International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 3, May-Jun 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Autonomous Ships

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ABSTRACT

Autonomous ships (AS), also known as autonomous cargo ships or maritime autonomous surface ships (MASS), are vessels that can navigate, operate, and make decisions with minimal or no human intervention, relying instead on advanced technologies like AI and robotics. Autonomous shipping vessels stand to revolutionize the maritime sector, offering groundbreaking advantages in efficiency and sustainability. They promise a wide range of benefits, including improved safety, optimized logistics chains, improved cargo capacity due to reductions in crew, increased fuel efficiency, reduced emissions, and reduced operational and maintenance costs. In this paper, we will delve into the realm of autonomous ships.

KEYWORDS: *autonomous shipping, autonomous ships, autonomous boats, maritime industry, maritime autonomous surface ships (MASS)*

How to cite this paper: Matthew N. O. Sadiku | Paul A. Adekunte | Janet O. Sadiku "Autonomous Ships" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-3, June 2025, pp.1347-1357, URL: www.ijtsrd.com/papers/ijtsrd97172.pdf

IJTSRD97172

INTRODUCTION

The maritime industry has been around for centuries, and it is a vital part of the global economy; cargo vessels transport goods all over the world, creating millions of jobs. The industry has seen a lot of changes and advancements over the years. The latest development in autonomous shipping technology is set to change the face of shipping forever. Autonomous technologies are reshaping the maritime industry, streamlining operations and enhancing safety and efficiency. Autonomous shipping – ranging from remote control operation to fully unmanned vessels – represents a significant evolution in the maritime industry. Autonomous ships use various technologies to control speed and direction, avoid collisions, and navigate. They represent a significant evolution in the maritime industry, moving from traditional manual operations towards increased automation and, potentially, full autonomy. The main objective of the development of autonomous ships is to make shipping safer, more efficient, and cost-effective than before, while reducing the need for human crew members on board.

The feverish race to produce the shiniest, safest, speediest self-driving car has spilled over into our wheelchairs, scooters, and even golf carts. Recently, there has been movement from land to sea, as marine autonomy stands to change the canals of our cities, with the potential to deliver goods and services.

WHAT IS AN AUTONOMOUS SHIP?

The term "autonomous ship" (AS) in maritime industry can be defined by three main aspects – location of control, degree of system independence, and human involvement. Autonomous ships can range from those with automated processes and decision support systems, to those that are remotely controlled, and finally, to those that are fully autonomous and operate without any human intervention. They utilize technologies such as AI, sensors, GPS, and sophisticated navigation systems to perceive their environment, plan routes, avoid collisions, and execute tasks.

There are three key factors that autonomous ships are focused on [1]:

1. *Collision Avoidance Systems:* These systems can detect objects and other ships, measure the

distance from them, and alerts the crew with risk assessment of a possible collision using AI, making autonomous ships safer for everyone.

2. *Control Algorithms*: These algorithms are very important as ultimately, they are the "brain" of the ship. Control algorithms receive data, and then interpret that data following maritime rules and regulations.
3. *Sensors*: Sensors are already used in ships, often in the form of a radar. However, autonomous ships will take it one step further. For these ships, input from multiple sensors is highly preferred. Autonomous ships make use of radars, thermal imaging, HD cameras, and climate indicators, all at once.

Autonomous shipping can be separated into four broad categories [2]:

- *Remote Control*: The activities of the onboard operation are transferred to a location other than the vessel. The operator is responsible for the vessel's function and does not rely on the use of an autonomous system for decision making or decision support.
- *Decision Support:* When conventional vessels are equipped with a decision support system, it functions as an advisory system, like a co-pilot. The system acquires real-time data, analyzes information, plans actions, and advises the operator on potential courses of action. Among the different aspects of autonomous shipping, decision support systems are most prevalent on the market today.
- *Supervised Autonomy*: Similar to a decision support system, but with the distinction that the system is capable of autonomous action without waiting for acknowledgment. Key autonomous functions include safety measures like auto-lookout and collision avoidance, as well as operational optimizations like remote navigation and monitoring.
- *Full Autonomy:* This has the same goal as the supervised autonomy system with even more benefits. However, in this case, the vessel acts independently, and the human operator is only involved in exceptional circumstances. In the longer run, autonomy is expected to develop more towards unmanned, fully autonomous vessels as technologies, regulations, and norms evolve.

The degrees of autonomy have been identified by the Maritime Safety Committee at the International Maritime Organization (IMO) as [3,4]:

- *Degree one*: Ship with automated processes and decision support. Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
- *Degree two*: Remotely controlled ship with seafarers on board. The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
- *Degree three*: Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
- *Degree four:* Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself. Fully autonomous operations would allow the ship to sail without any human interference, gathering information and data from its surroundings and enacting a decision based on it.

Autonomous ships achieve autonomy by the use of technologies similarly found in autonomous cars and autopilots. They rely on a suite of sensors, cameras, GPS, navigation systems, artificial intelligence, machine learning, and the Internet of things, to perceive their environment and execute tasks with precision. These technologies enable them to make decisions and operate safely and efficiently. Cameras provide visual data, allowing ships to recognize other vessels, navigational aids, and potential hazards. Think of sensors as the eyes and ears of autonomous ships. The data from sensors are processed by several systems, such as the autonomous navigation system, optical surveillance and analysis system, coordinated motion control system, engine controls, technical monitoring systems, and human interfaces. Some autonomous ships are displayed in Figure 1 [5]. The timeline for autonomous ships is shown in Figure 2 [6].

Different nations are experimenting on autonomous ships. While Norway is pioneering the technological development of autonomous ships (AS), other countries such as China, Finland, and USA have also made significant progress. Norwegian Forum for Autonomous Ships Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) is the first project dedicated to the development of autonomous ship technology. The electric powered autonomous ship, YARA Birkeland, is the world's first fully electric autonomous container ship, with zero emissions. The Yara Birkeland is expected to start trading remotely in 2020 and fully autonomously by 2022. Figure 3 shows Yara Birkeland - the world's

first autonomous cargo ship, with zero carbon footprint [7]. Figure 4 shows Hyundai's autonomous ship, the first to make a transoceanic journey [8].

Regulations will be changed to accommodate autonomous vessels. A key aspect of this will be how ports will need to adapt to welcome autonomous ships. Ports need to consider the implications of autonomous ships on their operations. As shipowners look towards automating their operations, so too are ports. The Port of Rotterdam, Netherlands is the largest port in Europe; its aims is to be prepared for autonomous ships by 2030. The port is shown in Figure 5 [9]. Countries such as China, the Netherlands, the US, as well as Scandinavian nations are operating MASS and will be undergoing similar legal and regulatory considerations.

APPLICATIONS OF AUTONOMOUS SHIPPING

Autonomous ships come in various sizes, from small boats to large container ships, and serve different purposes like transporting goods, watching over maritime areas, conducting research, and more. Current commercial uses are fairly narrow and involve a human that is either in direct control of the ship, or can take control, if needed. Examples of autonomous ship applications include the following [4,10-12]:

- *Autonomous Cargo Ships*: These are also known as autonomous container ships or maritime autonomous surface ships (MASS). They are crewless vessels that transport either containers or bulk cargo over navigable waters with little or no human interaction. MASS could be controlled remotely from a nearby ship, an onshore control center, or even through artificial intelligence and machine learning. A fully autonomous ship would be capable of making navigation decisions on its own, charting the most efficient and effective course without human intervention. MASS technology continues to advance at a rapid pace around the globe. Various nations have reported trials conducted on MASS. For example, in 2021, Russian companies conducted trials of autonomous navigation systems during 28 commercial voyages. Due to promising results achieved, the maritime authorities of Russia have allowed any shipping company to equip its ships flying the flag of Russia with autonomous navigation systems and operate them in their regular activities as part of the national experiment, subject to some conditions.
- *Autonomous Boats:* An autonomous boat or robotic boat (roboat) navigates autonomously using algorithms similar to those used by self-driving cars, but now adapted for water. Roboats can deliver people and goods, and connect with other Roboats to form a range of autonomous platforms to enable water activities. Self-driving boats have been able to transport small items as well as adding human passengers. Figure 6 shows a typical autonomous boat [12].
- *Coast Guard:* As autonomous ship technologies develop, countries are pursuing various approaches to regulating them. The Coast Guard is the federal agency responsible for the safety of US waterways to ensure that they are safe and secure. It regulates the design, construction, and operation of autonomous ships through existing laws and regulations, which are sufficient for it to execute its safety mission. International Maritime Organization (IMO) is a specialized agency of the United Nations responsible for the safety, security, and environmental performance of international shipping. It is developing a regulatory framework for commercial autonomous ships that addresses issues such as safety, training, and legal liabilities. The Coast Guard is the lead agency for the US delegation to the IMO and is helping to develop this framework.
- *US Navy:* The US Navy recently submitted a Fleet Force Structure plan that includes a requirement for 148 uncrewed vessels, including 78 autonomous surface ships. Survival at sea for a Navy ship consists of 1% combat and 99% overcoming the challenges and hazards presented by the ocean itself, every day, all day, all night. The ocean is a harsh, dangerous, and unforgiving environment that brutally punishes the unprepared ship and sailor. Autonomous vessels complete missions while the Navy uses its team of highly skilled sailors to work on more critical missions. A destroyer built to Navy standards can cost billions of dollars and take five or more years to build, while dozens of autonomous vessels can be built for a fraction of that price in a fraction of that time. For example, "Sea Ranger" is designed to expand and accelerate the US Navy's experimentation of larger and highly autonomous vehicles.
- *Cargo Transportation:* The world is interconnected through global trade on the basis of the transportation industry. Maritime transportation, in spite of being the backbone of the global economy, is overlooked by most since it is usually invisible to the end consumer. Autonomous container ships and bulk carriers can transport goods across navigable waters.

- *Coastal Surveillance*: Autonomous vessels can be used for monitoring maritime areas, conducting research, and other specialized tasks. Imagine ships that watch over the sea like vigilant guardians. Autonomous ships use smart sensors to keep an eye out for danger, avoiding accidents that can happen due to human mistakes. These smart ships swiftly spot obstacles and change their course, making voyages safer for them and other ships.
- *Environmental Monitoring:* AI and sensors can provide real-time monitoring of vessel operations, identifying potential mechanical issues or hazards faster than human crew members. AS possess a huge potential to enhance safety and efficiency, lower down operational costs, and reduce the impact of shipping operations on the environment. They can be deployed for tasks like collecting data on ocean conditions and pollution levels.
- *Specialized Missions:* Beyond the commercial, autonomous vessels are of great interest for military purposes. Autonomous vessels are also being developed for specific tasks like underwater exploration and resource management.

BENEFITS

The benefits of autonomous ships include improved efficiency of ships, data-driven operations, and increased capabilities such as remote and autonomous operations.

Autonomous ships also offer potential benefits like improved safety (due to reduced human error), increased efficiency (through optimized routes and speeds), cost savings (reduced labor costs), enhanced operational flexibility, and workforce diversity. Other benefits include [4,13,14]:

- *Automation:* The cost of labor is high, and maritime injuries are common. Automation provides employers with the ability to bypass serious safety problems, not through safer policies, but by eliminating the human element. Businesses should invest in automation underpinned by transformational technologies of artificial intelligence and machine learning, as the ultimate solution to improve productivity, efficiency, and safety by eliminating human errors. Autonomous shipping is the future of the maritime industry.
- *Safety:* In the world of technology, safety is first. The interaction between humans and machines is crucial. Between 75% and 96% of maritime-related accidents are caused by human error, due to employee fatigue, personal judgement errors, negligence and/or inadequate training. Autonomous ships will change the risk picture because they are less susceptible to human error. The introduction of fully autonomous and semi-autonomous ships will reduce the number and severity of these accidents. Autonomous ships are equipped with advanced technologies which can help optimize vessel operations, enhance safety, and reduce the possibility of human error.
- *Cost Reduction:* Lowering the cost of labor is the primary profit source for autonomous vessels. An onboard crew member costs in the form of salaries, insurances, and on-board provisions. Autonomous cargo vessels would not require any crew, which would save companies millions per year. Semi-autonomous or fully autonomous ships can potentially reduce and eliminate the costs, creating an incentive for shipping companies who strive for cost reduction in an increasingly competitive market. More savings would come from vessels no longer requiring shift changes or pauses in navigation.
- *Energy Efficiency:* The removal of human crews would allow the construction of ships without ship facilities needed for human operation such as the bridge or for human livability such as sleeping quarters, plumbing, mess hall, and electrical wiring, reducing weight and increasing reliability. This would allow autonomous ships to be built lighter and use less of its size for the crew, reducing fuel consumption and environmental impact
- *Remote Operations:* Autonomous ships can be controlled from shore-based control centers by using real-time data and communications systems. They can monitor and control the ship's movements, navigation, and other operational functions. This allows ships to be operated with greater efficiency, reduced costs, and enhanced safety.
- *Environmental Impact:* Autonomous ships are like eco-friendly explorers. By using fuel more wisely and taking shorter routes, they produce fewer pollution-causing gasses. This is good news for the environment and helps the maritime world follow cleaner practices. While autonomous ships offer potential environmental benefits, such as optimized routes and reduced fuel consumption, there is a need to assess their complete environmental impact.
- *Fighting Pollution:* The rise of oceanic traffic has led to increased pollution levels, with commercial marine shipping industry being a major

contributor to global air pollution. To combat the rising pollution, Yara Birkeland and Kongsberg have teamed up to build the world's first autonomous and zero-emission container vessel.

- *Reliability:* One of the foremost concerns with autonomous ships is ensuring their reliability. While AS are designed to navigate independently, there is always a worry about how well they can respond to unexpected situations. The absence of human judgment onboard raises questions about whether the technology can reliably handle complex and dynamic maritime environments.
- *Piracy:* This is another reason companies have considerable reason to invest in autonomous vessels. Remote or fully autonomous navigation, combined with zero human crew members, immediately makes piracy obsolete. Pirates would have no way of seizing or taking control of a ship, as autonomous control would eliminate the need for a human-operated bridge. The lack of human crew members would make ransoms or hostages impossible, eliminating the most lucrative incentive for piracy.

Some of the benefits of autonomous shipping are displayed in Figure 7 [6].

CHALLENGES

While autonomous ships offer many benefits, there are also some challenges associated with this technology. Before autonomous and remotely operated ships can be effectively deployed, numerous challenges must be addressed, spanning from ensuring the reliability of onboard machinery, to guaranteeing the stability and cybersecurity of essential software, and finally, navigating the complex landscape of national and international rules and regulations. Most predictions are that autonomous or semi-autonomous operation will be limited to short voyages, for example from one specific port to another, across a short distance. Other challenges include [4,13,15,16]:

- *Cost*: Autonomous ships may increase onshore costs in the form of large upfront investments and upkeep of control and operations centers, sensors, data servers and communication assets such as high-bandwidth satellites. Critics highlight that in the short term, autonomous technology may increase costs due to the need for specialized infrastructure and expertise. They argue that efficiency gains might not be substantial enough to offset automation costs and that infrastructure upgrades may slow widespread adoption.
- *Safety:* Implementing robust safety measures and collision avoidance systems is vital. Uncrewed or fully autonomous technologies may pose new safety risks in the maritime environment. At the moment, there is insufficient training for human operations involved in degrees one, two, and three of maritime autonomous surface ships, creating an insecure operational environment.
- *Regulation:* A main challenge of autonomous shipping is regulatory. The deployment of autonomous ships faces significant regulatory challenges, including the lack of international standards, complex regulatory compliance, lengthy approval processes, and uncertainty around liability and insurance. International regulation is seen as one of the biggest challenges facing autonomous ships. Developing international standards and regulatory frameworks for autonomous ships is crucial. Without any human on-board autonomous vessels, it will be a difficult task to comply with these regulations. The maritime industry must work with governments and regulators to develop clear and consistent standards for the deployment of autonomous ships. International maritime organizations, governments, and industry stakeholders must engage in dialogs to establish a framework that addresses safety, liability, and operational standards for autonomous ships.
- *Lack of International Standards:* The International Maritime Organization (IMO) is still developing guidelines for MASS. Key issues include defining roles and responsibilities for remote operators and legal liability in accidents. Without clear global standards, different countries may impose conflicting regulations, complicating international voyages.
- *Collaboration*: The maritime industry operates internationally, and harmonizing regulations for autonomous ships across various jurisdictions is a complex task. Creating a consistent legal framework that covers issues like liability in case of accidents, collision avoidance protocols, and compliance with maritime rules is a challenge that requires collaboration among nations and organizations.
- *Technical Challenges*: Autonomous ships rely on sensors to provide real-time information about the ship's environment, such as its location, speed, and direction. These sensors must be able to operate accurately and efficiently in the marine environment, and the data they generate must be processed in real time to support the safe operation of the ship. Figure 8 shows some connectivity challenges of an autonomous ship [17].

- *Cybersecurity:* Cybersecurity is a major concern when it comes to autonomous ships. Ensuring the security of autonomous systems against cyber threats is essential. Cyber attacks have become an increased threat in maritime shipping, where hackers have managed to compromise systems. Cyber criminals can gain access to sensitive data stored on the ship, such as personal information or trade secrets, which may have serious consequences. Presently, cybersecurity training for crew is not required. Maritime companies should invest in cybersecurity training for their employees to help them understand the importance of protecting the ship from cyber attacks and how to identify potential threats.
- *Legal Framework:* Existing maritime laws may need to be adapted to address the unique aspects of autonomous shipping. While these technologies may allow for smaller crews, when in US waters, such ships must still comply with the statutes that established minimum crew size by vessel.
- *Liability:* It is unclear who would be liable in the event of an accident with an autonomous ship: several parties, such as the company, the software provider, hardware provider or the onshore monitoring stations might be at fault. Historically, captains are assumed to be in overall command of their ships and are the first to be put under scrutiny if anything happens. Without a clear leader in charge, international regulation must determine who is ultimately responsible for any incidents involving autonomous ships.
- *Complexity:* The intricate web of sensors, AI, and interconnected systems that power autonomous ships also introduces complexity in terms of maintenance and repair. Ensuring that these technologies continue to function properly in harsh maritime conditions and are readily serviced when needed is a logistical challenge. Insurers may charge more due to the untested nature of autonomous technology and the complexity of liability.
- *Ethical Concern:* The concept of autonomous ships raises ethical questions about potential job losses for crews and the loss of the human touch in maritime operations. Society's acceptance of these technological changes, especially in terms of safety, job impact, and the overall role of humans in maritime endeavors, needs to be addressed.
- *Job Losses:* A most pressing challenge is to gain public acceptance, especially concerns about technologies eating up jobs. The shift to autonomous ships could disrupt maritime employment, leading to resistance from crews and unions while creating new challenges for workforce management. Automation could eliminate roles traditionally held by seafarers, leading to widespread job displacement in the maritime sector. Use of automation technology does not necessarily mean reduction or elimination of the crew. While elimination or reduction of crew provides attractive cost savings, vessel owners indicate that there is also value in reduction of risk. Figure 9 shows the potential number of displaced jobs worldwide [6].
- *Trust:* Another challenge is earning trust - the trust of society, regulators, shipowners, and operators themselves. As with any new technology, trust will build slowly over time as reliability is proven over and over again. Automation technology will go from assisting crew operations and situational awareness to allowing fewer crew to do more, to permitting remote operations, to allowing fully autonomous operations. The maritime industry is traditionally risk-averse, particularly when it comes to safety. Building trust in autonomous technology will require extensive testing, incident-free operations, and robust fail-safe measures.

CONCLUSION

Technological innovation within the maritime industry is resulting in rapid developments that will see the commercial use of autonomous ships, whether they are controlled remotely or are fully autonomous. Autonomous ships are expected to play an increasingly important role in the future of maritime transportation, transforming the way goods are moved across the globe. These ships are developing domestically and abroad and have the potential to transform the maritime environment.

Like autonomous or self-driving cars, autonomous ships are a reality and will likely revolutionize many aspects of shipping and maritime security. Autonomous ships are revolutionizing the maritime industry by introducing new technologies, processes, and business models that have the potential to transform the way ships traditionally operate.

Right now, ships with autonomous capabilities represent a tiny fraction of the many vessels in operation today. But in the future, self-steering ships could make all sorts of water-based activities more convenient. The integration of autonomy in the maritime industry is a gradual process, and commercial operators are taking a phased approach toward adopting autonomous technology. This

approach allows the operators to assess the benefits and limitations of the technology, and make necessary adjustments. In the near future, autonomous ships are expected to be launched commercially, adding a new dimension in the merchant shipping industry. More information about autonomous shipping can be found in the books [18-22] and the following related journals:

- Journal of Marine Science and Engineering
- International Journal on Marine Navigation and Safety of Sea Transportation

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Figure 1 Some autonomous ships [5].

Figure 2 The timeline for autonomous ships [6].

Figure 3 Yara Birkeland, the world's first autonomous cargo ship [7].

Figure 4 Hyundai's autonomous ship, the first to make a transoceanic journey [8].

Figure 5 The Port of Rotterdam, Netherlands [9].

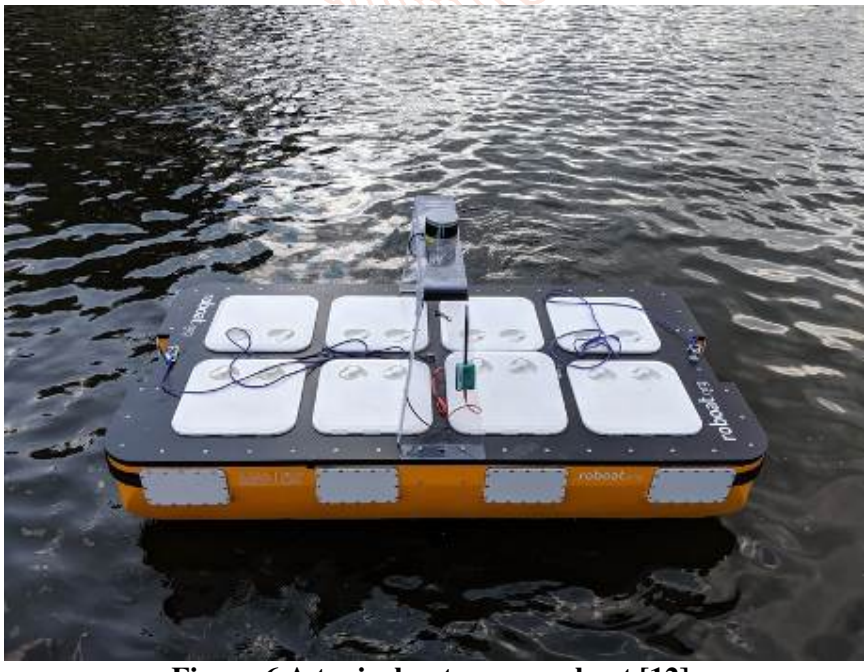

Figure 6 A typical autonomous boat [12].

Figure 7 Some of the benefits of autonomous shipping [6].

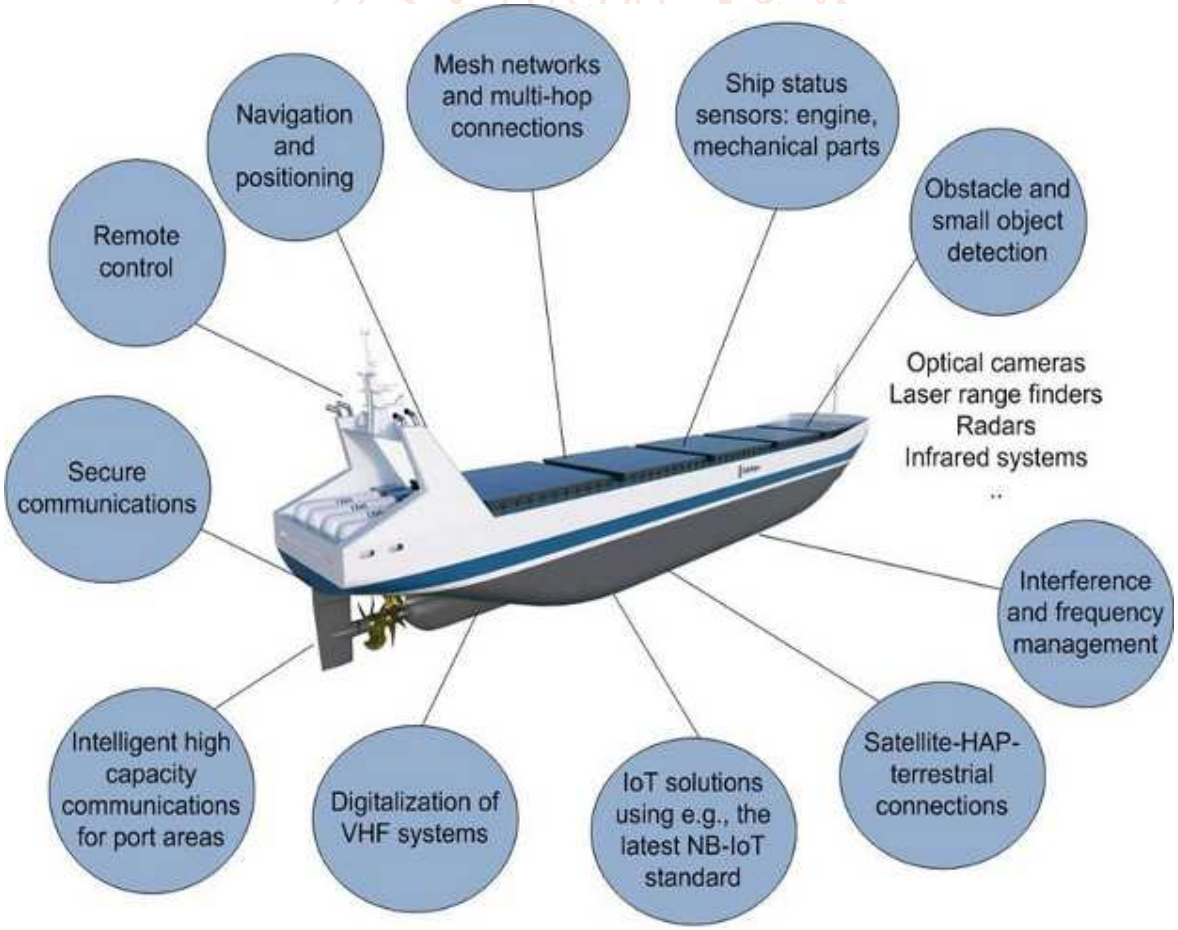

Figure 8 Connectivity challenges of an autonomous ship [17].

Figure 9 Potential number of displaced jobs worldwide [6].