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Advanced Regulations for Autonomous Vessels to Avoid Collisions

J. Elwin Raj[1], Mohammed Ismail Russtam Suhrab[1,*]

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ABSTRACT

More than a thousand autonomous vessels are presently operational worldwide. However, appropriate guidelines to standardize the operation of autonomous vessels are currently lacking in the marine sector. The current COLREG is still appropriate for the operation of autonomous vessels, and no regulation changes are needed. However, to define the standard operating procedure of an autonomous vessel and prevent collisions, COLREG requires extra parts. Autonomous vessels can also follow the existing COLREG regulations. Yet, they need certain extra elements because they rely heavily on technology and artificial intelligence to navigate while operating with fewer crew members. Thus, the goal of this study is to identify the topics that should be added as an additional part of COLREG for autonomous vessels and the most crucial topic to be proposed for Maritime Autonomous Surface Ships (MASS) to be included as a separate part of COLREG for autonomous vessels. To accomplish this goal, this study aims to determine the topics that maritime experts believe should be included in COLREG for autonomous vessels and use the Analytic Hierarchy Process (AHP) to identify the most suitable topic to be suggested for Maritime Autonomous Surface Ships (MASS). The findings of this study could be utilized by the International Maritime Organization (IMO) to operate autonomous vessels in the future. They could also serve as a wake-up call for other businesses considering investing in autonomous vessels.

1. Introduction.

1.1. Research Background.

A ship is any substantial floating craft that can travel over open waters, unlike a boat, which is often a smaller craft. Originally used to describe sailing vessels with three or more masts, the word is often used to describe vessels with a displacement of 500 tonnes or more. No matter how big they are, submersible ships are always referred to as boats.

American businessman Malcolm McLean invented the intermodal shipping container in 1956. It was the first container vessel generally created. Later on, the vessel was converted to an =ideal X' World War II tanker vessel. —Ideal X traveled from the port of Newark to the port of Houston. It carried 58 containers for transportation|| (Ben Thompson, 2018).

1.1.1. Technological development of vessels in past decades.

Over the past decades, the vessels have grown into dominant decision-makers in the economy. It influences the economic stability of countries by increasing the efficiency of vessels through technological development. The technological development of vessels focuses on increasing efficiency and reducing time, cost, and fuel consumption.

The development of vessels had occurred in these specific aspects as per below:

a. Marine infrastructure and logistics.
The adoption of technology has kept up with the innovation in industry machinery, regardless of the ship's power source, hull design, engine, or propulsion units. Fossil fuels are the most widely utilized energy source in ships today. However, there have been initiatives for sustainable expansion in shipping due to the growing environmental concerns regarding greenhouse gas emissions. Modern technology is being employed to support a low carbon footprint while substantial improvements are being made

[1]Department of Nautical Science, Faculty of Maritime Studies, Universiti Malaysia Terengganu, 20130, Kuala Nerus, Terengganu, Malaysia.
*Corresponding author: Mohammed Ismail Russtam Suhrab. E-mail Address: m.ismail@umt.edu.my.

to ship design in order to maintain the green construction requirements set out by the IMO. There are no ballast ships, LNG fuel for the propulsion unit and auxiliary engines, upgraded rudder and propeller systems, sulfur scrubber systems, waste heat recovery, exhaust gas circulation, better pump and water cooling system, and solar.

b. Navigational Equipment.
Ships have employed navigational aids for hundreds of years to navigate the oceans while avoiding hazards and other perils successfully. The first navigational aids were buoys, lighthouses, beacons, and nautical charts. These tools have grown in sophistication and become firmly entrenched in the maritime sector. Ship navigation has significantly improved as a result of the development of the Global Positioning System (GPS). Today's usage of satellite-based aids, automated identification systems (AIS), electronic chart displays and information systems (ECDIS), and other technologies makes navigating simpler and more effective than ever. The benefit of virtual navigation aids over real ones is that they are easier to install and require less maintenance.

c. Firefighting Equipment.
Fire is one of the dangerous and unexpected hazards that can cause damage to the vessel and lives onboard. Techniques for increased security. Foam extinguishers, dry powder and carbon dioxide extinguishers, and soda acid extinguishers are just a few portable fire extinguishers readily accessible today. Better fire suppression and prevention techniques have also been made possible by cutting-edge technology, including thermal imaging, infrared detection systems, unmanned aerial vehicles to monitor ships, and enhanced ventilation techniques.

d. Security System.
Numerous risks to the marine sector exist, including piracy, hijacking, armed robbery, smuggling, drug trafficking, illegal immigration, etc., all of which are detrimental to the populace and the nation. In order to combat this, the International Ships and Port Facility Security Code has focused efforts on enhancing security on ships, leading to the deployment of new goals; technology is crucial since modern security systems and software are highly effective at identifying and minimizing possible dangers to ships. X-ray, gamma, neutron scanners, and other tools maintain vessel security.

e. Rescuing Technology.
Despite high-security measures, ships can sometimes be lost, hijacked, or wrecked. In such cases, technology is invaluable in running a search and rescue operation to save the lives of the people onboard the ships. The Global Maritime Distress and Safety System (GMDSS) is used to convey the status of a ship in distress to port authorities. Search and Rescue Transponders and hand-held personnel location detectors can be used to detect the position of the sailor/ship with maximum accuracy. Ship-to-shore security alerts, satellite-based location detection, digital calling, etc., are some of the means used to sound distress alerts indicating that the ship is in trouble. Physical distress indicators like smoke signals and pyrotechnics are also a part of the search and rescue portfolio.

1.1.2. International Maritime Organization (IMO).

The International Maritime Organization (IMO), originally known as the Intergovernmental Maritime Consultative Organization (1948–1982), is a specialized body of the United Nations (UN) established to draught international agreements and other procedures for marine safety. The IMO resolutions have a critical role to play in the formulation of national ocean law and policy instruments of States in the Asia-Pacific region whereby recommendations on technical global maritime rules and standards'(Mary George, 2009)

1.1.3. Autonomous Vessel.

Autonomous vessels are crewless ships that are able to function and make decisions by themselves. The Defense Science Board Task Force on the Role of Autonomy in DoD [U.S. Department of Defense] Systems defines autonomy as —a capability (or a set of capabilities) that enables a particular action of a system to be automatic or, within programmed boundaries, self-governing|| (Savitz et al., 2020). Usually, these vessels will be operated with the aid of humans monitoring the autonomous vessel from offshore or another vessel. —Enabled by artificial intelligence (AI), systems with higher levels of autonomy can learn from their environment and make decisions in response to new inputs. They can essentially solve new problems in ways that are meaningful and, therefore, useful to humans. (Hellyer, 2016). The main reason for implementing autonomous vessels is to reduce the human force on vessels, which will reduce the cost. Other than that, the risk that the company bears in maintaining the safety of the crew will also be reduced. With the development of this technology, the first autonomous vessel was Yara Birkeland, which was developed in 2017. ||The Yara Birkeland, the world's first net-zero, battery-powered autonomous container ship, was delivered to Norwegian fertilizer company Yara Norge AS in November 2020.|| (Michelle Lewis, 2021).

1.2. Problem Statement.

Autonomous vessels are advanced vessels, but obstacles still hold the vessel back from fully operating in the seas. The primary factor causing this predicament is the conflicting operations of autonomous and conventional vessels. —Every ship has to comply with the International Regulations for Preventing Collisions at Sea (COLREG), which sets out, among other things, the =Rules of the Road 'or navigation rules to be followed by ships and other vessels at sea to prevent collisions between two or more vessels.|| (Borges,1918). This issue might be directed to one or more collision situations. ||Major challenges in the construction of the autonomous navigation system are related to the generation of a recommended maneuver and solving collision situations||(Pietrzykowski et al., 2022).

According to a statement from =The Maritime Executive, 'There are currently more than 1000 autonomous vessels around the world, ready to operate. However, the maritime field is still lagging behind in terms of proper guidelines to standardize the operation of autonomous vessels. One of the important guidelines is the enhancement of COLREG. The current COLREG is still suitable for autonomous vessel operation, and no amendments are required to the existing rules. However, COLREG requires additional parts to specify the standard of working procedure of autonomous vessels to avoid collision.

The six parts of COLREG each establish and explain the specific standard operating procedure for each criterion:

- Part A: General.
- Part B: Steering and Sailing Rules.
- Part C: Lights and Shapes.
- Part D: Sound and Light Signals.
- Part E: Exemption.
- Part F: Verification of Compliance With The Provisions Of The Convention.

All conventional vessels are obligated to follow and maintain the operation procedure that has been stated in these parts. Autonomous vessels are able to follow these rules as well, but they do require some additional parts as they function with fewer men onboard and conduct navigation by highly depending on artificial intelligence and machinery. Currently, there are also many autonomous vessels being developed with different AI technology and machinery, which might result in conflict with one another.

Considering IMO's consideration, several initiatives have been encouraged to make autonomous vessels practical. — Items under consideration include remote control station regulation, determination of remote operators as mariners, and regional-specific regulations|| (DOUGHERTY, 2021), which are among the procedures that IMO has discussed. Still, there is no proper regulation for the autonomous vessel or operator to make the implementation of an autonomous vessel possible.

1.3. Research Questions.

Based on these issues, a few questions have been raised in order to form this research. Basically, these are the questions that form this research in order to provide an answer and solution to the situation. These are the questions raised based on the issue:

i. What are the specifications that should be added to the additional parts of autonomous vessels COLREG?.
ii. How do we determine the key specifications to suggest to the Maritime Autonomous Surface Ships (MASS)?.

1.4. Research Objective.

In order to answer the research questions, there should be objectives that guide the research to achieve its goals.

a. To determine the topic that should be added as the additional part of COLREG for autonomous vessels.
b. To determine the most important topic that should be put forth for Maritime Autonomous Surface Ships (MASS).

1.5. Justification of the Research.

This research aims to offer further clarification and an in-depth explanation of what an autonomous vessel needs to do to prevent a collision at sea. Although COLREG is capable of handling both conventional and autonomous vessels, autonomous vessels still need extra specifications because they allow AI and machines to make decisions. To preserve the safety of ships and marine life, it is necessary to specify their norms and guidelines. However, autonomous vessels must adhere to all of the COLREG's current regulations without any changes. If the suggested specifications are approved by Malaysian Autonomous Surface Ships (MASS), they will only be added in the existing new parts. As a result, the specification will be the cutting- -edge law that will serve as the direction for autonomous vessels to avoid collision.

2. Literature Review.

Autonomous vessels have always been a debatable topic in many aspects. Implementation of autonomous vessels is highly possible in this era, but there are still rising issues that disagree with the legal terms for implementing this type of vessel on the sea. In order to understand this circumstance, the history of autonomous vessels needs to be understood.

2.1. History of Autonomous Vessel.

Autonomous vessels have a long journey that develops their function and efficiency over time. Many parties have contributed to the advance of the vessel's growth. The idea of autonomous vessels was born in 1970, and the growth has given us a significant possibility of implementing it very soon.

1. Ship and shipping of tomorrow.
   The concept that brought the autonomous vessel to the world was first introduced in 1970 by Rolf Schonknecht. In his book =Ships And Shipping Of Tomorrow 'he mentioned that =Captains will perform their duties from an onshore office building and the vessels will be navigated with the use of computers' (Rolf Schonknecht, 1970).
2. Ship Project.
   The goal of this project, which was carried out in Japan between 1983 and 1988, was to create highly dependable machinery and highly automated operating systems for the maritime industry. This project aimed to create highly autonomous operation systems that integrated the maritime and terrestrial sides and involved activities like high-seas shipping, port entry, berthing, anchoring, and

cargo handling. A shore-based system that is connected via satellites would provide assistance for this technology, which was designed to manage ships without any involvement from the personnel on board. A computer simulation of each system was performed in 1988. —The FOC is part of a comprehensive system that covers the functions required for operating autonomous ships|| (Riviera News, 2021).

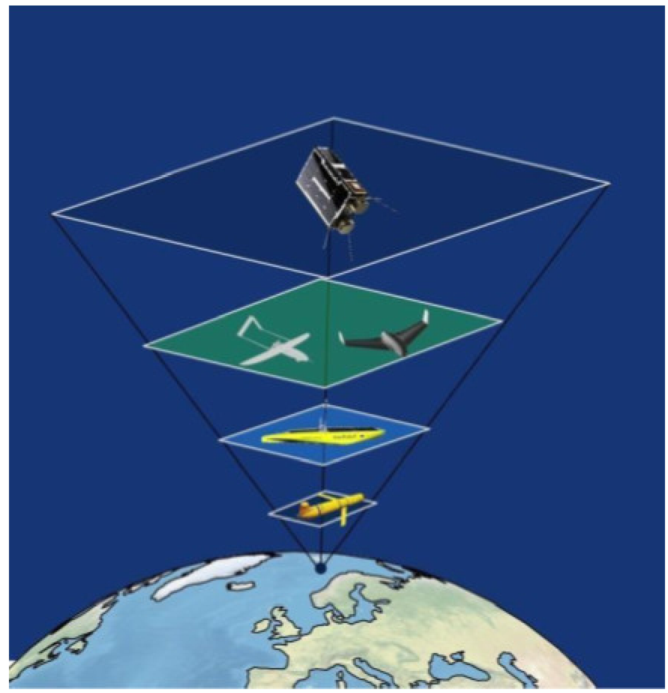
3. Korea-Autonomous Unmanned Surface Vessels (USV) For Maritime Survey And Surveillance.
   This initiative, supported by the Ministry of Oceans and Fisheries, began in 2011 and is being headed by the Korea Research Institute of Ship & Ocean Engineering (KRISO). In order to address national issues, this project focuses on developing autonomous unmanned surface vessels (USV) for maritime survey and surveillance. It also develops and conducts research in the fields of ”environmentally friendly future shipping technology, ships, and ocean engineering, maritime accident response and marine traffic system technology, and underwater robot and maritime equipment technology, (KRISO, 2014).

Figure 1: Korea Research Institute Of Ships & Ocean Engineering.

Source: Pacific Northwest National Laboratory (2014).

4. Project-Maritime Unmanned Navigation through Intelligence In Navigation In Networks (MUNIN).
   The European Commission financed the development of Maritime Unmanned Navigation via Intelligence in Networks (MUNIN) through its Seventh Framework Programme (FP7), which was introduced in 2012. Examining the technical, financial, and legal viability of unmanned ships was the goal of this study. —MUNIN's goal was to create and test a concept for an autonomous ship, which is described as a ship that is mostly steered by automated onboard decision systems but is under the remote supervision of a shore-side control station|| (MUNIN, 2014)
5. Revolt (DNV-GL).
   ReVolt, a novel idea for an autonomous ship, was launched by DNV-GL in 2013. Launched in 2014 was the project itself. ReVolt is a design for unmanned, battery-powered, zero-emission ships for short trips. The vessel has a 100 TEU capacity box ship and a dwt of roughly 1,800. The autonomous ship design idea behind DNV GL is called ReVolt. Students at NTNU in Trondheim are currently testing autonomy and remote control functions using a scale model built on the basis of this idea. —Today's technology is promising for more efficient, environmentally friendly, and safer ships in the future|| (Tvete, 2015).
6. Autonomous Unmanned Vehicle System.
   In order to develop a leading global center for autonomous marine operations and control systems, the Norwegian Organization AMOS (Centre for Autonomous Marine Operations and Systems) was founded in 2013. —This concept can be developed and streamlined, especially when it comes to faster data interpretation. We have worked with biologists to customize this approach according to what they need, but it can be used for other purposes as well,|| (Asgeir, 2023).

Figure 2: Autonomous Unmanned Vehicle System.



Source: Project 5. Autonomous UAV - AMOS(2023).

7. Advanced Autonomous Waterborne Application Initiative (AAWA).
   Rolls-Royce introduced the Advanced Autonomous Waterborne Applications Initiative (AAWA) in that year. The goal of the AAWA project was to examine problems in several scientific disciplines that are connected to autonomous marine operations. It created systems for navigation, equipment, and other onboard operating systems that could operate autonomously and remotely. DNV GL, NAPA, Deltamarin, and Inmarsat are the project's further industrial partners. University of Turku, Aalto University, Tampere University of Technology, Bo Akademi University, and the Finnish VTT Technical Research Centre are a few institutions with research divisions. —This is happening. It's not if, it's when. The technologies needed to make remote and autonomous ships a reality exist. The AAWA project is testing sensor arrays in a range of operating and climatic conditions in Finland and has created a simulated autonomous ship control system that allows the behavior of the complete communication system to be explored. We will see a remote-controlled ship in commercial use by the end of the decade.|| (Oskar, 2020).

8. MOL launches R&D Autonomous Ocean Transport System.

   The Japanese government has been supporting this initiative since it began in 2017. MOL and other partners make up the project's research consortium. Drawing on the strengths of each participating company and Organization, the consortium members will develop the technological concept for autonomous vessels, charting a course for the development of the technology required to realize autonomous vessels that can offer dependable, safe, and effective ocean transportation. As part of the research grant, the companies are to foster a movement to develop the required infrastructure and win public support for the implementation of these advanced technologies by sharing the results with society and the maritime industry as the research progresses,|| (MOL, 2017).

9. Rolls Royce Demonstrates World's First Remotely Operated Commercial Vessel.

   One of Svitzer's tugs, the 28-meter-long Svitzer Hermod, successfully completed a series of remote-control operations earlier this year. The ship's Captain moored it alongside the quay in Copenhagen Harbour, undocked it, rotated 360 degrees, and steered it to the Svitzer HQ before docking again. Kristian Brauner, Chief Technology Officer, Svitzer, said; —Disruption through innovation is happening in almost every industry and sector, and technology will also be transforming the maritime industry. As the largest global towage company, Svitzer is actively engaging in projects that allow us to explore innovative ways to improve the safety and efficiency of towage operations to benefit our customers and our crews. With its direct impact on our customer performance, operational cost, and environmental footprint, vessel efficiency remains a main driver now and going forward. We are proud to be partnering with Rolls-Royce in this high-level research and development of remote operation systems. The skipper was stationed at the ship's remote base at Svitzer headquarters|| (Svitzer, 2017).

10. Hull to Hull (H2H) Project.

    The Hull to Hull (H2H) project was started by Kongsberg Seatex in 2017 with funds provided by the European GNSS Agency as part of the European Union's Horizon 2020 research and innovation programme. The H2H project will address the need to navigate safely near other stationary or moving vessels and objects with the aid of the European Global Navigation Satellite System (GNSS), EGNOS, and Galileo, assisting mariners in making informed navigation decisions and laying the groundwork for autonomous vessels. —We will implement the pilot system that will form the basis for all three demonstrations. This includes integrating sensors, building 3D models, and implementing relative GNSS and communications protocols,|| (Erik, 2018).

Figure 3: Hull to Hull Project.

Source: The Foundation for Industrial and Technical Research (2018).

11. Worlds First Autonomous Shipping Company-Massterly Is Born.
    By delivering a whole value chain for autonomous ships, from design and development to control systems, logistical services, and vessel operations - by forming the firm Massterly Wilhelmsen and KONGSBERG are collaborating to advance autonomous shipping in 2018. As a world-leading maritime nation, Norway has taken a position at the forefront of developing autonomous ships. Through the creation of the new company named Massterly, we take the next step on this journey by establishing infrastructure and services to design and operate vessels, as well as advanced logistics solutions associated with maritime autonomous operations. Masterly will reduce costs at all levels and apply to all companies with a transport need || (Wilhelmsen, 2018).

Figure 4: Mastery.

Source: Wilhelmsen (2018).

2.2. *Legal Acknowledgements for Autonomous Vessel.*

The development of autonomous vessels has encouraged many parties to provide proper guidance for their legal movement and operation on the sea. This proper guidance aids the autonomous vessels in functioning efficiently at sea.

I. DNV GL's Autonomous and Remotely Controlled Ship Guideline.

The guideline addresses novel operational ideas that don't comply with current laws and technologies that manage tasks that people would typically handle. When it comes to novel operational concepts, the guideline provides those who want to implement them with a method for getting flag state approval under alternative design specifications. Suppliers can use the directive to get preliminary approval for new technology.

The rule encompasses communications, remote control centers, vessel engineering, and navigation. Cyber security and software testing are two crucial topics that arise from autonomous and remote ideas' reliance on software and communications systems.

Cybersecurity considerations are part of the risk analysis in both the idea-qualifying phase and the technology qualification process. Cyber security should be considered not just for the systems themselves but also for the accompanying network and infrastructure elements, servers, operator stations, and other endpoints, encompassing several levels of protection when practical. Software quality assurance is crucial for software-based systems, and to assure secure operation, a multidimensional end-product testing approach should be used together with a well-established development process. —This is the first step in the process of fully realizing these technologies. However, we continue to develop experience from several projects currently underway. In some areas, such as navigation systems and engineering functions, we can already offer technical guidance based on our current class rules, and as we progress, new guides and rules will follow (Ørbeck-Nilssen, 2018).

II. Lloyd's Register: Cyber-Enabled Ships: Shipright Procedure Guidance - Autonomous Ships.

"Deploying information and communications technology in shipping - Lloyd's Register's approach to assurance" is LR's guidance on cyber-enabled ships, which was released in February 2016. Following these instructions, LR created and released Cyber-enabled ships. In July 2016, autonomous ships will use the ShipRight protocol. Revision of the LR Cyber-enabled Ships Update The ShipRight process went live in December 2017. The update includes knowledge gained from participation in various initiatives involving cyber-enabled ships, as well as recommendations for autonomous and remote operation. We are delivering consultancy and assurance services for the assignment of Autonomous Level (AL) Descriptive notes supported by the Lloyd's Register Cyber-Enabled Ships Autonomous Ships ShipRight procedure and Guidelines.|| (Sundberg J, 2018).

III. IMO, Maritime Autonomous Surface Ships (MASS).

The International Maritime Organization (IMO), which oversees international shipping, has started investigating how IMO instruments may address Maritime Autonomous Surface Ships (MASS) operations in a safe, secure, and ecologically responsible way.

The Maritime Safety Committee (MSC), the top technical body of the Organization, approved a framework for a regulatory scoping exercise as a work in progress, including draught definitions of MASS and levels of autonomy, as well as a methodology for carrying out the exercise and a plan of work. A "Maritime Autonomous Surface Ship (MASS)" is a ship that can operate in part without human intervention for the purposes of the regulatory scoping exercise. The degrees of autonomy are organized to aid in the development of the regulatory scoping exercise.

- Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated.
- Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location, but seafarers are on board.
- Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
- Fully autonomous ship: The ship's operating system can make decisions and determine actions by itself.

2.3. Complications of autonomous vessels in implementing COLREG.

There is little research proving that COLREG is not suitable for autonomous vessels, as it was invented for human operation. COLREG was written in 1972 to avoid collision between vessels. Although it suits the operation of a conventional vessel operated by humans, it does not suit the vessel that developed according to technological advancement. —Although technological advancement has been significant since their publication in 1972, COLREG-compliance for autonomous vessels is still understudied. One of the main challenges is that the COLREGs were written for humans to interpret and require a translation to a machine-readable and verifiable format. Another potential challenge is the indirect communication that occurs when two vessels meet in a situation with a high risk of collision. For instance, the COLREGs require sharp maneuvers to communicate clearly between vessels when a high-risk situation occurs. However, this is often not the optimal behavior from an energy efficiency (or even collision risk) point of view. So long as there may be both human and autonomous operators of marine vessels at sea, the autonomous controller should behave in a way that a human-operated vessel can interpret its intent|| (Heiberg et al., 2022).

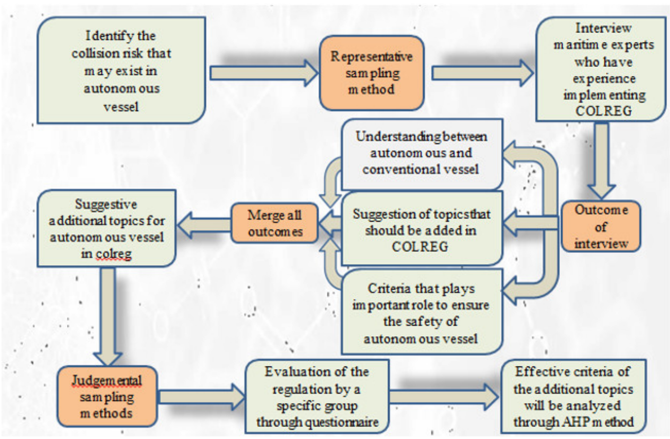
3. Methodology.

Based on the above situation, we may understand that one of the main reasons for the restriction of Autonomous vessels is the limitation of COLREG. Therefore, this research will draw an advanced regulation for autonomous vessels to comply with COLREG. The formation and efficiency of this regulation require specific procedures to increase the possibility of implementing it.

3.1. Flowchart.

Through the flowchart, we can understand the steps that are taken to justify the research, which is forming a regulation.

Figure 5: Framework of research.



Source: Authors.

3.2. Data collection strategy.

This research requires two-stage data collection as we encounter two-level verification. At the first level, we gather suggestions and ideas from experts who have experience implementing COLREG. In the second level, the suggestions will be compiled together and given to experts with a questionnaire to evaluate the suggested regulation.

3.2.1. Interview.

In the first level, an interview will be conducted with specifically selected persons using a representative sampling method. Selected persons for the Interview are experienced in the maritime field and familiar with COLREG. The Interview will be conducted based on these questions, which will generate answers that can be suggested in the regulation.

- What is your experience in maritime?
- Do you think that autonomous vessels are fully capable of adapting COLREG?
- What kind of risk of collision that autonomous vessels are upholding?
- What are the topics that you suggest should be added to COLREG?

3.2.2. Questionnaire.

This strategy will be used to identify the possibility of implementing suggestive advance regulation in the maritime field. Therefore, the questionnaire will be given to a specific group with practical maritime knowledge and experience in implementing COLREG. The questionnaire contains criteria derived by the interviewees who suggested the topics to form the regulation. The derived criteria from them should be used to form the questionnaire. The judgmental sampling method will be used to select our responding group.

3.3. Sampling Strategy.

The representative sampling strategy is selecting our sample specifically according to our required criteria. In that case, the accuracy of data can be maintained in good quality. In this research, a representative sampling strategy will be used to select respondents who have practical experience in the maritime field and are familiar with COLREG.

3.3.1. Representative sampling method.

The representative sampling strategy is selecting our sample specifically according to our required criteria. In that case, the accuracy of data can be maintained in good quality. In this research, a representative sampling strategy will be used to select respondents who have practical experience in the maritime field and are familiar with COLREG.

3.3.2. Judgmental sampling strategy.

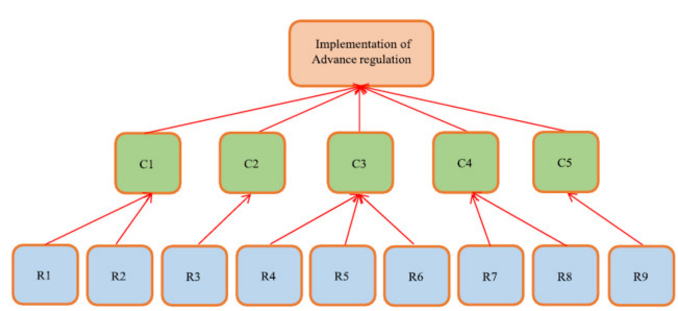
Judgmental sampling includes gathering a selection of items for testing based on examiners' professional judgment, expertise, and knowledge to target known or probable areas of risk. According to this research, we will be targeting individuals who have practically implemented COLREG at sea. This is to ensure that individuals responding to the questionnaire are aware of the importance of COLREG and able to understand the difficulties the autonomous vessel faces.

3.4. The Analytic Hierarchy Process (AHP).

The AHP method offers a supporting process for weighing criteria, making the pairwise comparison straightforward for setting priorities. It asks each participant which criterion is more important and by how much. Then, everyone can review the comparisons and agree on the values. This research will review and compare criteria derived from the suggestive regulation. After completing the data collection process, each criterion will be analyzed through the AHP method to identify the highest to least criteria supporting this suggestive regulation's implementation. AHP involves a structure of steps to achieve its result.

Step 1: Develop a hierarchical structure with a goal at the top level. The criteria are at the second level, and the alternatives are at the third level.

Figure 6: Analytic Hierarchy Process.



Source: Authors.

Step 2: Determine the relative importance of different attributes and criteria with respect to the goal. The relative importance will be identified through =Pair wise comparison method '. The pairwise comparison method is created with the help of a scale of relative importance.

Table 1: Scale of relative importance.

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate importance
1/3, 1/5, 1/7, 1/9	Values for inverse comparison

Source: Authors.

The collected data of each respondent will be inserted into a table where the columns and rows will be filled according to the criteria.

Table 2: Pairwise comparison matrix table.

	C1	C2
C1	1	
C2		1

Source: Authors.

$$\frac{\varphi\chi(\text{Row element})}{\chi(\text{Column element})} \pm \text{Element value}$$

The sum of each column is calculated and divided by all the elements of the column.

$$\frac{(\text{Element value})}{(\text{Sum of column})}$$

Step 3: A normalized pairwise comparison matrix will be done by calculating the criteria weight. The weights are calculated by averaging all the elements in the row.

$$\frac{(\text{The sum of all elements in the row })}{(\text{Number of criteria })} \pm \text{Criteria weight}$$

Step 4: The criteria weight will determine the value of each topic given by the respondent. At the end of the analysis, criteria that have been given the highest criteria weight from each respondent will be identified

4. Result and Discussions.

In this chapter, we will discuss the results gained from the data collected from Interviews and questionnaires. The result gained from the Interview was interpreted into a questionnaire to present to a larger group to evaluate through the questionnaire. Therefore, this chapter mainly focuses on analyzing the results gained from the questionnaire. The analysis will be done using the Analytic Hierarchy Process (AHP).

4.1. Result of Interview.

In total, 3 respondents were interviewed to acknowledge the topics that should be added to COLREG. The respondents were chosen according to their profession and years of experience in the maritime field. The collected data from the respondents is as follows:

Table 3: Interview result.

Question / Respondent	1	2	3	4
Captain Sritaran Ram K Kumar	-26 years maritime experience -2.5 years captain	Yes but need more input	Confusions between common and autonomous vessel	-Lidar Sensor -IP-enabled network (communication system)
Mr. Michealle	-Chief officer for tankers -MBI insurance agent	yes	Improper detection and action when detecting obstacle in passage	Adaptive velocity obstacle avoidance (AVOA)
Captain Amiruddin Sulong	-17 years maritime experience -Captain of RV Discovery UMT	yes	-Difficulty in maintaining watchkeeping -Soulfully depending sensors might provide false due to hacking by third party	-(Sensor Data Attack) Cyberattack -Autonomous Navigation System

Source: Authors.

Based on the collected data, we have 5 topics that they suggest to be added in COLREG for the safe and collision-free navigation of autonomous vessels. These topics were interpreted and briefed in the questionnaire so that the respondents could have a picture of the topic and the importance of its implementation. The topics were labeled as criteria to be used in the AHP questionnaire and analysis. The briefed topics in the questionnaire are as stated:

a. LIDAR Sensors.
LIDAR (Light Detection and Ranging) can add value to inshore, near shore, and inland waterway surveys by recording 3D point clouds above the water line. This data complements and can be collected at the same time as underwater sensor data such as single or multibeam echosounders, sub-bottom profilers, and sides that can sonar. Deploying survey boats is expensive, and simultaneous data collection saves valuable time and money. The resultant collective 3D data forms a complete picture of above and below the waterline and ensures all data for a site/project is collected irrespective of the state of the tide at the time of collection.

b. IP-enabled network.
From sensors on board in an unmanned vessel to the reliable software that guarantees cyber-secure operations — autonomous vessels must comply with national and international maritime rules such as the International Convention for the Safety of Life at Sea (SOLAS). Part of the SOLAS regulation requires the need for onboard general alarm systems and onboard communication systems for emergency events. The CCTV System by Zenitel can also be used for navigational purposes and control cargo, engine rooms, perimeter control, and more. Since the CCTV system is IP-based, it can connect with the IP-based communication system. If any unwanted events are monitored, the onshore control centre dispatches an information message through either the intercom or the PAGA system for safe operations and warning.

c. Adaptive velocity obstacle avoidance (AVOA).
The algorithm is called adaptive velocity obstacle avoidance (AVOA) and takes into consideration the kinematic and dynamic constraints of autonomous vessels along with a protective zone concept to determine the safe crossing distance to obstacles. A configuration space that includes both the position and velocity of static or dynamic elements within the field-of-view of the ASV supports a particle swarm optimization procedure that minimizes the risk of harm and the deviation towards a predefined course while generating a navigation path with capabilities to prevent potential collisions. Extensive experiments demonstrate the ability of AVOA to select a velocity estimative for ASVs that originates a smoother, safer, and, at least two times more effective collision-free path when compared to existing techniques.

d. Cyber-attack (Sensor Data Attack).
If an attacker attacks the vulnerable points at the AI learning stage, it can lead to wrong judgments due to erroneous learning. In such cases, an attack scenario can be anticipated in which a threat is mistaken for a safe element during the ship's voyage, and the ship is led to allow access. Security requirements are formulated to achieve security objectives, such as ensuring that users and applications are identified and authenticated, that only authorized data and services can be accessed, and that intrusion attempts by unauthorized users are detected. Security requirements, including identification, authentication, and authorization, can be formulated to achieve these general security goals.

e. IMU (Inertial Measurement Unit).
IMU sensing devices will form two vital units within the autonomous vessel's navigation suite, constantly delivering precise 3-axis data on angular rate and acceleration plus roll, pitch and heading angles, altitude and pressure, and temperature to the ship's autopilot.

4.2. *Result of Questionnaire.*

A total of 19 respondents answered the questionnaire. The respondents are individuals who have experience in the maritime field as Captains and Officers. Suggested topics are labeled as criteria to adapt to the Analytic Hierarchy Process method.

Criteria 1: C1: LIDAR Sensors
Criteria 2: C2: IP-enabled network
Criteria 3: C3: Adaptive velocity obstacle avoidance (AVOA)
Criteria 4: C4: Cyber-attack (Sensor Data Attack)
Criteria 5: C5: IMU (Inertial Measurement Unit)
Respondents: R

The questionnaire was given to the respondents as per below:

Table 4: Questionnaire.

Name																				
Profession																				
Years of experience in maritime field																				
Compare the criteria listed above and evaluate a score based on how important they are to put into implementation in COLREG.																				
Criteria 1	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 1 2
Criteria 1	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 3
Criteria 1	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 4
Criteria 1	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 5
Criteria 2	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 3
Criteria 2	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 4
Criteria 2	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 5
Criteria 3	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 4
Criteria 3	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 5
Criteria 4	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	Criteria 5

Source: Authors.

4.3. *Respondent details.*

a. Profession.
The respondents that we chose for this section through the judgemental sampling method are captains. 10 respondents generally mentioned their profession as Captain while the other 9 specified their current working company.

b. Years of experience.
According to the pie chart, 52.6% (10 respondents) have experience of 10 years and above as Captain.. 26.3% (5 respondents) consist of 5 years and above experienced Captain, whereas 21.1% (4 respondents) are less than 5 years as a Captain.

4.4. Data Analysis.

4.4.1. Criteria Weight.

To identify the most qualified topic to be suggested to Maritime Autonomous Surface Ships (MASS), each respondent's data needs to be analyzed individually according to the AHP method. The Criteria weight of each topic from each respondent will be derived. The topic that most respondents have given the highest criteria will be the topic that will be suggested to MASS.

Respondent 1.

Table 5: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	7	8	6	3
C2	0.14	1	0.25	0.5	3
C3	0.13	4	1	7	4
C4	0.17	2	0.14	1	0.17
C5	0.3	0.3	0.25	6	1
Sum	1.74	14.3	9.64	20.5	11.17

Source: Authors.

Table 6: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.5747	0.4895	0.8298	0.2926	0.2685	0.4910
C2	0.0804	0.0699	0.0259	0.0243	0.2685	0.0938
C3	0.0747	0.2797	0.1037	0.3414	0.3581	0.2315
C4	0.0977	0.1398	0.0145	0.0487	0.0152	0.0631
C5	0.1724	0.0209	0.0259	0.2926	0.0895	0.12026
Sum	1.74	14.3	9.64	20.5	11.17	

Source: Authors.

Respondent 2.

Table 7: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	0.2	0,25	5	0.2
C2	5	1	5	0.33	0.2
C3	4	0.2	1	2	0.2
C4	0.2	3	0.5	1	6
C5	5	5	5	0.17	1
Sum	15.2	9.4	11.75	8.5	76

Source: Authors.

Table 8: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.0657	0.0212	0.0212	0.5882	0.0263	0.1827
C2	0.3289	0.1063	0.4255	0.0388	0.0263	0.1851
C3	0.2631	0.0212	0.0851	0.2352	0.0263	0.1261
C4	0.0131	0.3191	0.0425	0.1176	0.7894	0.2563
C5	0.3289	0.5319	0.4255	0.02	0.1315	0.3235
Sum	15.2	9.4	11.75	8.5	7.6	

Source: Authors.

Respondent 3.

Table 9: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	9	5	6	3
C2	0.11	1	2	3	0,33
C3	0.2	0.5	1	0.2	6
C4	0.17	0.33	5	1	0.25
C5	0.33	3	0.17	4	1
Sum	1.81	13.83	13.17	14.2	10.58

Source: Authors.

Table 10: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.5525	0.6507	0.3796	0.4225	0.2835	0.4577
C2	0.0607	0.0723	0.1518	0.2112	0.0312	0.1054
C3	0.1105	0.0361	0.0759	0.0140	0.5671	0.1607
C4	0.0939	0.0238	0.3796	0.0704	0.0236	0.1182
C5	0.1823	0.2169	0.0129	0.2817	0.0945	0.1576
Sum	1.81	13.83	13.17	14.2	10.58	

Source: Authors.

Respondent 4.

Table 11: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	0.14	4	0.5	0.2
C2	7	1	5	0.33	0.2
C3	0.25	0.2	1	0.33	0.17
C4	2	3	3	1	0.2
C5	5	5	6	5	1
Sum	15.25	9.34	19	7.16	1.77

Source: Authors.

Table 12: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.0655	0.0149	0.2105	0.0698	0.1129	0.0947
C2	0.4590	0.1070	0.2631	0.0460	0.1129	0.1976
C3	0.0163	0.0214	0.0526	0.0460	0.0960	0.0464
C4	0.1311	0.3211	0.1579	0.1396	0.1129	0.1725
C5	0.3278	0.5353	0.3157	0.6983	0.5649	0.4884
Sum	15.25	9.34	19	7.16	1.77	

Source: Authors.

Respondent 5.

Table 13: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	7	0.14	4	0.12
C2	0.14	1	5	6	6
C3	7	0.2	1	3	6
C4	0.25	0.17	0.33	1	3
C5	8	0.17	0.17	0.33	1
Sum	16.39	8.54	6.64	14.33	16.12

Source: Authors.

Table 14: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.0610	0.8196	0.0210	0.2791	0.0074	0.2376
C2	0.0085	0.1170	0.7530	0.4187	0.3722	0.3338
C3	0.4270	0.0234	0.1506	0.2093	0.3722	0.2365
C4	0.0152	0.0199	0.0496	0.0697	0.1861	0.0681
C5	0.4881	0.0199	0.0256	0.0230	0.0620	0.1237
Sum	16.39	8.54	6.64	14.33	16.12	

Source: Authors.

Respondent 6.

Table 15: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	2	4	0.25	0.25
C2	0.5	1	7	5	0.2
C3	0.25	0.14	1	0.33	0.17
C4	4	0.2	3	1	4
C5	4	5	6	0.25	1
Sum	9.75	8.34	21	6.83	5.62

Source: Authors.

Table 16: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.1025	0.2398	0.1904	0.0366	0.0444	0.1227
C2	0.0512	0.1199	0.3333	0.7320	0.0355	0.2543
C3	0.0256	0.0167	0.0476	0.0483	0.0302	0.0336
C4	0.4102	0.2398	0.1428	0.1464	0.7117	0.3301
C5	0.4102	0.5995	0.2857	0.0366	0.1779	0.3019
Sum	9.75	8.34	21	6.83	5.62	

Source: Authors.

Respondent 7.

Table 17: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	4	6	5	3
C2	0.25	1	5	0.17	3
C3	0.17	0.2	1	0.33	5
C4	0.2	6	3	1	0.2
C5	0.33	0.33	0.2	5	1
Sum	1.95	11.53	15.2	11.5	12.2

Source: Authors.

Table 18: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.5128	0.3469	0.3947	0.4347	0.2459	0.387
C2	0.1282	0.0867	0.3289	0.0147	0.2459	0.1608
C3	0.0871	0.0173	0.0657	0.0286	0.4098	0.1217
C4	0.1025	0.5203	0.1973	0.0869	0.0163	0.1846
C5	0.1692	0.0286	0.0131	0.4347	0.0819	0.1455
Sum	1.95	11.53	15.2	11.5	12.2	

Source: Authors.

Respondent 8.

Table 19: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	7	5	0.33	0.5
C2	0.14	1	4	6	7
C3	0.2	0.25	1	0.33	4
C4	3	0.17	3	1	0.2
C5	2	0.14	0.25	5	1
Sum	6.34	8.56	13.25	12.66	12.7

Source: Authors.

Table 20: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.1577	0.8177	0.3773	0.0260	0.0393	0.2836
C2	0.0220	0.1168	0.3018	0.4739	0.5511	0.2931
C3	0.0315	0.0292	0.0754	0.0260	0.3149	0.0954
C4	0.4731	0.0198	0.2264	0.0789	0.0157	0.1627
C5	0.3154	0.0163	0.0188	0.3949	0.0787	0.1648
Sum	6.34	8.56	13.25	12.66	12.7	

Source: Authors.

Respondent 9.

Table 21: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	2	3	2	4
C2	0.5	1	0.33	3	5
C3	0.33	3	1	0.25	0.25
C4	0.5	0.33	4	1	0.25
C5	0.25	0.2	4	4	1
Sum	2.58	6.53	12.33	10.25	10.5

Source: Authors.

Table 22: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.3875	0.3062	0.2433	0.1951	0.3809	0.3026
C2	0.1937	0.1531	0.0267	0.2926	0.4761	0.2284
C3	0.1279	0.4594	0.0811	0.0243	0.0238	0.1433
C4	0.1937	0.0505	0.3244	0.0975	0.0238	0.1379
C5	0.0968	0.0306	0.3244	0.3902	0.0952	0.1874
Sum	2.58	6.53	12.33	10.25	10.5	

Source: Authors.

Respondent 10.

Table 23: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	7	8	9	7
C2	0.14	1	0.17	4	0.2
C3	0.12	6	1	4	0.2
C4	0.11	0.25	0.25	1	7
C5	0.14	5	5	0.14	1
Sum	1.51	19.25	14.42	18.14	15.4

Source: Authors.

Table 24: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.6622	0.3636	0.5547	0.4961	0.4545	0.5062
C2	0.0927	0.0519	0.0119	0.2205	0.0129	0.0779
C3	0.0794	0.3116	0.0693	0.2205	0.0129	0.1387
C4	0.0728	0.0129	0.0173	0.0551	0.4545	0.1225
C5	0.0927	0.2597	0.3467	0.0077	0.0649	0.1543
Sum	1.51	19.25	14.42	18.14	15.4	

Source: Authors.

Respondent 11.

Table 25: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	4	0.2	4	5
C2	0.25	1	0.25	0.5	3
C3	5	4	1	0.25	0.2
C4	0.25	2	4	1	3
C5	0.2	0.33	5	0.33	1
Sum	6.7	11.33	10.45	6.08	12.2

Source: Authors.

Table 26: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria Weight
C1	0.1492	0.3530	0.0191	0.6578	0.4098	0.3177
C2	0.0373	0.0882	0.0239	0.0822	0.2459	0.1385
C3	0.7462	0.3530	0.0956	0.0411	0.0163	0.2504
C4	0.0373	0.1765	0.3827	0.1644	0.2459	0.2013
C5	0.0298	0.0291	0.4784	0.0542	0.0819	0.1346
Sum						

Source: Authors.

Respondent 12.

Table 27: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	0.25	0.2	0.2	5
C2	4	1	0.2	4	5
C3	5	5	1	0.25	5
C4	5	0.25	4	1	0.25
C5	0.2	0.2	0.2	4	1
Sum	15.2	6.7	5.6	9.45	16.25

Source: Authors.

Table 28: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria Weight
C1	0.0657	0.0373	0.0357	0.0211	0.3076	0.0934
C2	0.2631	0.1492	0.0357	0.4232	0.3076	0.2357
C3	0.3289	0.7462	0.1785	0.0264	0.3076	0.3175
C4	0.3289	0.0373	0.7142	0.1058	0.0153	0.2403
C5	0.0131	0.0298	0.0357	0.4232	0.0615	0.1126
Sum						

Source: Authors.

Respondent 13.

Table 29: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	5	5	5	5
C2	0.2	1	0.2	5	0.25
C3	0.2	5	1	5	0.2
C4	0.2	0.2	0.2	1	4
C5	0.2	4	5	0.25	1
Sum	1.8	15.2	11.4	16.25	10.45

Source: Authors.

Table 30: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.5555	0.3289	0.4385	0.3076	0.4784	0.4216
C2	0.1111	0.0657	0.0175	0.3076	0.0239	0.1051
C3	0.1111	0.3289	0.0877	0.3076	0.0191	0.1708
C4	0.1111	0.0131	0.0175	0.0615	0.3827	0.1171
C5	0.1111	0.2631	0.4385	0.0153	0.0956	0.1847
Sum						

Source: Authors.

Respondent 14.

Table 31: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	6	7	5	6
C2	0.17	1	0.25	0.25	0.2
C3	0.14	4	1	0.5	0.17
C4	0.2	4	2	1	2
C5	0.17	5	6	0.5	1
Sum	1.68	20	16.25	7.25	9.37

Source: Authors.

Table 32: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria Weight
C1	0.5952	0.3	0.4307	0.6896	0.6403	0.5311
C2	0.4464	0.05	0.0153	0.0344	0.0213	0.5674
C3	0.0833	0.2	0.0615	0.0689	0.0181	0.0863
C4	0.1190	0.2	0.1230	0.1379	0.2134	0.1586
C5	0.1011	0.25	0.3692	0.0689	0.1067	0.1791
Sum						

Source: Authors.

Respondent 15.

Table 33: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	6	7	0.2	6
C2	0.17	1	0.2	0.25	0.2
C3	0.14	5	1	5	0.17
C4	5	4	0.2	1	6
C5	0.17	5	6	0.17	1
Sum	6.48	21	14.4	6.62	13.37

Source: Authors.

Table 34: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.1543	0.2857	0.4861	0.0302	0.4487	0.281
C2	0.0262	0.0476	0.0138	0.0377	0.0149	0.0280
C3	0.0216	0.2380	0.0694	0.7552	0.0127	0.2193
C4	0.7716	0.1904	0.0138	0.1510	0.4487	0.3151
C5	0.0262	0.2380	0.4166	0.0256	0.0747	0.1562
Sum						

Source: Authors.

Respondent 16.

Table 35: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	6	4	3	0.33
C2	0.17	1	3	4	0.25
C3	0.25	0.33	1	0.25	4
C4	0.33	0.25	4	1	0.25
C5	3	4	0.25	4	1
Sum	4.75	11.58	12.25	12.25	5.83

Source: Authors.

Table 36: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria Weight
C1	0.2105	0.5181	0.3265	0.2448	0.0566	0.2713
C2	0.0357	0.0863	0.2448	0.3265	0.0428	0.1472
C3	0.0526	0.0284	0.0816	0.0204	0.6861	0.1738
C4	0.0694	0.0215	0.3265	0.0816	0.0428	0.1083
C5	0.6315	0.3454	0.0204	0.3265	0.1715	0.2990
Sum						

Source: Authors.

Respondent 17.

Table 37: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	0.2	0.25	4	4
C2	5	1	0.25	5	2
C3	4	4	1	0.2	2
C4	0.25	0.2	5	1	3
C5	0.25	0.5	0.5	0.33	1
Sum	10.5	5.9	7	10.53	12

Source: Authors.

Table 38: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria Weight
C1	0.0952	0.0338	0.0357	0.3798	0.3333	0.1755
C2	0.4761	0.1694	0.0357	0.4748	0.1666	0.2645
C3	0.3809	0.6779	0.1428	0.0189	0.1666	0.2774
C4	0.0238	0.0338	0.7142	0.0949	0.25	0.2233
C5	0.0238	0.0847	0.0714	0.0313	0.0833	0.0589
Sum						

Source: Authors.

Respondent 18.

Table 39: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	5	6	0.2	5
C2	0.2	1	0.33	5	0.2
C3	0.17	3	1	6	5
C4	5	0.2	0.17	1	5
C5	0.2	5	0.2	0.2	1
Sum	6.57	14.2	7.7	12.4	16.2

Source: Authors.

Table 40: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria weight
C1	0.1522	0.3521	0.7792	0.0161	0.3086	0.3216
C2	0.0304	0.0704	0.0428	0.4032	0.0123	0.1118
C3	0.0258	0.2112	0.1298	0.4838	0.3086	0.2318
C4	0.7610	0.0140	0.0220	0.0806	0.3086	0.2372
C5	0.0304	0.3521	0.0259	0.0161	0..0617	0.0972
Sum						

Source: Authors.

Respondent 19.

Table 41: Pairwise comparison matrix.

	C1	C2	C3	C4	C5
C1	1	8	7	0.12	0.25
C2	0.12	1	0.14	2	3
C3	0.14	7	1	0.25	0.17
C4	8	0.5	4	1	2
C5	4	0.33	6	0.5	1
Sum	13.26	16.83	18.14	3.87	6.42

Source: Authors.

Table 42: Normalized pairwise comparison matrix.

	C1	C2	C3	C4	C5	Criteria Weight
C1	0.0754	0.4753	0.3858	0.0310	0.0389	0.2012
C2	0.0090	0.0594	0.0077	0.5167	0.4672	0.212
C3	0.0105	0.4159	0.0551	0.0645	0.0264	0.1144
C4	0.6033	0.0297	0.2205	0.2583	0.3115	0.2846
C5	0.3016	0.0196	0.3307	0.1291	0.1557	0.1873
Sum						

Source: Authors.

After calculating the criteria weight of each topic given by each respondent, the highest topic will be identified. In the table below, the weights of each criterion given by each respondent are arranged. Yellow represents the highest criteria weight of each respondent.

Table 43: Criteria weight table.

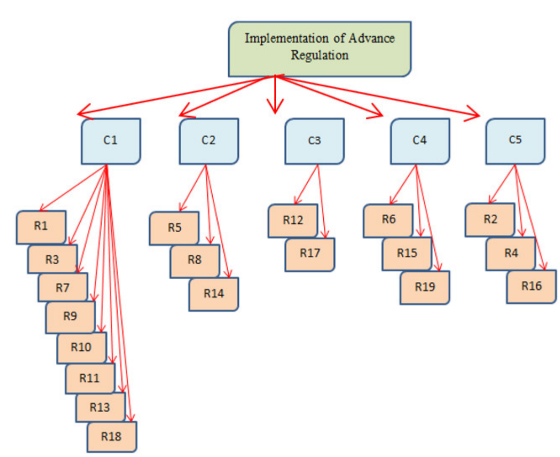
	Topic 1	Topic 2	Topic 3	Topic 4	Topic 5
Respondent 1	0.4910	0.0938	0.2315	0.0631	0.1202
Respondent 2	0.1827	0.1851	0.1261	0.2563	0.3235
Respondent 3	0.4577	0.1054	0.1607	0.1182	0.1576
Respondent 4	0.0947	0.1976	0.0464	0.1725	0.4884
Respondent 5	0.2376	0.3338	0.2365	0.0681	0.1237
Respondent 6	0.1227	0.2543	0.0336	0.3301	0.3019
Respondent 7	0.387	0.1608	0.1217	0.1846	0.1455
Respondent 8	0.2836	0.2931	0.0954	0.1627	0.1648
Respondent 9	0.3026	0.2284	0.1433	0.1379	0.1847
Respondent 10	0.5062	0.0779	0.1387	0.1225	0.1543
Respondent 11	0.3177	0.1385	0.2504	0.2013	0.1346
Respondent 12	0.0934	0.2357	0.3175	0.2403	0.1126
Respondent 13	0.4216	0.1051	0.1708	0.1171	0.1847
Respondent 14	0.5311	0.5674	0.0863	0.1586	0.1791
Respondent 15	0.2810	0.0280	0.2193	0.3151	0.1562
Respondent 16	0.2713	0.1472	0.1738	0.1083	0.2990
Respondent 17	0.1755	0.2645	0.2774	0.2233	0.0589
Respondent 18	0.3216	0.1118	0.2318	0.2372	0.0972
Respondent 19	0.2012	0.2120	0.1144	0.2846	0.1873
Total	8	3	2	3	3

Source: Authors.

4.5. *Discussion.*

As the final result of this research, Topic 1 has been given the highest criteria weight by 8 out of 19 respondents among the 5 topics presented. Therefore, Topic 1, - LIDAR SENSORS', is the most suitable topic to suggest to the - Maritime Autonomous Surface Ships' MASS. According to the AHP analysis method, all 5 topics may be suggested to MASS, although only one will be the most suitable topic to put forward. The final output of - Analytic Hierarchy Process'as per below:

Figure 7: Analytic Hierarchy Process of this research.



Source: Authors.

Conclusions.

As a conclusion of this research, Advanced Regulation for Autonomous Vessels to Avoid Collision 'autonomous vessels do require additional topics in COLREG to avoid Collisions. The main objective of this research - To determine the topic that should be added as the additional part of COLREG for autonomous vessels 'is achieved by interviewing the Captain's and deriving 5 topics from them. The secondary objective, - To determine the most important topic that should be put forth for Maritime Autonomous Surface Ships (MASS) 'also been achieved by identifying the most supported topic by 19 respondents through the Analytic Hierarchy Process (AHP), and the result concludes that - LIDAR SENSORS 'is the most important topic to suggest to - Maritime Autonomous Surface Vessels.' Therefore, both objectives of this research have been achieved.

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