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"Autonomous Vessels: Towards a New Phase in Maritime Transportation"

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Abstract: The shipping industry is undergoing a paradigm shift with the development of alternative marine fuels like Liquefied Natural Gas (LNG), offering safer, greener, and more efficient ships. The development of autonomous vessels, which operate without a crew and are remotely controlled by operators or artificial intelligence systems, has the potential to transform the way goods and people are transported across the world's oceans. However, the labor market is expected to tighten due to the lack of ship officers, dangerous working conditions, and competition. The International Maritime Organization (IMO) has identified four levels of autonomous shipping: decision support and automated processes, remote control with seafarers on board, remote control without seafarers, and no crew. Addressing these challenges requires a multi-faceted approach that includes technological advancements, comprehensive training programs, stringent regulations, and proactive risk management strategies.

This study aims to explore the potential of self-driving ships in the maritime sector by assessing their development, technology, and potential drawbacks.

This study revealed that the marine industry is embracing autonomous vessels, necessitating research to ensure safety, cybersecurity, and efficient communication. Systems and interfaces should integrate AI, IoT, and cloud computing, while environmentally responsible design methods and renewable energy sources should be developed.

This study recommends that autonomous vessels have the potential to revolutionize the maritime transportation industry by enhancing safety and efficiency and reducing costs. However, safety standards must be set to ensure their safe operation. Collaboration among researchers, engineers, and stakeholders is crucial to overcome challenges and ensure regulatory reforms. The adoption of autonomous vessels is ongoing, requiring significant research directions and recommendations.

Key words: Autonomous Vessels, Paradigm Shift , Potential , Maritime, Revolutionize, Regulatory.

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CHAPTER 1: INTRODUCTION

1.1. Background

A new paradigm shift is currently taking place with quickly developing technology regarding alternative marine fuels, which promise safer, greener, and more efficient ships in response to stricter standards of international legislation than ever before. The First Industrial Revolution in the 1800s signaled the start of the first shift, which saw the development of mechanized power and coal-fired steamboats (Batten, 2022). The next phase was consistently addressed Midway through the 20th century. The development of diesel motors made ships sturdier and more effective by using oil as a second fuel source. This was when modern upheaval began. In the 1970s, computerized ship control was introduced as part of the Internet and digital revolution, commonly called the Third Industrial Revolution (Shahbakhsh et al., 2022). With the advent of petrol as a fuel, particularly Liquefied Natural Gas (LNG), we are getting closer to the "Shipping 4.0" paradigm, which includes cyber-physical systems and autonomy (Sepehri et al., 2022).

Universally sea is viewed as a job player in merchandise transportation, energy investigation, and the travel industry. More than 80% of the world's cargoes are shipped by sea. It has been observed that human error accounts for 70–90% of marine accidents (Lan et al., 2023). Such an accident causes environmental contamination, cargo loss, human casualties, and financial losses. The autonomous vessel concept has several advantages and has been established to improve vessel competitiveness and remove human error onboard (Ugurlu & Cicek, 2022). The key advantages of an autonomous vessel are decreased operating costs and integrated navigational safety.

Digitalization, automation, and cutting-edge information technology all have the potential to fundamentally alter sea transportation. The development of completely or partially autonomous ships will present opportunities and challenges for the industry regarding safety, security, sustainability, current legal frameworks, and operations, in keeping with the Commission's dual fundamental objectives of digitalization and sustainability (Chen et al., 2023).

The Baltic and International Maritime Council (BIMCO) and the International Shipping Federation (ISF) jointly reported to the International Maritime Organization (IMO) in 2010 regarding the labor market in the shipping industry. Their research showed that the industry would likely have a considerable tightening of the labor market soon. This will primarily be the case since there is a continuing lack of ship officers. The dangerous working circumstances that officers frequently face and the extended length of time spent away from land are the primary factors contributing to this labor shortage (Mi et al., 2022). In addition to the difficulties presented by the labor market, those working in the shipping industry have had to contend with severe competition and the drive to attain economies of scale. These factors have contributed to a significant increase in the amount of pressure placed on freight rates and have caused an oversupply of capacity in the

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industry. Because of this, shipping companies have been forced to investigate new avenues for maintaining their competitive edge in this cutthroat industry (Wang et al., 2022).

Porathe and co-workers provide four explanations for the consideration and investigation of autonomous shipping, including the need for a better working environment for crew members onboard and a reduction in the likelihood of a future seafarer shortage, efforts to lower transportation costs, the need to reduce emissions globally, and the need to enhance shipping safety (Sharma & Kim, 2022). Developing more eco-friendly, sustainable, and secure methods of maritime transportation has increased interest in autonomous ship technology. The deployment of economically viable solutions for autonomous ships has been the subject of international efforts. To successfully construct and operate autonomous ships, safety is a major consideration that must be carefully addressed. Even when fully unmanned ships are employed, the human aspect will still be crucial, as the employment of autonomous ship technology is linked to safety challenges (Palaniappan & Vedachalam, 2022). It is anticipated that substantial training will be necessary for autonomous systems to cover the gamut of possible real-world scenarios. While the interaction between manned and unmanned ships in the same traffic area is still uncertain, the safety challenges posed by autonomous ship operations are increasing. That's why it's important to consider autonomous ship technologies while teaching future sailors. The navigation of autonomous ships highlights the need to include the human factor in designing the future generation of autonomous ships (Sürer & Arat, 2022).

According to the IMO, the degree of autonomy distinguished with the end goal of the checking exercise (Viljanen, 2023) were:

First level: Ship with decision support and automated processes: Sailors are ready to work and control shipboard frameworks and capabilities. A few tasks might be mechanized and, on occasion, be solo yet with sailors on board prepared to assume command.

Degree two: Ship that is controlled remotely and has seafarers aboard. The boat is controlled and worked from another area. The ship's systems and functions can be controlled and operated by seafarers who are on board.

Degree three: Ship controlled remotely but without any seafarers aboard. The boat is controlled and worked from another area. On board, there are no seafarers.

Degree four: Ship with no crew: The ship's operating system can autonomously decide and plan actions.

Numerous attempts for autonomous shipping have steadily evolved in marine transportation. For instance, Rolls-Royce and Finferries exhibited the world's first completely autonomous ferry in Finland in 2018 (Kurt & Aymelek, 2022b). On one sailing leg, the ferry operated independently, but the remote control took over the return leg. Yara International is creating the first autonomous

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zero-emission cargo ship in a different project, the Yara Birkeland. The creation of autonomous ships is now technically achievable, as shown by these and other initiatives (Rødseth et al., 2023). Furthermore, because of the improved safety and security, this advancement is anticipated to reduce maritime accidents. Additionally, it is anticipated that the advancement of autonomous ships will have an impact on society and the environment and inspire new economic strategies for ship builders.

The connection between the economic and logistical aspects of autonomous ships has received less attention than other research publications on safety, navigation control, design, project, and prototype (Lazarowska, 2022) (Brett, 2022) (Emad et al., 2022; Gerrits & Schuur, 2022). Some estimates place a strong emphasis on the immediate advantages of decreased crew expenses, more cargo room, and less fuel use. New autonomous warships will cost more to build than traditional ones, though. Additionally, it has been stated that autonomous ships may incur increased costs for port-related expenses and surveillance from onshore control centers. The debate over whether liner shipping companies and other significant market actors should act in favor of or against the autonomous shipping trend centers on the trade-off between cost savings and added expenses. Researchers at Rolls-Royce Maritime contend that putting technology prospects for autonomous shipping into practice depends on how the major players in the maritime sector see business opportunities (Baum-Talmor & Kitada, 2022).

(Kurt & Aymelek, 2022a) assert that the unmanned ship can be expected to be safer than the conventional units despite admitting that they are missing important details regarding her design and operation during a quantitative safety assessment of the unmanned bulk carrier idea.

Additionally, most of the dangers identified by that study are associated with people, and it doesn't appear that the effect of human absence on how the accident's aftereffects evolve has been well taken into account. We draw the conclusion from our analysis that it would be very difficult to develop a technology system that could handle or avoid all potential fire scenarios. For instance, it is asserted that redundancy is a key strategy for minimizing the effects of accidents, yet in other situations, such as fire disasters, this strategy may not be practical. Additionally, insurance firms have some reservations regarding the concept of unmanned ships. The notion is anticipated to take decades rather than years to become operational and accepted by the law. However, it might provide a more affordable option for short-sea shipping, using a convoy formation with manned ships guarding and monitoring the unmanned ships (Theotokatos et al., 2023).

1.2. Statement of Research Problem

The transportation industry has witnessed significant advancements in recent years with the advent of autonomous technologies. The maritime transportation industry also wants to use these technologies to improve efficiency, make shipping safer, and lower operational costs. The goal of

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this research is to find out how self-driving ships can change the way people travel by sea. The research will examine where autonomous ships are now, what technology is behind them, and what problems they face. The research will also examine the pros and cons of self-driving ships in the maritime industry. The study will figure out who will be most affected by the use of self-driving ships. This includes regulators, shipbuilders, ship owners, and seafarers.

The research problem is critical as it addresses a significant shift in the maritime industry that will have far-reaching impacts. The adoption of autonomous vessels has the potential to improve efficiency, reduce costs, and enhance safety, but it may also result in job losses and require significant regulatory changes. Therefore, understanding the implications of autonomous vessels is crucial for all stakeholders involved in the maritime industry.

1.3. Research Questions

How can autonomous vessels revolutionize the maritime transportation industry?

- ***Sub-questions***

- What are the advantages and disadvantages of autonomous vessels compared to traditional ships?
- What are the technical and technological requirements for developing and deploying autonomous vessels?
- What are the potential economic benefits of autonomous vessels, and how do they compare to traditional ships?
- How can the safety and security of autonomous vessels be ensured, and what are the potential risks associated with their operation?
- How can regulatory frameworks be developed to support autonomous vessels' safe and efficient operation?
- How can the workforce in the maritime transportation industry adapt to the introduction of autonomous vessels?
- How can autonomous vessels contribute to reducing the environmental impact of the maritime transportation industry?
- What are the potential challenges and opportunities for stakeholders such as ship owners, operators, and ports in the era of autonomous vessels?
- What are the implications of autonomous vessels for international trade and logistics?

1.4. Aims and Objectives of Research

The aims and objectives of the current research study are given as follows:

- ***Aims***

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This study aims to analyze the possible influence that autonomous vessels could have on the maritime transportation business and investigate how this technology could transform how goods are delivered by sea.

- ***Objectives***

- To evaluate the benefits and drawbacks of autonomous ships over conventional ships.
- To determine the scientific and technological prerequisites for creating and using autonomous vessels.
- To evaluate the possible economic advantages of autonomous ships over conventional ships.
- To research the security and safety concerns related to the use of autonomous vessels and to suggest risk-reduction measures.
- Assess the legal frameworks necessary to support autonomous ships' effective and safe operation.
- To investigate the effects of the introduction of autonomous vessels on the workforce in the marine transportation sector.
- To determine whether autonomous ships could help the maritime transportation sector have a smaller negative environmental impact.
- To assess the benefits and challenges stakeholders face in the age of autonomous vessels, such as ship owners, operators, and ports.
- To look into how autonomous ships might affect logistics and global trade.

This research study aims to provide insights into the potential of autonomous vessels and contribute to understanding how this technology can transform the maritime transportation industry.

1.5. Scope of Research

The scope of the research will cover the potential impact of autonomous vessels on the maritime transportation industry. The research will focus on the technical and technological aspects of autonomous vessels, including their advantages and disadvantages compared to traditional ships and the requirements for their development and deployment. The economic benefits of autonomous vessels and their potential impact on international trade and logistics will also be analyzed. Additionally, the research will assess the regulatory frameworks required to support autonomous vessels' safe and effective operation and the safety and security concerns related to their operation. Additionally, the study will assess the opportunities and challenges facing stakeholders like ship owners, operators, and ports in the age of autonomous vessels, as well as the potential effects that autonomous vessels may have on the workforce in the maritime transportation sector.

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While the research will address some of the environmental impacts associated with the operation of autonomous vessels, the study will not focus exclusively on environmental issues. The scope of the research will be limited to the potential of autonomous vessels to transform the maritime transportation industry and their impact on stakeholders. The research will primarily be based on secondary data, including academic journals, industry reports, and government publications, with some limited primary data collection, such as interviews with industry experts.

1.6. Methodology of Research

The research methodology will be based on a secondary qualitative approach, which involves analyzing and interpreting existing data from academic journals, industry reports, and government publications. The research will systematically review relevant literature on autonomous vessels and their potential impact on the maritime transportation industry.

The first step will involve identifying key concepts and themes related to autonomous vessels and their impact on the maritime transportation industry. A comprehensive literature search will be conducted using databases such as Google Scholar, ScienceDirect, and Web of Science to gather relevant literature.

The literature will be evaluated based on predetermined inclusion and exclusion criteria. Inclusion criteria may include peer-reviewed articles published in the last five years, while exclusion criteria may include articles unrelated to the topic or not in English.

The data will be analyzed using thematic analysis to identify themes, patterns, and relationships. The analysis will use a coding system to categorize the data into themes and sub-themes. The identified themes will be synthesized into a coherent narrative that addresses the research questions and objectives.

The secondary qualitative approach will provide a comprehensive understanding of the potential impact of autonomous vessels on the maritime transportation industry, drawing on existing literature to address the research questions and objectives.

1.7. Limitations of Research Methodology

The secondary qualitative approach has several limitations that should be acknowledged. These limitations include:

- The literature may be biased toward certain perspectives or viewpoints, which could influence the research findings.
- Since the data used in the research is pre-existing, the researcher has limited control over the data collection process, which may result in missing important information.
- The limited scope of analysis: The analysis of existing data may be limited to available data and may not provide a complete understanding of the topic.

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- The accuracy of the data used in the research cannot be verified, which may impact the reliability of the findings.
- The research findings may not be generalizable to other contexts or populations since the data used in the research is specific to the sources analyzed.
- The secondary qualitative approach may not be able to explore complex relationships between variables since the data is pre-existing, and the researcher may not have control over how the data is categorized.

To mitigate these limitations, the research will involve a rigorous literature search and multiple data sources to ensure the findings' validity and reliability. Additionally, the limitations of the research methodology will be acknowledged in the research, and efforts will be made to provide a balanced and comprehensive interpretation of the findings.

CHAPTER 2- History of Maritime Transportation

2.1. Introduction

Autonomous vessels, also known as crewless or autonomous ships, are vessels that operate without a crew on board and are remotely controlled by operators on shore or by artificial intelligence operating systems. The development of autonomous vessels represents a new phase in maritime transportation that has the potential to transform the way goods and people are moved across the world's oceans. There are several potential benefits of autonomous vessels. For example, they could reduce the risk of accidents and improve safety by removing human error. They could also reduce costs by eliminating the need for crew accommodations, provisions, and salaries. In addition, autonomous vessels could operate 24/7, making them more efficient and reducing transit times (Altan et al., 2022).

The development of autonomous vessels is still in its early phases, and various technical, regulatory, and legal difficulties must be overcome before they become a reality. For instance, there are concerns over how to guarantee the security and safety of autonomous vessels and settle disputes regarding liability in the event of an accident (Theotokatos et al., 2023). Despite these difficulties, work on developing autonomous ships has already begun. Numerous businesses and institutions are developing the technology for autonomous vessels, and some of these vessels are now in use. In the next few years, we'll likely see more autonomous ships on the world's waters as technology advances and matures.

2.2. History of Maritime Transportation

The history of maritime transportation is lengthy and extensive, spanning thousands of years. People have utilized boats and ships to move goods, people, and ideas across waterways since the dawn of human civilization. The development of automation technologies, which have altered how

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ships are handled and managed, is one example of how eras of innovation and technical improvement have characterized the history of marine transportation. Using sails to harness the power of the wind was one of the earliest examples of automation in maritime transportation. The invention of sails allowed ships to sail quicker and more effectively, allowing sailors to discover new parts of the globe. The invention of steam-powered engines revolutionized maritime transportation in the 19th century. Ships could go farther and carry more cargo thanks to steam engines.

Additionally, they improved ship dependability and decreased the possibility of becoming stranded because of unfavorable winds or currents. The development of radio communications and radar technologies in the 20th century led to the next significant advancement in automated maritime transportation. Through the use of these technologies, ships could communicate with one another across great distances and detect obstacles and other ships nearby, increasing safety and lowering the likelihood of collisions.

In the latter half of the 20th century, the development of computer technology and automation systems transformed maritime transportation once again. Ships may now be handled with minimal crews thanks to automated steering, computerized navigation, and other automation technology (Jović et al., 2022). This lowers expenses and boosts productivity. These days, many big commercial ships are run by highly automated systems that don't need much help from people. In recent decades, the maritime transportation sector has experienced substantial automation and digitalization advancements. Many aspects of ship navigation, including steering and propulsion, are now managed by computerized systems. The sophisticated sensors, GPS systems, and other technologies on modern ships enable them to operate more safely and effectively. Technology for autonomous vessels is the most recent development in automated maritime transportation. Autonomous ships could completely change how goods and people are transported across the world's oceans, which offers a new chapter in this important industry's ongoing story of innovation and technical advancement (Raza et al., 2023).

2.3. Autonomous Vessels

With the growing popularity of autonomous vessels worldwide, several academics have expressed an interest in contributing to the field by studying and developing autonomous vessels. This study is central to understanding the significance of environmental analysis and personal health monitoring. In this sense, automation is any procedure that can be performed by a machine under the direction of artificial intelligence (Carter et al., 2022). The precise nature of an autonomous vessel is subject to change from one project to another. A computerized vessel that can function without human intervention is what the Norwegian Forum for Autonomous Ships (NFAS) calls an autonomous ship. According to the European Commission's MUNIN initiative, an autonomous

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ship is a vessel that employs cutting-edge control and communication technologies to allow for remote, semi-autonomous, or fully-autonomous operation (Makkonen et al., 2022). The International Maritime Organization's Maritime Safety Committee (MSC) defined an autonomous ship as a "Maritime Autonomous Surface Ship" (MASS) that can be controlled with different degrees of human intervention. The definition of "Maritime Autonomous Surface Ship" does not address how such a vessel would function in practice, **Figure 2.1**. Several projects and characteristics of autonomous vessels have allowed us to arrive at the following definition: an autonomous vessel is a vessel in which Artificial Intelligence (AI) and the Internet of Things (IoT) are used to allow the vessels to operate without human intervention (Jović et al., 2022).

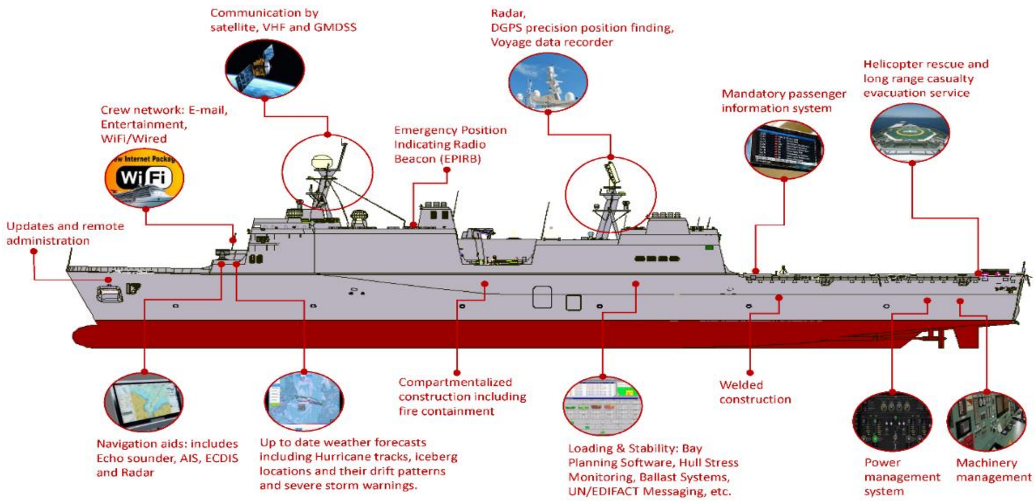

Figure 2.1. Ship automation technologies for the autonomous future.

(source: "Cybersecurity Challenges in the Maritime Sector" by Frank Akpan ,Gueltoum Bendiab Stavros Shiaeles , Stavros Karamperidis and Michalis Michaloliakos published in https://www.mdpi.com/2673-8732/2/1/9)

2.4. Properties of autonomous vessel operations

The autonomous vessel does not require human participation; as a result, the algorithm is used to make all decisions. After analyzing the circumstance, a vessel can avoid collision by employing planning based on the developed set of electronic sensors for machine learning. The algorithm serves as the equivalent of the human brain in autonomous operation, removing human error from navigation. (Baum-Talmor & Kitada, 2022). Seafarers use their knowledge and experience to avert accidents as the ship must deal with numerous unknown scenarios and injuries throughout the journey. The NYK project presented the technical process in four steps; gathering information, analyzing, and planning (4) Permission (Rahman, 2022). **Table 2.1** gives insight into the primary automation systems found in contemporary, self-navigating ships.

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According to the Rolls Royce-led Advanced Autonomous Waterborne Applications Initiative (Maimon, 2022), three significant areas for the Autonomous vessel are:

2.4.1. Sensor fusion

Sensor technology, which is currently seeing significant development for use in autonomous vehicles, is also being developed for use in vessels. The AAWA project has investigated a variety of sensors to gather information. These sensors include radars, thermal imaging, high-definition visual cameras, and Light Detection and Ranging, all of which are necessary to analyze the vessel's surroundings in any case.

2.4.2. Control algorithms

In order to maintain safe navigation and avoid a collision at sea, the vessel in question is obligated to take the necessary steps whenever there is a possibility of either scenario occurring. The decision algorithms that are utilized in machine learning need to be flawless and in accordance with the International Convention for the Prevention of Collisions at Sea. As a result of this reason, the process of developing algorithms is the most important and difficult component of the vessel.

2.4.3. Communication and connectivity

The connection capacity of the autonomous vessel must be sufficient for remote monitoring and control of the vessel. The ship's sensors must be enabled to interact properly with satellite and land-based systems.

2.5. Types of autonomous vessels

There are several types of autonomous maritime vessels, each with unique features and capabilities.

2.5.1. Unmanned Surface Vehicles (USVs)

Unmanned surface vehicles, or USVs, are self-contained boats operating on the water's surface. These boats can be employed for *various* jobs, such as surveillance, search and rescue missions, and environmental monitoring. USVs can be big and able to tow heavy payloads or compact and agile, allowing them to maneuver in confined locations. To gather information and maneuver safely, they can also be fitted with *various* sensors, including cameras, radar, and sonar.

2.5.2. Autonomous Underwater Vehicles (AUVs)

Autonomous underwater vehicles, often known as AUVs, are submersibles that function underwater without the presence of a human operator. Numerous activities, such as oceanographic research, underwater mapping, and exploration, *use* these vehicles in various capacities. Various sensors, such as sonar and cameras, are installed on AUVs so that the vehicles may gather information regarding the marine environment. Because they can function without human intervention for extended periods, they are ideally suited for research endeavors that span multiple years.

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2.5.3. Autonomous Cargo Vessels

Autonomous cargo vessels are unmanned ships designed to transport goods without the need for a crew on board. These vessels can be used for various applications, including shipping, offshore support, and mining operations. Autonomous cargo vessels are typically equipped with advanced sensors and navigation systems to operate safely and efficiently without human intervention.

2.5.4. Autonomous Ferry Boats

Ferry boats that operate without human crew members are known as autonomous ferry boats. These boats transfer passengers and vehicles across waterways. These vessels are fitted with cutting-edge navigation and sensing systems, enabling them to function without a crew member's assistance while maintaining high safety and productivity. Autonomous ferry boats are being researched and developed as a more environmentally friendly and time-saving method of transporting people and commodities across waterways.

2.5.5. Autonomous Warships

Unmanned vessels that have been specifically intended for use in military activities are known as autonomous warships. These vessels are versatile and can be utilized for various purposes, including reconnaissance, surveillance, and offensive operations. Warships that are capable of operating alone are referred to as autonomous warships. These ships are outfitted with sophisticated sensors, weaponry systems, and navigation systems.

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Systems	Purpose
Automatic Identification System (AIS)	Support for and monitoring of maritime transportation
	Report the ship's location to the appropriate ports and maritime authorities.
	The ship's distance from the other ships must be determined.
	Maintain maritime order through constant surveillance.
	The Search and Rescue Process Following an Accident
Electronic Chart Display Information System (ECDIS)	Synthesize information from several electronic navigation sensors.
	Displays the live location of the ship.
GPS and GNSS	Displays the ship's location
	Shows the speed as well as the distance and time
	Gives details about the area around the ship.
Radar	Gives details about the area around the ship.
	Detection of an object's location and speed
Global Maritime Distress System (GMDSS)	Send out distress signals about potential dangers
	Receiving and sending urgent safety notifications
Global Industrial Control Systems (GICSs)	Help to reduce human errors
	Boost the output of resources.
	Prolong the equipment's life.
	Control and keep an eye on the ship's settings.
Very Small Aperture Terminal (VSAT)	Offers a range of communication and security services and transmits and receives data via a satellite network.
	Monitoring and controlling propulsion monitoring and controlling onboard equipment
Systems for managing machinery, power, and propulsion	Observe and control steering
	Keep track of transport activities in sizable storage spaces.
	Tracking the movement of huge vessels
Video Surveillance System	Used to communicate, receive, and store data for internal and external processes
	For the benefit of the crew
Systems for IT Network	For crew members' personal gadgets (BYOD)
	Receiving and sending urgent safety notifications
	Help to reduce human errors.

Table 2.1. A list of the primary automation systems in contemporary, self-navigating ships.
Source: Bathla, G., Bhadane, K., Singh, R. K., Kumar, R., Aluvalu, R., Krishnamurthi, R., Kumar, A., Thakur, R., & Basheer, S. (2022). Autonomous vehicles and intelligent automation: Applications, challenges, and opportunities. *Mobile Information Systems, 2022.*

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2.6. Advantages and Disadvantages of Autonomous Vessels

There is great potential for numerous benefits to be gained from autonomous vessels; however, many problems and concerns need to be resolved before they can be widely implemented. As is the case with any emerging form of technology, it will be essential to thoughtfully weigh the benefits and drawbacks of the new system while also making efforts to address any feasible concerns or problems (Du et al., 2022).

Here are some of the key advantages and disadvantages of autonomous vessels:

2.6.1. Advantages

- Increased Safety: One of the primary advantages of autonomous vessels is increased safety. Removing humans from the equation reduces the risk of accidents caused by human error, fatigue, and other factors.
- Greater Efficiency: Autonomous vessels can operate 24/7 without the need for rest breaks, making them more efficient than manned vessels. This can result in faster transport times, reduced costs, and increased productivity.
- Lower Costs: Autonomous vessels require fewer crew members and support staff, which can lead to significant cost savings for shipping companies and other organizations that rely on maritime transportation.
- Improved Environmental Impact: Autonomous vessels can be designed to operate using renewable energy sources, such as wind and solar power, reducing their environmental impact compared to traditional vessels that rely on fossil fuels.
- Enhanced Capabilities: Autonomous vessels can be equipped with advanced sensors and navigation systems that allow them to operate in challenging conditions and navigate safely through congested waterways.

2.6.2. Disadvantages

- High Initial Costs: Developing and deploying autonomous vessels can be expensive, requiring significant investment in research, development, and infrastructure.
- Limited Flexibility: Autonomous vessels are designed to operate within specific parameters and may not be able to respond to unexpected changes in weather or other conditions.
- Limited Human Oversight: While autonomous vessels are designed to operate without human intervention, they still require human oversight to ensure they are operating safely and within legal guidelines.
- Cybersecurity Risks: Autonomous vessels rely on complex computer systems and networks that are vulnerable to cyber-attacks and other security threats.

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- Legal and Regulatory Challenges: Many legal and regulatory issues still need to be addressed before autonomous vessels can be deployed on a large scale, including issues related to liability and responsibility in the event of accidents or other incidents.

2.7. Causalities related to Maritime

The global nature of the maritime transportation industry, as well as its working conditions, autonomy, and complexity, all contribute to the unique maritime culture that exists within this sector. Because the shipping industry operates on a global scale, there is intense competition on a global scale, which compels ship owners to search for ever more effective ways to cut costs. The global economy, international trade, and the environment substantially impact maritime shipping, exacerbated by the recession that followed the COVID-19 pandemic in 2020 (Kamal et al., 2022). There are 98,140 commercial ships in the world's fleet that are 100 GT or more, as reported by UNCTAD in 2020. Over the course of the year 2020, the largest increases were seen in the fleets of gas carriers, oil tankers, bulk carriers, and container ships (Kong et al., 2022).

In spite of significant advancements in technology, methods, procedures, training, and laws, a distressing number of maritime vessels over 100 GT were lost between the years 2017 and 2020. The primary causes of these losses were attributed to sinking, which accounted for approximately 62% of incidents, grounding, which constituted about 15% of the accidents; fire/explosion, responsible for approximately 10% of the occurrences, machinery damage/failure, contributing to around 6% of the cases (Dominguez-Péry et al., 2021).

It is crucial to acknowledge that the size of the ship and the nature of its cargo significantly influence the severity and repercussions of a maritime catastrophe. Throughout the period between 2010 and 2019, the annual average volume of crude oil transported by sea exceeded a staggering 1,800 million metric tons. These figures illustrate that crude oil alone constituted approximately 17 to 20 percent of all seaborne products loaded within that time frame (Jolliffe et al., 2021).

The recent and widely-publicized incident involving the Ever Given vessel becoming "wedged" in the Suez Canal serves as a poignant reminder of how vessel size and cargo type can directly impact safety measures, effective fire prevention strategies, and salvage operations in the event of an accident. This incident captivated global attention, emphasizing the importance of addressing the challenges posed by large-scale maritime transportation and the need for comprehensive safety protocols. Moreover, examining the interplay between vessel size and cargo type unveils the complexities associated with mitigating risks in maritime operations. For instance, the Ever Given, one of the world's largest container ships, was carrying an extensive cargo load. Consequently, when the vessel experienced navigation difficulties, the repercussions reverberated throughout the global supply chain, disrupting trade routes and emphasizing the need for swift and efficient response strategies.

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In light of these observations, it becomes evident that ensuring the safety and security of maritime operations necessitates a multi-faceted approach that encompasses not only technological advancements but also comprehensive training programs, stringent regulations, and proactive risk management strategies. By addressing the specific challenges posed by vessel size and cargo type, stakeholders in the maritime industry can work towards minimizing the frequency and severity of accidents, ultimately safeguarding both human lives and the environment.

The size and carrying capacity of ships have expanded by 1,500% over the previous 50 years, with the largest container ships currently being bigger than the largest oil tankers and cruise ships (Ros Chaos et al., 2021). The ITOPF reports that between 2010 and 2018, 91 percent of all oil spills were the result of 10 accidents, up from the prior decade, when only 75 percent of oil spills were the result of 10 incidents (Chen et al., 2019). In fact, several studies show that collisions or intrusions account for a significant portion of oil spill mishaps, occurring most often when the boats are underway or in the open ocean. Accidents involving huge vessels carrying higher volumes of very harmful pollutants can have devastating and frequently long-lasting effects on people, the economy, and the environment (Dominguez-Péry et al., 2021). This study's primary objective is to analyze human error in all forms of maritime transportation. The researchers hope that by better understanding these faults, they would be better able to prevent future mishaps that could have catastrophic consequences.

In addition to growing the size of their vessels, ship owners frequently minimize their fixed expenses by either employing international crews from developing nations or cutting back on the number of crew members they have on board. Both of these strategies are fairly prevalent. This frequently results in the de-prioritization of employee training and increasing communication and understanding problems among the multi-lingual and multi-cultural crew, who cannot speak with one another effectively or understand one another's languages or cultures. It is also inevitable that crew members will transfer their own cultural ideas, stereotypes, and racial prejudices to one another, which will result in cultural difficulties and strained relationships. Long working hours, a noisy atmosphere, a sense of isolation and loneliness, inadequate and sometimes shared housing arrangements with limited privacy, and the inability to get away to spend leisure time by oneself are factors that further exacerbate these tensions. Living and working in such conditions for extended periods can negatively impact crew morale and boost stress levels, which can eventually lead to exhaustion, loss of concentration and focus, decreased productivity, and, ultimately, accidents (Zodiatis et al., 2021).

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CHAPTER-3

The Disruptive Potential of Autonomous Vessels in Maritime Transportation

3.1. Introduction

The development of autonomous ships has accelerated recently. Underwater gliders, unmanned surface vessels, autonomous underwater vehicles, and the Marine Autonomous Surface Search System (MASS) are only a few of the products of the seagoing industry's present disruptive technological change, which is currently taking place. This is because of the rapid advancement in the field of autonomous technology in recent years. As the quantity and scale of projects involving unmanned vessels or autonomous ships grow on a global scale, the technology for automated vessels is rapidly making the transition from the theoretical to the practical application stage. They have seen extensive use in a variety of military and industrial applications, including the operation of underwater production systems, marine surveillance, coast guard and inspection, and other similar tasks. The economic benefits and concerns over safety are the key motivating factors for the rapid development of autonomous vessels. Accidents at sea are a leading cause of death, as well as property and environmental damage and economic losses. The development of autonomous marine ships has the potential to improve things and is anticipated to be a more cost-effective option than conventional ships. Additionally, the development of these ships is expected to increase safety and reduce the amount of impact they have on the marine environment.

3.2. Automatic Control

Automatic control is a critical technology in the development of autonomous vessels. Autonomous ships are being used more and more in maritime transportation because they can make things more efficient, safer, and cheaper to run. Autonomous ships with automatic control can run on their own with little help from humans. This reduces the chance that a person will make a mistake (Stateczny & Burdziakowski, 2019).

The automatic control system in autonomous vessels comprises various sensors, actuators, and control algorithms that enable the vessel to perceive its environment, plan its route, and control its motion. These systems make decisions and improve performance by using high-tech tools like artificial intelligence, machine learning, and data analytics. One of the best things about self-driving ships with automatic control is that they can quickly adapt to changing conditions (Rødseth et al., 2023). The system can pick up on changes in the environment, such as weather, traffic, and obstacles, and react to them to keep navigation safe. This technology also makes it possible to keep an eye on how the ship is doing all the time. This lets potential problems be found early and preventive maintenance be done. Even though automatic control has benefits, there are also possible drawbacks to think about. The technology is very complicated and needs a lot of expertise

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to build and keep up. Concerns have also been raised about cybersecurity and the possibility of cyberattacks on self-driving ships (Höyhtyä & Martio, 2020).

A model of an under-actuated autonomous surface ship was used by Xu and colleagues to propose a nonlinear vector field guiding law for the purpose of path-following and collision avoidance. The method that is being proposed enables the autonomous ship to navigate along the preset path while automatically avoiding any impediments that it encounters. Using simulations and actual ship models, we have evaluated the efficiency of the integrated system of autonomous ships to determine their usefulness (Xu et al., 2021). In order to control the speed and course in order to follow a curved line while taking into consideration the sideslip angle, a line-of-sight guiding law that is adaptive was developed. The author Jin et al. described a system for tracking the trajectory of twin-hull USVs. The unmanned surface vehicle known as the "Jiuhang 490" is used in sea trials to validate the proposed control system (Jin et al., 2021). Underwater autonomous homing and docking of AUVs was a topic of investigation for the researchers (Zuo et al., 2021). After the strategy was combined with task planning, guidance, control design, and thrust allocation, simulators were utilized to test the strategy's effectiveness. One of the most essential pieces of marine gear is the underwater glider, which was created specifically for the purpose of performing activities related to the continuous and in-depth monitoring of the marine environment. A fuzzy adaptive linear active disturbance rejection control has been developed for trajectory control (Wang et al., 2021). The findings of the simulation demonstrate how the proposed approach may increase performance while simultaneously reducing overshoot.

3.3. Maneuverability

The maneuverability of autonomous vessels is a critical aspect of their design and operation, as it directly affects the safety of the vessel, its cargo, and the environment (Kim et al., 2022). Several things affect an autonomous vessel's ability to move, such as its size, shape, propulsion system, and control system. Most research on maneuverability has been about making control algorithms and systems that can accurately steer and control the ship. One of the biggest problems with making control algorithms for self-driving ships is that the marine environment is hard to predict and can change a lot depending on where the ship is the weather, and other factors. Researchers have conducted several studies to evaluate the maneuverability of autonomous vessels. Simulation software and real-world models have been used in these studies to test how well different control algorithms and systems work. The results of these studies show that unmanned ships can move just as well as, or even better than, ships with people on board. But a few problems still need to be fixed before autonomous ships can be used safely and effectively in the real world (Li et al., 2023). Costa et al. (2021) proposed a reliable parameter estimation technique based on free-running ship model tests for nonlinear maneuvering modeling. Truncated singular value decomposition

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technology was used to lessen the multicollinearity, which in turn reduced the parameter uncertainties brought on by noise. The validation process involved comparing the measured values' outcomes with the maneuvering models' forecasts. In order to predict the heading angle and trajectories of a model ship from the output rudder angle command, Moreira and Guedes Soares (2022) implemented ANNs. The main strength of this study is that it shows how the ANN can pick up new information even from sparse, noisy data. A fishing boat's ability to maneuver in shallow water was predicted using an empirical formula (Kim et al., 2021). The findings of this study can be used to run simulations and provide specific fishing vessel parameters that can be used to create autonomous vessels. The Ship Maneuvering Simulation Methods database, was used for the validation of the nonparametric modeling techniques proposed by Xue et al., 2021, and the results show that the identified model is accurate and exhibits good generalization performance.

3.4. Collision Avoidance

Collision avoidance is a crucial aspect of safe navigation in the maritime industry (Vagale et al., 2021). With the rise of autonomous ships, research into how to avoid collisions is becoming more and more important. The development of self-driving ships could reduce human mistakes and improve efficiency, but new ways to avoid collisions will also be needed. Using radar, sonar, LIDAR, cameras, and other sensors, among other things, has been suggested as a way for autonomous ships to avoid collisions. These sensors send information about the ship's surroundings to the ship's computer, which uses this information to make navigation decisions and avoid collisions (Akdağ et al., 2022).

Autonomous ships have to deal with the need to combine data from many sensors in order to avoid collisions. For example, radar might be better at finding big things, while sonar might be better at finding dangers under the water. The challenge is to put together information from different sensors in a way that gives a full and accurate picture of what's around the ship. Another problem with avoiding collisions is making sure that autonomous ships follow international rules. The IMO has put out rules for how autonomous ships should be run. These rules include rules for safety, security, and avoiding collisions. For autonomous vessels to be widely used, it will be important to meet these requirements (Markopoulos et al., 2019).

A novel collision avoidance algorithm built on the modified artificial potential field approach was proposed by Zhu et al. in Zhu et al. (2022). This research took into account both the ship's motion characteristics and the International Regulations for Preventing Collisions at Sea. In the west sea of Korea, a data-driven approach was used to gather 12-month Automatic Identification System data in order to evaluate autonomous ship collision avoidance algorithms. The information was utilized to categorize and organize scenarios for objective navigation. It is planned that the results will be applied to develop a collision avoidance test environment for MASS. Using the dynamic

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navigation ship domain, the author of (Deng et al., 2021) proposed a dynamic obstacle avoidance technique for USVs, according to COLREGs (DNSD). The suggested DNSD-based obstacle avoidance algorithm was successfully simulated, and the outcomes proved its superiority.

3.5. Ship Target Identification

Ship target identification is crucial to autonomous vessels' navigation and safety systems. This technology lets self-driving boats find and identify other boats nearby, so they can avoid collisions and keep going safely (Escorcia-Gutierrez et al., 2022). Research on ship target identification in autonomous maritime vessels is important for making navigation systems that work well and can be trusted. One of the hardest parts of ship target identification is making sure that ships can be found and identified correctly in different sea conditions and settings. The research has been mostly about making and testing different sensor technologies, such as radar, LIDAR, and cameras, to help ships find their targets more easily. Ship targets have also been easier and faster to find with the help of machine learning algorithms and computer vision techniques (Chen et al., 2020).

Ship target identification communication protocols and standards are something else that has been looked into. Autonomous ships will share the water with ships that humans operate, so it is important that they can talk to each other easily. Standardized communication protocols can ensure that vessels can exchange critical information, such as position, speed, and course, in real-time, reducing the risk of collisions and improving safety (Pedersen et al., 2020).

A Bayesian-Transformer Neural Network was suggested by (Z. Kong et al., 2022) to finish the ship target identification task utilizing tracking data. The experiments' results indicate that, compared to conventional methods, the suggested strategy can increase identification accuracy by 3.8%. Yang et al. (Yang et al., 2022) introduced a novel ship-type recognition strategy based on a ship navigation trajectory and convolutional neural network to address the issue of missing ship-type information in AIS. Using the YOLOv5s algorithm, a target visual detection system was developed (Zhou et al., 2021) for the real-time detection of an unmanned fishing speedboat close to a ship ahead. The findings demonstrate that the suggested strategy is capable of detecting and classifying a variety of ships. AUVs can also use object recognition for precise navigation (Bobkov et al., 2021), which was made possible by routinely updating the coordinate references to SPS objects while the AUV was moving continuously in SPS space. The suggested technique was examined in a testing environment with the Karmin2 stereo camera.

3.6. Motion Planning

Motion planning in autonomous maritime vessels is a crucial aspect of their operation, as it determines how the vessel will navigate through the water without human intervention. An autonomous ship's motion planning system must be able to make decisions in real-time about the

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ship's speed, course, and how to avoid collisions (Vagale et al., 2021). Autonomous ships have to use real-time data from sensors and weather forecasts, for example, to ensure they can navigate safely and efficiently. This is one of the biggest challenges of motion planning. The motion planning system must also be able to make decisions based on where a ship wants to go, taking into account things like wind and currents (Lazarowska, 2021).

To deal with these problems, researchers have come up with different ways to plan motion, such as rule-based systems, model predictive control, and methods based on artificial intelligence. Rule-based systems are based on rules that have already been set up to tell the ship how to act in different situations. Model predictive control uses mathematical models of the ship and its surroundings to predict what will happen in the future and find the best path for the ship to take. Artificial intelligence-based methods use machine learning algorithms to learn from data and make decisions based on that learning (Liu et al., 2022). Recent improvements in machine learning have shown promise for making the motion planning systems in autonomous ships more accurate and reliable. Deep reinforcement learning algorithms, for example, have been used to improve the ship's behavior in different situations and to learn from data from the real world (Felski & Zwolak, 2020). Under the influence of the navigation environment, Wu et al. (Wu et al., 2021) explored motion planning for USVs to get the ideal path (wind and current). This research presents a multi-objective optimization technique and validates it via simulation. Addressing the structural design concerns of AUVs was the work presented by (Yang et al., 2021).

3.7. Buckling Analysis

The buckling analysis of autonomous maritime vessels is crucial to ensuring these vessels' structural integrity and safety. The buckling analysis examines the vessel's structural behavior under compressive loads, such as those that may occur during harsh weather conditions or collisions. Buckling can occur when a vessel's weakest point is loaded to its compressive limit (Johansson et al., 2021). Several studies were carried out with the assistance of cutting-edge software that takes into consideration a wide variety of parameters, such as the properties of the material, the dimensions, and the loading circumstances. The findings of the analysis contribute to the identification of potential failure modes and deformation patterns, which can then be used to optimize the design of the vessel and ensure that it maintains its structural integrity (Macaulay & Shafiee, 2022). The variable stiffness composite pressure structure of the AUV's critical buckling problem was examined using a discrete finite element method based on the curve fiber path function (Yang et al., 2021).

It is impossible to overestimate the significance of doing buckling analysis on autonomous vessels. Given that these vessels function with limited human involvement, any structural collapse could result in catastrophic outcomes. In addition, the use of lightweight materials and unorthodox

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structural designs, such as those employed in autonomous boats, provides distinct issues that need specialist analysis methods. These challenges are presented as a result of the use of lightweight materials.

Chapter 4- Artificial Intelligence: Future of Autonomous Vessels

4.1. Introduction

Autonomous vehicles (Avs) have completely revolutionized transportation. The benefits it promises much outweigh the difficulties in making this technology accessible to the general public and economically viable. A variety of intelligent systems are integrated and made operable through the design and development of AVs employing machine learning and deep learning techniques. Nearly all of the major automakers, including Daimler with MBUX, Hyundai with Smart Sense, Audi with MMI Virtual Cockpit, and many others, in addition to the involvement of tech firms like Watson, IBM, Google, and Nvidia, are realizing the impact of AI on the services provided and are moving toward the development and nurturing of AI (Bathla et al., 2022). The most common testing methods used today, such as the number of miles driven and the frequency of human interaction, are insufficient to adequately support an autonomous vehicle's safety. Such methods are deceptive and fall short of meeting all of an autonomous vehicle's safety standards. The autonomous car system could fail as a result of flawed assumptions (Suresh). The quality of those decisions cannot be left to manual testing because the autonomous car itself leverages numerous AI technologies for various decisions for two reasons:

(i) The high density of errors that might occur in systems with AI-enabled components is caused by algorithmic bias and poor prediction algorithms. The entire AI-enabled system is extremely difficult to test and verify because the prediction of failure is so nondeterministic.

(ii) Testing without AI could produce a lot of human-caused errors, which could undermine the entire idea of automation.

Researchers investigated various testing modalities for autonomous vehicles in order to address these problems. The autonomous car is a masterful fusion of AI-based technologies, so it then evaluates AI testing methodologies. AI-enabled methods can help makers of vehicles test and verify their products more quickly, which will help make them safer. Unexpectedly, autonomous vehicles seem to be making their way from science fiction to reality. Scientists and engineers have been slaving away at it for the past 15 years (Chai et al., 2021). The AI algorithms that make up the brain of the AV are currently being fine-tuned by automakers through mechanical arms of barriers and environments.

The employment of multifunctional sensors, such as LiDAR, imposes significantly different testing criteria with regard to the precision of measurement of these devices rather than vehicle

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movement (Ahmed et al., 2021). The introduction of 5 G expands the field of possibilities for autonomous vehicle development. Testing of autonomous cars will need to go from component-level functional testing to full autonomy testing in order to meet these various testing needs. Prior to the creation and development of these vehicles as well as throughout the whole lifecycle of the component in question, we must be aware. For instance, because they are programmable and customizable and can process large amounts of data in parallel on a single chip, FPGAs are appropriate for the requirement of high levels of parallel, time-critical, and fault-tolerant computing. The lifespan of these chips must be at least ten years. No one has examined how long these chips last under real-world driving situations over a ten-year period. Therefore, to verify the quality of these autonomous vehicles, we need a thorough testing approach and approaches to handle operational as well as software scenarios. There are views of the parts of autonomous vehicles. GPS, radar, sensors, and computer unit components must be tested for the AV to operate more effectively (Brown et al., 2022).

Automation and artificial intelligence (AI) have the potential to increase safety in intricate transportation networks. However, it appears that realizing that potential will require both a seamless integration of human and machine control and effective risk management techniques in a dynamic context. In recent years, a new application of vehicle automation called MASSs has evolved, bringing with it new difficulties and a thriving research community (Fonseca et al., 2021). Research on MASSs has been contributed by a variety of disciplines, including risk and safety science, human factors, politics, and engineering, against the backdrop of rapid technological advancement.

Shipping is regarded as a dangerous industry with a high rate of fatal injuries and substantial repercussions of marine disasters, despite consistently improving safety records. It is said to as "probably the most international of all the main industries of the world and one of the most dangerous" by the Worldwide IMO, the United Nations body that oversees international maritime safety (KIRVAL & ÇALIŞKAN). According to some estimates, "human error" is the single biggest contributor to marine accident investigations, accounting for between 75 and 96 percent of all incidents. Invoking its accuracy and tireless skills, automation proponents have long promised an end to human errors. The facts, however, seem to remain the same: according to recent safety analysis, human error will still account for between 75% and 96% of marine events in 2020 (Wróbel, 2021). Including in the instance of ship navigation, the propensity of automation applications to produce new causes of mistakes while successfully resolving established ones has been well-documented. Since new hazards associated with interactions between humans and AI appear to be only partially countered by fewer instances of human mistake, the risk landscape developing in the wake of MASS progress is still unclear (Qiao et al., 2020).

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Although it is difficult to measure the direct influence of automation on overall safety, comparisons of annual safety reports show that maritime safety is typically improving. Automation in shipping has gradually advanced since the transition from sails to engines and from manual rudder control to powered steering. These days, ships include "autopilot" systems with controls resembling those on automobiles, as well as Dynamic Positioning controls on vessels like ferries, offshore supply ships, survey vessels, cable-laying vessels, and drilling vessels that need to navigate accurately (Hahn et al., 2022). Even if automation and safety seem to be evolving at the same time, it is not obvious how tightly or, if at all, by what mechanisms they are connected. In order to represent this trend toward the marine industry's digital transformation, the phrase "Maritime 4.0," which specifically refers to the automated integration of real-time data into decision-making, was coined at the beginning of the 2010s. The MUNIN is the first large autonomous ship project. Two Norwegian companies, Yara and Kongsberg, declared their plans to construct the Yara Birkeland, an autonomous cargo ship that will serve three ports in Southern Norway, in 2017. (Ichimura, 2021). Currently in its early stages, "fully autonomous operation" is expected to begin in 2022. In certain ferry applications, recent improvements have demonstrated "auto-crossing" and "auto-docking" (Veitch et al., 2022). Combining their abilities, these technologies successfully handle whole crossings between terminals without the need for a human operator, relying instead on the bridge crew to take action to avoid potential collisions.

As the most recent indication of better system safety addressing the widespread "human error" problem, AI is announcing the next automation level in transportation applications. Applications for deep learning include flaw identification in mooring lines, obstacle avoidance, and obstacle detection. In terms of research finance, the area of artificial intelligence has had "AI Springs" and "AI Winters," or times of tremendous advancement and financing (Karim et al., 2023). New advances in AI at the beginning of the 2010s signaled a new AI Spring, which was made possible in part by improved computational power in graphics processing units (GPUs). It also represented the first-ever significant effort to create autonomous ships in the maritime sector (Arsenyan & Piepenbrink, 2023). Since 2018, MASS has received official recognition from IMO, the UN organization responsible for promoting marine safety worldwide. Meeting the growing need to balance the apparent benefits of MASS implementation with mounting safety concerns is at the top of their priority list for MASS (Albotoush & Shau-Hwai, 2023).

4.2. Shore-based ship management for unmanned vessels

The goal of MASS operations in the future is to have fewer people on board and more coordination and control on land. A Shore Control Center, also known as a Remote Control Center or Remote Operation Center, addresses the increased demand for centralized coordination regarding monitoring, supervising, and intervening in MASS fleet operations (Janßen et al., 2021). Open-

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ocean, short-sea, inland, urban, and mission-oriented operations are all included in the scope of MASS operations for this article. These operations have specific navigation, regulation, and safety management requirements. While short-sea shipping routes require heavily frequented shipping lanes with established Vessel Traffic Services coordination, open-ocean MASS operations often involve less difficult navigation. Urban applications relate to small ships that transport people or commodities in urban canals or waterways, inland applications relate to inland freight vessels in inland waterways, and data-collection applications relate to the use of autonomous surface vessels (ASVs) in scientific investigation and fieldwork exploration (Veitch & Alsos, 2021). While the execution of land-based operational activities like supervision, monitoring, and control intervention can serve as a conceptualization of an SCC, the work that its operators are involved in would vary greatly depending on the MASS applications. For instance, urban passenger transport will place greater demands on safety management than mission-oriented ASVs, whose payload is only measurement equipment and data; short-sea shipping will place greater demands on navigation than open-ocean applications (Mukherjee, 2023).

4.3. Applications for marine operations

AI has no established definition. The earliest informal definition can be linked to an AI workshop that took place in 1955 at Dartmouth College, which is widely regarded as the field's birthplace. This idea was built on the hypothesis (Leymarie, 2021)that "every facet of learning or any other trait of intelligence may, in principle, be so thoroughly characterized that a machine can be made to replicate it." This definition remains true today in large part, and many of the initial research areas of the inaugural AI workshop, including natural language processing, neural networks, machine learning, and reasoning, continue to act as compass points for modern AI researchers and developers. It's not always a problem when there isn't a formal definition. According to a committee of top experts, the absence of a specific, widely accepted definition of AI "probably has helped the discipline to expand, blossom, and advance at an ever-accelerating speed," according to a recent paper about the state-of-the-art in AI research. Researchers have looked at computer vision and AI applications for avoiding collisions in the context of marine navigation (Mou, 2019). Examining technological issues is current; the emphasis is on how they affect risk assessment, hazard identification, and human-computer interaction, with particular attention paid to the pertinent theories and methodologies utilized across disciplines.

4.4. The fragility of AI

While artificial intelligence (AI) has a tremendous potential to increase safety by decreasing "human errors" in marine operations, numerous features of the technology point to potential new risks (Veitch & Alsos, 2022). For instance, deep learning-based computer vision is vulnerable to what is known as "adversarial attacks," in which carefully altered images, which are frequently

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invisible to the human eye, trick the algorithms and result in catastrophic errors. Examples of adversarial attacks in the real world have been investigated for autonomous cars but not yet for ship computer vision. The issue of "tail effects," also known as low-probability events that are difficult or impossible to train as inputs into a deep learning training dataset, is related. This introduces a subversive "tail risk," specifically the risk associated with performing particular tasks like navigation in an unfamiliar setting or under novel circumstances. The vulnerability of AI systems emphasizes the need for "people in the loop" (Chen, 2022). The amazing capacity of human operators to integrate information in unfamiliar circumstances and with seemingly little information is especially evident when they are experienced. This can be viewed as an addition to AI systems, that the ability to make accurate decisions depends on how similar the input is to their training set. The IMO named the "Remote control station/center" as one of its "high-priority concerns" in the much-awaited "Outcome of the regulatory scoping study for the use of MASS." They stated in their letter that this method of running a MASS was "a new concept to be applied and a common theme recognized in various instruments as a potential deficiency" (Wang et al., 2021). Furthermore, it was stated that the "most challenging concerns to be solved" included SCC operators' qualifications, accountability, and function. This illustrates the necessity for the SCC (also known as Remote Control Station/Center by the IMO) to be defined before researchers from various sectors may work together to address the underlying research and design gaps.

4.5. Over-automation and new security threats

Interaction with highly automated systems has been recognized as a primary factor in recent examinations of high-profile accidents in the transportation sector (Hancock et al., 2020). The Maneuvering Characteristics Augmentation System (MCAS), which was supposed to automatically regulate pitch based on sensor readings of airflow, failed in both the Boeing 737 MAX crashes in 2018 and 2019 (Johnston & Harris, 2019), causing the nose to descend in response to a phantom stall. A fatal accident in California was investigated by the National Transportation Safety Board, which concluded that "system limitations" and "ineffective monitoring of driver engagement, which facilitated the driver's complacency and inattentiveness," were likely causes of the tragedy. It is well known that humans are not well suited to the work of monitoring automated systems, whether as a qualified pilot or a passenger, due to the risks involved and the necessity to immediately assume control (Saraçyakupoğlu, 2020). Both the Boeing and Tesla cases show how human-in-the-loop and resilience should be prioritized throughout system design to prevent the kinds of disastrous outcomes that are unacceptable to consider (Rhue & Washington, 2020). Applications in MASS operations face the same fundamental human-system integration challenges as operations involving control intervention in safety-critical situations. There are notable differences, though; for instance, ships travel much slower than airplanes, lessening the

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urgency of takeovers and simplifying interface design. Ships are "under-actuated" because they have fewer inputs than degrees of freedom and may also have very high inertia. Therefore, navigational choices must be made in advance of the vessel's actual response. Human-AI interaction is a possible source of mistakes, especially for the time- and safety-critical actions, and must be controlled within acceptable risk levels for MASS operations.

CHAPTER-5 RECOMMENDATIONS AND CONCLUSIONS

5.1. Recommendations

In the following section, we are going to talk about some of these recommendations and directions, which are as follows:

- The formulation of regulations and standards for safety is an important area of research that should be pursued in the realm of autonomous boats. Because autonomous vessels operate with just a limited amount of human assistance, it is of the utmost importance to guarantee that the safety standards for these vessels are at least equal to those that apply to manned vessels, if not higher. In addition, it is essential to draught regulations that will govern the operation of autonomous vessels. These regulations should include the procedure for obtaining certification, training requirements, and remote monitoring and control recommendations.
- The possibility of cyberattacks becomes a big worry as the number of autonomous vessels operating in the world's waters increases. Hackers can infiltrate the vessels' systems, which might lead to their failure to work properly or pose a risk to navigation. The primary focus of research ought to be on developing cybersecurity measures to protect autonomous vessels against the possibility of cyberattacks. This includes the identification of vulnerabilities, the development of secure communication protocols, and the creation of systems for monitoring cyber threats and responding to them.
- Although autonomous vessels require just a limited amount of human participation, human operators are still required to monitor and manage the vessels. As a result, the primary focus of research should be on developing systems and interfaces that make it possible for human operators to communicate with autonomous vessels efficiently. This includes designing efficient communication systems, user interfaces, and decision-support technologies to allow operators to make educated decisions in real time.
- Technologies Autonomous vessels rely on the integration of a variety of advanced technologies, including AI, IoT, and cloud computing. As a result, the primary objective of research ought to be the development of methods and instruments for successfully integrating various technologies. This comprises the development of interoperable software and hardware systems, the optimization of communication networks, and resolving issues connected to data confidentiality and safety.

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- Both the creation of autonomous vessels and their use in navigation could potentially have a large adverse effect on the environment. For instance, the utilization of lightweight materials and innovative structural designs might result in a rise in the number of emissions as well as environmental contamination. Therefore, the primary focus of research should be on developing environmentally responsible design methods for autonomous vessels. This involves the creation of materials and manufacturing processes that have a lower impact on the environment, as well as the creation of propulsion systems that employ sources of renewable energy.
- Just as with any other brand-new piece of technology, it is essential to put autonomous boats through comprehensive testing and validation before using them in the real world. The primary goal of research needs to be the development of testing and validation procedures that are tailored to autonomous vessels. This includes developing simulation tools that allow testing in a controlled environment and creating field testing protocols that guarantee safe and effective testing in real-world settings.
- The adoption of autonomous vessels will have important economic and business implications for the marine industry. These outcomes are expected to occur in the near future. Research should concentrate on examining the potential impact that autonomous vessels could have on the sector. This should include the possibility that jobs could be lost and an assessment of the costs and benefits of adopting autonomous vessels. In addition, research must concentrate on finding new business models and opportunities made possible by the introduction of autonomous vessels.
- The use of autonomous vessels brings up a number of ethical and legal issues that need to be resolved before their widespread implementation. For instance, who is responsible for paying damages in the event of an accident involving a vessel that operates on its own? In addition to this, there is a pressing need to address concerns over data ownership and privacy. The primary focus of research should be the establishment of ethical and regulatory frameworks that address these challenges and ensure the development and deployment of autonomous vessels in a responsible manner.
- Therefore, it is widely accepted that the introduction of autonomous vessels into the marine industry would result in profound changes. As a result, collaborative efforts between academics, engineers, and other interested parties to overcome the obstacles and restrictions of autonomous vessels are essential. The above-mentioned research directions and recommendations are a good place to start when trying to solve these problems and guarantee autonomous vessels' effective and secure functioning.
- Developing countries face several challenges when it comes to adopting new technologies, such as autonomous shipping. One of the significant issues is the lack of infrastructure, including port facilities and navigational aids. This means that implementing autonomous shipping technology

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will require significant investment in infrastructure to support the operations of autonomous vessels.

- Another issue is the lack of a legal framework to govern the operation of autonomous vessels, which must be addressed by the concerned Maritime Administrations.
- A skilled workforce is another issue that needs to be addressed. There may be a shortage of personnel with the necessary technical and operational expertise to operate and maintain autonomous shipping systems.
- With the right investments, policies, and partnerships, these problems can be solved, paving the way for a brighter future for autonomous shipping.

5.2. Conclusion

Autonomous vessels have the potential to revolutionize the maritime transportation industry by enhancing safety, improving efficiency, and reducing operational costs. The development of AI has made autonomous driving a solution that is within reach. However, implementing several other cutting-edge technologies, including block-chain, the Internet of Things, cloud computing, fog computing, edge computing, and artificial intelligence, is necessary to bring autonomous systems into the real world. However, it is essential to keep in mind that artificial intelligence is subject to several severe constraints, and to guarantee the safe functioning of autonomous vessels, safety standards will need to be set. This study has extensively reviewed artificial intelligence in autonomous vehicles and driving systems. The results of this research have highlighted the necessity of using intelligent tools in the design and development process. In addition, operational testing is essential to ensure that autonomous vessels can effectively work in their intended capacities. Through this work, the many testing methods utilized by businesses and researchers have been dissected, and the shortcomings of present testing methods have been brought to light.

It is essential that those involved in the maritime transportation business, including researchers, engineers, and stakeholders, collaborate to overcome the issues and constraints associated with autonomous vessels as the maritime transportation industry continues to undergo change. It is necessary for all parties involved to collaborate in order to ensure that the operation of autonomous vessels is both safe and effective. The deployment of autonomous vessels will necessitate considerable regulatory reforms. In general, autonomous vessels represent a new phase in marine transportation, and the industry as a whole need to be prepared to adjust to this new period of rapid technological advancement. The adoption of autonomous vessels in the maritime industry is continuing, and there are a number of significant research directions and recommendations that should be taken into consideration as a part of this process. This will ensure that the operation of these vessels is carried out in a safe and effective manner.

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