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RESEARCH ARTICLE

A Research on The Opportunities of Autonomous Unmanned Marine Vehicles to Enhance Maritime Safety and Security*

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ABSTRACT

Today, technology affects every aspect of life. In recent years, one of the most important technological developments in the field of maritime transportation has been "autonomous/unmanned marine vehicles". With the rapidly developing technology in the "Industry 4.0" era, these vehicles have begun being used in the maritime field. These vehicles are expected to provide further efficiency in both civilian and military maritime operations in a safer and more secure manner. This study aims to examine and determine the usage opportunities (concepts) of autonomous/unmanned marine vehicles to enhance maritime safety and security. With this aim, a Delphi research with 18 participating experts was conducted in addition to the literature review (document analysis). Because of the Delphi research, 18 usage concepts, eight of which reached consensus at the end of three Delphi sessions, were found based on expert opinions. The results of this study are expected to contribute to the maritime literature and future projects to enhance maritime safety and security.

Keywords: Autonomous Unmanned Marine Vehicle, Maritime Security, Maritime Safety, Transportation Safety, Logistics Safety

1. Introduction

A look at the technological development history of the maritime industry shows that there have been significant transformations, such as the transition from sail to steam, to diesel from coal to oil, and the development of complex automated power/engine control systems and navigational equipment of ships, including the gyro compass, radar/ARPA and terrestrial navigation systems, GMDSS, VDR, AIS, and ECDIS. It also shows that many new technologies provide improvements in safety or working/living conditions onboard ships (IMO, 2018). Today, with the rapid development of technology in the era process called Industry 4.0, autonomous/unmanned vehicles have begun to take their place in our lives. They have also begun to be developed as an alternative to conventional marine vehicles, and their use has become widespread. It is possible to handle the developments regarding autonomous/unmanned marine vehicles over the last decade from two perspectives: civilian maritime and military maritime. Examples of autonomous/unmanned marine vehicle development projects in the field of civilian maritime are "ARAGON" which is an unmanned surface vehicle for ocean observation and sea surveillance by the South Korea Research Institute of Ships and Ocean Engineering, "Maritime Unmanned Navigation Through Intelligence in Networks (MUNIN)" by the European Union (EU), "Marine Autonomous and Robotic Systems (MARS) fleet" by the Natural Environment Research Council of UK National Oceanography Centre, "Advanced Autonomous Waterborne Applications (AAWA)" by Rolls-Royce, and other projects based in Finland and Norway such as "Revolt ", "Yara Birkeland", "Falco" etc. (Emad et al., 2020; ThinkTech, 2021; NOC, 2022; Yılmaz & Önaçan, 2019). Examples of autonomous/unmanned marine vehicle development projects in the military field are "ULAQ" armed unmanned marine vehicle by Turkiye (Ares & Meteksan, 2022), "REMUS 600" autonomous underwater vehicle for mine search and identification operations by the US Office of Naval Research (NATO/OTAN, 2019) and "KATANA" autonomous surface ship by Israel Aerospace Industries Ltd. (IAI, 2022), etc. Figure 1 shows the classification of autonomous marine vehicles.

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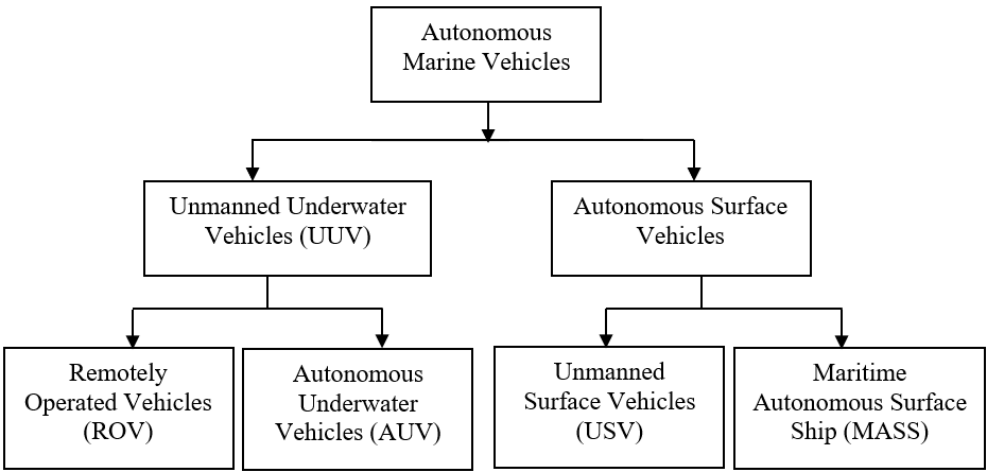

Figure 1. Classification of autonomous and unmanned marine vehicles (NAP, 2020)

ROVs are underwater robots used to explore the deep sea and oceans. It can also be used for shallow water operations. ROVs are attached to a ship via cables and controlled with a joystick. It sends its data directly through a communication cable. ROVs; It can be equipped with tools such as instruments, cameras, water samplers, lights, claws, robotic arms, and cutting blades that measure salinity, depth, and temperature. Cameras capture videos and photos of the underwater environment. Robotic arms pick up attach hooks, cut lines, or small objects to larger objects (Wilson, et al., 2021). AUVs are programmable robots that can move through water or are battery-powered without an operator guiding them. Unlike the ROV, there is no cable providing the connexion between the AUV itself and the research vessel. Similar to ROVs, they perform underwater missions such as detecting and mapping sunken ships, examining the deep seafloor, and finding obstacles that may be dangerous to ships. AUVs are efficient and productive due to their propulsion and navigation systems that allow them to move independently and accurately in any direction in the water. AUVs can also be equipped with a variety of instruments and sensors that provide information and make measurements as they move through water. AUVs survey depths ranging from 16 feet to approximately 20,000 feet below the surface (Wilson, et al., 2021). USVs can be defined as a comprehensive vessel designed to operate without a human operator on board (Burdziakowski & Stateczny, 2019). USVs can be operated by human operators via remote control, or they can be operated as autonomous vehicles that can make decisions on their own according to the conditions in which human control is minimal, using artificial intelligence and various operating systems (Bolat & Koşaner, 2021). MASS is defined as "*a ship capable of operating independently of varying degrees of human interaction*." by the United Nations International Maritime Organisation (IMO). According to MSC.1/Circ.1638 published by the IMO in 2021, the autonomy levels of marine vehicles are determined as follows (IMO, 2021):

"Level 1. Ship with automated processes and decision support: Seafarers operate and control the ship's systems and functions. Some operations are automated, but seafarers are ready to take control at any time.
Level 2. Remotely controlled ship with the seafarer on board: The ship is controlled and operated from another area. Seafarers are on board the ship to take control and operate the ship's systems and functions.
Level 3. Remotely controlled ship without the seafarer on board: The ship is controlled from a remote-control centre and its operation is ensured. The seafarer is not on the ship.
Level 4. Fully autonomous ship. "The operating system of the ship is based on autonomous decision-making and reaction."

In terms of this study, the "autonomous/unmanned marine vehicle" refers to vehicles with an autonomy level determined by IMO as Level 3 and Level 4; that is; it refers to marine vehicles that are unmanned and can perform their functions fully autonomously.

On the other hand, ensuring and enhancing maritime safety and security is a critical issue for the international maritime community, which aims to achieve safer, more secure, and sustainable maritime transportation. It is possible to use autonomous/unmanned marine vehicles as the new marine technology of the Industry 4.0 era to increase maritime safety and security. However, such usage opportunities/concepts have not been properly addressed; hence, this study will provide good insights. In this context, this study examines and determines the usage opportunities (concepts) of autonomous/unmanned marine vehicles to enhance maritime safety and security. With this aim, a Delphi research with 18 participating experts was conducted in addition to the literature review (document analysis) in the study.

2. Literature

During the literature review, it is observed that previous studies covering both topics "*autonomous/unmanned marine vehicles*" and "*maritime safety & security*" related to the subject of this study are quite limited in the civilian field and are mainly concentrated in the military field, as summarised below. De vs et al. (2021) performed a statistical analysis and concluded that applying autonomy

to small cargo ships under 120 m in length may provide the greatest safety benefit because these ships account for the majority of recorded casualties and ship losses. Agarwala (2022) addressed the great opportunity and need for employing micro-ROVs in port security. The NAP (2020) stated that the use of unmanned technologies in tasks such as reconnaissance, surveillance, intelligence gathering, drug smuggling, immigrant smuggling, illegal fishing, search and rescue, and oil spill response can increase maritime awareness and permanence. Savitz et al. (2013) stated that USVs are suitable for many missions of the US Navy such as characterising the physical environment, defence against small vessels, search and rescue, support of other unmanned vehicles, testing and training, electronic warfare/information operations/military deception, mine warfare, and collection and observation of enemies. The US Coast Guard (USCG) aims to use autonomous/unmanned marine vehicles to combat drug, immigrant smuggling, maritime search and rescue, combat illegal fishing, collect ocean and environmental data, map surface/underwater/under-ice oil spills, and provide navigational aids (buoys and beacons). It also develops various projects for using lighthouses and responding to marine pollution incidents (TRB, 2020). The South Korea Coast Guard aims to use autonomous/unmanned marine vehicles for purposes such as surface surveillance, mine detection, preparation training support, environmental research at sea, inspection of underwater objects, search and rescue operations at sea, 24-hour uninterrupted coastal and port security, fire extinguishing, and illegal fishing boats for civilian purposes such as monitoring their operations (Lee, 2022) and to monitor the illegal operations of fishing boats (Sae-jin, 2017). The Singapore Police Coast Guard aims to use autonomous/unmanned marine vehicles for coastal defence, port protection, search and rescue, marine logistics and oceanographic research purposes (Heo et al., 2017 ; HST, 2023). The Australian Maritime Border Command (MBC) aims to use autonomous/unmanned marine vehicles for wide-area reconnaissance, surveillance, and oceanographic purposes (Mugg et al., 2016). The Brazilian Navy uses autonomous/unmanned marine vehicles to clean oil spills and search for mines or submarines. (Savitz, 2021). The UK Royal Navy aims to use autonomous/unmanned marine vehicles for the purposes of detecting and neutralising naval mines (Thales, 2021) and for reconnaissance and surveillance (Royal Navy, 2021). The Royal Norwegian Navy and the Royal Danish Navy aim to benefit from unmanned marine vehicles, especially for neutralising sea mines (Hagen et al., 2003; Lauv, 2022). ULAQ, Turkiye's first armed unmanned marine vehicle, aims to protect critical bases and ports by gaining patrol boat characteristics by integrating remote-controlled combat systems (Şahin, 2021). Because of the literature review, the usage concepts of autonomous/unmanned marine vehicles observed in the literature are shown in Figure 2.

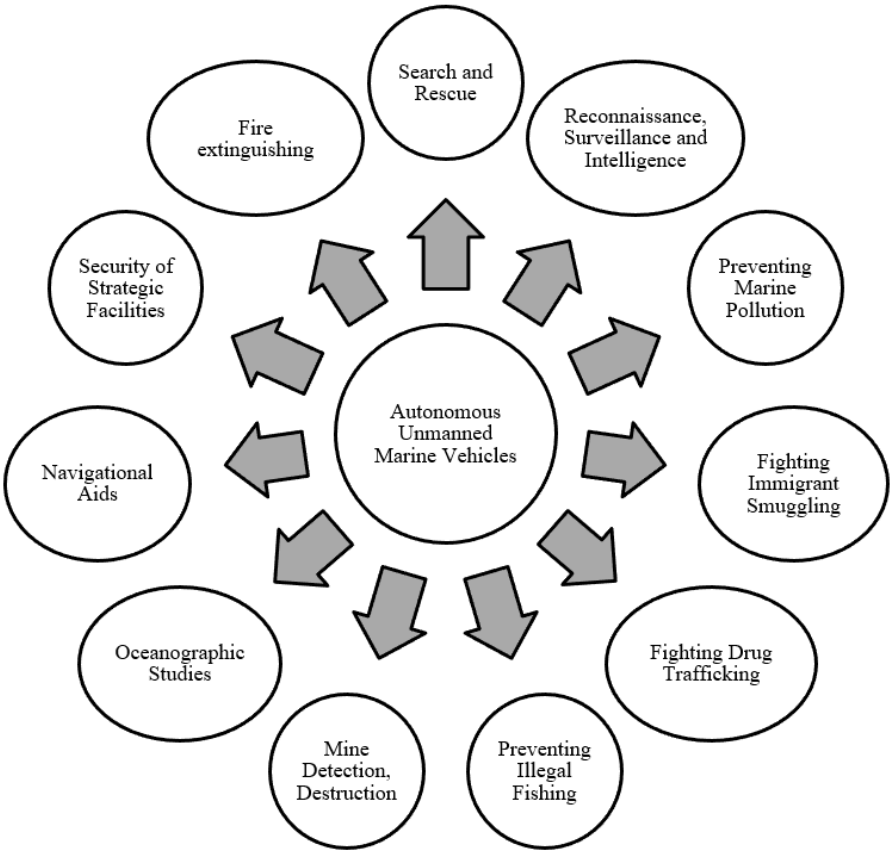

Figure 2. Usage concepts of autonomous/unmanned marine vehicles in the literature (*Figure has been created by the Authors based on Hagen et al., 2003; Mugg et al., 2016; Heo et al. 2017; Sae-Jin, 2017; Thales, 2019; TRB, 2020; Royal Navy, 2021; Savitz, 2021; Şahin, 2021; Lauv, 2022; Lee, 2022; HST, 2023.*)

These usage concepts observed in the literature were also brought to the attention of the Turkish experts in the 1th Delphi session.

3. Materials and Methods

This study is exploratory in terms of its purpose and qualitative in terms of its data collection and analysis method. Qualitative research is a research method in which data collection methods such as observation, interview, and document analysis are used, and situations are presented realistically or close to reality in their natural environment. Qualitative research examines the research problem using an interpretive approach by adopting the holistic (inductive) method (Karataş, 2015). The main research question of this study was "*Can autonomous/unmanned marine vehicles be used to increase maritime safety and security?" For what purposes can they be used?*". At the beginning of the study, a literature review (document analysis) was conducted, and then the data collection and analysis process based on expert opinions was started using the Delphi technique.

3.1. Methodology of the Delphi Technique

The Delphi technique, developed by Dalkey and Helmer in the 1950s, is a technique used by experts to express their own opinions on a predetermined topic and to make predictions about the future by reaching consensus on these opinions, especially in order to form a common opinion and reach a decision on complex issues (Dalkey & Helmer, 1963; Atasoy et al., 2021). The steps of Delphi research that are followed in this study are shown in Figure 3.

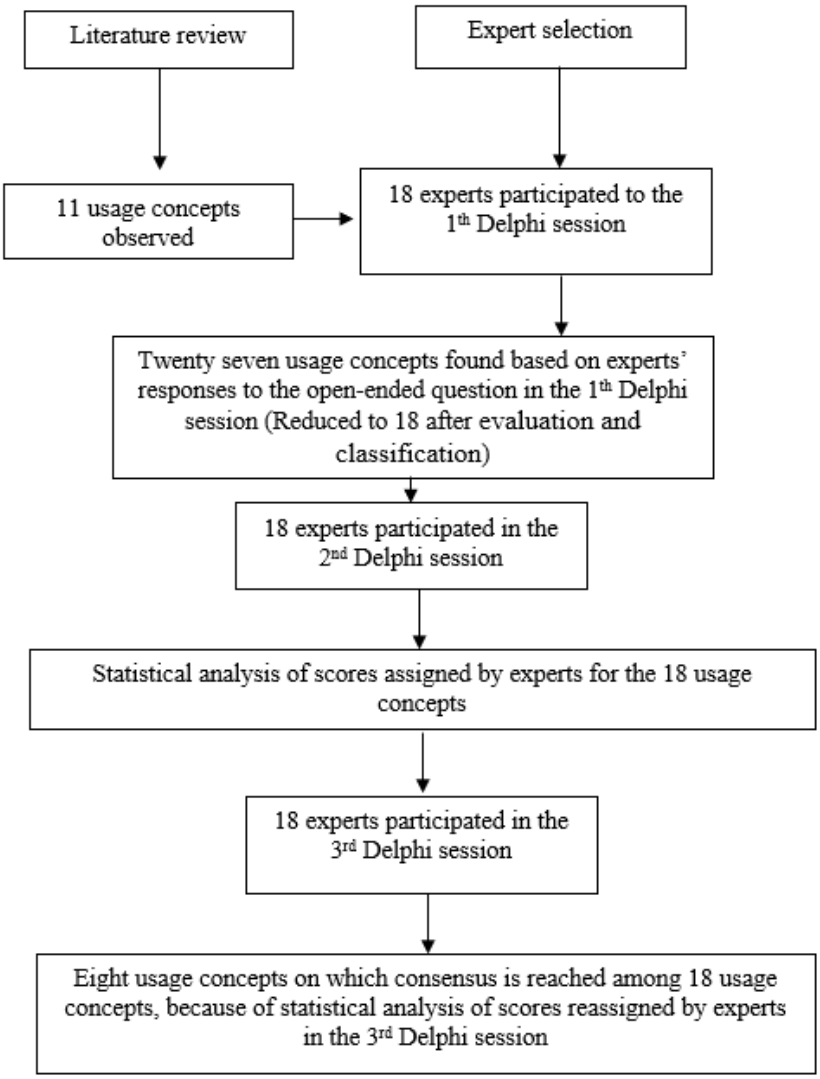

Figure 3. The steps of Delphi research that are followed in this study

Within the scope of Delphi research, 18 experts with undergraduate or graduate education in at least one of these two fields, who are knowledgeable about maritime safety and security and have experience in determining how technological developments will affect these fields, participated in the Delphi sessions. Participating experts have worked or are currently working in institutions

operating in the fields of maritime safety and security. The characteristics and participation status of the experts who participated in the Delphi research within the scope of this study are shown in Table 1.

Table 1. Characteristics and status of participating experts in Delphi research

Expert (E) No.	Profession	Sector in which he/she works	Title	Experience/ Seniority (years)	1. Delphi session	2. Delphi session	3. Delphi session
E1	Maritime Safety and Security	Special	Project Manager	32	√	√	√
E2	Maritime Safety and Security	Special	Business Development Manager	22	√	√	√
E3	Maritime Safety and Security	Public	Programme Manager	20	√	√	√
E4	Maritime Safety and Security	Public	Prof. Dr.	23	√	√	√
E5	Maritime Safety and Security	Public	Dr. Lecturer	18	√	√	√
E6	Maritime Safety and Security	Public	Ship/Boat Commander	16	√	√	√
E7	Maritime Safety and Security	Public	Ship/Boat Commander	18	√	√	√
E8	Maritime Safety and Security	Public	Ship/Boat Commander	11	√	√	√
E9	Maritime Safety and Security	Public	Ship/Boat Commander	9	√	√	√
E10	Maritime Safety and Security	Public	Ship/Boat Commander	11	√	√	√
E11	Maritime Safety and Security	Public	Ship/Boat Commander	8	√	√	√
E12	Maritime Safety and Security	Public	Ship/Boat Commander	8	√	√	√
E13	Maritime Safety and Security	Public	Ship/Boat Commander	8	√	√	√
E14	Maritime Safety and Security	Public	Ship/Boat Commander	33	√	√	√
E15	Maritime Safety and Security	Public	Maritime Pilot	20	√	√	√
E16	Maritime Safety and Security	Public	Maritime Pilot	20	√	√	√
E17	Maritime Safety and Security	Public	VTS Operator	12	√	√	√
E18	Maritime Safety and Security	Public	Ship Captain	15	√	√	√
				TOTAL	18	18	18

The Delphi study was conducted in three sessions, and a 5-point Likert scale was used in the second and third sessions, as shown in Table 2.

Table 2. Likert score scale used in the second and third Delphi sessions

Point	Score Scale
1	I do not agree at all.
2	I do not agree
3	Partially Agree
4	I agree
5	Absolutely, I agree

The Delphi study was conducted via email with 18 participating experts. In the 1st session, an open-ended question "*In what fields can Autonomous/Unmanned Marine Vehicles be used within the scope of maritime safety and security?*" had been asked of the participating experts; therefore, 27 usage concepts were found based on the responses of the participating experts. After the evaluation and classification, the 18 usage concepts shown in Table 3 were determined, and the 2nd Delphi session was started.

Table 3. Usage concepts found in the 1st Delphi session (regardless of prioritisation)

No	Concept
1	Use for reconnaissance, surveillance, and intelligence
2	Use for protection of strategically important facilities/security of critical coastal facilities, bases, and ports
3	Use for combating illegal fishing (detection, identification)
4	Use for Fighting immigrant smuggling (detection, identification)
5	Use for search and rescue activities at sea
6	Use for combating marine pollution (detection, diagnosis)
7	Use for escorting cruise (passenger) ships
8	Use as a navigation aid in bad weather conditions (lights, buoys, meteorological sensors)
9	Use for marine traffic management/mobile traffic observation station
10	Use as a surface/underwater marine vessel for special purpose services (scientific research, hydrocarbon exploration, cable and pipe laying, etc.)
11	Use for explosives/mine detection, reconnaissance, and destruction
12	Use for underwater ship survey/observation
13	Use for ship backup purposes (autonomous/unmanned tugboat, etc.)
14	Use in oceanographic studies
15	Use for surveillance of “Blue Homeland” borders, detection of border violations, and demonstration of uninterrupted presence (flag)
16	Use to ensure the safety of civilian ships in military training and exercise firing areas
17	Use for fire extinguishing purposes on ships/coastal facilities
18	Use for combating smuggling activities (humans, drugs, weapons, fuel, etc.)

3.2. Consensus Criteria

In the 2nd Delphi session, participating experts were asked to assign a score to these 18 usage concepts on a 5-point Likert- type scale with a score of 1-5. For each usage concept, statistics including 1st Quartile (Q1), 3rd Quartile (Q3), Interquartile Range (R), and Median (MD) values were calculated. In the 3rd Delphi session, participating experts were asked to re-assign their scores by presenting the calculated statistics in the 2nd session. The consensus criterion was set as “MD as 4 or more” and “CR as 80% or more” and “R as equal to or less than 1”.

1st Quartile (Q1) means the value that includes 25% of the answers to the left and 75% to the right. In other words, the median of the first half of the series, which is divided into two parts by the median, is called the 1st Quarter. 3rd Quartile (Q3) is the value that includes 25% of the answers to the right and 75% to the left. In other words, the median of the second half of the series, which is divided into two parts by the median, is called the 3rd Quarter. Interquartile Range (R) indicates the difference between Q1 and Q3. If R is equal to or less than 1 ($R=Q3-Q1\leq1$), it indicates that there is a consensus. If R is more than 1 ($R=Q3-Q1>1$), it indicates that there is no consensus. Consensus Rate (CR) is the percentage that indicates the level of consensus. It is calculated as the sum of the percentages of those who responded "4 point: I agree” and “5 point: I absolutely agree” on a 5-point Likert scale in the 2nd and 3rd sessions (Bahar& Somuncu Demir, 2021).

4. Findings and Discussion

At the end of the 3rd session, it was found that there are eight usage concepts in Table 4 on which a consensus has been reached in compliance with the consensus criterion.

Table 4. Usage concepts on which consensus has been reached after 3rd Delphi session

Usage Concepts		MD	Q1	Q3	R	CR (%)
1	Use for reconnaissance, surveillance, and intelligence purposes	5	5	5	0	99
2	Use for explosives/mine detection, reconnaissance, and destruction	5	5	5	0	96
3	Use for surveillance of “Blue Homeland” borders, detection of border violations, and for demonstrating uninterrupted presence (flag)	5	5	5	0	96
4	Use for protection of strategically important facilities/security of critical coastal facilities, bases, and ports	5	4	5	1	89
5	Use for combating illegal fishing (detection, identification)	4.5	4	5	1	87
6	Use for underwater ship survey/observation purposes	4	4	5	1	85
7	Use for oceanographic studies	4	4	5	1	85
8	Use for combating immigrant smuggling (detection, identification)	4	4	5	1	84

The concept of “Use for Reconnaissance, Surveillance and Intelligence Purposes” is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 5, R of 0, and CR of 99%. Huntsberger and Woodward (2011) states that autonomous surface and underwater vehicles could perform several missions, such as surveillance, reconnaissance, and intelligence, in both military and civilian operations. Reconnaissance, surveillance, and intelligence activities in the field of military and security are of great importance and provide power to countries; therefore, autonomous/unmanned marine vehicles can also be used for these purposes.

The concept of "Use for Explosives/Mine Detection, Reconnaissance, and Destruction Purposes" is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 5, R of 0, and CR of 96%. Yılmaz (2012) states that naval mines are used by terrorist organisations and states because of their low cost and high destructive power. With different types, these are dangerous elements of naval warfare, and it is difficult to detect them at sea. For this reason, focussing on explosives/mine detection, reconnaissance, and destruction activities through autonomous/unmanned marine vehicles can prevent terrorist activities and prevent the loss of human life in any adverse situation. For this reason, some countries that are aware of this opportunity have accelerated their efforts to develop autonomous/unmanned marine vehicles (Yılmaz, 2012). Members of the US Office of Naval Research (ONR) launched the REMUS 600 autonomous underwater vehicle for mine search and identification operations in the Baltic Sea in 2018 (NATO OTAN, 2019). KATANA, developed by Israel Aerospace Industries (IAI), performs mine countermeasure duties (IAI, 2022). Silver Marlin, USV (Unmanned Surface Vehicle), was developed in 2007 for coastal reconnaissance, port security, minesweeping, and combat purposes and has been used by the Israeli Navy since November 2009 (Heo et al., 2017). Three LAUVs (Light Autonomous Underwater Vessel) were projected to be delivered to the Danish naval base in 2022 to neutralise naval mines (Lauv, 2022). It is considered that autonomous/unmanned marine vehicles can also be used for explosives/mine detection, reconnaissance, and destruction purposes.

The concept of "Use for the Purpose of Surveillance of the Blue Homeland Borders, Detection of Border Violations, and Display of Uninterrupted Presence (Flag)" is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 5, R of 0, and CR of 96%. “Blue Homeland” is the homeland territory that covers maritime jurisdiction areas such as Turkiye’s territorial waters, exclusive economic zone, and continental shelf in the Black Sea, Mediterranean and Aegean Sea, and all living and non-living beings found there (Aydın, 2022). Protecting Turkiye’s Blue Homeland borders is of great importance, and it is important to detect border violations and display our uninterrupted flag in the "Blue Homeland". Today, this duty is carried out by the Naval Forces Command and the Coast Guard Command. However, in cases of border violations, it may take time for the notification to be received, for the ships/boats to react, and for the incidents to be detected. In this context, autonomous/unmanned marine vehicles can be positioned in certain places at certain distances within Turkiye’s Blue Homeland borders to detect and record border violations and display the flag uninterruptedly 24/7.

The concept of “Protection of Strategically Important Facilities/Use for Security Purposes of Critical Coastal Facilities, Bases and Ports” is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD value of 5, R of 1, and CR of 89%. For example; Katana was designed by Israel Aerospace Industries (IAI) for use in a wide range of missions, including port security, surveillance, and protection of oil, gas, and other critical assets in coastal waters, shallow waters, and

territorial waters (IAI, 2022). Strategically important facilities/critical facilities and ports are places of critical importance where intelligence activities are conducted today. The main threats to these areas are maritime terrorism, piracy, and wars. Therefore, the measures to be taken here are of great importance for states and countries. Such facilities protect 24 h a day by their own private security teams and law enforcement forces. It is considered that autonomous/unmanned marine vehicles can also be used by law enforcement forces for this purpose.

The concept of "Use for the Purpose of Combating Illegal Fisheries Fishing (Detection, Identification)" is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 4.5, R of 1, and CR of 87%. Fighting illegal seafood hunting is important for protecting sustainable marine resources. Illegal seafood hunting is one of the most important duties of coast guard organisations. Autonomous underwater vehicles can be actively used to prevent illegal aquaculture hunting (TRB, 2020). To take legal action against a boat/ship due to illegal fishing, it is first necessary to prove that that boat/ship is engaged in this activity. Real-time images of ships/boats suspected of being involved in illegal aquaculture fishing can be taken with autonomous/unmanned underwater vehicles, especially in bad weather conditions and in cases requiring confidentiality, and the image can be instantly transmitted to the relevant control centre.

The concept of "Underwater Ship Survey / Use for Observation Purposes" is the concept on which consensus was reached in the 3rd Delphi session, with an MD of 4, R of 1, and CR of 85%. One of the reasons for the emergence of autonomous/unmanned marine vehicles is to minimise the loss of life by performing the activities performed by humans by vehicles. Underwater ship survey/observation is not among the duties of coast guard organisations or military forces of countries, but falls within the field of maritime safety within the scope of maintenance, attitude, and inspection required for the safety of ships. The DNV GL uses ROVs to conduct underwater surveys of ships (DNV GL, 2020). It is considered that the survey and inspection activities carried out by flag States, port states, and/or classification societies using divers to observe the underwater situation of the ship can be carried out safely by autonomous/unmanned underwater vehicles.

The concept of "Use for Oceanographic Study Purposes" is the concept on which consensus has been reached in both 3rd Delphi sessions, with an MD of 4, R of 1, and CR of 85%. Autonomous/unmanned marine vehicles use in oceanographic studies, especially by the USCG, Australian Border Protection Command, and Singapore Coast Guard Police. Mugg et al. (2016) stated that unmanned marine vehicles are used as patrol boats for wide-area reconnaissance, surveillance, and oceanographic purposes. Vigilant Class Independent Unmanned Surface Vessel (IUSV) is used by the Singapore Police Coast Guard in tasks such as coastal defence, port protection, search and rescue, marine logistics, and oceanographic studies (Heo et al., 2017). It is considered that autonomous/unmanned marine vehicles can also be used for oceanographic studies.

The concept of "Use for the Purpose of Combating Immigrant Smuggling (Detection, Identification)" is the concept on which consensus has been reached in both the 2nd and 3rd Delphi sessions, with an MD of 4, R of 1, and CR of 84%. Immigrant smuggling incidents, due to their nature, are events that can turn into search and rescue incidents at any time. This extremely important task, which concerns human life, is performed by institutions such as the naval force command or the coast guard command in countries. Because it constitutes one of the primary duties of the United States Coast Guard Command, it is considered that studies on autonomous/unmanned marine vehicles cover this usage concept (TRB, 2020). It is considered that autonomous/unmanned marine vehicles can also be used to combat immigrant smuggling.

It is estimated that the idea of "*There must be seafarers onboard the marine vehicle for this operation, absolutely!*" may have been influential in the scoring of another 10 usage concepts on which consensus has not been reached by the experts. However, these concepts are also important and should be examined by future studies for comparison with the findings of this study.

5. Conclusion

The aim of this study is to examine and determine the usage opportunities (concepts) of autonomous/unmanned marine vehicles to enhance maritime safety and security. With this aim, a Delphi research with 18 participating experts was conducted in addition to the literature review (document analysis) in the study.

As a result of the literature review, it is observed that autonomous/unmanned marine vehicles have begun to be used in many countries in the fields of civilian maritime, military maritime, and coast guard operations, and various projects are still being developed to expand their usage areas. Therefore, their use will become widespread as they offer important opportunities to increase maritime safety and security in both civilian maritime and military maritime. It is also observed from the literature that research and development (R&D) research regarding the use of unmanned/autonomous marine vehicles to enhance maritime safety and security has been mainly conducted in the field of military maritime.

Because of Delphi research conducted in this study, a total of 18 usage concepts, 8 of which consensus is reached by experts, have been found, as shown in Tables 3 and 4. According to the key findings of this study, it can be stated that autonomous/unmanned marine vehicles can be used for the following purposes:

- "Reconnaissance, surveillance and intelligence",
- "Explosives/mine detection, reconnaissance and destruction",
- "Surveillance of "Blue Homeland" borders, detection of border violations",
- "Demonstrating uninterrupted presence (flag)",
- "Protection of strategically important facilities/security of critical coastal facilities, bases and ports",
- "Combating illegal fishing (detection, identification)",
- "Underwater ship survey/observation purposes", "oceanographic study purposes", and
- "Combating immigrant smuggling (detection, identification)".

These concepts have been compared and discussed with other studies. As observed from the literature, autonomous/unmanned marine vehicles have already begun to be used in some countries by institutions responsible for the protection of maritime jurisdictions under their sovereignty. Therefore, it has been concluded that autonomous/unmanned marine vehicles can be used for enhancing maritime safety and security and for other missions.

The results of this study are expected to contribute to the maritime literature and future projects to be developed with the aim of enhancing maritime safety and security. However, these dynamic topics are open to new technological developments every day and require close monitoring. Therefore, it would be useful to examine the usage concepts presented in this study separately and in more detail in future studies by comparing with the findings of this study as well.

Finally, because autonomous/unmanned marine vehicles are a newly developing technology, the literature in this field is limited by the insufficient number of scientific publications or the inability to access sufficient information due to the degree of commercial/military secrecy. Therefore, the data collection and analysis process based on expert opinions using the Delphi technique is critical for this study. There was a limitation that experts in the field whose opinions would be consulted tended to keep their opinions confidential for commercial or security reasons or to give superficial answers. To overcome this limitation, it was well explained to the experts that the necessary confidentiality and ethical rules would be strictly adhered. On the other hand, the reliability of the Delphi technique depends on the qualifications, knowledge, and experience of the participating experts; more time is spent than the planned process while receiving feedback from the participants; and heterogeneous large groups cooperate and reach a consensus. Therefore, if similar research is conducted with more heterogeneous and larger expert groups over longer periods of time in the future, it is possible to obtain more reliable findings.

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