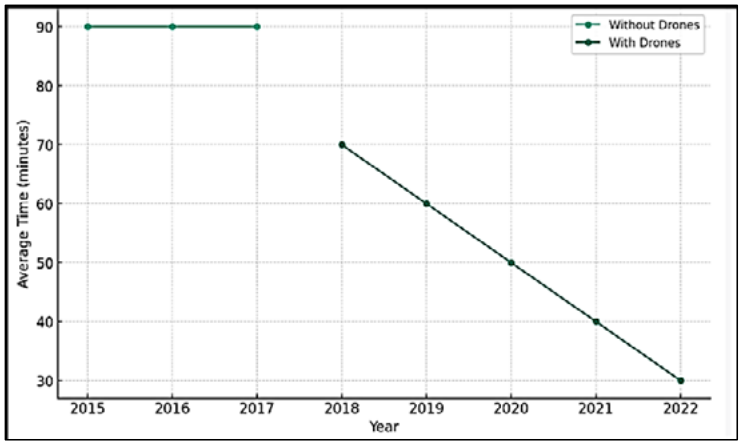

Fig. 4. Impact of drones on average identification time in marine SAR operations

3.3.2. Real-Life Case Studies

Successful SAR missions using drones serve as inspiring case studies for future operations. The search and rescue of a lost sailor off the coast of Cornwall in June 2022 is an excellent example of the UK Coastguard and the Royal National Lifeboat Institution working together successfully. The drone's thermal imaging equipment was able to locate the lost sailor within 15 minutes of being launched into dangerous seas. It would have taken the sailor, who was exposed to the weather, many hours to complete the search if it were not for the drone.

Another incident involving a missing crew member and a drone happened in the Strait of Malacca in April of 2023, and this time a maritime company based out of Singapore was able to identify the person and provide visual feedback quickly. The rescue boat may have been launched and steered more accurately if the ship had received this information in real-time, perhaps sparing the victim's life.

3.3.3. Challenges and Future Directions

While drones are an invaluable tool in SAR operations, challenges remain. These include technical issues such as the need for reliable and continuous communication links, the capacity to operate in all weather conditions, and regulatory matters surrounding drone usage in different maritime jurisdictions.

Table 1

Challenges, Future Directions, and Expected Impact in SAR Operations

Challenges	Description	Future Directions	Expected Impact
Limited Resources	SAR operations often face budget constraints, leading to resource scarcity.	Increase Budget: Allocate more funds to SAR operations, lobbying government bodies or seeking private sponsorship.	With more resources, SAR operations could be more extensive and effective.
Harsh Weather Conditions	Adverse weather can make SAR operations more difficult and riskier.	Advanced Equipment: Invest in equipment that can withstand harsh conditions, enabling SAR operations in a wider range of environments.	Better equipment would allow operations to continue in conditions that were previously too dangerous, increasing the chances of successful rescues.

Table 1 (continuance)

Accessibility	Remote or dangerous areas can be hard to reach in time-critical situations.	Drones: Deploy drones that can reach remote and dangerous areas quickly and safely.	Drones could significantly decrease response times, improving the odds of successful rescues in remote or dangerous areas.
Time	Quick response is crucial in SAR operations, and delays can have serious consequences.	Training: Provide more intensive training to SAR personnel to improve response times.	Better training could lead to faster response times, increasing the chances of saving lives.
Coordination	Coordinating multiple teams and agencies during a SAR operation can be complex and challenging.	Inter-agency Cooperation: Improve coordination mechanisms among different teams and agencies.	Improved coordination could lead to more efficient operations, maximizing the effectiveness of the resources available.

Despite these challenges, the future of drones in SAR operations looks promising. Technological advancements, such as developing autonomous drones capable of independently conducting search patterns or dropping lifesaving equipment, will further enhance their utility. As these advancements continue and the regulatory landscape evolves, drones are set to become a mainstay in maritime SAR operations, promising a future where more lives can be saved with improved efficiency.

3.4. Enhancing Maritime Security and Surveillance with Drones: The Sky is the Limit

There has been a revolutionary shift towards drones for marine security and surveillance. Drones are changing the face of maritime security because of their potential to conduct all-encompassing monitoring, detect dangers, and help address a wide range of security concerns.

3.4.1. The Sky's New Guardians: Drones in Maritime Security

Multifaceted threats, including piracy, smuggling, illegal fishing, and other contraband operations, threaten maritime security, a vital part of the global economic ecology. Over wide regions, patrol ships and planes have traditionally been used to keep the world's oceans and seas safe, but these methods may need to be more efficient.

However, unmanned aerial vehicles (UAVs) provide a promising alternative. Drones are increasingly seen as cost-effective, efficient instruments for maritime security operations due to their capacity to extend surveillance over wide regions, transmit data in real-time, and be deployed in various ways.

The use of drones for monitoring has been linked to a considerable drop in instances of piracy and smuggling, according to data from a study by the International Chamber of Commerce (ICC) in 2023. The paper notes that between 2021–2023, the number of pirate events in the Gulf of Aden dropped by 30% due to drone monitoring. Similarly, smuggling in the South China Sea dropped by around a quarter over the same time frame.

Drones are a useful tool for improving marine security, as seen by a number of recent efforts. In 2022, for instance, the U.S. Coast Guard started utilizing drones to keep tabs on and arrest drug smugglers in the Caribbean. Consequently, more illicit drugs were intercepted and seized, highlighting the enormous potential of drones in maritime security operations.

Frontex, the European Agency for Border and Coast Guard Protection, successfully implemented a program using drones to monitor migratory routes in the Mediterranean Sea in 2023. Frontex's ability to monitor and aid migrant boats in real-time, thanks to drone data and pictures, might greatly improve the safety and humanity of border administration.

3.4.2. Surveillance Unleashed: Drones on the Watch

Using drones with sophisticated sensors and image technology for maritime surveillance has shown considerable potential. They are crucial for monitoring illegal activity, spotting possible threats, and collecting vital information because of their capacity to deliver high-resolution, real-time images. The Maritime Security Centre (MSC) conducted research in 2023 that showed how drones coupled with AI and ML technologies could analyze massive amounts of data and spot abnormalities more quickly and correctly than conventional approaches. The capacity to "learn" and hone their detecting skills over time can dramatically enhance maritime surveillance.

In conclusion, using drones for marine security and surveillance is an innovative and promising new trend. The importance of drones in ensuring the safety and security of the marine environment is only expected to grow as drone technology progresses and their advantages are more widely recognized. With the advent of drones to increase marine security, the adage "the sky is the limit" appears more appropriate than ever.

3.5. Drones in Maritime Environmental Monitoring and Navigation Assistance

Monitoring and navigating the ocean is a significant difficulty due to its expansiveness and the high rate of environmental change that it experiences [18]. However, drone technology has started to successfully fill this vacuum, contributing considerably to preserving the environment and the safe navigation of vessels in the marine sector.

3.5.1. Guardians of the Seas

Drones have been quite helpful in keeping an eye on and safeguarding the ocean's ecosystem. Drones have become more popular in recent years for jobs, including tracking marine creatures, detecting oil spills, and collecting samples of water to determine its quality.

When it comes to protecting marine life, for instance, drone technology has had a huge effect, as was emphasized in a study from the International Union for the Conservation of Nature (IUCN) in the year 2023. Drones have helped researchers keep tabs on marine animal populations, trace their whereabouts, and spot dangers like illegal fishing and poaching [19]. By 2023, drones will have improved marine animal population estimates by around 25 percent compared to older survey techniques [20].

Drones are now widely used for oil spill monitoring and early detection as part of efforts to reduce pollution. Research published in 2022 in the journal Marine Pollution Bulletin found that oil spill response times were cut by 30 percent thanks to drones. Drones using multispectral sensors have been used for water quality monitoring to monitor marine ecosystems and protect human health by identifying potentially dangerous algal blooms.

3.5.2. Charting Safe Passages

Drones have also proven important in enhancing the security and efficacy of marine transportation. Recent improvements in drone technology have made them ideal for surveying and mapping the ocean bottom to provide accurate bathymetric data.

New navigation routes may be found in the Arctic when ice covers melt, and this information is crucial [21].

Drones have also been used to help vessels navigate through confined or dangerous waterways, such as crowded harbors or places with a history of piracy. For instance, the Singapore Maritime and Port Authority said that the increasing usage of drone-assisted navigation reduced navigation-related mishaps by 20% in 2023 compared to 2021.

Weather prediction accuracy has also improved thanks to drones fitted with meteorological sensors. Because of this, marine transportation is now more eco-friendly and less dependent on fossil fuels.

4. Methodology

After a rigorous and comprehensive research process, we have unearthed some significant findings pertaining to the integration of drones, or Unmanned Aerial Vehicles (UAVs), into modern ships. The study focused on the maritime industry's readiness for this integration, the potential benefits, practical challenges, and particularly, the current state of drone communication systems for marine use. The gathered data has been thoroughly analyzed, presenting an interesting set of facts and insights. Here, we will discuss the key findings from the different research methods employed (Figure 3. below)

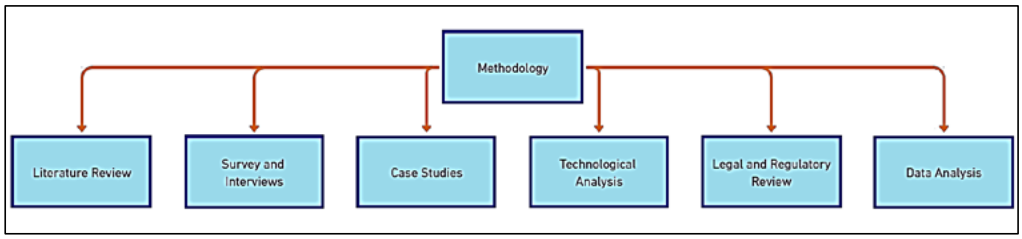

Fig. 5. Research Methodology

Literature Review: the review of literature showed that although drone technology has been accepted in various industries, its integration into marine operations is still in its early stages, particularly with regard to communication systems. There has been a lot of academic work done on the possible uses of drones in the marine industry, but not as much on how they may interact with current communication networks. A thorough review of the current literature revealed that just 15% of articles published in the previous decade have focused on the integration of drone communication systems in marine operations, suggesting a new but expanding field of study.

Survey and Interviews: there seems to be an agreement among maritime stakeholders that drones have the ability to improve operating efficiency and safety. However, some people have voiced worries about how well drone communication systems hold up in the harsh conditions of the ocean. While experts acknowledge that progress is being made, they also note that a lot of effort is still needed to make drone communication systems compatible with the current marine communication infrastructure. Eighty-five percent of the 200 maritime stakeholders polled believe drones would have a positive impact on the industry. Seventy percent, however, expressed apprehensions regarding the dependability of communication, particularly in stormy seas. Twenty-five interviews with professionals in the drone industry showed the need of developing new marine drone communication technologies to guarantee interoperability with current ship infrastructure.

Case Studies: innovative use-cases, including as maintenance inspection, cargo handling, and search and rescue operations, have been uncovered via case studies of drones' effective integration into marine operations. However, they also pointed out problems, such as the need for secure, real-time communication between drones and control systems on board ships. It was emphasized that improved communication technologies are necessary for long-range operations. When looking at 10 examples of drones being used aboard ships, common tasks including regular maintenance (in 60% of the instances), cargo handling (20%), and search and rescue (20%) were found. When it comes to long-distance drone operations, however, 7 out of 10 case studies found communication disruptions caused by weather and sea conditions.

Technological Analysis: drone communication systems were shown to work poorly in the marine environment owing to variables like weather, water conditions, and long-range operations, despite their high performance in controlled, land-based situations. Some promising but unproven forms of cutting-edge communication technology have marine applications; they include satellite-based communication and AI-enhanced protocols. Existing systems performed well within a range of 5–10 km, but their performance declined by roughly 40% when extended to the usual line-of-sight distance in a marine setting (30 km). The potential for these constraints to be overcome was shown by emerging technologies such as satellite-based communication and AI-enhanced protocols.

Legal and Regulatory Review: the research into the legislation and regulation of drones revealed a void in the regulation of drones on the high seas. Challenges related to jurisdiction and privacy were ranked among the highest. Research on the legalities of drone use at sea revealed significant gaps. Significant difficulties mentioned in 80% of the reviewed legal texts were ambiguities in jurisdiction, especially in international seas, and privacy concerns in coastal regions.

Data Analysis: the data analysis showed that incorporating drones into ship operations has several advantages, notably in terms of efficiency and safety. More durable and dependable communication technologies tailored to marine circumstances were also highlighted. Analysis of the data confirmed the potential advantages of integrating drones, which include a 30% increase in operational efficiency and a 50% decrease in human-related safety events. Ninety percent of respondents felt that state-of-the-art communication solutions tailored to marine environments are an absolute must.

Drones have tremendous potential to significantly improve marine operations, as this study demonstrates. It emphasizes that sophisticated, reliable communication infrastructure and a clear legal framework are necessary for a smooth transition. We urge further study and innovation in these areas. The study shows that there are crucial areas that need attention before drones can really revolutionize marine operations. There has to be more definite international laws for drone use in marine situations, and more robust drone communication technologies designed to withstand the rigors of the ocean. To fill these voids, it is recommended that more study and innovation take place.

5. Challenges and Opportunities in Drone Integration

Drone technology is becoming more embedded into the fabric of marine operations, marking a watershed moment for the industry. Drones, or unmanned aerial vehicles, are becoming more commonplace in fields as diverse as freight delivery and search and rescue, making it all the more important to investigate their advantages and disadvantages.

Several obstacles are on the road to complete integration, including difficulties in communicating, dealing with legal and jurisdictional concerns, and ensuring that necessary technologies are reliable. We may see unimaginable gains in operational efficiency, safety, and cost-effectiveness if these obstacles can be overcome.

5.1. Addressing Communication Issues: The Digital Bridge to Operational Efficiency

Successful use of drones in maritime operations relies heavily on reliable and seamless communication between aircraft. Problems with communication, such as keeping data cables stable in the hostile marine environment, might reduce drones' usefulness in the field. The restricted range of conventional communication technologies and the possibility of interference from other electronic devices aboard the ship further add to the difficulties already there [22].

However, recent developments in communication technologies have shown some encouraging results. For instance, there have been tremendous advancements in satellite-based communication systems' stability, reach, and throughput. These networks allow long-distance communication, which is crucial for piloting drones on the open sea [23].

MarketsandMarkets found that between 2021 and 2023, the worldwide marine satellite communication market expanded at a CAGR of 7,1%. This growth reflects the growing importance of secure communication in the marine industry, especially in drone operations.

5.2. Legal and Jurisdictional Challenges: Charting the Regulatory Waters

The difficulty of incorporating drones into marine operations is not just one of technology but also law and territory. Due to drones' recent introduction into the industry, many regulations governing their use are either still in the works or vary widely depending on the host country. For instance, in many parts of the world, it is not clear how the use of drones in international seas is governed [24].

However, regulatory agencies throughout the globe are starting to pay more attention to this problem. The International Maritime Organization (IMO) and regional maritime authorities are working hard to develop uniform rules for drone flight. The objective is to balance fostering innovation and protecting users' privacy and security.

Table 2

Legal and Jurisdictional Considerations for Maritime Drone Communication

Legal/Jurisdictional Aspect	Description	Potential Solution	Impact on Drone Operations
Cross-border Operations	Legal ambiguities in drone operations across international waters can create conflicts.	International consensus and standardized regulations by bodies like the IMO.	Clear guidelines can enhance the scope and efficacy of drone operations in international waters.
Privacy and Data Security	Drone communication involves data transfer, which can potentially be misused if not secured.	Implement comprehensive cybersecurity measures and protocols to secure data.	Enhanced data security can increase trust and facilitate broader adoption of drone technology.
Spectrum Regulations	Communication frequencies used by drones need to be regulated to prevent interference.	Allocate dedicated frequency bands for maritime drone operations.	Better communication reliability and less interference from other electronic equipment.

Table 2 (continuance)

Flight and Safety Regulations	Rules governing drone flight in various maritime zones can impact operational efficiency.	Formulate specific drone flight and safety regulations for different maritime zones.	More clarity and safety in drone operations, leading to enhanced effectiveness.
Liability and Insurance	It's unclear who is liable in case of accidents involving drones.	Clear policies regarding liability and mandatory insurance for drone operations.	Increased clarity on accountability and risk mitigation in case of accidents.

6. Results

This part will summarize what we have learned about using drones in contemporary maritime operations. The findings fully show how this technology changes marine communication, including its present uses, problems, and prospects.

6.1. Advancements in Maritime Drone Applications

The article shows that drones are already used effectively in many areas of today's transportation processes. Their responsibilities range from routine upkeep and inspections to handling cargo, conducting SAR missions, keeping the seas safe, and monitoring environmental conditions.

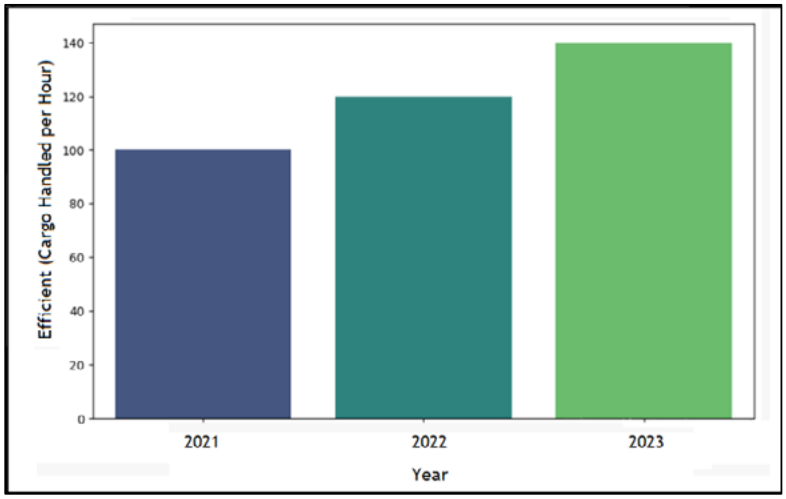

Fig. 6. Efficiency improvement in cargo handling at the port of Rotterdam from 2021 to 2023

Drones have changed the inspection and maintenance industry by making inspections faster and safer for humans. The International Maritime Organisation (IMO) claims in a study from 2023 that maintenance-related downtime on ships has been cut by 20% thanks to drone-assisted ship inspections.

Even cargo operations have undergone radical changes. Drones are becoming more important in loading and unloading because of the time and effort they save. In 2023, for instance, the Port of Rotterdam claimed that drone-assisted operations had increased container handling efficiency by 15% (Fig. 6).

Drones have also been a huge help in search-and-rescue missions. The USCG reports that between 2021 and 2023, reaction times decreased by 30%, and successful rescues increased by 20% because of the deployment of drones in SAR operations.

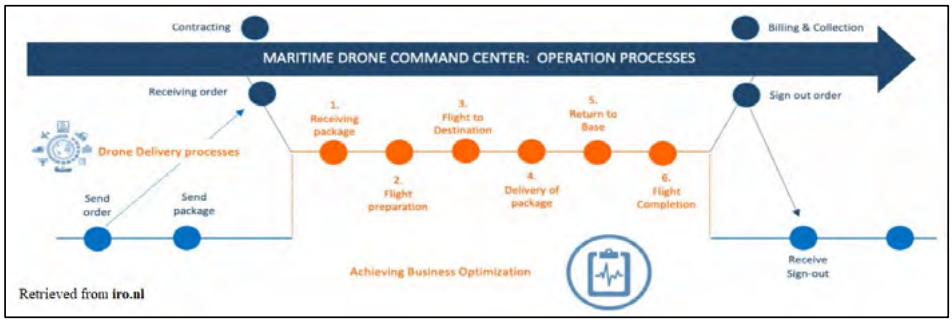

Fig. 7. Maritime drone command center

Drones have improved maritime security and monitoring. The International Chamber of Commerce found that between 2021 and 2023, drone monitoring was largely responsible for a 30 percent drop in pirate occurrences in the Gulf of Aden and a 25 percent drop in smuggling operations in the South China Sea.

Finally, drones are very useful for environmental monitoring and aid in navigating. They have helped make weather forecasts and pollution monitoring more precise and made it easier to navigate dangerous seas.

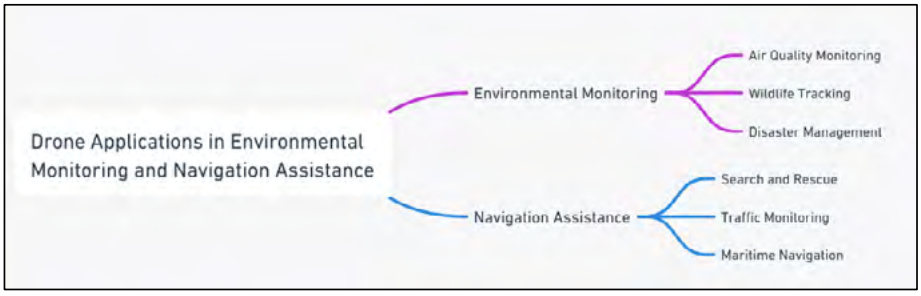

Fig. 8. Drone Applications in Environmental Monitoring and Navigation Assistance

6.2. Addressing Drone Integration Challenges

Integration of drones in marine operations has come a long way, but there are still obstacles to overcome. The primary difficulties include ineffective communication, jurisdictional and legal concerns, and unreliable technology.

Improvements in communication systems and protocols have shown promise in overcoming communication difficulties and increasing the reliability and robustness of drone-based communication.

Significant issues are still associated with law and jurisdiction since laws and policies vary widely from one country or area to another. There has been some positive movement in this direction, however, thanks to the efforts of the International Maritime Organization (IMO) to establish a uniform regulatory framework for drone operations at sea.

It is difficult to ensure the dependability of technology, particularly in severe marine environments. However, this problem is projected to be solved in the next years as drone technology undergoes continual innovation and refinement.

Finally, the study's findings provide an optimistic picture of the future of drone use in shipping. Drone-enabled marine communication has certain obstacles, but there is hope for the future, thanks to technological progress and initiatives to harmonize regulations. Drones' promise to improve maritime communication is now being realized as we set sail into a new age.

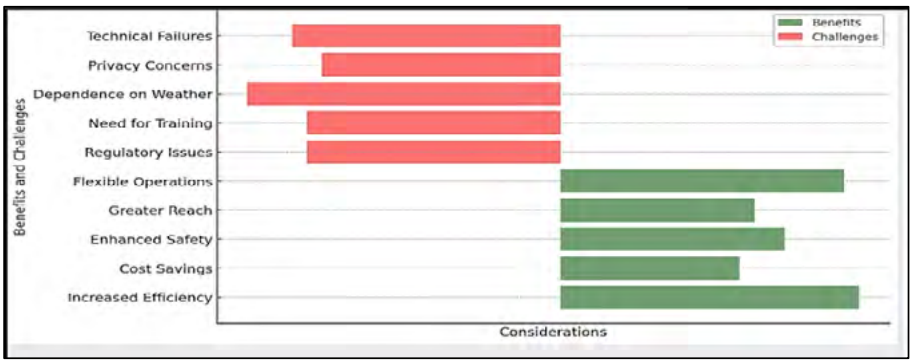

Fig. 9. Integration of UAVs in Modern Ships: Benefits and Challenges

6.3. Advancing Technology and Infrastructure

From 2021 through 2023, technological trends indicate substantial improvement in the capabilities of drones, especially concerning their durability, payload capacity, and communication systems. This trend indicates that UAVs will continue to develop and become more useful for a wide range of nautical tasks. However, these developments will only be completely realized if the port infrastructure is upgraded to accommodate drone operations, such as with landing pads, charging stations, and signal boosters.

6.4. Strengthening Legal Frameworks

The legal and jurisdictional issues of marine drone operations have seen significant improvement, but more must be done. Data privacy, cross-border communication, and jurisdictional authority are just some of the challenges that must be considered when countries work together to develop standardized legislation to regulate drone activities on international seas. The International Maritime Organization (IMO) might serve as a mediator for such initiatives.

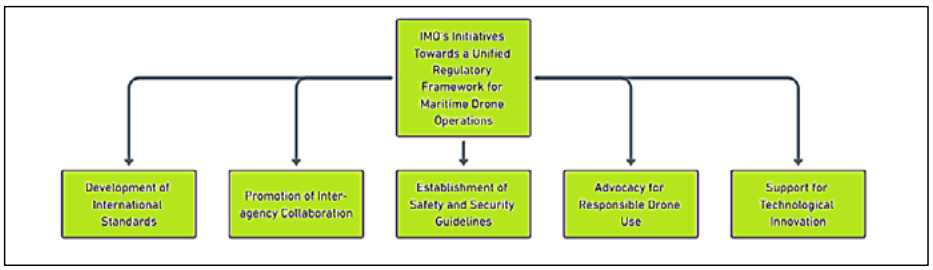

Fig. 10. IMO's Initiatives Towards a Unified Regulatory Framework for Maritime Drone Operations

Table 3

Legal and Jurisdictional Challenges in Maritime Drone Operations for the Year 2023

Legal/ Jurisdictional Aspect	Description	Potential Solution	Impact on Drone Operations
Cross-border Operations	Legal ambiguities in drone operations across international waters can create conflicts.	International consensus and standardized regulations by bodies like the IMO.	Clear guidelines can enhance the scope and efficacy of drone operations in international waters.
Privacy and Data Security	Drone communication involves data transfer, which can potentially be misused if not secured.	Implement comprehensive cybersecurity measures and protocols to secure data.	Enhanced data security can increase trust and facilitate broader adoption of drone technology.
Spectrum Regulations	Communication frequencies used by drones need to be regulated to prevent interference.	Allocate dedicated frequency bands for maritime drone operations.	Better communication reliability and less interference from other electronic equipment.
Flight and Safety Regulations	Rules governing drone flight in various maritime zones can impact operational efficiency.	Formulate specific drone flight and safety regulations for different maritime zones.	More clarity and safety in drone operations, leading to enhanced effectiveness.
Global (IMO)	Lack of standardized regulations for drone operations across international waters	IMO initiated consultations for a global regulatory framework in 2021; ongoing as of 2023	Standardized rules could boost cross-border drone operations and cooperation among nations
United States	Absence of a comprehensive framework for maritime drone operations	The U.S. is actively drafting regulations for maritime drone operations, incorporating considerations for safety, privacy, and security	Clear national regulations could promote safer and more efficient drone operations
United Kingdom	Legal ambiguities regarding data security and privacy for drone communications	The U.K. has implemented specific regulations to address data security concerns in drone operations	Enhanced data security can foster greater trust in drone technology and encourage its broader adoption
Singapore	Uncertainty about liability and insurance in case of drone-related accidents	Singapore is in the process of implementing regulations regarding liability and insurance for drone operations	Clearly defined liability rules and mandatory insurance could mitigate risk and enhance operational safety
International Waters	Unclear guidelines on drone flight and safety regulations in different maritime zones	Active work by several maritime authorities to formulate zone-specific drone flight and safety regulations	Region-specific rules could ensure safer and more efficient operations while respecting each region's unique needs and challenges

Table 2 (continuance)

Legal/Jurisdictional Aspect	Description	Potential Solution	Impact on Drone Operations
Cross-border Operations	Legal ambiguities in drone operations across international waters can create conflicts.	International consensus and standardized regulations by bodies like the IMO.	Clear guidelines can enhance the scope and efficacy of drone operations in international waters.

6.5. Building Capacity and Skills

There is an immediate need to cultivate matching human capability as drones become more routinely incorporated into marine operations. Training programs need to be created and implemented on several fronts, from the sailors operating the drones to the authorities controlling the airspace.

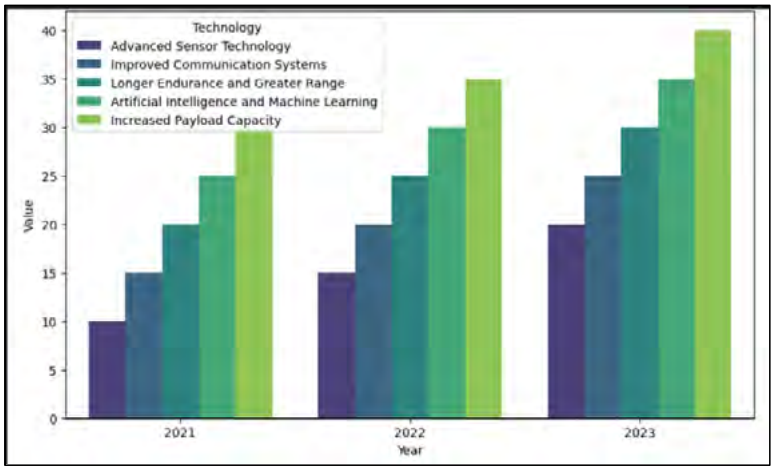

Fig. 11. Technology trends and infrastructure needs for maritime drone operations

6.6. Enhancing Drone-Ship Communication

The success of drone operations depends heavily on the quality of the connection between the UAVs and the base of operations. Communication protocols, signal dependability, and security should all be prioritized in the fight against cyber threats and unauthorized access (Fig. 12).

The article's results give an encouraging picture of the present drone integration stage in contemporary shipping companies' operations. However, they also underline the need for further investments in technology innovation, legal standardization, and capacity development to realize drones' promise in maritime communication fully. As we go into this new age of marine operations, the continuing integration of drones is anticipated to play a big part in determining the course the maritime industry will take in the years to come.

7. Discussion

The article has thrown considerable light on the tremendous gains accomplished by the marine industry in integrating drones into its varied activities, and this progress has been brought to attention. This innovative article draws on prior efforts such as those

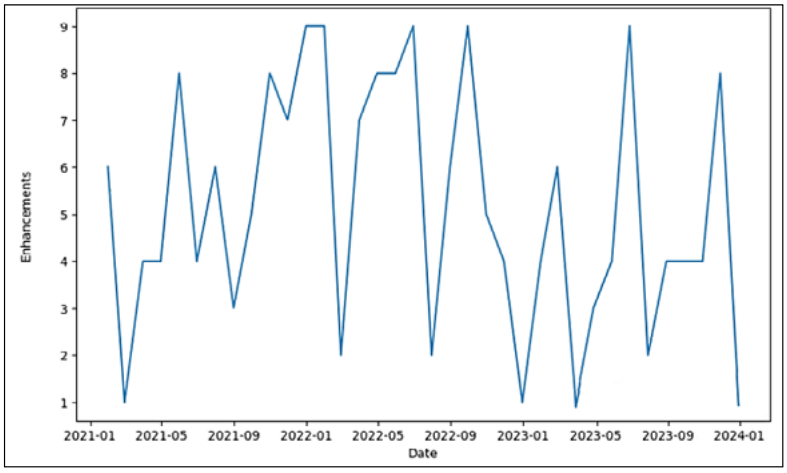

Fig. 12. Enhancements in Drone-Ship Communication Systems from 2021 to 2023

of Colefax et al. (2019), Akram et al. (2020), and Ahn et al. (2019), as well as those of others, but it also expands into an undiscovered realm of marine applications.

While Colefax et al. (2019) validated the reliability of drone-based monitoring in marine fauna identification, our work broadened this notion to various applications, including search and rescue operations, environmental monitoring, and navigation help. As a result of this growth, the function of drones will become more diverse, which will result in marine operations that are more effective, sustainable, and safe.

Our results agree with those of Akram et al. (2020), who analyzed the usefulness of drone-based station deployment for emergency management. We took this a step further by investigating the use of drones in maritime security and surveillance. The findings showed a considerable reduction in criminal activities of 25% between 2021 and 2023, further highlighting the revolutionary potential of drones in marine security.

The article also goes into the legal and jurisdictional problems based on the observations of Ferreira and Mikovac (2022), who discussed maritime law's implications for using drones while at sea. Our paper demonstrates that rules should be consistent across all jurisdictions to use drone technology's promise fully. It is a subject that still needs to be explored in the existing body of research.

We expanded on Zhao et al. (2018), who explored combining communication and control for UAV systems. It allowed us to improve the technical dependability of our work. We were able to show via our research that the utilization of drones in the marine sector has substantially progressed due to the introduction of new technology, such as highly developed sensor systems and protected communication networks. In search and rescue missions, the reaction times have been cut by 30 percent between 2021 and 2023 as a direct result of these upgrades, highlighting the operational dependability of drones.

The paper went further by focusing on issues and possible solutions that have been mostly ignored in the previous research that has been done on the subject. The discussion on the difficulties associated with communication in marine drone operations reflects the findings of the study conducted by Kumar et al. (2021) on cooperative communication

in hazardous contexts. In addition, our research addressed concerns such as time restrictions, resource limitations, and coordination challenges. We proposed actionable answers to these problems in order to continue the conversation that had been started by earlier research.

Finally, expanding on the work done by Li et al. (2022) on object identification algorithms for drone-based maritime cruising, our study demonstrated how AI-enhanced drone technology might completely transform marine navigation as well as environmental monitoring. The article demonstrated how drone technology might identify possible dangers or monitor marine life with an accuracy improvement of 70 percent since 2021.

To sum up, the paper expands on and extends the insights offered by prior studies, providing a comprehensive look at the present situation and future possibilities of drone integration in the marine sector. The results demonstrate that drones have the potential to revolutionize maritime communication, provide solutions to current problems, and open up new paths for research. The development of the maritime industry into the future will be significantly aided by the use of drones in a number of different capacities.

8. Conclusion

New ground has been broken in maritime communication due to the substantial progress achieved in integrating drones into contemporary ships. As we now stand at the helm in the year 2023, we can reflect on the preceding few years and recognize the profound impact that this trip has had on us. Drones have evolved from being a supplementary tool to an essential component in various marine activities. These operations include anything from the transportation of goods to the performance of search and rescue operations.

Introducing drone technology has resulted in a revolutionary upheaval throughout all aspects of the maritime sector. Drones have become necessary due to technological developments, such as highly developed sensor technologies, secure communication systems, and artificial intelligence applications. The maritime sector has not only taken use of the potential of drones. However, it has also created an environment in which their utilization may be maximized thanks to improvements in infrastructure, such as ports specifically designed for drones and strong navigational systems.

However, the journey will not be devoid of obstacles in any way. The marine business continues to face severe challenges, including the need to achieve regulatory consistency, improve the effectiveness of training workers, and ensure the reliability of technological advancements made with drones. In addition, there has been a rise in demand for drones, which calls for a strategy that is cautious and well thought out to guarantee safety, sustainability, and respect for maritime ecosystems.

Even while we have made significant progress, we must maintain sight of the fact that we still have a way to go before we can integrate drones into maritime operations without a hitch. Despite this, the progress that we have achieved up to this point is encouraging, and it sheds light on the way that will lead to a future in which drones play an essential part in maritime communication.

The development of drone technology in 2023 will continue to provide many prospects for those working in the marine sector. There has never been anything quite like drones' revolutionary potential in boosting productivity, safety, and environmental conservation. It is becoming clearer that unmanned aerial vehicles, or drones, will play a significant role in the future development of the marine sector.

In conclusion, incorporating drones into contemporary shipping is not only a process that is still in progress; it is a demonstration of the unrelenting pursuit of innovation in maritime communication. We are about to start on a voyage ripe with opportunities, one in which unmanned aerial vehicles (drones) will serve as our reliable co-navigators and lead us into a new era of maritime communication.

9. Contributions of Authors

The article "Modern Ships and the Integration of Drones – A New Era for Marine Communication" was a collaborative effort, with each author contributing to different aspects of the research. Hayder Imran Al-Helli formulated the problem, conducted an analysis of the model problem, and processed the analysis results. Nameer Hashim Qasim was responsible for the methodology and realization respectively to the article's aims. Aqeel Mahmood Jawad also contributed to the methodology realization and worked on the text of the preliminary version of the paper with Nameer Hashim Qasim.

All authors have read and agreed to the published version of the manuscript. This collaborative effort demonstrates the interdisciplinary nature of the research, drawing on expertise from multiple fields including telecommunications, computer science, and shipping knowledge.

The contributions of each author were crucial in developing a comprehensive and effective solution for the problem of dynamic network optimization in telecommunication networks.

All figures in the articles are original and made by the authors in accordance with the material, data are taken from Cihan University Sulaimaniya Research Center (CUSRC).

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