ESCOLA NAVAL

António Maria de Amaral Candeias

Role of Unmanned Vehicles in Harbour Protection:

A case study on Sines Harbour in different operational scenarios

A dissertation submitted in partial fulfilment of the requirements for the degree of Naval Military Sciences, specialization in Navy

Alfeite

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Epigraph

"Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur"

- General Giulio Douhet

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A heartfelt thank you to my parents, João and Marla for raising me, educating me, for being always there for me and for always doing their very best.

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Abstract

The increasing complexity of threats to ports and maritime infrastructure calls for innovative approaches. This dissertation examines the role of Unmanned Vehicles (UxVs) in the protection of Sines Harbour, one of Portugal's largest deep-water ports, considering both a security role during routine port operations and a defensive role in the event of an external attack by state or non-state actors. The study begins with a review of NATO doctrine on Harbour Protection and the legal framework related to Port Security. An analysis of classification methods for all types of unmanned systems (UAVs, USVs, UUVs and UGVs) is presented, along with an assessment of their employment in recent conflicts and in leading international ports (Antwerp, Los Angeles and Haifa). The research also includes a detailed assessment of Sines Harbour, covering meteorological characteristics, security posture, criticality, threat and vulnerability assessments, complemented by expert interviews on the application of UxVs in both security and defence contexts. A tailored employment concept for UxVs in Sines is proposed, with specific operational requirements for each system type. This proposed model focuses on security applications. The results highlight the potential of UxVs to enhance the overall protection of Sines Harbour, particularly in surveillance, persistent coverage and threat response, while also identifying challenges related to interoperability and operational procedures.

Keywords: Harbour Protection; Unmanned Vehicles; Port Security; Maritime Infrastructure.

Resumo

A crescente complexidade das ameaças às infraestruturas portuárias e marítimas exige abordagens inovadoras. Esta dissertação analisa o papel dos Veículos Não Tripulados na proteção do Porto de Sines, um dos maiores portos de águas profundas de Portugal, considerando tanto o seu emprego em funções de segurança durante operações portuárias de rotina, como em funções de defesa perante um ataque externo por atores estatais ou não estatais. O estudo inicia-se com uma revisão da doutrina da NATO sobre Proteção Portuária e do enquadramento legal aplicável à segurança portuária. É apresentada uma análise abrangente dos métodos de classificação dos diversos tipos de veículos não tripulados (UAVs, USVs, UUVs e UGVs), bem como uma avaliação da sua utilização em conflitos recentes e em portos internacionais de referência (Antuérpia, Los Angeles e Haifa). A investigação inclui uma avaliação detalhada do Porto de Sines, que abrange características meteorológicas, postura de segurança, análise de infraestruturas, bem como avaliações de ameaças e vulnerabilidades, complementada por entrevistas a peritos sobre a aplicação de UxVs em contextos de segurança e defesa. É proposto um conceito de emprego de UxVs especialmente adaptado para o Porto de Sines, com requisitos operacionais para cada tipo de sistema. Este modelo proposto foca-se apenas na componente de segurança. Os resultados evidenciam o elevado potencial dos UxVs para reforçar a proteção do Porto de Sines, especialmente nas áreas de vigilância, cobertura persistente e resposta a ameaças, identificando igualmente desafios relacionados com a interoperabilidade e os procedimentos operacionais.

Palavras-Chave: Proteção Portuária; Veículos não Tripulados; Segurança Portuária; Infraestruturas Portuárias.

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Table of Acronyms and Abbreviations

AIS	Automatic Identification System
ALARS	Autonomous Launch and Recovery System
AMN	*Autoridade Marítima Nacional,* Portuguese Maritime Authority
ACC	Air Component Commander
APP	*Autoridade de Proteção Portuária,* Port Protection Authority
ATP	Allied Tactical Publication
AUV	Autonomous Underwater Vehicles
BCAA	Belgian Civil Aviation Authority
BVLS	Beyond Visual Line of Sight
CCOPP	*Centro Coordenador de Operações de Proteção do Porto*
CCTV	Closed-Circuit Television
C-IED	Counter-Improvised Explosive Device
CIC	Combat Information Centre
CITAN	Centro Integrado de Treino e Avaliação Naval
COE CSW	Centre of Excellence for Operations in Confined Waters
COMINT	Communication Monitoring and Intelligence
COTS	Commercial off-the-shelf
CS	Critical Spots
C-UAV	Counter Unmanned Aerial Vehicles

C2	Command and Control
C3	Command, Control and Communications
C4ISTAR	Command, Control, Communication, Computers, Intelligence, Surveillance, Target Acquisition and Reconnaissance
DGRM	*Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos*
EASA	European Union Aviation Safety Agency
EDA	European Defense Agency
EEZ	Exclusive Economic Zone
EME	Electromagnetic Environment
EO	Eletro-Optical
EOD	Explosive Ordinance Disposal
EW	Electronic Warfare
FAA	Federal Aviation Administration
FMV	Full-motion video
FPC	Force Protection Coordinator
FPV	First Person View
FOC	Full Operational Capabilities
GNR	*Guarda Nacional Republicana*
GPS	Global Positioning System
HALE	High Altitude Long Endurance
HARMSPRO	Harbour and Maritime Surveillance and Protection
HCI	Human-Computer Interface
HP AOI	Harbour Protection Area of Interest
HPC	Harbour Protection Commander

HP COP	Harbour Protection Common Operational Picture
HPL	Harbour Protection Level
HPM	Harbour Protection Module
HPO	Harbour Protection Operation
HP TAOR	Harbour Protection Tactical Area of Responsibility
HRI	Huma-Robot Interaction
IDF	Israel Defense Forces
IED	Improvised Explosive Device
IFF	Identify Friend or Foe
IOC	Initial Operating Capability
IPC	Israel Port Company
IMO	International Maritime Organization
IR	Infrared
ISPS	International Ship and Port Security
ISR	Intelligence, Surveillance and Reconnaissance
LCC	Land Component Commander
LiDAR	Light Detection and Raging
LOS	Line of Sight
LORA	Levels of Robot Autonomy
LoRa	Long Range
LPS	Local Positioning System
MALE	Medium Altitude Long Endurance
MCC	Maritime Component Commander

MCM	Mine Countermeasures
MTOW	Maximum Take-off Weight
MUM-T	Manned-Unmanned Teaming
OCC	Operations Command Centre
OTC	Officer in Tactical Command
POLA	Port of Los Angeles
PFSO	Port Facility Security Officer
PFSP	Port Facility Security Plan
RADAR	Radio Detection and Ranging
RAM	Rocket, Artillery and Mortar
RCS	Radar Cross Section
RF	Radio Frequency
RHIB	Rigid Hull Inflatable Hull
ROV	Remotely Operated Vehicle
RTB	Return to Base
RTK	Real-Time Kinematic
SAFIR	Safe and Flexible Integration of Initial U-space Services in a Real Environment
SAR	Synthetic Aperture Radar
SIS	*Serviços de Informações de Segurança*
SLAM	Simultaneous Localization and Mapping
SOLAS	Safety of Life at Sea
STANAG	Standardization Agreement
TCS	Container Terminal

TEU	Twenty-Foot Equivalent Unit
TGL	Liquid Bulk Terminal
TGN	Natural Gas Terminal
TPQ	Petrochemical Terminal
TTP	Tactics, techniques and procedures
UAE	United Arab Emirates
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UCCF	*Unidade de Controlo Costeiro e de Fronteiras*
UGV	Unmanned Ground Vehicles
U.S.A.	United States of America
UNCLOS	United Nations Convention on the Law of the Sea
USV	Unmanned Surface Vehicle
UxV	Unmanned Vehicles
VTOL	Vertical take-off and landing
VTS	Vessel Traffic System

1. Introduction

1.1 Motivation

On August 4, 2020, the world witnessed an explosion that killed more than 200 people and injured about 6500 (Matthias & Meg, 2024). Beirut's Port explosion, although an accident, is a perfect example of what a well-executed attack on this type of infrastructure can accomplish. A similar disaster, a fire on a large oil tanker or any of a host of other events could close a port indefinitely, with catastrophic economic and ecological effects (Galdorisi G., 2022). More recently, on April 26, 2025, an explosion occurred at the Port of Shahid Rajaee in southern Iran, resulting in 40 deaths and approximately 2,200 injured. This incident reportedly originated in a storage area containing chemical and explosive materials, possibly intended for fuelling Iranian missiles (Euronews, 2025). The high number of casualties, in both explosions, was partly due to the frequent proximity between ports and nearby industrial and residential areas.

The ongoing Russo-Ukrainian war has already exposed vulnerabilities in traditional Harbour Protection strategies. Ukraine's disruptive operations in Sevastopol forced Russia to redeploy its naval assets to Novorossiysk. (McBride, 2024). This demonstrates that conventional protective measures may be insufficient against modern, asymmetric threats. This conflict serves as a stark reminder of the dynamic and unpredictable nature of maritime security challenges.

In response to these multifaceted threats, leading harbours worldwide are increasingly turning to Unmanned Vehicles (UxVs) to enhance their security posture. For instance, the Port of Los Angeles has successfully demonstrated the use of Unmanned Surface Vehicles (USVs) to enhance monitoring and patrolling efficiency (Hydro International, 2025). Similarly, the deployment of unmanned aerial vehicles (UAV) at the Port of Antwerp highlights the practical benefits of these systems in achieving continuous, cost-effective surveillance and incident management capabilities (Port of Antwerp-Bruges, 2023).

Harbour Protection is an increasingly critical aspect of national defence, particularly considering emerging threats to maritime infrastructure. Portugal has the third biggest exclusive economic zone (EEZ) of the European Union comprised of 3 subareas: continental subarea (287 521 km^2), subarea of Azores (930 687 km^2) and subarea of Madeira (442 248 km^2) (DGRM, 2025). With roughly 1794 Km of coastline (Gama, 2024), strategically located at the western edge of Europe, Portugal's ports, particularly Lisbon, Leixões and Sines, serve as a gateway to Europe, facilitating international trade. As Portugal's busiest deep-water port in terms of moved cargo (APS, 2025), Sines plays a vital role in the national economy. Its strategic importance is not only due to its role as a key entry point for energy supplies, including oil and its derivatives, but also to its geographic location and characteristics. Given its significance, ensuring the security of Sines Harbour is a priority that requires continuous adaptation to modern challenges. The integration of UxVs into Harbour Protection represents a modern and innovative approach to improve protection measures.

The rapid evolution of UxV technology, along with its successful deployment in various international contexts, underscores its potential in safeguarding critical maritime assets. For the Portuguese Navy and *Autoridade Marítima Nacional* (AMN), responsible for protecting national waters and harbours, assessing the applicability of this technology is essential, especially in response to evolving threats to Portugal and its allies.

Furthermore, Portugal is the NATO nation responsible for the Harbour Protection doctrine and currently in charge of updating it, additionally is one of the four nations invested in the Harbour and Maritime Surveillance and Protection (HARMSPRO) project and has defined as a NATO Capability Target the development of a Harbour Protection Module (HPM) until the start of the year 2026.

Since this thesis focuses on Sines Harbour, it might seem more related to port security than Harbour Protection. However, the term "protection" is used to cover both security and defence measures needed to safeguard Sines Harbour in two different scenarios. The first scenario looks at how UxVs can support and enhance existing security measures under routine conditions. The second explores how UxVs could be used to defend the harbour against potential asymmetric or unconventional threats. By addressing these scenarios, this thesis uses Sines Harbour as a case study for any civilian harbour that may host a Harbour Protection Operation (HPO) while also seeking to enhance its existing security measures.

1.2 Methodology

This thesis adopts a qualitative research methodology to explore the role of UxVs in Harbour Protection, with a specific focus on Sines Harbour. This includes the analysis of existing literature and resources (civilian and military), case studies of three civilian ports that are using or testing UxVs in their security frameworks and six interviews with experts in UxV technology, Harbour Protection and Port Security. Additionally, a field visit to Sines Port provided first-hand insights into its infrastructure, vulnerabilities and current security measures.

Based on the collected data and information, contributions will be made toward a proposal for the integration of UxVs in Sines Port. This proposal aims to align with the needs of the Sines Port Administration and current trends in UxV technology. This proposal includes a SWOT analysis of the current security framework and a series of radar plots that help to visualize key technical features of selected platforms, such as endurance, speed and payload capacity.

1.3 Objectives

This research aims to explore the role of UxVs in enhancing the security and defence of Sines Harbour. To achieve this, the current thesis work is guided by the following objectives:

- **Study the potential security applications of UxVs in Sines Harbour**

This thesis will explore how UxVs can contribute to surveillance and incident response. The study will assess their role in enhancing routine security operations and analyse three different situations where Port Administrations are integrating UxV technology in their security frameworks.

- **Study the potential defensive applications of UxVs in Sines Harbour**

The study will analyse the use of UxVs for detecting and countering external asymmetric or unconventional threats, thus ensuring the harbour's defence in heightened threat scenarios. It will analyse two modern conflicts were UxVs are performing a major role in both defence and attack.

- **Provide contributes to an implementation plan of UxVs in Sines Harbour**

Based on the findings, this objective aims to contribute to an implementation plan for the adoption of UxV technology in Sines Harbour. This plan will be a contribute to the security of one of Portugal's most important commercial ports by aligning it with the practices of other nations that have already integrated UxV technology into their port security frameworks.

By addressing these objectives, this dissertation seeks to align with the modernization of maritime protection strategies, supporting the Portuguese Navy and *AMN* in safeguarding national maritime infrastructure.

1.4 Thesis Structure

To fulfil the mentioned objectives, the master's dissertation is divided into seven chapters that contribute to their achievement. The first chapter, introduction, offers the motivation behind this study, utilized methodology, the thesis objectives and structure.

Chapter two, background, will provide the foundation upon which the rest of the thesis will be built. It focuses on the Harbour Protection doctrine, legal framework governing international and Portuguese harbours and will address the classification terminology for UxVs.

The third chapter, state of the art, will analyse their applications in conflicts and their role in international harbours. The objective of this chapter is to analyse existing technological developments and operational uses of UxVs in the world.

The fourth chapter, analysis of Sines Harbour, will examine its geographic and physical characteristics, existing security measures and vulnerabilities. This chapter will identify potential risks and evaluate the current security framework of Sines Harbour to understand where UxVs can enhance protection efforts. This chapter will also include a criticality, threat and vulnerability assessments.

The fifth chapter, analysis on the application of UxVs in Sines Harbour, will assess how UxVs can be used for security applications and defence applications through interviews made to experts in the field. These interviews aim to provide qualitative perspectives on the practical challenges and advantages of UxV integration in harbours.

Chapter sixth chapter, contributes for an implementation proposal of UxVs in Sines Harbour, will detail the main objectives of integrating UxVs in Sines, selection of UxV types, their operational requirements as well as key challenges and limitations that should be addressed.

The seventh and last chapter, conclusions, will summarize the results of the research, reflect on the limitations of the study and suggest future work in the field.

2. Background

This chapter provides the background for the entire thesis. Harbour Protection is a complex concept with distinct interpretations in civilian and military contexts. In civilian literature, there is often a lack of clear distinction between Harbour Protection and port security. In fact, most civilian documents that refer to Harbour Protection are, in practice, addressing port security.

The civilian dimension is defined by international, European and national legislation, most notably the ISPS Code. This document establishes both mandatory and recommended security measures, including the use of physical barriers such as fencing, access control systems, surveillance equipment and coordination mechanisms among stakeholders.

The military dimension, on the other hand, provides a different perspective on Harbour Protection. Although no NATO-approved definition currently exists, the concept is articulated in the Allied Tactical Publication - 94 (ATP-94), the principal military doctrinal document addressing this subject. This document will be analysed as the primary military reference for Harbour Protection.

Both perspectives, civilian, through legal frameworks and military, through doctrinal guidance, will be explored in the following subchapters. Understanding these two approaches is essential to grasp the full complexity of Harbour Protection and to appreciate how they differ yet complement one another.

Additionally, UxV classification systems will be addressed to introduce accepted terminology and categories. This classification supports the technical analysis in subsequent chapters.

2.1 Doctrine Analysis

The NATO reference for Harbour Protection is the (ATP-94). This document provides an overview of several aspects of Harbour Protection, covering its purpose, scope, planning factors and employment considerations for conducting a HPO, (NATO, 2017). In addition, it outlines the underlying philosophy, guiding principles and contextual background of HPOs. Notably, the document remains NATO UNCLASSIFIED, allowing civilian stakeholders to use it as reference.

Published in 2017, ATP-94 is the result of the work carried out by a NATO Specialist Team on Harbour Protection, led by Portugal in collaboration with the Centre of Excellence for Operations in Confined and Shallow Waters (COE CSW).

2.1.1 Harbour Protection Fundamentals

According to ATP-94, Harbour Protection encompasses the safety and security measures necessary for protecting units, facilities and critical infrastructure located in port and harbour areas, as well as associated anchorages. (NATO, 2017). It is important to keep in mind that this definition of Harbour Protection presented in ATP-94 is not, yet NATO approved.

Although not mentioned in ATP-94, it is useful to distinguish between a port and a harbour. A Harbour is a sheltered body of water where ships, boats and barges can be moored. A port is a maritime facility comprising one or more loading areas, where ships load and discharge cargo and passengers (Wikipedia contributors, 2025). According to this definition, a harbour, either natural or artificial, can include one or more ports.

According to ATP-94, an HPO is the combined activity of harbour defence and port security. Harbour defence refers to the defence of a harbour, anchorage and its water approaches against external asymmetric/unconventional threats. Port security is the safeguarding of vessels, harbours, ports, waterfront facilities and cargo from internal threats such as destruction, loss or injury from sabotage or other subversive acts, accidents, thefts, or other causes of similar nature. Conventional threats, such as traditional military operations, are more difficult to conceal and should be countered by conventional capabilities which are out of the Harbour Protection spectrum (NATO, 2017).

2.1.2 Harbour Protection Module

A critical component of an HPO, highlighted in ATP-94, is the HPM. The HPM is an integrated, deployable, modular, interoperable and armoured system of systems, which can be employed either ashore or aboard a ship (whether berthed or at anchor) (NATO, 2017). At its core, it consists of a manned Combat Information Centre (CIC) with an Information Management and Combat Direction System, integrated communications, sensors and effectors. Together, these elements create a Command, Control, Communication, Computers and Intelligence, Surveillance, Target Acquisition and Reconnaissance (C4ISTAR) system which helps to build up a Harbour Protection Common Operational Picture (HP COP). This 24/7 operational awareness assists the Harbour Protection Commander (HPC) and assigned forces in detecting, monitoring and responding to asymmetric tree-dimensional threats within the Harbour Protection Tactical Area of Responsibility (HP TAOR), (NATO, 2017). The concept of a HPM is depicted in **Figure 1**.

Figure 1- Harbour Protection Module[1]

[1] Figure taken from (NATO, 2017)

Although a NATO-approved standard for a HPM has yet to be established, Portugal has defined as a NATO capability target the development of such module until 2026. Various modules have already been tested, including one, jointly operated by the Portuguese and German navies during an exercise off the coast of Portimão in 2015 (DOĞAN, D. & ÇETİKLİ, D., 2023). More recently, the German Navy employed a similar module to assist in the C2 of its Skeldar V-200 rotary-wing UAV, during REPMUS 2024.

2.1.3 Harbour Protection Areas

Due to the complexity of a harbour, ATP-94 divides the harbour into several distinct areas, each with specific characteristics and levels of importance.

- Harbour Protection Area of Interest (HP AOI): Area in which developments are likely to affect the outcome of Harbour Protection Operations. It includes locations where adversary actions will influence the commander's decisions.
- Harbour Protection Tactical Area of Responsibility: Area in which the HPC is responsible for conducting Harbour Defence and Port Security activities.
- Harbour Safety Area (HSA): Area where the HPC must guarantee that port operations can be conducted at a minimum risk.
- Critical Spots (CS): Specific areas that if affected, are likely to compromise the outcome of the HPO.
- Exclusion Zone (EZ): Advertised and protected area, near or within a harbour where civilian movements are prohibited.
- Electromagnetic Environment (EME): Operational environment that encompasses the totality of electromagnetic phenomena existing at a given location.

A visual representation of some of these areas is presented in **Figure 2**.

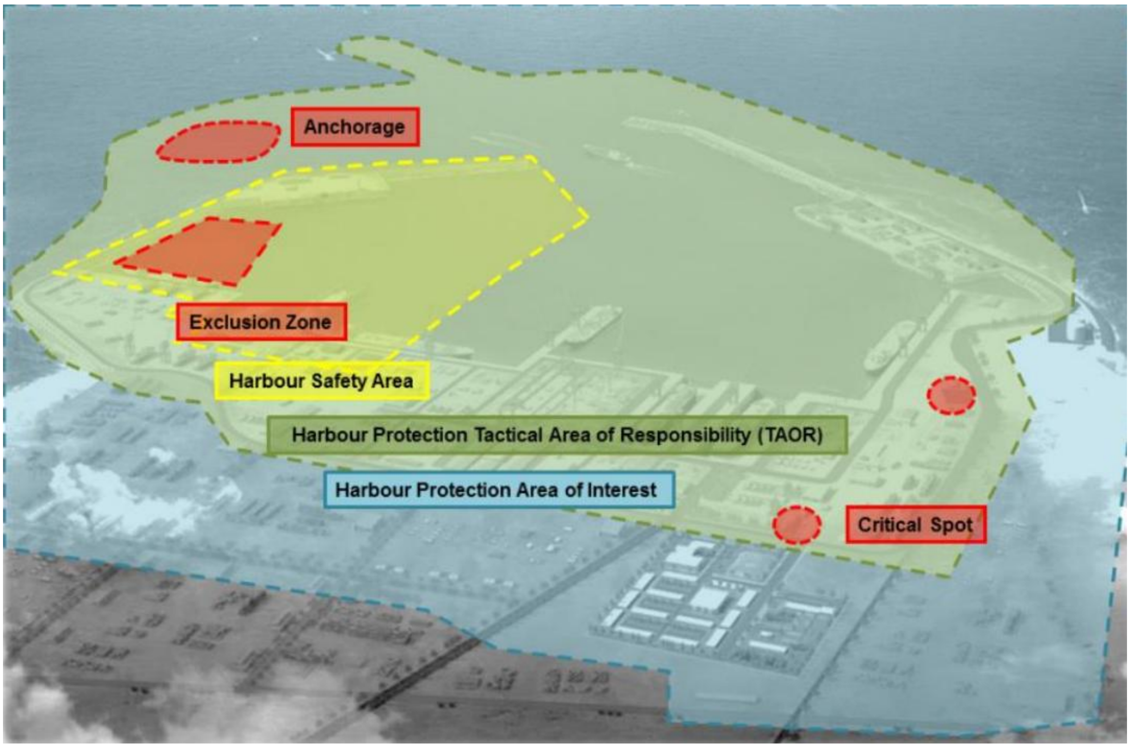

Figure 2- Harbour Protection Areas[2]

2.1.4 Harbour Protection Considerations

According to NATO doctrine, the Harbour Protection Commander (HPC) is an operational experienced staff officer assigned by the Officer in Tactical Command (OTC) to exercise command/control of forces conducting Harbour Defence/Port Security tasks. The HPC should be in close coordination with the Port's Civilian Administration and with the *Capitania.* In routine port operations there is no HPC, making the coordination between the Administration and the *Capitania* extremely important. The mechanisms underlying this coordination, along with the national legislation governing the process, are detailed in Chapter 4.2.4.

[2] Figure taken from (NATO, 2017)

ATP-94 analyses the planning process of an HPO, detailing best practices and key considerations. One of the most important steps in planning a HPO is the Hazard and Threat Identification. This process consists of three key assessments: criticality, threat and vulnerability assessments. The criticality assessment should identify all assets that, if attacked or disrupted, would result in mission failure. The infrastructure or areas that fall into this category are designated CS and require especial protection measures. It is very important to consider every aspect of the port facility security plan (PFSP) in this planning stage. The PFSP is a plan done by the contracting government that includes an extensive list of the port infrastructure's safety and security considerations. The threat assessment should define the likely threats and hazards to the mission, while taking into account the opponent's capacities (NATO, 2017). The vulnerability assessment should identify inherent weaknesses in the infrastructure and facilities to be protected that can be exploited by opposing forces (NATO, 2017). The full planning process is illustrated in **Figure 3.**

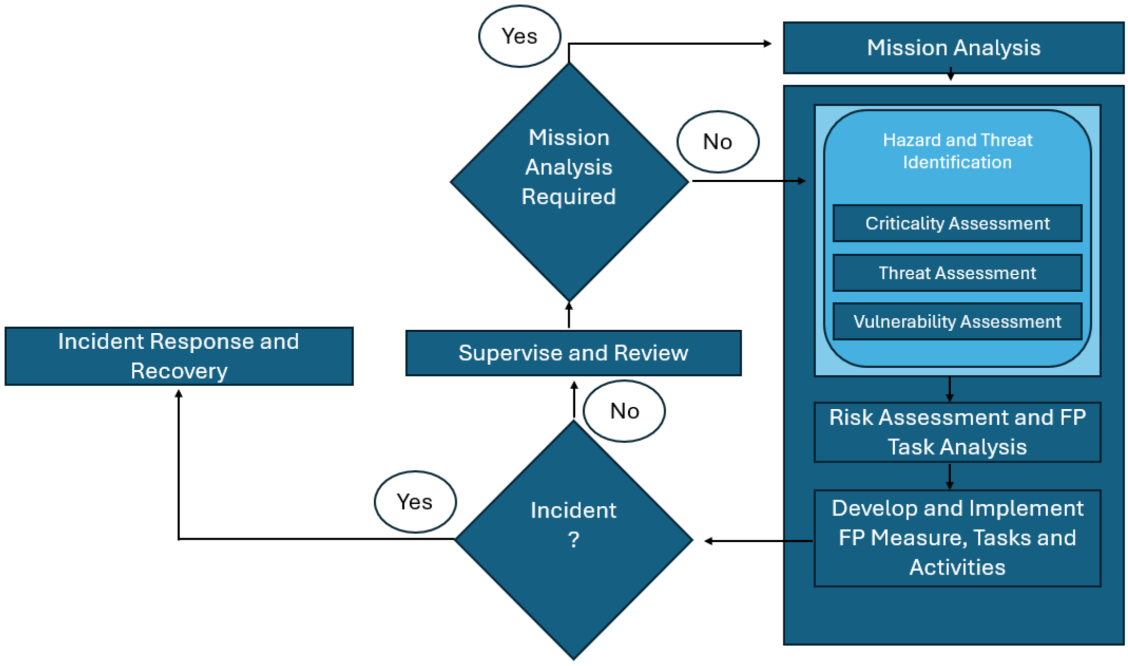

Figure 3- Harbour Protection Planning Steps[3]

Another key planning factor is the location of the Harbour Protection Module or a correspondent C2 structure. Its placement is influenced by several factors, including the topography and geometry of the Harbour, available assets and capabilities, the location of critical spots and proximity to anchor areas among others (NATO, 2017). This is also true for the Administration's Command, Control and Communication (C3) structure.

An essential aspect of Harbour Protection planning is the integration of intelligence and surveillance with environmental analysis. Key factors such as oceanographic characteristics, climatic conditions, sunspot activity, geospatial data, maritime traffic and the electromagnetic environment (EME) are vital for establishing a clear understanding of the operational area (NATO, 2017).

[3] Information retrieved from (NATO, 2017)

The ultimate objective of a HPO is to safeguard both forces and critical infrastructure. To achieve this, a high degree of coordination is required across maritime, air, land and force protection components.

If the port hosting the HPO complies with the ISPS Code, it provides a solid foundation upon which to build the Harbour Protection capabilities. All existing ISPS security measures should be fully utilized and supplemented with additional protective measures as necessary.

While an HPO aims to achieve Full Operational Capability (FOC) for all its assets, it is important to note that the port's security elements, the Port Administration and the *Capitania,* should already have a well-established Common Operational Picture (COP) for port routine operations. This security COP should serve as solid foundation to the achievement of the FOC. The FOC is only achieved when the HPM is fully connected with all actors and a comprehensive HP COP is established (NATO, 2017).

According to NATO's ATP-94, to reach FOC, the HPC should utilize all assigned forces, regardless of service branch, that can provide the following capabilities:

- Protect the land and seaward HP TAOR;
- Conduct Area surveillance and reconnaissance in wet and dry areas;
- Conduct Explosive Ordnance Disposal (EOD)/Counter-Improvised Explosive Devices (C-IED)/Improved Explosive Devise Disposal;
- Provide air defence against asymmetric air threats;
- Conduct Very Shallow Waters Mine Countermeasures (VSWMCM);
- Conduct Escorting Operations on Sea;
- Conducting military logistic operations;
- Conduct intelligence gathering activities.

The final objective a HPO is to detect, identify, track, intercept and engage all suspect or hostile targets before they enter the HP TAOR (NATO, 2017).

2.1.5 Harbour Protection Coordination

One of the HPC tools to coordinate the forces response is through the establishment of the appropriate Harbour Protection Level (HPL) and promulgation of a set of Harbour Protection Measures (HPROMs). There are five HPL:

- HP Level 5. Normal security measures.
- HP Level 4. General threat against HPO, the nature and extent of which is unpredictable.
- HP Level 3. Increased and more predictable threat against HPO.
- HP Level 2. Unlawful action or attack is imminent against HPO.
- HP Level 1. After an unlawful action or attack has occurred or a threat in a specific location or by a specific actor is likely.

The HPROMs will be issued by the HPC in accordance with the operational requirements and the prevailing tactical scenario. A list of reference HPROMs can be found in **Annex A**. However, the HPC retains the authority to establish additional HPROMs as needed to better respond to evolving tactical situations.

It is relevant to understand how the HPL relates with other alert and readiness sates. In **Table 1** we can see the relationship between the HPL, the Force Protection Level (FPL), the Security Alert State (SAS) and the Security Level of the International Ship and Port Facility Security (ISPS) code.

<table>
<tr><th>Harbour Protection Level</th><th>Force Protection Level</th><th>Security Alert State</th><th>ISPS Code</th></tr>
<tr><td>ONE</td><td>ONE</td><td rowspan="2">DELTA</td><td rowspan="2">THREE</td></tr>
<tr><td>TWO</td><td>TWO</td></tr>
<tr><td>THREE</td><td>THREE</td><td>CHARLIE</td><td rowspan="2">TWO</td></tr>
<tr><td>FOUR</td><td>FOUR</td><td>BRAVO</td></tr>
<tr><td>FIVE</td><td>FIVE</td><td>ALFA</td><td>ONE</td></tr>
</table>

Table 1-Relationship between HPL-FPL-SAS-ISPS[4]

The FPLs are detailed in Allied Maritime Force Protection doctrine (ATP-74) and serve as a standardized mechanism for the Force Protection Commander (FPC) to counter threats effectively. They have a direct correlation with the HPLs.

Security Alert States (SAS) are security arrangements applied across all NATO military installations. SAS levels ALFA, BRAVO and CHARLIE are inversely related to HPL THREE, FOUR and FIVE. The first two levels (HPL ONE and TWO) both fall under the category of security alert state DELTA. This alert state is activated in the immediate area where a terrorist attack has occurred or when intelligence indicates that a terrorist action against a specific location or person is likely.

The ISPS code is a comprehensive security framework developed by the International Maritime Organization (IMO) to enhance the security of ships and port facilities.

- Security Level 1. Normal operating level for the port facility. Minimum appropriate protective security measures shall be maintained at all times. It corresponds to HPL 5.

[4] Table taken from (NATO, 2017)

- Security Level 2. Applied when there is a heighten risk of a security incident. Additional protective security measures shall be maintained for a period of time. It corresponds to HPL 3 or 4.
- Security Level 3. Activated when an attack is probable or there is an imminent risk of a security incident. Further specific protective security measures shall be maintained for a limited period of time. It can correspond to HPL 1 or 2.

There is no strict relationship between the alert/readiness states mentioned. The HPC is responsible for determining the appropriate HPL based on the type and timing of the threat. The FPC may choose to implement or adjust the corresponding FPL but is not mandatory. Similarly, the ISPS Code level may remain unchanged, even if the HPL is adjusted.

Depending on the size and complexity of the HP TAOR, the HPC can subdivide the area and apply different HPLs across various sectors, ensuring a flexible and adaptive security approach.

2.2 Legal Framework

Given the number of legal documents governing the Law of the Sea and the regulations applicable to harbours, it is essential to provide a solid legal ground. This framework aims to analyse key regulations related to Harbour Security and the responsibilities of key stakeholders in the area.

2.2.1 United Nations Convention on the Law of the Sea (UNCLOS)

The UNCLOS is an important reference for all sea-related affairs. It provides definitions for key maritime terms and offers guidelines for the regulation of maritime activities.

Article 25.º of UNCLOS is of special importance for this thesis work because it outlines the rights of coastal states regarding the protection of their maritime spaces. It explicitly grants coastal states the authority to take necessary measures to prevent the entry of vessels into internal waters or harbour facilities, if such entry would violate the conditions set for admittance. This provision establishes a legal foundation for pre-emptively securing port installations from unauthorized or potentially harmful maritime incursions.

2.2.2 International Convention for the Safety of Life at Sea (SOLAS) and the International Ship and Port Facility Security (ISPS) Code

SOLAS is generally regarded as the most important of all international treaties concerning the safety of merchant ships (International Maritime Organization, 2024). In Portugal, SOLAS has been integrated into national law, ensuring that its safety and security measures are implemented to protect lives at sea.

In response to the World Trade Center terrorist attacks, the Diplomatic Conference of the IMO introduced amendments to the SOLAS convention, including the addition of Chapter XI-2 "Special measures to enhance maritime security" and the adoption of the ISPS Code in 2004. Chapter XI-2 provides the legal framework for the security of passenger ships, cargo ships, mobile offshore drilling units and port facilities serving such ships engaged in international voyages (International Maritime Organization, 2024).

Regulation 3 of the stated chapter establishes the Contracting Governments responsibilities in setting the appropriate security levels for their territorial waters and ports. These security levels must be communicated to ships operating within their jurisdiction and port facilities. This security levels, already showed in **Table 1**, try to ensure a more flexible security posture. All companies operating ships must comply with the security level to ensure coordination. Compliance with security standards is promoted by regulation nine of this chapter. It states that all ships in port are subject to control and inspection by port state authorities. This control is carried out through the inspection of the ship's certificate, the security level at which the ship is operating and has operated, as well as other relevant security procedures also stated in the current regulation. If a ship is found to be non-compliant with SOLAS or ISPS requirements, authorities have the right of delaying/detaining the vessel, restricting the ship's operation or movements within the port and can even expel it from port waters.

Regulation 10 introduces the mandatory compliance of port facilities with Part A of the ISPS Code while also recommending that they consider the guidance measures outlined in Part B.

Part A of the ISPS starts by providing definitions for key terms utilised throughout the Code. The Port facility security officer (PFSO), a key stakeholder in the safeguarding of the port facility, is the person designated as responsible for the development, implantation, revision and maintenance of the PFSP, (IMO, 2003). It also provides the full definition of each of the tree security levels already mentioned.

The Code follows by numbering the responsibilities of the Contracting Government in the promulgation of the appropriate security level and in the guidance for protection from security incidents. The port facility is required to act accordingly to the promulgated security level. ISPS stablishes the following mandatory security measures for security level 1:

1. Ensuring the performance of all port facility security duties;
2. Controlling access to the port facility
3. Monitoring of the port facility, including anchoring and berthing area(s);
4. Monitoring restricted areas to ensure that only authorized persons have access;
5. Supervising the handling of cargo;
6. Supervising the handling of ship's stores;
7. Ensuring that security communication is readily available.

Part A of the code only stipulates that at security level two, additional protective measures must be implemented for each measure of security level one, taking in consideration the optional measures outlined in part B of the current code. In security level 3, the Contracting Government may issue special instructions that the port facility is required to comply with.

A PFSP is developed by the Contracting Government who should integrate provisions for the three security levels. It is made upon a port facility security assessment. Among other factors, the port facility plan should address measures to prevent weapons, unauthorized access and dangerous substances of entering in the port facilities as well as procedures for responding to security threats, evacuation and any security related instructions given by the contracting government.

Part B of the code provides an extensive set of security measures that can be implemented at each security level. Even do optional, these measures are very important and cover the following aspects:

- Access to the port facility;
- Restricted areas within the port facility;
- Handling of cargo;
- Delivery of ship's stores;
- Handling unaccompanied baggage;
- Monitoring the security of the port facility.

Specially concerning the monitoring of port facility security, the code outlines the use of lighting, security guards, including foot, vehicle and waterborne patrols as well as automatic intrusion devices and surveillance equipment. The PFSP should provide the following recommended security measures:

Security Level 1

1. Observe the general port facility area, including shore and water-side accesses to it;
2. Observe access points, barriers and restricted waters;
3. Allow port facility security personnel to monitor areas and movements adjacent to ships using the port facility, including augmentation of lighting provided by the ship itself.

Security Level 2

1. Increasing the coverage and intensity of lighting and surveillance equipment, including the provision of additional lighting and surveillance coverage;

2. Increasing the frequency of foot, vehicle or waterborne patrols;
3. Assigning additional security personnel to monitor and patrol.

Security Level 3

1. Switching on all lighting within, or illuminating the vicinity of the port facility;
2. Switching on all surveillance equipment capable of recording activities within, or adjacent to the port facility;
3. Maximising the length of time such surveillance equipment can continue to record.

B part of the ISPS code ends by enumerating some essential knowledge and capabilities that port facility personnel should have.

- Knowledge of current security threats and patterns;
- Recognition and detection of weapons, dangerous substances and devices;
- Recognition of characteristics and behavioural patterns of persons who are likely to threaten security;
- Techniques used to circumvent security measures;
- Crowd management and control techniques;
- Security related communications
- Operations of security equipment and systems
- Testing, calibration and maintenance of security equipment and systems;
- Inspection, control and monitoring techniques;
- Methods of physical searches of persons, personal effects, baggage, cargo and ships stores.

2.2.3 European Union (EU) Legislation and Projects

At the European Union level, Regulation No. 725/2004 and Directive 2005/65/EC of the European Parliament and of the Council were adopted. These two legislative instruments provide a basis for the harmonised interpretation, implementation and Community monitoring of the special measures to enhance maritime security adopted by the Diplomatic Conference of the IMO on 2002, which amended the 1974 SOLAS Convention and established the ISPS Code (European Union, 2004.)

The European Defence Agency (EDA) established in March 2018 in a more civil-military cooperation approach project, the HARMSPRO. Portugal is a project member, alongside Greece, Poland and Italy, the project coordinator. HARMSPRO aims to implement a deployable, integrated capability for the continuous protection of vessels, ports and other critical littoral and offshore infrastructure against asymmetric threats (including UAVs) in a three-dimensional environment (European Union, 2018). The project envisions the module's application in civilian harbours, provided it is well-coordinated with local authorities and employs both civilian and military resources. Notably, UxVs are considered core assets in data collection and are fully integrated into the module alongside fixed surveillance and reconnaissance systems.

2.2.4 National Legislation

In Portugal, Decree-Law No. 226/2006, of 15th November was enacted with the purpose of defining the basic structure of the necessary national organization for the operationalization and implementation of Regulation No 725/2004 and Directive 2005/65/EC (DGRM, 2025b). This decree defines the entities responsible for port security in Portugal and the coordination measures between these entities, specifically the role of a *Centro Coordenador de Operações de Proteção do Porto (CCOPP).*

The *Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos (DGRM)* is the competent Portuguese government authority responsible for the protection of maritime transportation and harbours. It is responsible for the coordination, implementation and application of port security measures. This entity works closely with *AMN* to ensure that all port security measures are implemented and maintained. Within its respective jurisdiction the *Capitão do Porto* represents the *AMN* and oversees the PFSO, who is responsible for the development, maintenance and application of the PFSP.

The responsibilities of the *Capitão do Porto* or Harbour Master are defined in Article 13.º of Decree-Law n.º 121/2014, one must stress the first and second paragraphs that support the *Capitão do Porto* authority and responsibility of executing the states authority in the matters of policing and vigilance in its area of jurisdiction. This Decree-Law defines the structure, organization, functioning and responsibilities of the *AMN.*

The Port Administration, referred to as the *Autoridade de Proteção Portuária (APP),* is responsible for managing the harbour and ensuring the safe operation of the port. According to Decree-Law No. 226/2006, the *APP* collaborates with the PFSO on the elaboration, maintenance and application of the PFSP. The Port Administrations are the primary stakeholder responsible for port security all year round. Decree-Law No. 46/2002 is also relevant because it entrusts port authorities with the responsibilities for port safety within their areas of jurisdiction.

Decree-Law No. 226/2006 also envisions the identification of possible threats to homeland security in the harbour context, trough the action of the *Serviço de Informações de Segurança* (SIS).

2.3 Unmanned Systems Classification

This chapter presents and analyses various classification models for UxVs, with the objective of establishing clear definitions and terminology that will be used throughout this thesis. By examining both NATO standards and academic frameworks, this section provides a structured overview of UxV types, their operational characteristics and the various degrees of autonomy associated with these vehicles. This.

Unmanned systems are composed by the unmanned vehicle, communication facilities, control equipment and the personnel required C2 of the vehicle. According to Allied Maritime Tactical Instructions and Procedures (ATP-01), three primary categories of UxVs are identified:

- Unmanned Aerial Vehicle (UAV): A self-propelled air vehicle operating autonomously or under minimal supervision;
- Unmanned Surface Vehicle (USV): A self-propelled surface vehicle operating autonomously or under minimal supervision;
- Unmanned Underwater Vehicle (UUV): A self-propelled submersible operating autonomously or under minimal supervision;

Although not formally listed in ATP-01, Unmanned Ground Vehicles (UGVs) are widely employed in modern conflict scenarios, particularly for C-IED disposal operations and handling unexploded ordnance that may wash ashore.

ATP-01 does not account for the varying degrees of autonomy among these systems. Autonomy refers to a vehicle's ability to sense, perceive, analyse, communicate, plan, decide and act in pursuit of operator-assigned goals (Huang, 2008). Many researchers have proposed frameworks to define UxV autonomy levels. One prominent model is the Levels of Robot Autonomy (LORA) developed by Beer, Fisk and Rogers (2014), which breaks down autonomy into core tasks: Sense, Plan and Act. This model is shown in **Table 2**.

Level of Robot Autonomy (LORA)	Function Allocation			Description
	Sense	*Plan*	*Act*	
1. Manual Teleoperation	H	H	H	The human performs all aspects of task including sensing the environment and monitoring the system, generating plans/options/goals, and implementation.
2. Action Support	H/R	H	H/R	The robot assists the human with action implementation. However, sensing and planning is allocated to the human. For example, a human may teleoperate a robot, but the human may choose to prompt the robot to assist with some aspects of a task (e.g., gripping objects).
3. Assisted Teleoperation	H/R	H	H/R	The human assist with all aspects of the task. However, the robot senses the environment and chooses to intervene with task. For example, if the user navigates the robot too close to an obstacle, the robot will automatically steer to avoid collision.
4. Batch Processing	H/R	H	R	Both the human and robot monitor/sense the environment. The human, however, determines the goals and plans of the task. The robot then implements task.
5. Decision Support	H/R	H/R	R	Both the human and robot sense the environment and generate a task plan. However, the human chooses the task plan and commands robot to implement action.
6. Shared Control with Human Initiative	H/R	H/R	R	The robot autonomously senses the environment, develops plans/goals, and implements actions. However, the human monitors the robot's progress, and may intervene and influence the robot with new goals/plans if the robot is having difficulty.
7. Shared Control with Robot Initiative	H/R	H/R	R	Robot performs all aspects of the task (sense, plan, act). If the robot encounters difficulty, it can prompt the human for assistance in setting new goals/plans.
8. Supervisory Control	H/R	R	R	Robot performs all aspects of task, but the human continuously monitors the robot. The human has over-ride capability and may set a new goal/plan. In this case the autonomy would shift to shared control or decision support.
9. Executive Control	R	(H)/R	R	The human may give an abstract high level goal (e.g., navigate in environment to specified location). The robot autonomously senses environment, sets plan, and implements action.
10. Full Autonomy	R	R	R	Robot performs all aspects of a task autonomously without human intervening with sensing, planning, or implementing action.

**Note*: H = Human, R = Robot

Table 2- LORA Levels of Autonomy[5]

[5] Table taken from (Beer et al., 2014)

Earlier models such as the ones presented by Sheridan & Verplank (1978), Endsley & Kaber (1999) and Parasuraman et al. (2000), focus on automation levels or decision-making stages, but often lacked the full context of human-robot interaction (HRI). LORA incorporates this interaction directly.

The European Union proposed in 2013 a simpler categorization of autonomy based on the degree of human involvement:

- Human-in-the-loop systems: Remotely controlled systems that require real-time human input, though some functions may be delegated;
- Human-on-the-loop systems: Operate independently but under human supervision, with override capability;
- Human-out-of-the-loop systems: Capable of selecting and engaging targets without human oversight. If their operations are limited to predefined conditions, they are denominated as “automated”. “Fully autonomous” systems are capable of operating in dynamic, unpredictable environments.

2.3.1 Unmanned Aerial Vehicle Classification

When it comes to UAVs, NATO, trough the Unmanned Aircraft System Tactics, Techniques and Procedures publication (ATP-3.3.8.2), classifies them based on maximum take-off weight and operating altitude, as seen in **Table 3**.

- Class I – Small/Mini/Micro Unmanned Aerial Systems (UAS): Small, self-contained and generally man-portable. They usually operate at low altitudes and support small unit ground forces. Are generally controlled by a single individual who also views the sensor images and/or full-motion video (FMV) usually in Line of Sight (LOS) operations;
- Class II – Tactical UAS: Systems that support manoeuvre commanders at various tactical levels of command and can also support small combatant teams when so employed. Their communication system can allow Beyond Visual Line of Sight (BVLOS) with communication relays or satellite datalinks. Data products can expand beyond FMV and may be disseminated to combat teams real-time via One System

Remote Video Terminal/Remotely Operated Video Enhanced Receiver or distributed among supported tactical command elements;

- Class III – Medium Altitude, Long Endurance (MALE)/High Altitude, Long Endurance (HALE)/Strike UAS: Generally deployed to support theatre-wide requirements. They provide varied and raging support from tactical combat teams and subordinate command levels to component operational and strategic level commanders, depending on the type of UAS and capabilities.

NATO UAS CLASSIFICATION						
Class	Category	Normal Employment	Normal Operating Altitude	Normal Mission Radius	Primary Supported Commander	Example Platform
Class III (> 600 kg)	Strike/ Combat *	Strategic/National	Up to 65,000 ft	Unlimited (BLOS)	Theatre	Reaper
	HALE	Strategic/National	Up to 65,000 ft	Unlimited (BLOS)	Theatre	Global Hawk
	MALE	Operational/Theatre	Up to 45,000 ft MSL	Unlimited (BLOS)	JTF	Heron
Class II (150 kg - 600 kg)	Tactical	Tactical Formation	Up to 18,000 ft AGL	200 km (LOS)	Brigade	Hermes 450
Class I (< 150 kg)	Small (>15 kg)	Tactical Unit	Up to 5,000 ft AGL	50 km (LOS)	Battalion, Regiment	Scan Eagle
	Mini (<15 kg)	Tactical Sub-unit (manual or hand launch)	Up to 3,000 ft AGL	Up to 25 km (LOS)	Company, Platoon, Squad	Skylark
	Micro ** (<66 J)	Tactical Sub-unit (manual or hand launch)	Up to 200 ft AGL	Up to 5 km (LOS)	Platoon, Squad	Black Widow

Table 3- UAV NATO Classification[6]

[6] Table taken from (NATO, 2020)

The US Army classifies UAVs based on their wing type, which is useful on the battlefield as it is a readily identifiable characteristic that is associated to certain capabilities. This classification is available in **Table 4.**

Type	Advantages	Limitations
Fixed-wing	• Increased flight time. • Generally low audible signature. • Carry larger payloads. • Greater speed.	• May have increased operational and sustainment requirements. • Needs room for takeoff and landing. • Must constantly move forward, not able to hover.
Rotary-wing / multirotor	• Vertical take-off and landing capable, which means they can make off from almost anywhere. • Ability to hover and stare capability. • Requires little training. • Low cost easy to acquire and conceal.	• Low load carrying capacity. • Limited speed.
Balloon	• Long duration. • Able to operate at high altitudes. • High load carrying capacity.	• Limited ability to maneuver. • Needs room for takeoff and landing.

Table 4- UAV Type Classification[7]

Fixed-wing UAVs and rotary wing UAVs differ fundamentally in design and operational capabilities. Fixed-wing UAVs generate lift like conventional airplanes. Their superior engine efficiency allows them to cover large areas and be more resistant to side winds. One advantage of these systems is their ability to glide when faced with a total power failure. However, they are limited by their inability to hover and require a dedicated runway or launch system for take-off and landing, since only the smallest fixed-wing UAVs are suitable for hand launch and “belly landing” in an open field (Garg, 2022). In contrast, rotary wing UAVs use multiple propellers to achieve vertical take-off and landing (VTOL) capabilities and maintain stable hovering. This design makes them highly manoeuvrable and ideal for surveillance in tight spaces and urban combat, tough they generally exhibit lower flight endurance and speed due to the energy-intensive nature of their hovering capability (Garg, 2022). Ballon type UAVs are extremely

[7] Table taken from (Department of the Army, 2023)

restricted in terms of manoeuvrability but still see operational usage mainly as surveillance assets as witnessed in February 4, 2023 when a surveillance ballon traversed over continental United States (U.S. Department of Defense, 2023)

It is also important to consider how UAVs are flown. Many are operated using a pilot's ground-based perspective, but First Person View (FPV) UAVs offer an immersive experience by transmitting real-time footage from the UAV's onboard camera to a screen or video googles. This setup provides the operator with a direct visual feed from the drone's perspective (The Droning Company, 2025). FPV systems typically introduce a video delay ranging from 100 to 200 milliseconds (Ovenka, 2023). FPV UAVs are usually lighter, faster and more agile than traditional models, making them ideal for high-speed manoeuvring. They are usually more challenging to control and require greater piloting skills. (Ovenka, 2023).

2.3.2 Unmanned Ground Vehicle Classification

The U.S. Navy uses four categories to describe UGVs (C. Turner, 2019):

- Small < 181 kg;
- Lightweight 181-907 Kg;
- Medium 907 Kg- 15 tons;
- Large > 15 tons;

The U.S. Army uses four categories as well, but the weight classification differs (C. Turner, 2019):

- Micro (< 4.5 kg): Ultra-portable systems for reconnaissance and confined space operations;
- Small (4.5-91 Kg): Portable Systems for surveillance and EOD operations;
- Medium (91 Kg-1.36 tons): More capable systems used for logistics or mine clearance;
- Large (> 1.36 tons): Heavy-duty systems for transport and complex combat roles.

In addition to weight, the method of locomotion offers crucial insight into the operational suitability and performance characteristics of UGVs, such as speed and traction. Tracked systems provide enhanced traction on varied terrains by distributing the vehicle's weight over a larger surface area, while wheeled vehicles are optimized for speed and manoeuvrability in a more urban setting (Dinelli et al., 2023). Additionally, bio-inspired vehicles, such as legged robots, are becoming increasingly useful on the battlefield, performing roles that can range from reconnaissance to counter-terrorism (Wgi.world, 2024).

One of the most used asymmetric weapons is the Improvised Explosive Device (IED), (NATO, 2017). IEDs are "homemade" bombs or destructive devices, mainly used by criminals, vandals and terrorists with intend to destroy, incapacitate, harass or distract (The National Academies & Homeland Security, n.d.). Lessons learned from conflicts in the Middle East demonstrate how dangerous IEDs can be. In a large harbour, multiple locations could serve as potential targets where an IED could cause serious damage. UGVs equipped with the appropriate tools and controlled remotely have proven to be an effective means of dealing with IEDs and mitigating the casualties they can cause. (Bartnicki et al., 2014).

2.3.3 Unmanned Surface Vehicle Classification

USVs vary widely in size, capability and autonomy. A widely adopted classification, developed by Carderock Laboratory, is based on size (Dong et al., 2021):

- Small: < 1 ton;
- Medium: < 100 tons;
- Large: < 1000 tons;
- Extra-Large: > 1000 tons.

Carderock Laboratory's classification does not fully capture the operational diversity of USVs, especially among those in the small category (< 1 ton), the most prevalent type. These small USVs are currently being employed in the Ukrainian war for a wide range of roles, including kamikaze-style attacks, UAV deployment, torpedo launching, anti-air operations and both reconnaissance and surveillance missions (Sutton B., 2024).

2.3.4 Unmanned Underwater Vehicle Classification

UUVs are mainly categorized by their autonomy due to the limits of underwater communication (Ghatak et al., 2024). A distinction is drawn between Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs). The Naval Mine Warfare Principles publication (ATP-06) also makes this distinction.

ROVs are normally tethered and manually controlled in real time. The cable supply's communications usually acts as power supply but limits movement and risks of entanglement. According to Ghatak et al. (2024), ROVs are classified into seven types depending on their weight, depth range and horsepower:

- Micro-class: Usually under 3 Kg and can go a maximum depth of 100 metres with a work power inferior to 5 horsepower;
- Mini-class: <15 Kg and offer an alternative to diver's;
- General-class: Less than 5 horsepower and can carry more sensors like Sonar's. They can work at a maximum depth of 1000 metres;
- Inspection-class: Used for commercial or industrial operations;
- Light work-class: Up to 50 horsepower with polymer frameworks enables it to work at a depth up to 2000 metres;
- Heavy work-class: Typically powered with up to 220 horsepower with the ability to carry manipulators (claws). Depth range up to 3500 metres;
- Trenching and burial-class: Designed for high-powered work, typically in having 200 to 500 horsepower with an ability to work to 6000 metres.

AUVs are UUVs that are capable of executing their mission without external positive control. Following launch, AUV's perform their mission, either based on a pre-planned or programmed sequence or a decision algorithm and own sensor information

(NATO, 2019). According to Ghatak et al. (2024) these systems are further classified by propulsion method:

- Underwater Gliders: Rely on buoyancy changes and hydrofoils to move. They are extremely energy-efficient, capable of long missions at low speeds (0.6 knots). Ideal for oceanographic surveys;
- Propelled AUVs: Use of thrusters or propellers for dynamic movement and higher speed. Suitable for precision tasks like cable tracking and deep-sea missions;
- Biomimetic AUVs: Mimic marine animals using smart actuators like shape memory alloys or Ionic Polymer-Metal Composites to achieve natural undulatory or oscillator propulsion. Offer stealth and agility but pose challenges in control and implementation.

3. State of the Art

This thesis focuses on analysing the latest applications of UxVs, particularly their use in contemporary battlefield scenarios and within the security frameworks of harbours. First, a study of UxV deployment in the Ukraine War and the Gaza conflict will provide insight into recent trends, emerging technologies and the current capabilities of these systems. This will be followed by three case studies that illustrate how UxVs are being integrated or tested in International Harbours.

3.1 Unmanned Vehicles Used in Conflicts Through the World

Analysing the current use of UxVs in modern-day conflicts is essential for understanding their evolving role in modern warfare. This analysis not only highlights their operational significance but also sheds light on the emerging technologies being integrated into these systems that contribute to an enhanced performance and to the expansion of their capabilities both in the battlefield as in civilian applications.

3.1.1 UxVs in the Russia-Ukraine War

The war in Ukraine shows that UAVs, of various levels of sophistication, autonomy and types of functions, have become essential element of modern warfare (Rickli et al., 2024). This conflict has seen the extensive utilisation of unmanned systems by both sides. Especially in the realm of commercial UAVs, Ukraine has played a more disruptive and innovative role, leading the integration of unmanned systems into its tactics. In contrast, Russia has taken a more reactive approach, focused on countering Ukrainian UAVs while gradually incorporating its own systems into the battlefield (Pettyjohn, 2024). The agile integration of UAVs and the evolution of drone deployment are illustrated in **Figures 4** and **5**.

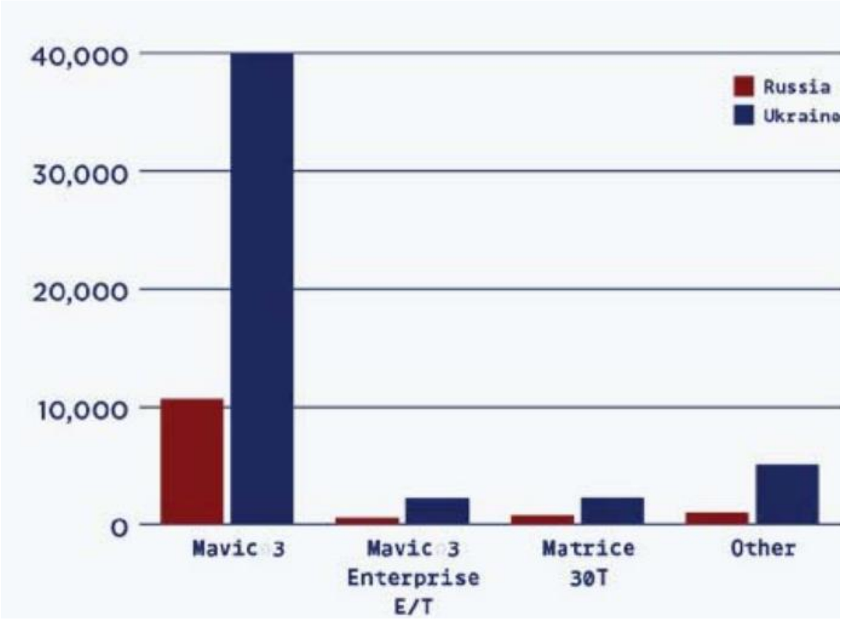

Figure 4- DJI Drone Detections in Ukraine, June-December 2022[8]

[8] Image retrieved from (Pettyjohn, 2024)

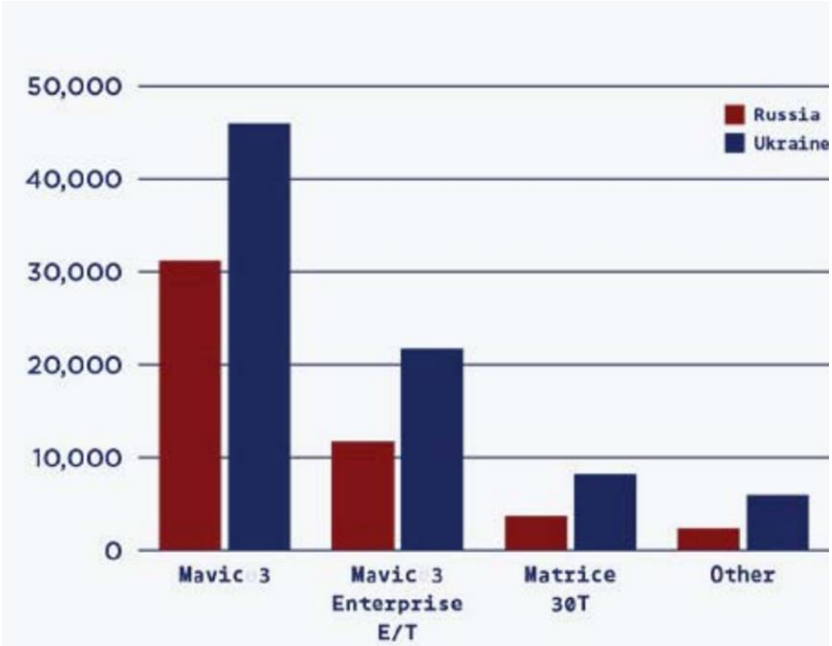

Figure 5- DJI Drone Detections in Ukraine, October 2022-March 2023[9]

In terms of military UAVs, a special note goes to the Turkish Baykar Bayraktar TB2. This MALE drone has a wingspan of 12m and weights 700kg, (Automated Decision Research, 2023). This Class III UAV can be seen in **Figure 6**. The TB2 was one of the few armed military UAVs that Ukraine had at the start of the war and the only one that carried precise laser-guided bombs (Pettyjohn, 2024). At that time, this UAV proved itself by attacking several columns of Russian vehicles. It played an important role on the defence of Snake Island. With the help of its Switchblade Electro-Optical (EO)/Infrared (IR) system it successfully provided surveillance and reconnaissance of Russian assets and then used its laser guided smart munition to take out a Russian landing craft (Payne, 2022). The TB-2 lost its freedom of operation when Russia began to activate its air defences and Electronic Warfare (EW) systems (Pettyjohn, 2024). It

[9] Image retrieved from (Pettyjohn, 2024)

now focuses more on surveillance and target detection for artillery strikes, a similar mission to other smaller and cheaper military UAVs.

Figure 6- Bayraktar TB-2 UAV[10]

Smaller military UAV's like the Furia UAV have been used continuously throughout the war with the purpose of providing accurate target data to artillery units, adjusting fires and damage assessment (Pettyjohn, 2024). This class I UAV measures 900mm length, 2,000 mm of width and has a maximum take-off weight of just 5.5 kg. Due to its power and size it can only operate with wind speeds of up to 15 m/s.

Russia also utilizes MALE UAVs. The Orion UAV has been deployed several times to drop explosive ordnance on Ukrainian tanks. The Orion is produced by Kronstadt Technologies with the mission of reconnaissance and ground attack. It has a bigger width of 16.0m but is 100kg lighter than the TB-2. It has two thermal cameras, one wide-angle TV camera and a laser designator for dropping guided munition (*OE Data Integration Network*, 2025). Although Russia has utilised Class II UAVs like the Orion UAV, Class I UAVs are much more utilised. The most used drone in the Russian arsenal is the Orlan-

[10] Figure taken from (BaykarTech, 2025)

10. (Pettyjohn, 2024). This medium range UAV developed by Special Technology Centre LCC in St. Petersburg is usually used for target detection and tracking. It measures 2.0 m of length and 3.1 m of width. It has a maximum take-off weight of 16.5 kg and comes equipped with a day-light camera and a thermal imaging sensor, enabling night operations (*Airforce Technology*, 2023).

Both Russia and Ukraine are using commercial off-the-shelf (COTS) UAVs to complement their few in number, high on demand military UAVs. Performing the same role as military UAVs in terms of surveillance and reconnaissance but with less autonomy and resistance to enemy jamming. The DJI Mavic 3 is the most common commercial quadcopter used in the Ukraine war. It measures only 347.5 mm in length, 283 mm width and weights one gram. It is manufactured by SZ DJI Technology in China. It comes equipped with a RGB camera and a thermal sensor. It has a maximum flight time of about 45 minutes. (DJI Enterprise, 2025).

The Russo-Ukrainian war exemplifies the ongoing race between systems and counter-systems. Both sides have mastered the use of UAVs and are now rapidly advancing their electronic warfare capabilities, particularly in the development and deployment of jamming technologies. In response, both Ukrainian and Russian forces have begun utilizing FPV UAVs controlled via thin fibre-optic cables, effectively neutralizing the impact of radio-frequency jammers. This war also exemplifies the impact of unmanned technologies in modern warfare, according to the New York Times, UAVs are currently the cause of about 70% of all casualties in Ukraine (Marti, 2025).

Even though, the battle in the UAV spectrum is becoming increasingly balanced as Russia catches up, in the USV spectrum it is a whole other business. Ukraine has successfully executed more than a dozen attacks using USVs, including six attacks on Sebastopol's Harbour (Mongilio H., 2023). One of the very first Ukrainian USVs to prove itself was the *Mykola.* It was successfully employed together with UAVs to infiltrate Sevastopol Naval Base, attack the frigate *Admiral Makarov* and the minesweeper *Ivan Golubets* in October 29, 2022. It has a length of 5.5 m, weights up to 1000 Kg, has a maximum speed of 43 knots and a maximum range of up to 430 nautical miles. It uses automatic Global Navigational Satellite System, an inertial navigation system and is capable of video transmission. It can carry up to 200 kg of explosives (Sutton B., 2024).

More recent USVs like the *Magura V5,* seen in **Figure 7**, are very similar to the *Mykola* in terms of physical characteristics but with a even higher range. They are being fitted with the capability of storage and launch for up to four quadcopters. Other modifications include the integration of anti-aircraft missiles with the intent to patrol the coast and to destroy Russian Helicopters (Kirichenko, 2025).

Figure 7- Magura V5 USV[11]

One of the biggest successes for Ukrainian USVs occurred on May 2, 2025, when a Magura USV, equipped with two anti-air missiles, successfully downed a Su-30 Flanker fighter jet operating in the eastern Black Sea (Sutton B., 2025). This marked a significant achievement for the Ukrainian forces, who managed to use a USV costing approximately $230,000 to destroy a modern fighter jet valued at around $50 million. Even more consequential is the loss of the two-seater aircraft experienced pilots, with years of

[11] Figure Taken from (McNeil & McNeil, 2024)

costly training who are difficult to replace. In contrast, the Magura's operator remained relatively safe at a nearby command base.

3.1.2 UxVs in the Gaza Conflict

While the Ukraine-Russia war has long been viewed as the primary showcase for the military usage of UAVs, the current war in Gaza is now revealing new developments, both in terms of their tactical deployment and the broader implications of drone warfare (Özdemir G., 2024). What makes this conflict particularly noteworthy is the extensive use of UAVs not only by state actors such as Israel and Iran but also by non-state groups like Hamas, Hezbollah and the Houthis. Footage published by Al Quassam Brigades, Hamas's military wing, showed that during the initial attacks of October 7, COTS UAVs were used to attack the perimeter defences of Israel (Gosselin-Malo, 2023). Iran's proxies are demonstrating increasing proficiency in drone warfare. Hezbollah has improved its counter-UAV capabilities, successfully intercepting and decrypting video feeds and communications from Israeli UAVs by employing a combination of electronic warfare and signals intelligence techniques (Ashour, 2024). This allowed Hezbollah to gain real-time access to Israeli UAV imagery and coordinate with ground units to detect and engage Israeli forces. The group was subsequently able to organize and direct its anti-tank teams, which ambushed Israeli Merkava-4 tanks using rocket launchers and anti-tank guided missiles.

Hezbollah has also successfully deployed its reconnaissance UAVs to take aerial pictures of sensitive locations in northern Israel, including the Port of Haifa and Hhayetet-7, Israel's submarine unit. These images were later shared publicly on social media.

It is estimated that Hezbollah possesses approximately 2000 UAVs in its inventory, including *Mirsad-1* (with a range of 124 miles), the *Ayoub* (a variant of Iran's Shahed-129 with a range of 1000 miles) and various Iranian-made systems such as the *Karrar*, Mohajer and Sammad (Helou, 2024).

Israel has deployed a range of advanced UAVs including the *Heron* TP, *Hermes* 900 and the smaller fixed-wing *Hermes 450* for precision missile strikes. Smaller UAVs such as the *Matrice600* and *LANIUS* quadcopters, have also been used and some of which, fitted with machine-guns and missiles (Euro-Med Human Rights Monitor, 2024).

According to Gloria Shkurti Özdemir of the Arab Center for Research and Policy Studies, UAVs in the Gaza conflict have been performing six primary roles:

- Surveillance and Reconnaissance. What can be described as the UAVs primarily role. Military and COTS UAVs have been employed to gather information on enemy movements and to gain a better perspective of the battlefield.
- Precision Strikes. Both missile carrying UAVs like the *Hermes* and kamikaze UAVs such as the *Ayuoub* are used for cost-effective, accurate target neutralization.
- Overwhelming Defence Systems. Non-state actors use multiple cheap UAVs to exhaust air defence systems.
- Disrupting Communications. Hamas has used UAVs to destroy communication towers and surveillance infrastructure, degrading the Israel defence forces (IDF) C3 capabilities.
- Strategic Purposes. Israel is forced to counter the drone threat with expensive air defence systems like the Iron Dome, eventually exhausting its capabilities. Iran's proxies can then use the ballistic missiles to much more effect.
- Political Purposes. UAVs offer a means of rapid retaliation without escalating to full-scale warfare. A notable example was Iran's massive UAV deployment in response to Israeli airstrikes.

While a less prominent in media coverage, USVs have also been playing a role in security operations off the Gaza coast since at least 2009. One of the most notable platforms is the Protector USV, a 4-ton rigid-hull inflatable vessel developed by Rafael Advanced Defense Systems. Equipped with a TOPLITE electro-optic surveillance and targeting system, a Mini Typhoon remote-controlled weapon station and land/naval attack Spike LR missiles (Naval UAVs, 2025). This medium sized USV, seen in **Figure 8**, is reconfigurable to perform several missions like anti-terror/force protection, intelligence, surveillance and reconnaissance (ISR), naval warfare, mine countermeasures, electronic warfare (EW) and harbour security missions (Gupta, 2013).

Figure 8- Protector USV[12]

3.2 Unmanned Vehicles in International Ports

3.2.1 Port of Antwerp-Bruges

The Port of Antwerp-Bruges is about 12000 hectares in size, making it the second largest port in Europe. It plays a relevant role in global trade. Located in Belgium, it serves as a vital gateway for goods moving between Europe and the rest of the world. It is home to over 1400 companies, providing more than 164000 jobs and contributing about 4.5% to Belgium’s GDP (Port of Antwerp-Bruges, 2025).

In March 2025, two United States Ships, the Endeavour and the Defender, arrived at the Port of Antwerp as part of Operation Atlantic Resolve. There, they

[12] Figure taken from (Naval Drones, 2025)

unloaded 1,700 pieces of military equipment, which were then transported by train and road through civilian logistics companies to their destinations in Eastern Europe. (*The Brussels Times*, 2025). This operation highlights the strategic military importance of ports and harbours. Recognizing this importance, Belgian Prime Minister De Wever had, back in September 2024, already expressed his intentions of installing anti-air defence systems at the Port of Antwerp, aiming to enhance its security against air threats (*The Brussels Times*, 2024)

At the forefront of innovation and sustainability, the Port of Antwerp-Bruges currently operates six Beyond Visual Line of Sight (BVLS) capable UAVs that patrol its 120-square-kilometre area. These UAVs conduct 16 daily patrols flights, focusing on berth management, monitoring, infrastructure inspection, oil spill detection, floating waste monitoring and providing support to security partners during incidents (Port of Antwerp-Bruges, 2023).

This initiative began in 2019 with the Safe and Flexible Integration of Initial U-space Services in a Real Environment (SAFIR) project, which was approved by both the Belgian Civil Aviation authority (BCAA) and the European Union Aviation Safety Agency (EASA). The SAFIR project involved a consortium between 13 public and private organisations (Amazon Prime Air, Aveillant, C-Astral, DronePort, Elia, Explicit, Helicus, Port of Antwerp, Proximus, SABCA, Skeyes, Tekever and Unifly) with the goal of sharing expertise and demonstrating the safe and economic viability of integrated drone traffic (Port of Antwerp-Bruges, 2019).

The ‘D-Hive drone-in-a-box’ network developed by Port of Antwerp-Bruges in collaboration with DroneMatrix, SkeyDrone and Proximus, is a product already being used in the Port. The ‘Drone-in-a-Box’ concept, seen in **Figure 9**, allows their YACOB UAV to charge and be stored inside a compact docking station. The drone integrates AI for live interpretation and evaluation of the images that make up the situation (*DroneMatrix*, 2025). It offers a high level of autonomy with features like sense-and-avoid systems, geofencing, 4D route planning and an Autonomous Launch and Recovery System (ALARS).

Figure 9- DroneMatrix Drone in a Box Solution[13]

The sense and avoid system is a Light Detection and Ranging (LiDAR) system. It works by emitting a series of laser pulses (usually in the infrared spectrum) toward a target area. When the laser hits objects or surfaces it bounces back. The system records the time taken for each pulse to return to the sensor thus calculating the distance to the object. One drawback of this system is that meteorological conditions like rain or fog can interfere with the laser and thus decrease its effective range. (Ramasamy et al., 2016).

Geofencing is a safety feature that keeps the UAV inside of a certain area that complies with EASA regulations. It works by constantly receiving the drone’s location and comparing it with the defined geographical boundaries. If the UAV crosses the geofence boundaries, it can be instructed to stop, change direction, land or take other action according to set configuration (Sánchez, 2023).

4D route planning adds a time component to a 3D path. Although computably more expensive, real-time applications like surveillance and monitoring benefit from 4D planning to ensure UAVs arrive at waypoints at specific times (Cicibas et al., 2016).

[13] Figure taken from (*IntroDroneMatrix*, 2025)

Drone Matrix's docking station for their UAV is called YADO. In addition to being the drone's battery charger trough a wireless power supply system, the YACOB concept allows the drone to operate without human intervention for launch and landing operations while offering protection from weather conditions (*DroneMatrix*, 2025).

SkeyDrone is a company that specializes in the safe flight of UAVs. This company offers software that allows a comprehensive air picture of both manned and unmanned traffic. Their product is also being tested at Brussels Airport with a larger focus on inspection of runways and taxiways (SkeyDrone, 2025).

YACOB is a benefiter of the new 5G network of Proximus. When the UAV moves beyond the range of a fixed Ethernet connection, it switches to 4G LTE or 5G networks in order to provide real-time telemetry, video streaming and ensure uninterrupted communications (Proximus Press Team, 2023).

In addition to surveillance and monitoring, the YACOB UAV is also being tested to improve the mooring process in the Port. Discrepancies in Automatic Identification System (AIS) or in Global Positioning System (GPS) can lead to misallocations of ships in their berths, causing delays. To address this issue the Port of Antwerp partnered once again with DroneMatrix to implement a drone-based remote sensing solution. Trough photogrammetric corridor mapping, UAVs surveyed over a kilometre of quay wall. This was done achieving accuracy as good as 5 cm. This data was processed to create coloured 3D point clouds of ships, enabling precise detection of the ship's bow and stern. The results exceeded the preliminary expectations and demonstrated how UxVs can significantly contribute to the improvement of the Port's overall efficiency (Baeck, 2021).

3.2.2 Port of Los Angeles

The Port of Los Angeles (POLA) spans across 3035 hectares of land and water. It is the main container port in the United States since the year 2000 and has handled in 2024 over 9.3 million twenty-foot equivalent units (TEUs) of cargo, transporting goods ranging from avocado to zinc. (Port of Los Angeles, 2025).

Currently, POLA monitors its entire port area using 500 cameras and a fleet of manned vessels. However, this approach faces challenges, particularly in accessing shallow areas and maintaining continuous 24/7/365 surveillance (Galdorisi G., 2022). Acknowledging this weakness, POLAS officials are exploring the use of unmanned systems to improve their port security capabilities.

A demonstration was conducted in POLAS using the MANTAS T12 USV. The MANTAS T-series are COTS USV's, built and designed by MARTAC, featuring a catamaran-style hull. These vessels range 8 to 38 feet of length (Galdorisi G., 2022).

The MANTAS T12 is a 12-foot-long and 3-foot-wide USV with a height of just 35.5 centimetres and a draft of 18 centimetres, allowing it to navigate shallow waters. The vessel weights 118 kilograms and has a payload capacity of 64 kilograms. Powered by a twin-screw, battery-driven electric propulsion system, the T12 can cruise at 20 knots in sea state four and has a range of up to 60 nautical miles (Hydro International, 2025).

Showed in **Figure 10**, the MANTAS T12 can be equipped with a variety of sensors including both above-surface and below-surface systems, water quality monitors and other environmental sensors. Real-time data transmission is enabled by the MANTAS communications package, which support redundant high-bandwidth networked radios, 4G LTE or satellite communications for reliable connectivity in diverse operational environments (Hydro International, 2025). **Table 5** presents a summary of some of its characteristics.

Figure 10- MANTAS T12 USV[14]

MANTAS T12				
Specifications		Applications		Sensors
		Defense	Security	
Length	12 ft (3.6m)	Mine Countermeasure	Asset Inspection	EO/IR Cameras
Max Payload	64 kg	SAR	Asset protection	SONAR
		Security Monitoring	Security Monitoring	
Powertrain	Electric	ISR Swarm	Environmental Monitoring	LIDAR
		EW/SIGINT	Bathymetry Mapping	
Burst Speed	30+ kts	Shallow and Deep Water Mine Countermeasure	Port/Harbor Security	Acoustic Modems
		Swarming Operations		

Table 5- MANTAS T12 Specifications[15]

[14] Figure taken from (*Maritime Tactical Systems*, 2025)

[15] Information retrieved from (MARTAC, 2025)

The demonstration of the MANTAS USV proved that its capabilities aligned well with the port's operational requirements. POLAS officials requested MARTAC to develop scaled-up versions of the T12 leading to the creation of the T24 and the T38 models. These two versions were more easily visible to other vessels in the harbour and offered extended operational range and increased sensor-carrying capacity.

In collaboration with SEALARTEC, MARTAC has introduced a fully ALARS, integrated in the T38. This system enables the autonomous launch and recovery of the T8 and T12 variants (MARTAC, 2025). SEALARTEC is a company that specializes in the launch and recovery of maritime vehicles. They have developed a Local Positioning System (LPS) that functions independently of GPS. It uses advanced sensor technology to provide real-time, relative positioning data, allowing vessels to perform accurate manoeuvres (Zamir, 2025).

3.2.3 Port of Haifa

With an area of its 2 km², the Port of Haifa is the largest seaport in Israel, capable of handling up to 1.5 million TEUS and 240,000 passengers. It is capable of handling 1.5 million TEUs and 240000 passengers annually. In terms of freight volume, it processes approximately 30 million tons of cargo per year. The Haifa port area is the most complex port compound in Israel, consisting of seven terminals handling various types of cargo, including containers, automobiles, bulk materials, grain, chemicals and cement. The Israel Port Company (IPC) is responsible for the securing, planning, development, construction, maintenance and enhancement of Israel's commercial seaports in Haifa, Ashdod and Eilat (Haifa Port, 2024).

Until recently, the Port of Haifa relied on fixed cameras and crewed speed boats to monitor and verify vessels navigating within the port area. However, recognizing the need for enhanced security and operational efficiency, the port has begun integrating autonomous surveillance solutions.

The Optimus System, developed by Ondas Holdings Inc., has successfully completed a series of tests and is now being implemented in Haifa's port security framework. This drone-in-a-box solution operates without on-the-ground human intervention. Each Optimus System includes a smart airbase that enables automated battery changes for 24/7 operations and supports the automated loading and installation of mission-specific sensors. The system is already in use in other parts of Israel and in the United Arab Emirates (UAE) (Ondas Holdings, 2023).

The Optimus UAV, presented in **Figure 11**, weights 10 kg and has a diameter of 4 feet. It boasts a flight range of up to 16 km and can operate in winds of up to 25 knots and light rain (Airobotics, 2024). It integrates 5G/LTE and long-range (LoRa) Radio Frequency (RF) communications and utilizes Real-Time Kinematic (RTK) GPS for enhanced positional accuracy. Safety features include Autonomous Flight Emergency Patterns, GPS-Denied Navigation Solutions and a certified deployable parachute (Airobotics, 2024).

Figure 11- Airobotics Drone in a Box Solution[16]

[16] Figure taken from (Airobotics, 2024)

Ondas UAVs have benefited from the collaboration with Kestrel Aerial, a company specializing in hyperspectral sensing, AI and machine learning technologies to enhance regulatory compliance for infrastructure asset owners (Kestrel Aerial, 2022).

This partnership contributed to a Federal Aviation Administration (FAA) license permitting BVLOS flights. Additionally, Ardenna, a leader in image processing software, has also contributed to the development of the Optimus System. This company is already achieving good results in the utilisation of AI in UAVs for the detection of rail gage, broken rails, cross tie health, cross tie skew, cross tie separation, ballast coverage, fastener presence, joint gaps and swich point health (*Ardenna*, 2025).

Before each flight, the Optimus UAV receives battery status, airspace awareness and weather updates. After completing its mission, it autonomously returns to its docking station. Inside the smart airbase, a robotic arm replaces the battery and retrieves its payload. The drone can be equipped with one of nine different payloads, including LiDAR, high-resolution cameras for 2D/3D mapping and EO/IR sensors. Each docking station can store up to eleven batteries in individual charging stations, allowing for 40-50 minutes of continuous flight. Remote pilots can monitor and control the Optimus UAV from an Operational Command Centre (OCC), (Grant B., 2024).

Because of its geopolitical situation, Israel, is not only truly concerned with Port Security, but also with Harbour Defence. As a result, strategic defence measures like the Iron Dome System are essential for the steady and predictable flow of cargo (Elsom, 2025).

The Iron Dome is a short-range, multi-mission air defence system designated to counter diverse aerial threats, including UAS, ballistic and cruise missiles, rockets, artillery, mortars (RAM) and precision-guided munitions (PGM) at ranges of up to 70 km. Each Iron Dome battery can provide coverage for an area of 150 km^2. Developed by Rafael Advanced Defence Systems in collaboration with Elta Systems, the Iron Dome consists of three primary components: a battle management and weapons control centre, three to four missile firing units and a detection and tracking radar system. Each firing unit can house twenty *Tamir* interceptor missiles. The system determines whether incoming threats will impact populated or critical areas and intercepts them accordingly (Shapir, 2013). During the 2014 Gaza war the Iron Dome system had more than 90% success rate (Michael Ray, 2025)

Israel exemplifies the necessary coordination between Port Administration and the Armed Forces. External threats are detected by Israel’s radar systems and countered by the military with defensive systems like the Iron Dome. The assessed threat level is then translated into a corresponding ISPS security level, which ships and port administrations must follow. On other hand, the measures implemented by the Port Administration with the goal to deal with contraband, illegal immigration, terrorism and sabotage end up improving the overall awareness and surveillance of the Harbour against not only internal, but also external threats. Port Officials report any detected threat to national authorities, effectively acting as warning systems that enable the military to protect both port infrastructure and the country’s borders.

4. Analysis of Sines Harbour

This chapter provides an analysis of Sines Port, focusing on its geographical, structural and operational characteristics. The aim is to identify features relevant to both port functionality and Harbour Protection. The chapter begins by outlining the port's location, infrastructure and traffic profile, followed by a sector-based spatial breakdown of the area under the port's administration jurisdiction. It then explores critical aspects such as access routes, key terminals, underwater infrastructure and bathymetric conditions, all of which influence both operational efficiency and security planning. This foundation overview sets the stage for subsequent assessments of criticality, threat and vulnerability in the context of Harbour Protection operations.

4.1 Geographic and Structural Overview

Sines Port is located on the southwestern coast of Portugal, approximately 150 km south of Lisbon, at coordinates 37°57'N, 08°53'W. Situated on Europe's Atlantic façade, the port holds a strategically advantageous position, serving as a key gateway for maritime routes connecting North and South America, West Africa and the Suez Canal (*APS*, 2025). This deep-water port is characterized by sandy and rocky seabed's and is not subject to significant sediment accumulation (*Instituto Hidrográfico*, 2024). It has a resident population of 13,577 (based on 2001 data), along with a floating population of approximately 5,000 tourists and temporary workers (*Instituto Hidrográfico*, 2024).

The jurisdictional area under the administration of the Port Authority can be seen in **Figure 12** and in **Figure 13**. It covers approximately 6.31 km² of land and an extensive 147.5 km² of maritime zone, which includes anchorage areas and approach channels (*APS*, 2025). In 2004, a total of 972 ships called at Sines Port, including 780 tankers, 46 bulk carriers, 55 container ships, 39 general cargo ships and 1 roll-on/roll-off (Ro-Ro) vessel. Of these, 753 flew foreign flags, while 219 were registered under the Portuguese flag. These vessels had a combined gross tonnage of 18,326,643 tons and handled a total of 22,476,068 tons of cargo. The cargo included 5,415,920 tons of solid bulk, 16,764,973 tons of liquid bulk, 5,016 tons of general break-bulk cargo and 250,159 tons of containerized cargo, equivalent to 19,211 TEUs. This level of maritime traffic positions Sines as the third busiest port in Portugal in terms of both ship calls and cargo volume and the leading national port for the supply of energy-related products (*Instituto Hidrográfico*, 2024).

Figure 12- Maritime Jurisdictional Area of Sines Port[17]

[17] Information retrieved from Sines Administration website and archived in https://archive.org/details/area-de-jurisdicao-do-porto-de-sines

Figure 13- Terrestrial Jurisdictional Area of Sines Port[18]

The port is structured around several specialized terminals, including: the liquid Bulk Terminal (TGL), the Petrochemical Terminal (TPQ), the Multipurpose Terminal (TMS), the Natural Gas Terminal (TGN) and the Container Terminal (TCS), along with auxiliary facilities dedicated to fishing, recreation and technical support. These terminals are protected by the West and East Breakwaters, each exceeding 2 kilometres in length, forming a sheltered artificial bay. In **Figure 14** we can see the referred terminals numbered and in **Table 6** their characteristics.

[18] Information retrieved from Sines Administration website and archived in https://archive.org/details/area-de-jurisdicao-do-porto-de-sines

Figure 14- Port Terminals[19]

[19] Information retrieved from (APS, 2025)

Terminal	Liquid Bulk	Container	Multipurpose	Petrochemical	Liquefied Natural Gas	Recreational and Fishing Port
Berths	6	1 150m	3	2	1	
Bathymetry (ZH)	28 m	17 m	18 m	12 m	15 m	5 m
Capacity	350000 DWT	1150 +200 m	190000 DWT	20000 m^3	225000 m^3	182 vessels
Cargo	Crude oil, refined petroleum products, Methanol and Naphtha	TEU	Diverse	Propylene, Ethylene, Butadiene, ETBE, Ethanol	Liquified Natural Gas	
Characteristics	Connected to the Sines refinery and submarine pipeline systems	Panamax Cranes and road/rail connection	Ro-Ro ramp and cranes	High containment safety	Cryogenic Storage, gas grid connection	
Image Number	1	2	3	4	5	6

Table 6- Terminal Characteristics[20]

Direct links to the national railway network and to major roads like the A26 and IP8 facilitate the cargo transportation process. From a Harbour Protection perspective, these geographical characteristics present both operational opportunities for rapid logistics while simultaneously introducing critical vulnerabilities, particularly in terms of access control, surveillance and the potential exploitation by malicious actors.

For a comprehensive analysis of critical infrastructure, the port area can be divided into three smaller sectors:

- West Area. Extends from the West Breakwater to the Fishing Port. It contains the petroleum and petrochemical storage facilities, the main command and control infrastructure of the port such as the Port Administration building, the Harbour Master's Office (*Capitania*), the Vessel Traffic System (VTS), its radar antenna and

[20] Information retrieved from (APS, 2025)

the Port Authority's Technical Building, which houses the main control centre and facilities for fire and security personnel. There is other important support infrastructure like the living quarters of the *Polícia Marítima* personnel and a Helipad as showed in **Figure 15**.

Figure 15- West Area of Sines

- Central Area: Comprises an artificial bay formed by the Fishing Port, Vasco the Gama Beach and Recreational Port as showed in **Figure 16**.

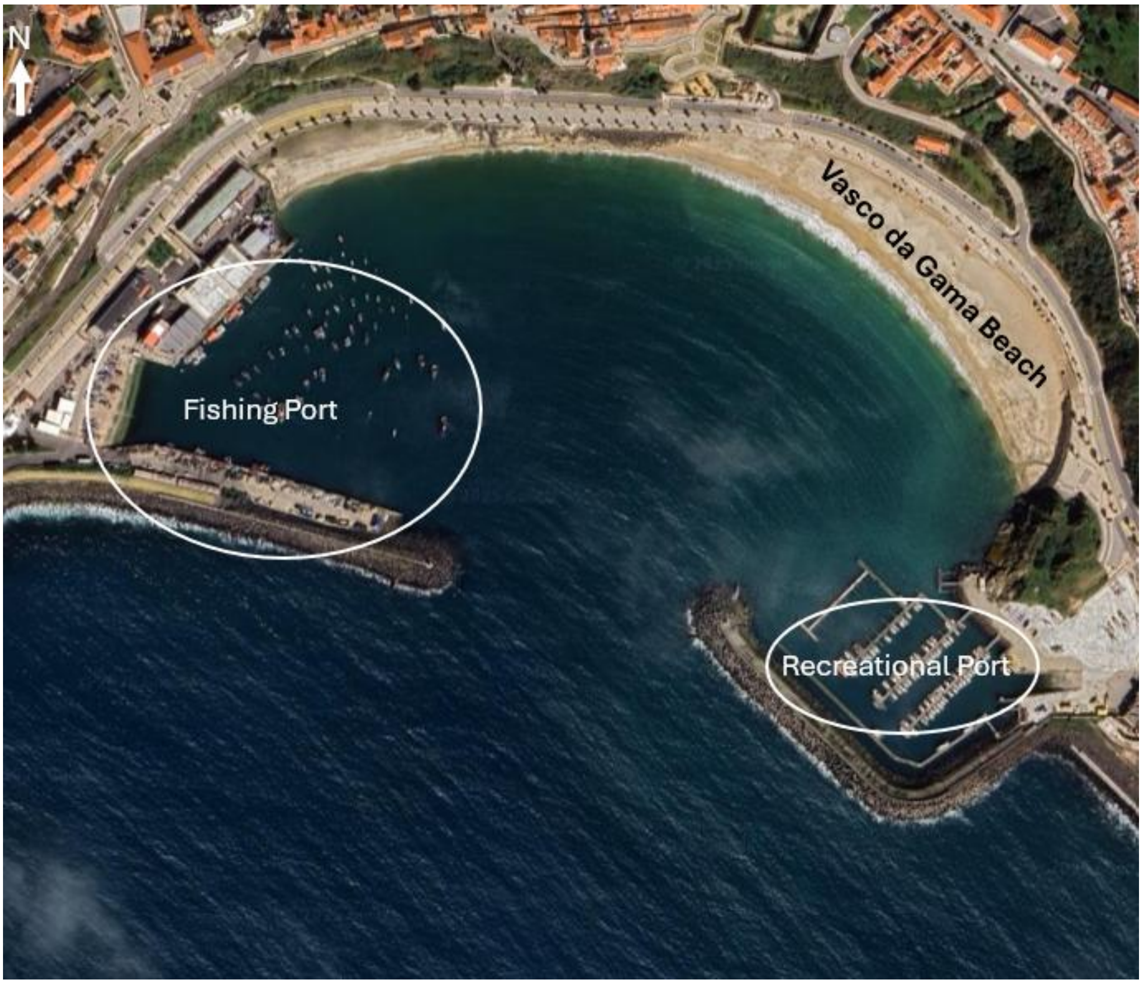

Figure 16- Central Area of Sines

- East Area: Hosts a liquid gas storage facility, a general cargo storage area, a logistics support centre, a second VTS radar antenna, direct connections to national highways, an electrified railway link and a logistical support terminal for NATO ships as showed in **Figure 17.**

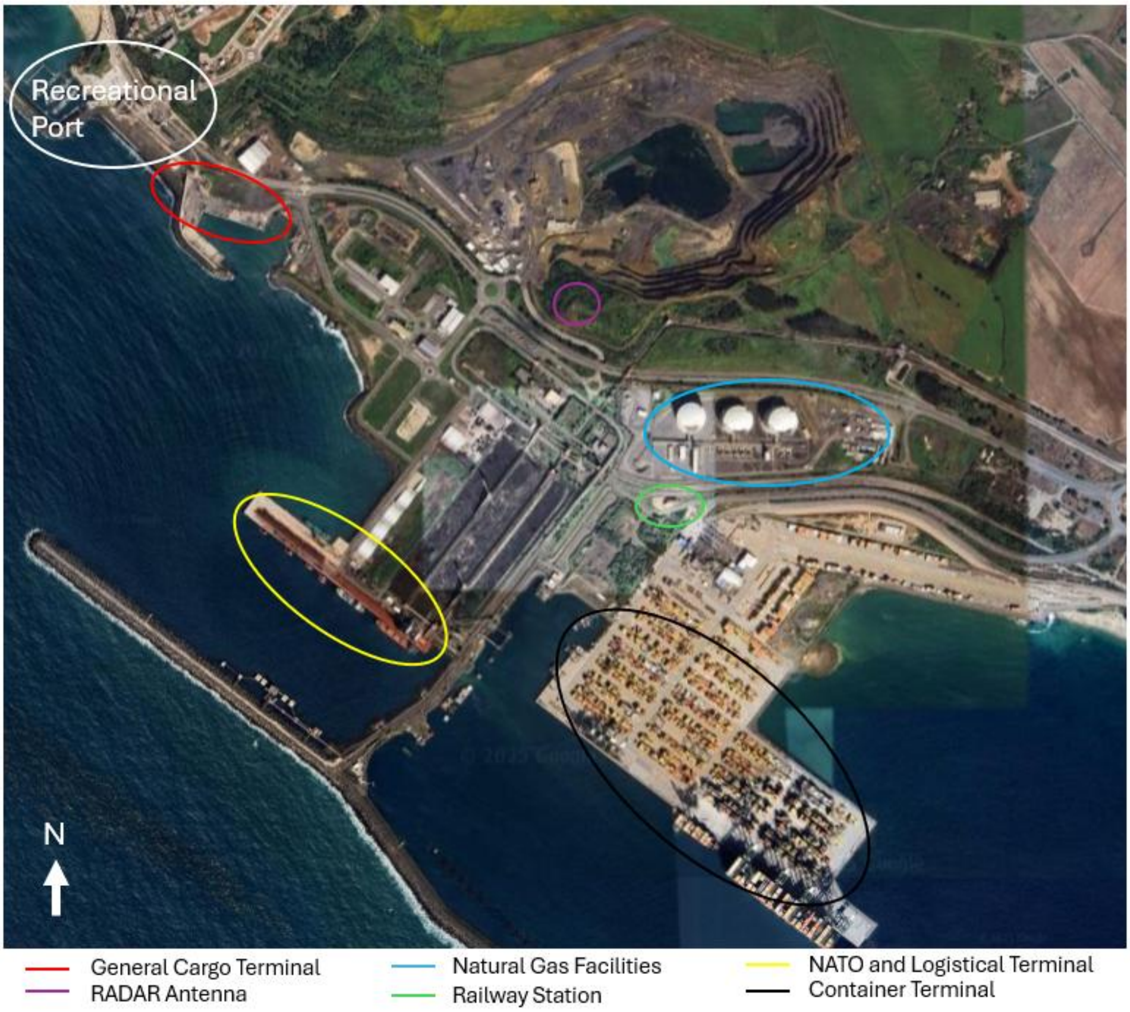

Figure 17- East Area of Sines

Analysing some of the geographical characteristics of Sines is important due to the localization of several anchorage areas, the presence of two transatlantic Underwater Infrastructure and an already designated area for offshore wind energy exploration as shown **Figure 18**.

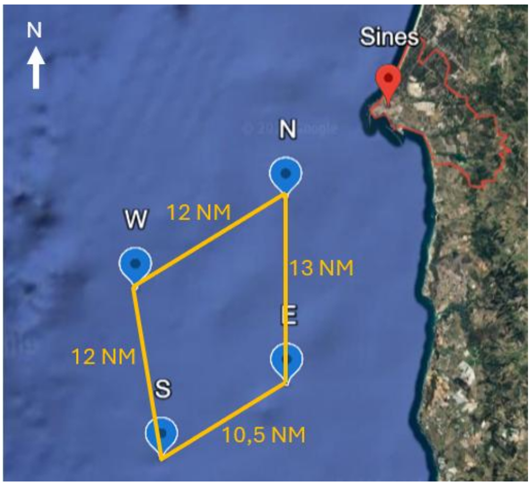

Figure 18- Area for Eolic Exploration[21]

Currently, two major sea cables land at Sines:

- EllaLink. A high-capacity, low-latency fibre-optic cable directly connecting Europe to Latin America. It also links the archipelagos of Madeira and Cape Verde. The system offers approximately 100 terabits per second across four fibre pairs and became operational in 2021 (Submarine Networks, 2025).
- Olisipo. A fiber-optic system developed by EllaLink that connects Sines to Lisbon, with a total design capacity of 4.3 Petabits per second. It became operational in 2024. (Submarine Networks, 2025).

There are also three upcoming Underwater Infrastructure: Nuvem, Equiano and 2Africa (Submarine Networks, 2025).

The location where a submarine cable "lands" is usually called a beach manhole. It seems that the beach manholes of these cables have a direct land connection to Start Campus data centre (Start Campus, 2025) and ZILS Global Parques (SINES TECH, 2025), seen in **Figure 19**.

[21] Information Retrieved from (*Conselho de Ministros*, 2025)

Figure 19- Locations of ZILS Parque and Start Campus Data Centre

The bathymetry between the breakwater is approximately 30 metres deep, with a seabed composed of a mixture of rock and sand. The bathymetric of 50 metres is situated about 1 nautical mile westward of the western breakwater of Sines. About 1.8 nautical miles westward, at the outer limit of the port authority's jurisdiction, the depth remains below 80 metres, predominantly with sandy seabed's (*Instituto Hidrográfico*, 2025).

In terms of currents, they are predominantly wind caused. The maximum values registered are in the 0.8 knots range. The western breakwater in junction with the cape of Sines produces a rotational clockwise current (*Instituto Hidrográfico*, 2024).

4.2 Meteorological Characteristics

Sines experiences a temperature range between 8.9°C and 27.2°C, rarely falling below 5.6°C or exceeding 32.2°C. Sea average temperatures vary between the 14.0°C in

February and the 17.2ºC in September, assuming the minimal registered values in March (10.5ºC) and the maximum values in August (224ºC). Regarding precipitation, the annual average is of 493 mm of rain. The wettest period occurs from November to January with the most wet month being December where it rains 8.3 days in average (Weather Spark, 2025).

In terms of humidity, Sines usually has a annual average relative humidity of 76% and 81%. When it comes to fog, on average, Sines experiences, 23 days of fog per year, with July to September being the most frequent time of the year for the occurrence of fog (*Instituto Hidrográfico*, 2024).

The length of daylight varies significantly, from 9 hours and 32 minutes on the shortest day to 14 hours and 48 minutes on the longest day (Weather Spark, 2025).

The brighter period of the year spans 3.4 months, from May 10 to August 21, with an average daily incident shortwave energy per square meter above 7.0kWh. The darker period lasts 3.5 months, from October 27 to February 12, with average daily shortwave energy below 3.4 kWh. The annual average energy is approximately 5.1 kWh. It is important to note that Sines experiences marked seasonal variations in cloud cover (Weather Spark, 2025).

As in other regions along the Portuguese coast influenced by the Azores Anticyclone, the predominant wind direction in Sines is from the North and Northwest. The windier part of the year spans 9.5 months, from October 29 to August 14, with average wind speeds exceeding 9,3 Knots (Weather Spark, 2025). February is the windiest month, with an average hourly wind speed of 10 Knots. The calmer period lasts for 2.5 months, from August 14 to October 29, with September being the calmest month at 6.8 Knots. **Table 7** shows the monthly average velocities and directions in Sines. It is also convenient to see the days per month during the wind reaches a certain speed. For that, data from the *Meteoblue* website was used. **Figure 20** shows a diagram based on 30 years of hourly weather readings.

	Wind - Sines (1971-90)																
	Frequency F(%) and Average Velocity V (Km/h) for each direction																
	N		NE		E		SE		S		SW		W		NW		Average Velocity
	F	V	F	V	F	V	F	V	F	V	F	V	F	V	F	V	Km/h
January	21,1	20,2	11,5	14,9	8,4	12	14,2	12,7	12,4	17,6	9,2	22,6	6,4	18,7	11,2	23,2	16,6
February	26,7	21	7,7	13,5	6,8	12,9	8,7	15,5	14,9	18,8	9	22,4	8,6	21,9	15,1	22,7	18,6
March	23,6	20,7	6,5	14,2	4,9	12,9	9,2	13,2	11,3	15,5	9,1	18	8,7	17,1	24	21,5	18
April	25,5	18,6	4,8	15,3	4	14,7	5,3	14,1	9,4	16,9	8,2	18,9	12,2	14,8	29,1	19,9	17,8
May	26,6	17,3	3,2	15	1,3	15,6	0,6	7,3	7,6	17,9	10	16,1	9,8	14,6	39,7	20,6	18,3
June	25,1	14,8	1,6	9,1	0,3	11,3	1,6	11,8	10,2	11,7	10,2	13,3	9,8	11,2	40	18,9	15,7
July	26,9	14,4	1,8	14	0,6	12,9	1	8,9	7,3	9,9	7,1	10,9	6,7	10	46,5	18,6	15,1
Augoust	28,9	13,6	3,5	9,8	0,7	8,8	0,8	11,8	8,2	10,7	6	9,7	5,4	9	43,1	17,9	14,8
September	29,7	12,6	5,4	10,9	0,9	5,9	3,7	11,7	14,1	12	9,1	11,5	5,7	9,2	27,3	14,7	12,6
October	29,8	15,8	7,6	11,1	2,7	10,7	7	11	16,7	14,9	5,4	15,8	7	13,8	19,3	18,2	14,6
November	27,2	17,3	9,9	12,5	6,8	11,3	13,3	11,6	14,2	16,8	6,7	17,8	5,2	21,9	11,9	18,1	15,9
Dezember	21,7	18,6	11,9	13,4	7,9	12,4	14,3	13	13,2	19,8	9,5	23,6	9,2	23	8,9	21,7	17,3
Year	26,1	16,9	6,3	13,1	3,8	12,3	6,7	12,7	11,6	15,5	8,3	17,1	7,9	15,6	26,3	19,2	16,3

Table 7- Wind in Sines (1971-90)[22]

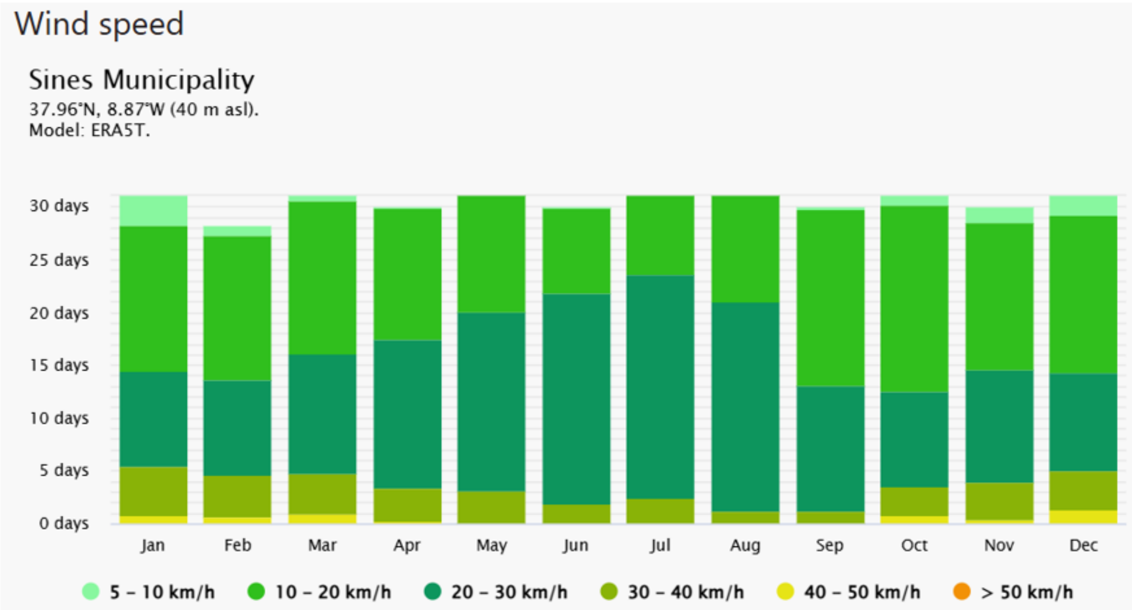

Figure 20- Days per month, during which the wind reaches a certain speed[23]

Regarding sea conditions, the most problematic wave direction is from the south and south-southwest, as it enters the port directly. In these directions, the breakwaters

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[22] Information Retrieved from (*Instituto Hidrográfico*, 2024)

[23] Diagram taken from (Meteoblue, n.d.)

provide minimal protection, making the port more exposed to wave energy. It is mostly protected from waves coming from the west and north. Northwest is the predominant waves direction with waves reaching heights of 7 and 8 metres. It is generally between the ends of October and April that the bad weather from Southwest is most felt (*Instituto Hidrográfico*, 2024).

4.3 Security Characteristics

Port of Sines is in total compliance with obliged ISPS regulations. ISPS states that restricted areas should be bound by fencing or other barriers. Regular inspections and appropriate maintenance are conducted to ensure their continued effectiveness. Additionally, a Port Single Card System regulates physical access to various port areas and vessels. Private security personnel are stationed at the main reception points to further safeguard the facility.

Sines Port has its own dedicated security personnel, equipped with fire extinguishing skills and equipment. They are trained to respond to security incidents, conduct patrols and perform inspections of the infrastructure. These random patrols, often conducted using vehicles, can be monitored trough a localization sensor system that confirms whether a specific location was visited and tracks the amount of time spent there. The Port's Administration works closely with the *Polícia Marítima,* a specialized police force integrated into the AMN that ensures legal compliance within the maritime public domain and port areas (*AMN*, 2025). Vessels of the *Polícia Marítima* are used to directly support the Sines Administration to respond to any event in the maritime area of their jurisdiction.

All entities involved in the safety and security of Port of Sines have access to a secure digital communications network operating in the UHF spectrum, enabling both voice and text communications (*APS*, 2016). There are also direct communication channels between the *Capitão do Porto* and the PFSO of the Administration, for day-to-day coordination on security matters and a direct line between the *Capitão do Porto* and the Board of Directors of the Sines Port Administration. As the *Capitão do Porto,* Commander Vasconcelos de Andrade states, “relationship between the entities is excellent”.

A key asset in the port’s security framework is the CCOPP which, according to Commander Vasconcelos, holds regular meetings between all the security stakeholders of the harbour.

An extensive grid of CCTV cameras serves as the eyes of this security framework. According to Eng. Luís Mourão, the PFSO, the port is aiming to modernize the camera system and even integrate an AI-based solution for image analysis that will be capable of face recognition and behavioural analysis.

In terms of maritime surveillance, the VTS system plays a vital role. It combines data from a radar antenna with VHF radiotelephony and the AIS to monitor vessel movements and ensure safe navigation within the port area (*DGRM*, 2025c). Through satellite images it is possible to depict two possible Radar antennas. One is located in the east area of the port in a more inland location with roughly 25 meters of terrain elevation. The other is located in the VTS building in the western area of the port roughly 35 meters above sea level. The location of both radar antennas is shown in **Figure 21**.

Figure 21- Possible Radar Antennas

The Port Administration has also established a Port Cyber Arena, a dedicated centre for enhancing cybersecurity and fostering the cyber-resilience of the Port (Assis, 2025).

4.4 Criticality Assessment

The criticality assessment is the identification of those assets that are considered vital to the mission goal achievement. These assets include personnel, material, facilities, information and activities that if disclosed, lost, injured, corrupted or damaged, would compromise the mission success (NATO, 2017). Considering that the mission is to ensure normal and safe operations in the Administration's jurisdictional area all year round, a criticality assessment is not only limited but should include the following:

Critical Assets

1. Liquid Bulk Terminal and adjacent infrastructure (refineries, storage facilities and pipeline system)
2. Underwater Infrastructure
3. Liquefied Natural Gas Terminal and adjacent infrastructure (storage facilities and gas grid connections)
4. Petrochemical Terminal and adjacent infrastructure (storage facilities)
5. Container Terminal and adjacent infrastructure (cranes and support facilities)
6. Railway Station
7. Multipurpose Terminal and adjacent infrastructure (ramps and cranes)
8. Access to the main road's (A26 and IP8)

Critical Assets in Maintaining the Safety and Security of Port Routine Operations

1. Port Facility Security Plan
2. Technical Building of the Port's Administration and Sines Security Personnel
3. VTS System
4. Administration Building

5. *Capitania* and elements of the *Polícia Marítima*
6. Communication Facilities
7. Fixed Camera Network
8. Fences
9. Access control systems
10. Helipad

4.5 Threat Assessment

Threat Assessment is a critical process that identifies and evaluates potential threats and hazards that may compromise mission success. This assessment considers the capabilities, tactics and intentions of potential adversaries and seeks to anticipate their possible courses of action. An example of what should integrate such assessment is given in ATP-94 and can be seen in **Figure 22**.

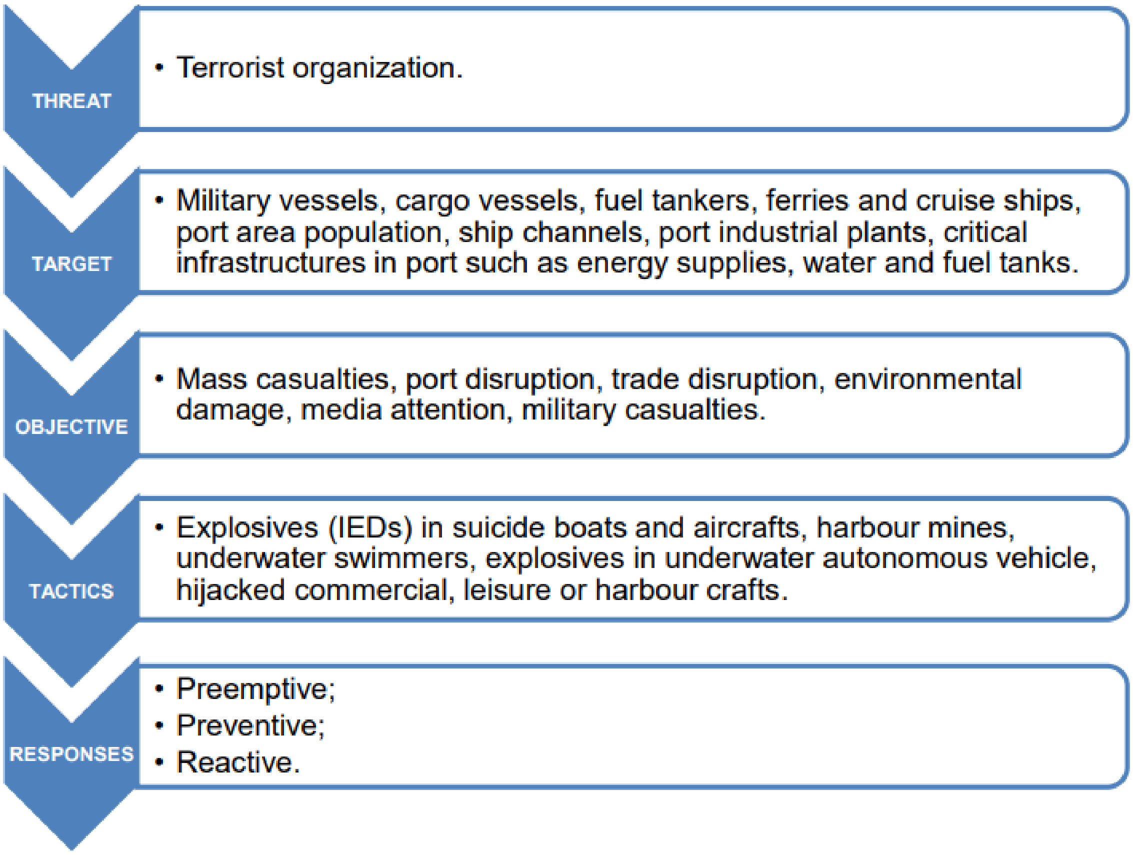

Figure 22- Harbour Protection Threat Profile[24]

This planning process supports the development of effective defensive measures to protect maritime infrastructure, personnel and port routine operations. Some of the threats to Sines Harbour can be observed in **Figure 23.**

[24] Figure taken from (NATO, 2017)

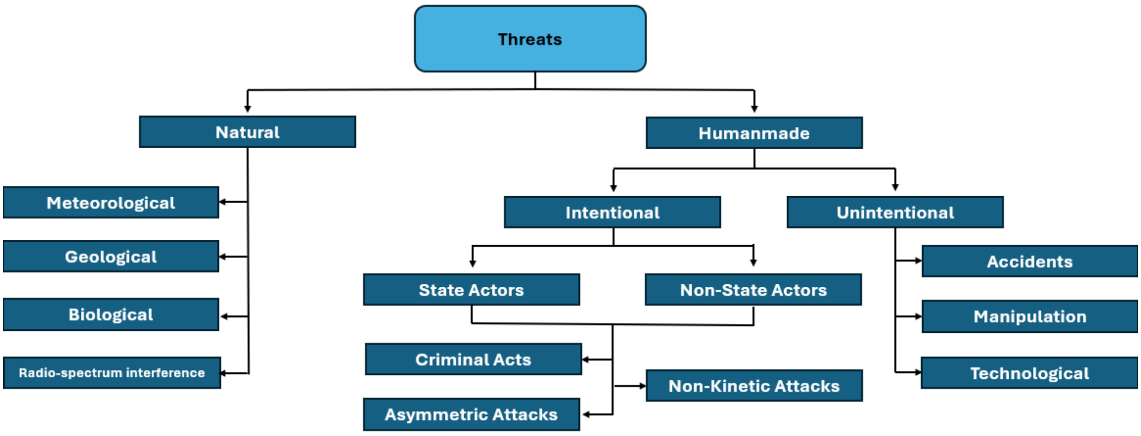

Figure 23- Sines Harbour Threats

Following the Harbour Protection threat profile of **Figure 22** it is necessary to list possible targets in Sines Harbour. This list is not limited, but should include the following:

- Terminals
- Underwater Infrastructure
- Storage facilities
- Refineries
- Support Infrastructure (Cranes, ramps, etc…)
- C2 Centres (Administration's Technical Building, *Capitania's* bulding, etc…)
- VTS System
- Communication Facilities
- Cargo Vessels
- Tankers
- Military Vessels

It is important to clarify the relationship between identified targets and the critical assets listed previously. Any port asset can be considered a potential target, as an attack on it may compromise the port's ability to fulfil its mission. However, not all potential targets are owned or managed by the port administration, and therefore do not qualify as port assets. For instance, merchant or military vessels docked at Sines Harbour are valid targets, but they are not permanent assets of the port itself.

Furthermore, while an attack on assets critical to the port routine safety and security operations, such as access control systems and communication facilities, could result in temporary disruption or reduced effectiveness of port functions, such incidents are unlikely to result in broader consequences. Some of the possible objectives behind an attack on Sines Harbour are:

- Environmental Damage
- Media Attention
- Civilian Casualties
- Mass Casualties
- Port Disruption
- Submarine Cable Disruption
- Disrupt Portugal's energy supply
- Test of Defence capabilities
- Induce economic losses

It is almost impossible to anticipate all the possible tactics that could be employed by someone seeking to attack Sines. Due to its coastal nature, Sines Harbour is exposed to a wide range of threats showed in **Figure 24**, including maritime, land-based, aerial and cyber-attacks.

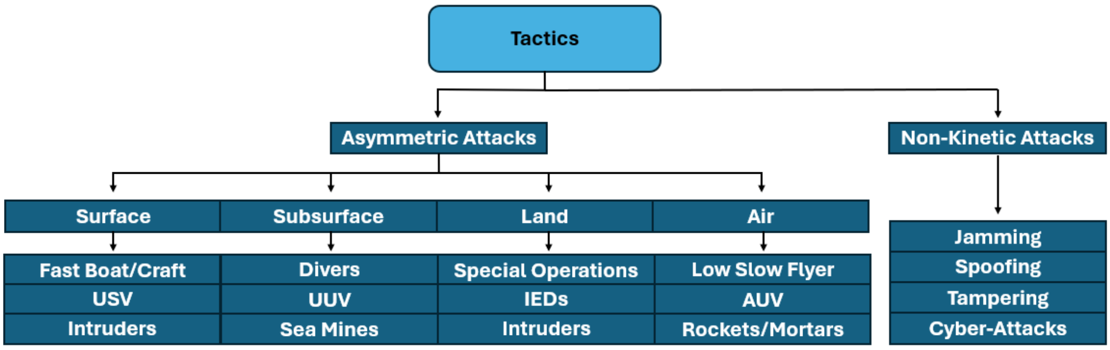

Figure 24- Possible Tactics used to attack Sines Harbour

Additionally, the deliberate use of an oil spill or a similar environmental disaster, could severely disrupt port operations and result in significant financial consequences.

In terms of possible responses to security threats against Sines Harbour, this work focuses primarily on preventive measures. However, it is also important to consider pre-emptive and reactive responses and to understand how UxVs can be effectively employed across all these stages. Some possible responses are illustrated in **Figure 25**.

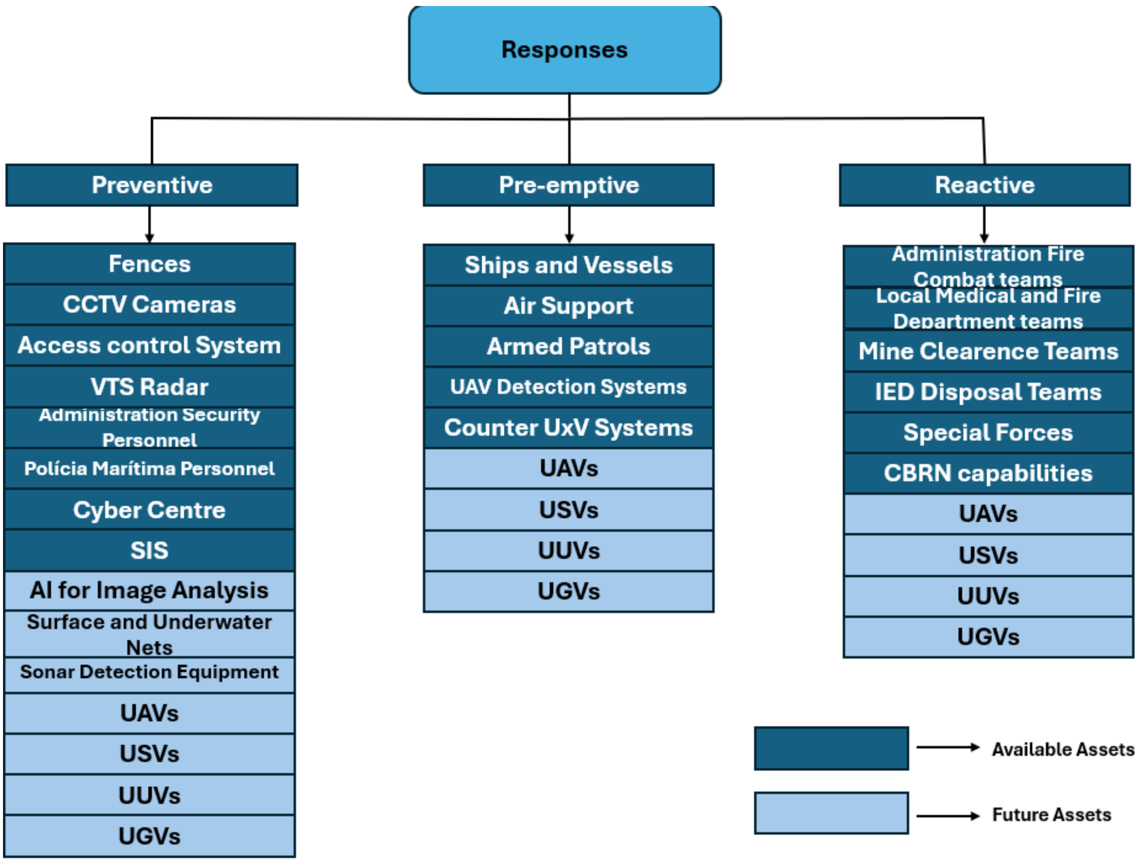

Figure 25- Possible Responses to Threats in Sines

4.6 Vulnerability Assessment

This assessment should be conducted by multidisciplinary teams that conduct operational analyses and evaluate the vulnerability of employed personnel and material assets (NATO, 2017). Nevertheless, the author has identified certain vulnerabilities in the course of its study on Sines Harbour.

- Perimeter Fencing Intrusion: While fences are an indispensable element of physical security, they are relatively easy to breach using wire cutters or ladders. The lack of intrusion detection systems makes them vulnerable to unauthorized access.
- Human Security Personnel Alertness: Although private security personnel are essential to daily port operations, their effectiveness relies heavily on individual alertness states that vary during the day. Fatigue and human error can result in critical lapses. Furthermore, the logistical and financial resources needed for the daily operation of a solely human based security are many.
- Patrol Monitoring System Bypass: The current patrol monitoring system, which verifies whether specific checkpoints have been visited, can potentially be bypassed through electronic means.
- CCTV System Tampering: While the CCTV network is a core component of surveillance and a key aspect envisioned in the ISPS Code, it likely contains blind spots and may be susceptible to tampering. Maintenance issues could result in the temporary loss of visual coverage over certain sectors. Additionally, the human capacity to monitor numerous live feeds simultaneously is limited, reducing the system's overall responsiveness in real time.
- Airspace Control: At present, neither the Port Administration nor the Maritime Authority (*AMN*) possesses the capability to effectively detect illegal unmanned aircrafts operating within port airspace. Detection is currently reliant on visual identification by security personnel, which is neither timely nor reliable, especially for small UAVs. The GNR has already acquired one drone detection and 3 counter-drone systems that were used during the Pope's visit to Portugal (Público, 2023). It is unclear if any of such equipment is ready to be used in Sines.
- Maritime Surveillance Coverage: The maritime jurisdiction of Sines Port Administration covers approximately 147.5 km², presenting a significant challenge for effective patrolling and interception of suspect vessels. The limited availability of manned patrol vessels operated by the Ports Private Security and *AMN* exacerbates

this issue. The simultaneous operation of recreational boats, fishing vessels and cargo ships transporting hazardous materials (such as liquified gas, petroleum and chemical products) increases the complexity and risk of maintaining maritime security. In terms of detection, the VTS system allows for some operational capability however, small surface vessels without AIS could remain undetected, especially if meteorological conditions deteriorate the detection capability of the radar system. These limitations significantly reduce the warning time available for port authorities to respond to threats and security incidents.

- Submarine Cable Integrity: The transatlantic Underwater Infraestructure that pass-through Sines and their landing sights represent critical infrastructure. Within the port's jurisdiction, these cables are located at depths of less than 100 meters, making them particularly vulnerable to interference or sabotage. The beach manholes of each cables connect directly to the ZILS Global Parques and the Start Capus data centre, which are high-value strategic assets and should therefore be subject to enhanced security measures.
- Storage Facilities Safety: The port hosts a high concentration of storage facilities for gas, petroleum and chemical substances. If inadequately secured or improperly maintained, these facilities pose both safety and security risks. Poor maintenance practices or mishandling of hazardous materials could lead to industrial accidents or create opportunities for targeted attacks.

4.7 SWOT Analysis of Sines Security

Strengths

- Cybersecurity: Sines has become a national leader in port cybersecurity through the inauguration of the Port Cyber Arena in January 2025 (APS, 2025b).
- Emergency preparedness: Sines conducts emergency exercises and maintains a PFSP that includes a comprehensive list of procedures for a wide range of emergency scenarios.

- Cooperation between the *Capitania* and the Port Administration: As stated by both the PFSO and the *Capitão* do Porto, the coordination between the Administration and the *Capitania* is "excellent".
- Cooperation with other state actors: According to the PFSO, cooperation with other national security entities such as SIS is strong.
- Well-established security infrastructure: All security measures required by the ISPS code are in place and tested, this provides a solid foundation for any additional security or defensive measures.

Weaknesses

- Concentration of Operators and of Maritime Traffic: Fishermen, gas companies, cargo and bulk carriers, recreational vessels and pipeline infrastructure, all operate in Sines Harbour, this leads to a high concentration of diverse and sometimes conflicting activities. This increases the complexity of maritime traffic and security operations.
- Size of Sines Harbour: As noted by the *Capitão do Porto*, one of the main challenges in securing Sines is the vast size of both its maritime and land areas, which complicates surveillance and rapid response efforts.

Opportunities

- Heli Dock: The existing Heli Dock offers the potential for rotary wing aircraft to take-off and land, which can be used for emergency evacuation, surveillance operations, or military coordination.
- Geographical Remoteness: The relative isolation of Sines from major urban centres like Lisbon and Porto can offer a more controllable environment with reduced exposure to urban threats.
- Proximity to Data Centres: Nearby data centres can enhance communication infrastructure and provide opportunities to improve digital connectivity and operational integration.
- Coordination with the armed forces. NATO focus on standardization and exercises such as REPMUS, represents an opportunity for the Port Administration to align with

military best practices, adopt interoperable procedures and participate in Harbour Protection training scenarios.

Threats

- An extensive list of threats as already been provided in **Figure 22**.

5. Applications of UxVs in Sines Harbour

This analysis is based on insights drawn from interviews with seven experts in the fields of Harbour Protection or unmanned systems as well as a visit to Sines Administration and an informal talk with the PFSO, Eng. Luís Mourão.

The interviewees were as follows:

- Commander Conceição Rosinha, currently in the transformation and innovation division of *Estado Maior da Armada;*
- Commander Sebatião Domingues, currently head of the department of analysis and development of *Centro Integrado de Treino e Avaliação Naval (CITAN);*
- Commander Anjinho Mourinha is the current director of the *Centro de Experimentação Operacional da Marinha* (CEOM);
- Commander Vasconcelos de Andrade is the current Harbour Master at Sines;
- Lieutenant Santos Bica, currently doing service in X31;
- Lieutenant Rodrigues Marante, currently doing service in X31;
- Lieutenant Borges Rodrigues is a professor at Escola Naval and at FCT NOVA as well as a machine learning enthusiast.

5.1 Expert Views on Security Applications

UAVs are among the most commonly employed unmanned vehicle in both modern theatres of war and port administrations who aim to enhance their security. According to Lieutenant Borges Rodrigues, one of the main advantages of UAVs is their top-down visual perspective: "The main advantage of UAVs is their capability of having an aerial perspective of events, allowing vigilance over large areas with minimal interference from physical obstacles like buildings or terrain elements". For example, the Port of Antwerp-Bruges uses six class I UAVs to patrol its 140 square kilometres. When considering the 6.31 Km2 of land comprising the jurisdictional area of Sines Port, it is likely that a single class I UAV could cover the entire area. However, deploying two or three UAVs would be advisable to ensure redundancy and enable simultaneous coverage of opposite areas, thereby improving response time. Lieutenant Santos Bica highlights the continuous surveillance potential of UAVs: "Depending on meteorological conditions and the way they are employed, it is possible to maintain several sensors permanently on station through the utilization of several UAVs". This ability to support 24/7 surveillance makes UAVs an invaluable asset in Harbour Protection.

Commander Conceição Rosinha emphasizes the importance of integrating UxVs within a multi-layered sensor framework: "UxVs are an advantage but are themselves limited in endurance and thus should be combined with other sensors in a layered fashion". This highlights the necessity not only for multiple UAVs but also for their integration with other surveillance technologies. Another significant capability, as noted by Lieutenant Borges Rodrigues, is the potential for automation: "These vehicles can be programmed to perform automatic patrols in defined areas, reducing the need for constant human intervention. In case of anomaly detection, they can generate real-time alerts for human operators".

Commander Sebastião Domingues also pointed to the importance of onboard cameras, which allow for the documentation of events and can serve as legal evidence. He added: "In the specific case of UAVs, there are advantages in integrating speakers or sound alert systems".

Commander Vasconcelos de Andrade stated that, in his opinion UAVs would be the most valuable asset in Sines Harbour and that systems like the ones in Antwerp and Haifa are a valuable addition: "In the future, fully autonomous UAVs that can self-charged trough docking stations would be a valuable addition".

When it comes to USVs, Lieutenant Santos Bica identifies them as highly valuable assets: "USVs are especially advantageous due to their cargo capacity, which allows the integration of heavier and more complex systems such as Synthetic Aperture Radars (SAR)". Lieutenant Borges Rodrigues adds: "USVs are particularly effective in the maritime areas of the harbour, where they can conduct patrol, intercept suspect vessels and integrate various systems like cameras, speakers and communication antennas to enhance deterrence, interdiction and surveillance capabilities". In addition to radar technologies, USVs can integrate sonar systems to detect potential threats to Underwater Infraestructure, both within the Port Administration's jurisdiction and beyond, under the responsibility of the *Capitania.*

USVs are by nature less sensitive to meteorological conditions than UAVs, particularly class I UAVs. During Sines windiest season, from October 29 to August 14, with average wind speed exceeding 9.3 knots, UAV operations are likely to be impaired. In contrast, USVs can endure stronger winds and higher wave conditions. An additional challenge to the operation of UAVs in Sines is interference from marine birds, as highlighted by the PFSO. One possible solution could be the acquisition of a larger class I industrial UAV, which would still benefit from agility and simplicity of class I UAVs but offer greater resistance to bird strikes. Another possible solution could be the usage of USVs, which are not affected by this issue at all.

Both UAVs and USVs should play an active role in detecting and tracking unauthorized UAVs operating within the port's jurisdiction. Although there are legal restrictions on UAV flights in the Sines area without prior authorization, the lack of an active UAV detection and mitigation system leaves the port vulnerable to potential security breaches. As commander Rosinha stresses: "Technology is fought with technology"

According to Commander Sebastião Domingues: "UUVs can become essential assets in the protection of Underwater Infrastructure, whose integrity is critical for global communications ". UUVs ability to operate in the water column and incorporate sonar systems makes them particularly well-suited for this task. Although their use in port security is still relatively rare, their use in Sines should be studied given the presence of Underwater Infrastructure. Since the Portuguese Navy already operates UUVs, such as the Teledyne Gavia, it would be both logical and cost-effective for the Navy to be responsible for their operation in Sines. This approach would leverage existing capabilities and reduce the need for additional investment or training by the Port Administration, with the main benefits of integrating this kind of technology being the improvement of submarine cable safety and better efficiency in piers inspections.

UGVs are typically not part of continuous surveillance systems but instead used in response actions. Commander Domingues explains: “UGVs have a particularly important role in IED disposal scenarios, reducing the risks associated with human exposure”. The Portuguese Army already operates such systems that could be deployed in support of port security if needed.

A critical aspect of integrating UxVs into the security architecture of Sines Port is the establishment of a robust Command and Control (C2) infrastructure. This infrastructure must allow human operators to supervise and manage the data collected by UxVs and associated sensors.

According to Commander Sebastião Domingues, when asked about the need for a Harbour Protection Module (HPM) dedicated to security roles, he remarked: “Most port administrations already have rooms dedicated to the C2 of their own assets, this reduces, in a certain way, the necessity for an additional module”. Sines Port already possesses a dedicated C2 room for the management of its assets, as well as a Cyber Centre tasked with countering cyber threats. Therefore, rather than establishing an entirely new HPM, the existing C2 room can be upgraded with capabilities specific to UxV operations. Some of the capabilities that should be integrated in the Administrations C2 room are Human-Computer Interface (HCI) tools for the control of unmanned vehicles and sensors, extra monitors with access to control sensors and UxVs, screens for video cameras and cameras on board UxVs, data fusion capability, data recording and playback capability, external interface adaptors and a dedicated small briefing area fitted with appropriate furniture and equipment like a projector, flip-chart, whiteboard, dedicated laptop and other C2 tools. It is important to have both *Capitania* and Port Administration operators present in this C2 room to ensure coordination with both entities.

AI is becoming increasingly vital in modern security frameworks. The PFSO highlighted ongoing efforts by the administration to incorporate AI into their security systems. Future capabilities are expected to include facial recognition and behavioural analysis powered by AI technologies.

AI integration will extend across the C2 system, onboard sensors and UxVs themselves. Commander Conceição Rosinha noted: “UxVs and sensors will generate a large quantity of data. AI will contribute to a better analysis of that data”. Lieutenant Santos Bica added: “AI has the power to efficiently retrieve and analyse data retrieved by the UxVs. AI also improves the autonomy of the UxV allowing it to do its own navigation, planning, identification, tracking and attack of possible threats”. Lieutenant Borges Rodrigues further emphasized: “One of the main advantages of AI is the ability to automate operations that currently demand human supervision, like surveillance and real time image analysis. Resorting to pre-planned flights and AI, it is possible to perform autonomous areal patrolling with threat detection and classification done autonomously”. These insights underline the pivotal role of AI and enhanced C2 infrastructure in elevating the operational effectiveness of UxVs in Harbour Protection. Commander Vasconcelos ends by stating: “I believe that AI will be beneficial as it can act as a facilitator in identifying targets that may pose a potential risk to safety/security, through the use of algorithms. It may also help detect abnormal situations that deviate from the normal pattern of port activity and issue the appropriate alerts”.

5.2 Expert Views on Defence Applications

For a country like Portugal, member of NATO and presented with the current geopolitical situation in Europe, it is essential to be prepared to complement the existing security measures in Sines Harbour with defensive capabilities tailored to counter threats to military vessels and the logistical transport of war material through the port. As Commander Conceição Rosinha explains: “A major challenge in Harbour Protection is the lack of mobility and freedom of action that warships experience while docked. A warship has very effective sensors and weapons, however, when moored, it becomes highly limited in terms of mobility, sensor usage and weapons employment.”

UxVs offer a good solution to highly boost defensive measures in the Harbour. Commander Anjinho Mourinha referred that “UxVs are designed to operate in dangerous, dirty and dull scenarios” and when it comes to Harbour Protection it all applies, especially the dull component, because there can be long periods of time where no threat is present.

Just as in security operations, UAVs offer enormous advantages in defence scenarios due to their top-down perspective. According to Lieutenant Rodrigues Marante, civilian rotary-wing Class I UAVs still provide significant benefits in Harbour Protection roles. However, in case of escalation, they should be complemented with fixed-wing UAVs of Class I or higher: "Fixed-wing UAVs are more suited to escalatory situations due to the complexity of their operation, particularly during take-off and landing. Generally, their cost is also higher, especially in the case of military-grade UAVs."

In a defensive context, a layered approach is fundamental to create redundancy and increase the likelihood of neutralizing threats. As Lieutenant Borges Rodrigues points out: "Harbour defence must rely on a multifaceted approach that leverages the complementarity between platforms and sensors. The combined use of different types of UxVs increases redundancy and resilience". Commander Rosinha adds: "It is essential to use all kinds of UxVs in conjunction with other sensors, as well as kinetic and non-kinetic countermeasures. We must analyse potential attack vectors and integrate monitoring and defence assets, such as UxVs, to neutralize threats." Commander Rosinha further stresses: "Unmanned systems must begin contributing more actively to the neutralization of other UxVs." Regarding the effectiveness of UxVs in countering enemy UxVs, Lieutenant Santos Bica notes: "So far, soft-kill measures have proven the most effective in neutralizing enemy UAVs. I believe that in the future, these systems will be refined and supplemented with hard-kill solutions, such as high-energy weapons, which are currently in testing." Lieutenant Borges Rodrigues highlights the cost-effectiveness of using UxVs in counter-UxV roles: "This approach is gaining importance, mainly because of the high cost of modern counter-UAV systems, such as guided missiles, being used to shoot down low-cost commercial UAVs. There is already extensive video evidence showing these tactics in real combat scenarios."

Lieutenant Bica emphasizes the unique advantages of USVs: "USVs generally have a greater payload capacity for larger sensors, which results in a higher-quality product and greater offensive potential." Commander Mourinha adds: "USVs can be used in surface surveillance with the capability of getting themselves between the threat and the port infrastructure. These systems can also carry kinetic measures to deal with threats". A notable example is the downing of a Su-30 Flanker fighter jet over the eastern Black Sea by a small Ukrainian *Magura* USV (Sutton B., 2025).

As stated by Commander Sebastião Domingues, USVs also benefit from agility and stealth characteristics: "A recent example of the importance of early warning systems against UxVs is the Ukrainian USV attack on the Russian naval base at Sevastopol. Their high speed and low radar cross-section (RCS) made them extremely difficult to detect and intercept."

UUVs also have a vital role in harbour defence. They can perform underwater surveys of piers and terminals, tasks that, when done autonomously or in support of human divers, greatly enhance operational efficiency and safety. Commander Domingues explains: "The need to conduct pier inspections before the arrival of warships or other critical vessels is a perfect example of how UUVs can improve the effectiveness and sustainability of Harbour Protection missions. When these checks must be conducted repeatedly, diver teams can use UUVs to extend high security levels over time, relieving pressure on human resources." Commander Mourinha concludes: "UUVs are useful in bottom surveys that allow to detect modifications to the bottom that could be connected to the positioning of mines and other explosive cargo".

All experts interviewed acknowledged the operational complexity of managing multiple unmanned systems, particularly, the difficulty of integrating data from different formats and sources. They stressed the importance of Standardization Agreements (STANAGs) and joint exercises like REPMUS. As Commander Domingues states: "One of the main capabilities that must be developed is training, but not just training. We also need doctrine. Specifically, ATP-94 must be updated. There is also an urgent need to increase standardization between systems." Commander Mourinha adds: "ATP-94 should be updated and include the specific tactics for the use of these unmanned systems”.

On the topic of C2, Lieutenant Santos Bica states: “One of the main challenges is the C2 architecture. Operating multiple UxVs increases complexity significantly, making interoperability between platforms essential. Exercises like REPMUS are vital for testing and enhancing this interoperability. In a single event, numerous systems can be deployed, allowing us to collect vast amounts of data.” He further explains NATO’s role on this topic: “NATO is addressing the interoperability challenge through the development of STANAGs, which aim to create synergies between private companies and operators. The goal is to establish common standards for coding languages and communication protocols.” Commander Mourinha complements: “The C2 of UxVs is a highly complex subject, it is essential to have a system to integrate all of the information. NATO is developing that ability trough STANAG 4817”.

Effective civil-military cooperation is also crucial. Commander Sebastião Domingues states: “In a Harbour Protection Operation, it is essential to ensure strong coordination between the HPC, the *Capitão do Porto* and the civilian port administration. The *Capitão do Porto* and the port administration run daily port security and have a deeper understanding of the port characteristics. For that reason, coordination must be close and constant.” It is recommended that the HPC operates upon the existing administrative security structure and leverage the current C2 infrastructure. This infrastructure must be upgraded with additional sensors and effectors, including sensors like air warning radars, satellite earth observation systems, Identify Friend or Foe (IFF) radars, satellite communications, HF/UHF/VHF communication capabilities, high-resolution cameras, infrared cameras, magnetic barriers and fixed sonar systems. In addition to sensors, it is imperative that the HPC has at his disposition soft/hard kill effectors like counter-UAV systems, Close in Weapons System (CIWS), remoted operated guns and anti-diver systems. As Commander Rosinha concludes: “The port infrastructure bears responsibility for protecting the ship. For that reason, it must be equipped with sensors and weapon systems that can substitute those available onboard.”

6. Contributes for an Implementation Proposal of UxVs in Sines Port

Drawing on the preceding chapter, this section outlines a proposal for the integration of UxVs into the security and operational framework of Sines Port, in a manner that aligns with the functions and responsibilities of the Port Administration. The proposal is structured around five key objectives. It begins by outlining the core goals behind the implementation of UxVs in Sines. It then defines the operational requirements necessary for their use, like physical dimensions, levels of autonomy and communication systems. This is followed by an explanation of the possible employment concept of such equipment, along with an analysis of operationally relevant UxVs currently in use across various military and civilian sectors. Finally, it considers the key challenges and limitations that may arise during the integration process.

6.1 Objectives of employing UxVs in Sines

6.1.1 UAVs

Primary Objectives:

Port Security. UAVs will provide an organic, mobile sensor to complement fixed CCTV, perimeter fences, access-control points and motorized patrols. By offering rapid aerial vigilance capabilities of intrusions detected on cameras or anomalous vessel movements, UAVs reduce reaction times and improve situational awareness.

Port Safety. UAVs must contribute to an improvement on safety. In high-risk maintenance or emergency scenarios, UAVs can supply real-time imagery. For example, during hot-work operations or firefighting, UAVs can help the administration to assess heat sources, identify hotspots and improve the C2 of personnel.

Secondary Objectives:

Infrastructure Inspection and Maintenance. Through the EO/IR and LiDAR equipment UAVs can provide valuable information on cranes, quays and detect cracks, corrosion or structural anomalies. Such unmanned inspections also decrease personnel exposure to hazards.

Environmental/Hazard Monitoring. UAVs can identify oil or chemical spills and help mapping affected areas as well as support containment efforts.

Search and Rescue. Although not an Administration responsibility, other actors like the *AMN* or the Navy could use these UAVs to scan large maritime areas in search of a person in distress.

6.1.2 USVs

Primary Objectives:

Port Security. USVs are to act in the wet area of the Harbour and provide radar, AIS and video information about ships and crafts in their jurisdiction. They can also use sonars to get information about the subsurface environment. They can also intercept vessels far from shore and relay messages and information directly from the *Capitania* and the Port Administration.

Navigation Safety. USVs must be able to deconflict the radar picture and provide the VTS system with valuable information about maritime traffic in the administration's jurisdiction.

Hydrographic surveys. Through sonar systems USVs are able to perform expedite hydrographic surveys of the bottom thus contributing to the safety of navigation and of underwater infrastructure.

Secondary Objectives:

Environmental monitoring. USVs fitted with pollution or oil spill detectors can provide real-time data to the *Capitania* thus contributing to the control and monitoring of a hazardous situation.

Ship Inspection. If fitted with high-resolution cameras and LiDAR a USV can perform close-range inspections of a ship's hull. This improves the chances of detection of structural damages and corrosion.

Search and Rescue. USVs could be use by the *Capitania* in Search and Rescue efforts to monitor large maritime areas, extend search efforts ana actively detect and save persons in distress.

6.1.3 UUVs

Primary Objectives:

Bottom Surveys. The UUVs must be able to execute frequent surveys thus detecting alterations objects in the sea bottom.

Underwater Inspections. UUVs must be capable of working independently or with divers to inspect ships hulls, piers and other underwater infrastructure.

Secondary Objectives:

Environmental Monitoring. UUVs can carry sensors to measure water quality, temperature, salinity and pressure.

6.1.4 UGVs

Primary Objectives:

Port Security. UGVs can serve as mobile ground-based surveillance assets to support and complement human personnel in the execution of routine patrols.

Secondary Objectives:

Port Safety. UGVs can contribute to the overall safety of port operations by providing live video feed or sensory data of dangerous access places for humans. They can also transport safety equipment.

6.2 Operational Requirements

The following operational requirements were developed considering the specific conditions of Sines Harbour, consultations with the *Capitania*, a talk with the Sines Port Administration, current UxV models employed in other harbours and a selection of commercially available systems. A total of 59 uncrewed systems were analysed using Python: 25 UAVs, 15 USVs, 11 UUVs and 8 UGVs. The results are presented in radar charts in Appendix B. These charts are structured around key parameters chosen for their operational relevance and their consistent availability in open-source technical specifications.

6.2.1 UAVs

Discussions with members of the Port Administration indicated that Class I rotary-wing UAVs would be the most suitable type of UxV for implementation in Sines Harbour. Rotary-wing configurations include quadcopters (4 rotors), hexacopters, (6 rotors), octocopters (8 rotors) and coaxial multirotor (stacked rotor pairs on each arm). Rotary-wing UAVs are simpler when it comes to take-off and landing and have the ability to remain stationary. These and other factor make rotary type UAVs the main type of UAV chosen by civilian authorities. In general, heavier and more powerful vehicles are needed to endure the high winds in Sines and carry the necessary payloads to execute the necessary missions. Wind resistance is influenced by thrust, weight, aerodynamic and size of the UAV (FlyEye.io, 2024).

Recent heavy-lift UAVs can carry tens of kilograms for long durations. The SiFly Q250 (an electric VTOL UAV) can lift 90 Kg for 90 minutes (Dukowitz, 2025). Similarly, the Skyfront Perimeter 8 (octocopter) can carry up to 10 Kg for 1 hour or 5 Kg for 2-3 hours (*Skyfront*, 2025) and Harris Aerial's Carrier H6 UAV (hexacopter) can fly up to 2.5 hours with 3-4 Kg payload (*Harris Aerial Carrier H6 Hybrid*, 2025). In the Class I upper limit with a MTOW of 140 Kg the Foxtech's coaxial THEA 200MP octocopter is capable of carrying 70 Kg (FOXTECH, 2025).

The following requirements outline the platform capabilities and standards that would contribute to efficient operation in Sines Harbour in support of port security, port safety, infrastructure inspection, environmental monitoring and search and rescue. These requirements are aligned with current practices and technological capabilities.

Endurance and Power: Many recent equipment's are already able to sustain 60 minutes of continuous flight. This provides increased mission flexibility. Achieving this kind of endurance often requires high-density power sources such high-capacity lithium-ion batteries or bigger gasoline-electric hybrid engines. This kind of endurance allows, the UAV not only to reach any part of the harbour but also to retain enough battery power to remain on station for a considerable amount of time.

Operative altitude: The UAV should be capable of flying up to 60 m or higher to safely clear port structures (the quay cranes at terminal XXI reach 55 m height). This allows an overhead view of the port and vessels. Most UAVs, even the smaller ones, are able to achieve this minimum altitude.

Speed and Wind Handling: There is no maximum speed required, however, the aircraft must have sufficient thrust and speed reserve to cope with winds up to 20 knots without losing ground. This would allow the UAV to have high monthly employment percentage.

Payload and Sensors: The UAV will need to carry several sensors to fulfil the different needs. The primary sensor is a stabilized EO/IR sensor mounted on a 3-axis gimbal controller for day and night surveillance. A typical surveillance payload could include:

- A high-resolution EO video camera with optical zoom for daytime imaging and identifying vessels or intruders. These gyro-stabilized camera systems usually weight between 1 and 2 Kg (Yangda Security, 2025).
- A thermal IR camera for night surveillance and fire/hot-spot detection. This enables the UAV to spot unauthorized personnel in darkness or assets heat signatures during firefighting operations.
- A LiDAR sensor for obstacle avoidance and structural inspection. LiDAR payloads can range from lightweight mapping units to high-definition

scanners. The UAV should be able to swap to a heavier LiDAR for infrastructure inspections.

Deployment: The rotary wing UAV should be quickly deployable and capable of autonomous take-off and landing. The UAV will require precision landing capability to touch down on a designated pad or dock. Given the need to respond to security intrusions or emergencies in the port, a rapid launch is critical. The system can be kept on standby or housed in a UAV dock like the ones used in Antwerp or Haifa. The vehicle should be capable of taking off and landing in confined surfaces without the necessity of having a dedicated runway.

Autonomy: The UAV should possess a high degree of autonomy in flight so that the human operator acts in a supervisory (on-the-loop) role rather than manually flying the UAV. In practice, this means the aircraft can follow pre-planned waypoints, automatically patrol a route and handle low-level flight control. While the operator monitors the mission and can intervene or re-task as needed. The autonomy level corresponds to a decision-support role in which the UAV can generate suggestions of modifications to its flight plan and the operator approves or modifies these suggestions. According to the LORA algorithm a decision-support level vehicle must be able to avoid obstacles and manage routine tasks, with a human making higher-level decisions. For Sines Harbour, such autonomy allows one operator to manage the UAV’s security patrols or inspection flights.

Navigation: The UAV must support top-down waypoint navigation and have the ability to upload GPS waypoints, altitude and speed parameters for the UAV to follow precisely. The system should also allow for a FPV navigation if required.

Obstacle Avoidance: It is required for safe autonomous flight in the port’s complex environment. The UAV should be equipped with proximity sensors to detect obstacles in its flight path (Fuchi et al., 2022). This capability is essential for autonomous operation beyond visual line of sight around structures. The system should continuously monitor its surroundings and actively avoid the obstacle.

Geofencing: The UAV control software must have geofencing tools to keep the UAV within approved areas. The Port Authority should designate exclusion zones around fuel depots, refineries and nearby residential areas. If the UAV approaches a restricted zone, it should automatically stop or turn back, unless overridden with proper clearance. Geofencing is also an EASA recommendation for UAV manufacturers (EASA, 2025).

Other Safety Features: Parachute recovery, automatic return to base (RTB) capability, positive buoyancy, navigation lights and emergency recovery signal.

Weather Resistance: Sines Harbour's coastal conditions demand a UAV resistant enough to operate in light rain or marine spray without issue. Typically, this means at least an IP54, IP66 or IPX5 ingress protection rating for the airframe. These ratings were defined by the International Standard IEC 60529 and are commonly used to specify the environmental protection of electronic devices, including UAV airframes. The UAV's Go/No-Go system should incorporate real-time wind readings to abort flights if the defined wind threshold is surpassed.

Communications: Line-of-sight radio standard bands (2.4 GHz/5.8 GHz) provide primary control and high-bandwidth video downlink at shorter ranges. BVLOS datalink extends the operational range and adds a layer of redundancy if the direct radio control is lost or out of range. A private 4G/5G network can enable real-time HD video feeds and sensor data relay. All communications should be secured with strong encryption and authentication to prevent interception or hacking.

Platform Weight: A rotary wing UAV in the range of 10-30 Kg of MTOW would offer greater mission flexibility and resistance to meteorological conditions, outperforming smaller micro-UAVs that often struggle with endurance and high winds. A class I UAV in these weight range has a grater probability of carrying the necessary sensors and have the necessary power to cope with the windy conditions of Sines.

6.2.2 USVs

Endurance and Speed: Diesel propulsion endows USVs with superior speed and range capabilities, making it the choice for large, ocean-going or high-performance vehicles, whereas smaller USVs built for slower-paced or closer to shore missions are trending toward electric drive systems (De Andrade et al., 2025). Following this trend and according to the main objectives of integrating USVs in Sines, an electric USV like the MANTAS T12 would enhance patrolling and survey capabilities. The T12 can reach a burst speed of 25 knots, enabling rapid deployment within the harbour and the interception of vessels. It cruises at 8 to 20 knots and has a cruising range of just over 35 nautical miles with the possibility of being solar charged (Bluezone Group, 2020).

Larger and heavier diesel-powered USVs, such as the 8.22 metre B7 Beagle and the 12 metre K3 Scout, are capable of achieving ranges of 800 (Smart Own, 2025) and 1000 nautical miles (KRAKEN TECHNOLOGY, 2025), respectively, making them suitable for extended missions requiring long endurance.

Payload and Sensors:

- A wind meter, a temperature and humidity sensors to capture local weather conditions. These support safe operation and collect environmental data relevant to harbour management.
- A radar or camera for surface target detection and tracking. This helps the USV and its operators to detect other vessels or obstacles in the harbour, especially in low visibility and aids in deconflicting the radar picture of the port VTS by providing an independent mobile station.
- AIS transceiver allows the unmanned system to receive AIS data from nearby vessels and broadcast the USV’s identity and position.
- CBRN sensors enable the USV to perform hazard detection in the port environment.
- Stabilized EO/IR camera for day and night surveillance.
- Multibeam Echo Sounder for underwater surveys.

- Loudspeakers allow remote operators to broadcast voice or signals to nearby vessels or persons.
- Lighting system for night operations.

Autonomy: The USV shall support multiple modes of operation, including fully manual control (fully manned), remote control and supervised “human-on-the-loop” autonomy. A real-world example is the Elbit Seagull, a 12 m USV which can be operated in both unmanned and manned modes as needed (Praveen, 2016).

Navigation and Obstacle avoidance: The USV must have an active collision avoidance and navigation safety system. Features should also include automated collision risk warnings at the control station and emergency stop.

Safety Features: These features include Search and Rescue support, physical safety equipment on the craft and clearly defined GO/No-Go criteria.

Weather Resistance: The USV shall be capable of fully operating in up to Sea State 5. Even if some specialized USVs are capable of enduring extreme conditions of sea state 9, tolerance to sea states 4 or 5 are the most frequently encountered in USVs (De Andrade et al., 2025).

Communications: The USV shall maintain a primary communication link for telemetry and command, utilizing marine radio frequencies (VHF/UHF band) suitable for line-of-sight coverage through the harbour. This link will carry control commands, status telemetry and video feeds between the USV and the shore control station. The communication suite should be encrypted and secure from interference and a secondary/redundant link (4G/LTE cellular connection or satellite link) is essential for backup.

Platform Weight and Size: It is important to keep the USV light and small to facilitate transportation. A small USV (under 1 ton displacement) would offer better portability making it easier to trailer, launch and recover from a small pier (De Andrade et al., 2025). Although small USVs are inherently more portable and can be rapidly deployed as needed in the harbour environment, it is important to note that bigger USVs are normally more stable in higher sea states, carry all the needed payload and be visible enough for not posing a threat to navigation. QinetiQ's 7 m Barracuda USV is a Rigid Hull Inflatable Boat (RHIB) design that can exceed 36 knots in sea state 2 (QinetiQ, 2025).

6.2.3 UUVs

The most important capability for an UUV operating in Sines is its surveying capacity, particularly for hydrographic mapping and seabed monitoring. According to Commander Anjinho Mourinha, the detection of underwater threats using friendly UUVs remains challenging due to current limitations in detection technologies and environmental complexities.

The Portuguese Navy operates the Teledyne Gavia UUV, a system that exemplifies the type of capabilities desirable for enhancing the security of Sines. Its modular design, survey sensors and operational flexibility demonstrate the potential contributions of UUVs in incrementing Sine's security. The Gavia AUV can be seen in **Figure 26**.

Vehicle Type: AUVs offer several advantages over ROVs, primarily due to their untethered and autonomous nature. Unlike ROVs, which require continuous human control via tether, AUVs operate independently without physical connection to the surface, allowing them to cover wider areas. This makes them particularly suited for hydrographic surveys and mine detection operations (Ghatak et al., 2023).

Depth Rating: Within the jurisdictional boundaries of the Port Administration of Sines, water depths do not exceed 100 metres. Most commercial AUVs easily surpass this depth limitation. For example, the REMUS 100 is rated to 100 metres, while more advanced platforms like the SeaRaptor, Gavia and HUGIN AUVs are capable of operating at depths ranging from 1000 metres to over 6000 metres, making them highly versatile for a variety of mission profiles.

Speed and Endurance: For the Gavia UUV, a typical defence or scientific configuration represents 7 to 8 hours endurance at 3 Knots per rechargeable battery module. With all sensors the Gavia endurance drops to 5 to 6 hours at 3 knots per rechargeable battery module (Gavia AUV, 2025).

Communications: The Gavia UUV utilises a wireless Lan IEEE 802 compliant, full global coverage satellite communications via iridium link and an acoustic modem for tracking and status updates (Gavia AUV, 2025).

Sensors: The Gavia supports a diverse suite of modular, survey-grade sensors, including Synthetic Aperture Sonars (SAS), Sub-Bottom Profiler (SBP), Multibeam Echo Sounder (MBES), Side-Scan Sonar (SSS), optical cameras, environmental probes and custom payloads (Gavia AUV, 2025).

Figure 26- Gavia UUV[25]

[25] Figure taken from (Gavia AUV, 2025)

6.2.4 UGVs

UGVs have been extensively used in IED neutralization. Almost 2,000 UGVs operated in Afghanistan with the main purpose of explosive ordnance disposal (D. Axe, 2011). UGVs are, however, becoming more versatile and being utilized for other tasks like reconnaissance, surveillance and patrolling duties (S. Magnuson, 2011).

In the case of Sines the addition of 1 or 2 UGVs would not significantly boost Sines Security as it would with other types of Unmanned Vehicles. It is, however, important to consider future technological ways to increase Port Security. To be a relevant asset in the security of Sines, UGVs should meet the following operational requirements:

Platform size, weight and mobility: The UGV should be compact enough to navigate through standard doorways, enabling its use in indoor environments when required. While high speed is not essential, the UGV must be capable of covering the perimeter areas in an efficient way.

Power Supply and Endurance: The UGV should be capable of operating for several hours without the need for recharging, to ensure sustained field performance. Field-deployed UGVs are now able to achieve several hours of endurance on battery power. For example, the small Clearpath Husky runs 4 hours on a standard pack (Clearpath Robotics, 2025) and the ULTRO UGV can operate for 12 hours (Valpolini P., 2023).

Weather Resistance: Given that the UGV would operate in close proximity to water, it is recommended that it have an IP rating of at least IP54 to ensure adequate protection. The UGV must be capable of withstanding rain, dust and marine spray, which are common in port and coastal environments. For example, platforms such as the Husarion Lynx, AVT-W9 4WD and Ghost Robotics Vision 60 all feature IP54 or higher rating (Husarion, 2025).

Autonomy and Navigation Systems: The UGV should be capable of autonomously following pre-planned patrol routes using GPS-based waypoint navigation. To ensure operational robustness, especially in areas where GPS signals may be degraded or unavailable, the UGV should also integrate LiDAR or vision based Simultaneous

Localization and Mapping (SLAM) technologies (M. Zaffar et al. 2018). Additionally, the system should support collaborative operations with multiple UGVs, enabling coordinated patrols and enhanced surveillance coverage. In line with the LORA framework, implementing a supervisory control or other "human-on-the-loop" approach is recommended. This model allows human operators to oversee missions and intervene when necessary, thereby reducing operator workload while maintaining oversight and mission flexibility.

Sensors:

- A high-resolution EO/IR camera system for day and night surveillance. This allows the UGV to perform area scans and record suspicious activities or individuals.
- LiDAR or visual odometry sensors for mapping, navigation and obstacle avoidance. This enables the UGV to autonomously navigate through the harbour.
- GNSS and IMU module for accurate localization and navigation. This combination contributes to a more precise orientation of the UGV.
- Sensor Suite for gas detection and air quality monitoring. Sensors to detect hazardous gases such as methane or carbon monoxide are useful when inspecting confined harbour areas.

Communication links: The UGV should be equipped with secure line-of-sight radio communications for on-site control and private cellular 4G/5G connectivity.

6.3 Employment Concept

6.3.1 UAVs

Deploying Class I UAVs at Sines Harbour can enhance daily surveillance while ensuring on-call responsiveness for incidents. One flight during the day and one or two at night, would greatly expand the security presence, as UAVs can maintain frequent patrols without the fatigue limits of human guards (JOUAV, 2024). These systems can serve as mobile surveillance platforms, reducing reliance on static cameras and sensors within the harbour. Their use enhances situational awareness, delivers real-time intelligence and increases overall operational flexibility. Incorporating UxVs into a C2 infrastructure can also enable real-time data transmission and communication among various protection assets, thereby facilitating quicker response times and more efficient deployment (Kim & Shin, 2024). Unmanned aerial patrols can cover perimeter and respond to incidents far faster than manned patrols (McNabb, 2019). The patrol frequency can also be escalated in proportion to threat levels, for example, if port security level 2 is applied, the number and frequency of patrols can increase. During routine flights the UAVs are to monitor the integrity of fences, CCTV towers and access gates, complementing motorized security patrols on the ground. This manned-unmanned teaming (MUM-T) allows each asset to play to its strengths. The UAV offers a high vantage point and rapid site access (even to hard-to-reach areas), while officers on the ground can respond immediately to any intrusion once its detected (McNabb, 2019).

Studies have stated that unmanned systems operating in tandem with human teams can reduce manpower requirements and improve efficiency (Stein, 2018). In practical terms, this means fewer personnel needed for constant perimeter checks and lower risk to human guards, since a UAV can be sent to investigate alarms or suspicious activity before officers intervene (JOUAV, 2025). To ensure quick reaction at all times, at least one UAV should remain on standby, fully charged, pre-flight checked and ready to launch on-demand. Modern autonomous UAV-in-box systems already enable around-the-clock deployments of this kind, capable of performing scheduled patrols and immediate incident response missions 24/7 (McNabb, 2019).

Effective use of these UAVs will leverage MUM-T with appropriate autonomy and division of labour. A single trained human can operate the UAV, especially if certain functions are automated or offloaded to the UxV's onboard systems. Ruff et al. (2004) has demonstrated that management-by-consent (where the UxV senses the environment and comes up with a plan, but a human operator is necessary to command the UxV to implement action) was superior to management-by-exception (where the UxV autonomously senses the environment plans and executes the plan if the human operator doesn't stop it). In the event of a security incident or any increase in task complexity, a second operator (or watch-stander) can be brought in to share the workload by taking over high-level mission management, communicating with ground teams and monitoring the broader situational picture while the first operator focuses on piloting or sensor imagery. Studies support this two-person approach. While a skilled individual can control multiple unmanned vehicles with the help of automation, adding another human teammate tends to improve performance and safety in high-stress or high-task-load scenarios (Porat, T. et al., 2016).

6.3.2 USVs

USVs are highly advantageous assets that could be employed not only by the Port Administration, but also by the *Capitania*, *AMN* and the Portuguese Navy. They offer several operational advantages. Operating at the water surface, USVs are less affected by the strong winds commonly experienced in Sines, wich could limit UAV operations. Furthermore, USVs are already in use in several harbours worldwide, such as in Los Angeles, where they support traffic monitoring and maritime domain awareness (Hydro International, 2025).

The acquisition of USVs with the operational requirements mentioned above do not replace the valuable rotative wing UAVs, capable of operating both in the dry as in the wet area of the port. It is very useful however to use these USVs in coordination with the UAVs.

These USVs would contribute to the overall security and safety of the harbour by conducting daily patrols of the waterside, monitoring vessel traffic and execute bottom surveys. USVs serve as force multipliers that increase manned capabilities, filling coverage gaps without risking crew fatigue or high operational costs (Naval News, 2022). In routine operations, these craft would scan for illicit activities or safety hazards.

USVs could be re-tasked on short notice for joint missions with the *Capitania*, the *AMN* and the Portuguese Navy. For example, a USV on patrol might be redirected by the *Capitania* to assist in a search and rescue mission.

Integrating USVs in the Port's security framework alongside human operators and UAVs would further amplify Sine's situational awareness and all-weather resilience. In a MUM-T framework, USVs and UAVs can share data and coordinate actions to create a comprehensive real-time picture of the port. An overhead UAV might provide wide-area surveillance or quickly investigate alarms, while an USV tracks contacts at the water level and can physically intercept or inspect objects of interest. Real-World exercises have demonstrated the value of collaboration between surface, aerial and underwater assets. For example, the United States Coast Guard successfully combined a small UAV with an ROV to map a disaster site, using the UAV's live aerial imagery to guide and optimize the search for submerged targets (United States Coast Guard, 2024).

6.3.3 UUVs

The Portuguese Navy could employ a Gavia or similar platform to execute systematic surveys of Sines Harbour bottom and piers. The AUV could thus provide high-resolution mapping of the Harbour's bathymetry and underwater infrastructure. Under Portugal's Maritime Authority system, Portuguese Navy crews could operate the Gavia in formal coordination with the Port Administration. UUVs, such as the Gavia or the SeaExplorer, are currently used by the Portuguese Navy to collect oceanographic data. These vehicles can be employed not only for seafloor scanning but also for measuring sound velocity, salinity and depth.

The AUV would be employed by performing pre-planned survey patterns. Launch and Recovery could be done by RHIB from one of Sines Terminal's or from a Portuguese Navy ship. In case of pier inspections, the AUV can be deployed from the pier itself.

UUVs still struggle to detect other assets in the underwater environment and thus UUVs in Sines should focus on surveys while other fixed measures like magnetic barriers and sonar systems would take part in the detection of threats. Many of underwater threats start falling out of the Port Security spectrum and start entering the Harbour Defence area. This means the primary stakeholder in the use of these assets should be the Portuguese Navy in coordination with the *Capitania.*

By employing UUVs in coordination with UAVs and USVs a complete operational picture could be obtain thus ensuring the security of Sines Harbour and of its critical infrastructure.

6.3.4 UGVs

The implementation of UGVs in Sines would contribute to support daily security operations, reduce human exposure to risk and enhance multi-agency coordination. Security UGVs can patrol around industrial facilities, monitor restricted areas and detect suspicious activity preventing sabotage (Robotnik, 2023).

One of the primary advantages of UGVs lies in their ability to operate in spaces that are inaccessible or dangerous for human personnel. In the context of Sines Port, this includes confined industrial zones, tight cargo holds and areas potentially affected by toxic atmospheres, such as those near fuel storages or chemical processing infrastructure.

UGVs are already being employed in routine patrols of critical infrastructure. At an U.S. Air Force base with steep, hazardous terrain, Ghost Robotics quadrupedal UGV patrolled the flightline fence autonomously. It eliminated the need for human patrols, reducing the number of guards on patrol from three per day to zero, while covering more ground (Ghost Robotics, 2025).

UGVs would be employed in daily patrol cycles, covering critical infrastructure such as fencing, entry points, cargo areas and terminals. Using predefined GPS waypoints, they will perform systematic checks for anomalies like breaches and unauthorized access.

UGVs must be able to cooperate with human patrol teams and other unmanned vehicles operating in the harbour. UGVs, similarly to other unmanned systems also support multi-agency coordination by streaming video or sensor data to a central C2 facility that can be shared with the administration and the *Capitania.* UGVs have also the benefit of being deployed in places where neither UAVs, USVs or UUVs can reach.

6.4 Operationally Relevant UxVs

By analysing the characteristics and operational requirements defined above and comparing them with current UxV systems (through radar chart assessments of various platforms), it becomes evident that certain unmanned platforms can closely fulfil key needs. In **Table 8** several UxV models were identified as particularly relevant for boosting Sines security.

UxV Type	Representative Models	Vulnerability's Addressed
UAV	**Falcon II** **Perimeter 8**	• Perimeter Fencing Intrusion • Human Security Personnel Alertness • Patrol Monitoring System Bypass • CCTV System Tampering • Maritime Surveillance Coverage • Submarine Cable Integrity • Storage Facilities Safety
USV	**B7 Beagle** **MANTAS T12**	• Human Security Alertness • Maritime Surveillance Coverage • Submarine Cable Integrity
UUV	**Gavia** **Iver4 900**	• Maritime Surveillance Coverage • Underwater Infrastructure Integrity
UGV	**RB-WATCHER** **Vision 60**	• Perimeter Fencing Intrusion • Human Security Personnel Alertness • Patrol Monitoring System Bypass • CCTV System Tampering • Storage Facility Safety

Table 8- UxV Models and Vulnerabilities Addressed

The Falcon II is a quadcopter capable of operating in adverse weather conditions over 60 knots wind with a big enough payload capacity to integrate several sensors (WaveAerospace, 2024). The Perimeter 8 UAV is an octocopter with flight endurance capable of exceeding 120 minutes (Skyfront, 2025). This allows for longer patrol missions or continuous monitoring of large areas. These UAVs, seen in **Figure 27** and **Figure 28**, directly address several vulnerabilities present in Sines and other similar harbours. Their aerial perspective enables detection of perimeter fencing intrusions and complements human security personnel. These types of UAVs can also mitigate vulnerabilities associated with the tampering or disabling of CCTV cameras. Furthermore, their endurance and weather resistance allow them to access the wet area of the port thus enhancing maritime surveillance.

Figure 27- Falcon II UAV[26]

[26] Figure taken from (WaveAerospace, 2024)

Figure 28- Perimeter 8 UAV[27]

In the USV category, the MANTAS T12, showed in **Figure 10** demonstrates capabilities well-suited to address several identified vulnerabilities in the security of Sines. Its autonomous navigation and real-time video transmission enhance situational awareness across the harbour’s wet zone by enabling continuous, pre-programmed patrols. The platform supports a range of modular payloads, including EO7IR cameras, LiDAR and subsurface sensors such as sonars, allowing it to monitor both surface and underwater activity (MARTAC, 2025b). In comparison, the larger Marakeb B7 Beagle, measuring 8.22 metres and powered by a diesel engine, offers an extended endurance of up to 800 nautical miles and can also carry EO/IR sensors and towed sonar systems (Smart Own, 2025). This vehicle can be observed in **Figure 29**. Both USVs provide valuable operational coverage for surface and subsurface surveillance, contributing to enhanced security of port waters.

[27] Figure taken from (Skyfront, 2025)

Figure 29- Marakeb B7 Beagle[28]

Within the UUV category, the Teledyne Gavia and L3Harris Iver4 900 represent two platforms capable of conducting extended underwater surveying missions that directly address key vulnerabilities in Sines, namely maritime surveillance coverage and the integrity of underwater infrastructure. Both systems are equipped with advanced survey-grade sensors such as side-scan sonar, multibeam echo sounders and sub-bottom profilers, enabling them to detect anomalies in the seabed. While similar in purpose, the Gavia, showed in **Figure 26**, offers greater modularity and a significantly higher depth rating, making it suitable for deeper and shorter inspections. The Iver4 900, seen in **Figure 30**, has a depth rating of 300 metres and up to 20 hours of endurance, is optimized for long-duration missions across large harbour sections (L3HARRIS, 2025). These platforms exemplify the type of UUV capability required to improve underwater situational awareness.

[28] Figure taken from (Smart Own, 2025)

Figure 30- Iver4-900 UUV[29]

In the UGV category, the Robotnik RB-WATCHER and Ghost Robotics Vision 60 have the ability to provide terrestrial surveillance and inspection capabilities across a variety of terrains. RB-WATCHER is a compact wheeled robot capable of navigating tight industrial areas (Robotnik, 2025), while the vision 60 is a quadruped system capable of traversing uneven ground (Ghost Robotics, 2025). Both platforms support modular sensor payloads, including 360º cameras and thermal imaging. These UGVs, seen in **Figures 31 and 32**, can monitor the perimeter fencing for breaches and support manned inspection of storage facilities. They are also able to provide redundancy to fixed CCTV systems and enhance overall situational awareness at ground level.

[29] Figure taken from (L3HARRIS, 2025

Figure 31- RB-Watcher UGV[30]

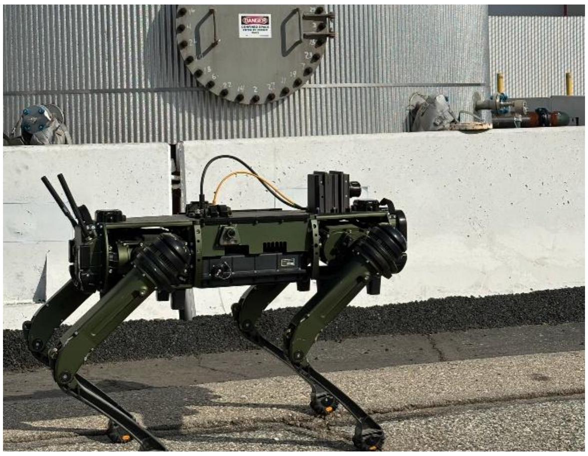

Figure 32- Vision 60 UGV[31]

6.5 Key Challenges and Limitations

The integration of unmanned systems, namely UAVs, USVs, UGVs and UUVs, into the security and monitoring architecture of Sines Harbour will be linked to operational

[30] Figure taken from (Robotnik, 2025)

[31] Figure taken from (Ghost Robotics, 2025)

benefits. However, their successful deployment faces several challenges that span across institutional, technical, financial and regulatory domains.

Personnel and Training Limitations. Personnel in Sines Harbour are, already, fully committed to maintaining 24/7 security coverage. As a result, any UxVs introduced into Sines security framework must possess a high degree of autonomy and facilitators of navigation thus saving precious human resources.

C2 Infrastructure. Integrating a heterogeneous fleet of UxVs requires an advanced C2 infrastructure. This includes not only control stations for individual vehicle types but also the backbone systems needed for real-time C3 of all assets, manned and unmanned. The complexity increases when unmanned systems operate simultaneously in multiple domains, air, land, surface and subsurface, each with different bandwidth needs, latency tolerances and positioning systems.

Financial Constrains. The cost of acquiring operating and maintaining unmanned systems remains significant. In addition to the upfront procurement of UxVs, ports must invest in infrastructure (charging stations, maintenance bays and secure data centres), personnel training and spare parts logistics. A comprehensive cost-benefit analysis is therefore essential to align capability ambitions with budget realities.

Regulatory and Legal Limitations. The employment of UxVs, especially in public and dual-use spaces like commercial ports, must comply with national and EU legislation. For UAVs, this includes regulations from EASA and ANAC and for UUVs or USVs, navigation rights and maritime safety protocols of the IMO must be respected.

Technical Limitations and Environmental Constrains. Despite advances in autonomy, many unmanned systems still struggle with environmental resilience. UAVs, for instance, are vulnerable to high wind speeds, particularly relevant in Sines' coastal climate, while UUVs must operate faced with turbidity and strong currents. Battery life, navigation accuracy and obstacle avoidance remain major technical hurdles.

Techniques and Procedures. Similarly to what happens in the military, civil entities that are looking to use UxVs in security roles often lack the proper tactics, techniques and procedures (TTPs) to do so.

Data Protection. Sensitive data retrieved by UxVs must be collected, transmitted, stored and processed in strict compliance with data protection regulation and national data privacy laws. The risks of data breach, cyberattacks or unauthorized access are amplified by the variety of unmanned systems available and reliance on wireless communication links. Special attention must be paid to ensuring end-to-end encryption, secure authentication mechanisms and controlled access to data storages.

7. Conclusions

Sines is a particularly important port in Portugal due to the significant volume of energy-related products it handles. Additionally, and no less critical, several submarine telecommunication cables land in Sines (with nearby data centre facilities), making it a key element of national and European critical infrastructure. Disruption to Sines' operations or its data connectivity could have far-reaching economic and security implications.

Protecting maritime critical infrastructure, especially energy hubs like Sines, has become an increasing priority for NATO. Achieving effective protection requires stronger civil–military cooperation and genuine synergies between military forces and local port authorities. Furthermore, dedicated funding and resources should be allocated across the responsible stakeholders to enhance port security measures, such as improved surveillance systems and response capabilities.

The current NATO doctrine for Harbour Protection is outdated for countering modern threats to maritime critical infrastructure. While expeditionary naval capabilities remain essential, it is equally crucial to ensure the protection of Allied nations' home ports. This includes equipping the civilian authorities responsible for port security with the necessary tools and training to fulfil their duties effectively. A notable gap in present doctrine is the underutilization of UxVs in Harbor Protection roles. NATO's HPM concept and associated documents should be updated to reflect modern security needs, aligning their requirements with capabilities envisioned in standards like STANAG 4817. In practice, although a full NATO-deployable Harbour Protection Module may not be permanently stationed at a port like Sines, certain capabilities provided by this module (especially those enabled by UxVs) should be made available to port administrations and other key stakeholders. An update to ATP-94 is recommended to fully integrate UxVs and to provide clear TTPs for their employment in Harbour Protection missions.

The research conducted for this dissertation demonstrates the substantial benefits that various UxVs can bring to Harbor Protection. UxVs offer persistent surveillance, faster response times and the ability to operate in conditions too dangerous or dull for human operators. However, to fully exploit these benefits, continued NATO-led standardization in this domain is important. Only through common standards and interoperability requirements will civilian companies be able to produce high-grade UxVs that align with ongoing European defence investments and meet the security needs of NATO member states. Standardization would also ensure that different unmanned systems can work together seamlessly in joint operations. In essence, NATO and civilian companies must work together to establish guidelines that drive the development of UxVs suited for critical infrastructure protection.

The ongoing conflicts in Ukraine and in the Middle East are starkly demonstrating the rapid evolution of unmanned warfare, with Ukraine, Russia, Israel, Iran and its proxies employing unmanned systems in innovative ways and becoming experts in this domain. These conflicts show how quickly adversaries can adapt cheap or commercial unmanned technologies for effective military purposes. NATO countries in Europe and North America should study these developments carefully to devise countermeasures and to improve their own use of UxVs. The lessons learned from Ukraine underscore the urgency of updating doctrine and investing in UxV capabilities now, so that allied forces are prepared to face a potential future threat from an adversary well-versed in unmanned warfare.

7.1 Limitations of the Research

At the beginning of this research, it was not entirely clear how distinct, yet complementary, the concepts of Harbour Protection and Port Security truly are. A more focused study might have been possible if the author had chosen to concentrate exclusively on one of these areas.

Throughout the course of this research, efforts were made to engage more closely with both the Sines Port Administration and the *Capitania* of Sines. While both institutions demonstrated interest in the topic of this dissertation and were open to collaboration, deeper cooperation was limited by external circumstances and scheduling constraints beyond their control.

Finally, because the research dealt with critical infrastructure, the author encountered multiple documents that were classified and therefore could not be accessed. This limitation posed an additional challenge to conducting a fully comprehensive analysis. Furthermore, due to the sensitive nature of the topics discussed, most interviewees declined to be recorded, which added complexity to the analyses and interpretation of the interview data.

7.2 Future Work

Looking ahead, further research should be conducted to explore the applications of UxVs in the security of Portuguese civilian harbours. This research would greatly benefit from being carried out in close coordination with both the Port Administrations and the *Capitanias*, as these stakeholders are directly responsible for the operational and regulatory aspects of harbour security.

More focused studies are needed to develop detailed TTPs for the effective use of UxVs in Harbour Protection operations. Such work should be made in coordination with CITAN and would contribute to fill a significant doctrinal gap and support the practical integration of UxVs into Harbour Protection Operations.

Additional research is required to better understand the optimal levels of autonomy that UxVs should exhibit, depending on both their operational domain (air, surface, subsurface, or land) and their mission role (Port Security or Harbour Protection).

Finally, AI, one of the most dynamic and promising areas of technological development, should continue to be studied and leveraged in this context. AI-driven capabilities, such as obstacle avoidance, threat detection, autonomous decision-making and swarm behaviours, offer significant potential to enhance the flexibility, resilience and effectiveness of UxVs in complex harbour environments.

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Appendixes

Appendix A- Interviews

Interview characterization

As part of the research for this thesis, a semi-structured interview was conducted with an expert involved in the development of NATO's Harbour Protection concepts. The goal was to collect insights regarding the use of UxVs in Harbour Protection Operations, the implementation of the HPM and the future role of AI in this field. The interview was conducted with Commander Sebastião Domingues, head of the Department of Analysis and development of CITAN, responsible for the future update of ATP-94.

Interview Transcription

Q1: How is Civil-Military coordination conducted during a Harbour Protection Operation (HPO)?

A1: Coordination begins with efforts to ensure that ATP-94 is classified as Unclassified, enabling civilian port authorities to access and use it as a reference.
In the event of an HPO, it is essential to guarantee effective coordination between the Harbour Protection Commander (HPC), the Harbour Master (*Capitão do Porto*) and the Port Administration. The latter, being responsible for day-to-day port security, typically has a deeper understanding of the port's characteristics than the HPC. Therefore, a close relationship between them is required. The HPC should have a dedicated liaison cell to maintain constant and effective communication with the Harbour Master and Port Administration.

Q2: The Harbour Protection Module (HPM) is considered a key component in the doctrine. Has any module been used so far?

A2: The Portuguese Navy has defined the development of an HPM as a NATO capability target to be achieved by 2026. Although some modules have already been developed by the defence industry, none has yet been officially adopted by NATO as the HPM standard.

Q3: How is the HPM expected to be used?

A3: The concept of the HPM originated from NATO's expeditionary needs. However, these needs have evolved over time and the missions that NATO is currently preparing for have different characteristics.

Q4: Does this module have any civilian applicability?

A4: Yes, but its necessity can be questioned, particularly in scenarios where robust civilian infrastructure already exists. Most civilian port authorities already operate dedicated Command & Control (C2) rooms for their own assets, reducing the need for an additional module. The HPM concept primarily addresses the need for a rapidly deployable solution to support expeditionary forces operating in environments without adequate local capabilities. In some cases, a warship equipped with appropriate capabilities could perform the functions of an HPM, eliminating the need for a shore-based module.

Q5: Which assets do you consider most important in an HPO?

A5: Sonars and radars. It is extremely important to ensure effective subsurface surveillance capabilities, as this is one of the most vulnerable pathways for unauthorized access to ports. Most protective nets at port entrances do not extend to the seabed, allowing for the potential intrusion of divers or UUVs. Therefore, it is essential to have detection systems capable of identifying underwater threats, ideally complemented by counter-diver systems. Radars play a crucial role in detecting and tracking surface vessels and vehicles, as well as providing early warning of potential threats. A recent example is the successful use of USVs in Sevastopol Harbour, where their high speed (35 knots) and low radar signature have made detection difficult, allowing them to approach the port undetected. These challenges highlight the need to enhance early warning capabilities and adapt response times to new threat types.

Q6: What benefits do you see in the use of UxVs for Harbour Protection and how can they be employed?

A6: UxVs offer an effective way to extend the endurance of forces engaged in Harbour Protection. A concrete example is the need to conduct regular pier inspections before the docking of warships. While these inspections are typically carried out before a military ship arrives (as part of security measures), integrating UUVs alongside diver teams would enable a more sustainable inspection process, reducing the operational burden on human resources and extending active surveillance over time.

Q7: What capabilities should UxVs possess or develop to support Harbour Protection Operations?
A7: UxVs must be equipped with recording and image registration systems to document events that can later serve as legal or operational evidence. This is particularly relevant in cases of intrusion, sabotage, or other suspicious activity near the port.
For UAVs, it would also be useful to equip them with acoustic warning systems (loudspeakers) to issue real-time warnings to unauthorized vessels or individuals, providing a non-lethal deterrent.

Q8: What types of UxVs do you consider most relevant for Harbour Protection?
A8: UAVs provide an aerial top-down perspective that is extremely useful for wide-area port surveillance and offer fast response times to incidents. UUVs are critical for protecting Underwater Infraestructure, which are vital for global communications. They are also highly effective for underwater pier inspections, whether operated autonomously or in support of divers, thereby enhancing both the efficiency and safety of operations.
UGVs are particularly valuable in IED neutralization scenarios, reducing the need to expose personnel to such risks.

Q9: What are the main challenges in using UxVs for Harbour Protection?
A9: The main challenge lies in the fusion and compilation of the large volumes of data collected by UxVs.

Q10: What capabilities should be developed to overcome these challenges?
A10: The primary capability that needs to be developed is training. Extensive training is required to validate Harbour Protection concepts. Standardization of equipment is also

crucial. Additionally, UxVs must be resilient against jamming and communications interference. It is not just about training. Given the current outdated state of ATP-94, doctrine also needs to be updated.

Q11: What will be the main benefits of integrating AI?

A11: Artificial Intelligence (AI) will play an increasingly important role. Pattern recognition capabilities are highly beneficial, given the volume of data collected by UxVs. A practical example is the use of AI for automatic image analysis from UUVs (such as Gavia), enabling the autonomous identification of naval mines or the detection of anomalies in Underwater Infraestructure. Automating these processes will increase operational efficiency, reduce human error and accelerate response times.

Interview characterization

The interview was conducted with Commander Conceição Rosinha, currently in the transformation and innovation division of *Estado Maior da Armada.* The objective was to collect practical insights regarding current challenges, the use of UxVs and the potential of AI integration in Port and Harbour Protection.

Interview Transcription

Q1: In your experience, what are the main challenges faced in maintaining port security and protection?

A1: One major difficulty in port protection is the lack of mobility of a warship when it is docked. A warship has highly effective sensors and weapons, but once moored, its movement, sensor use and weapon employment become very limited. Therefore, the Port Infrastructure itself must assume responsibility for protecting the vessel. This requires having its own sensors and weapons so that the ship does not need to be engaged in self-protection while in port. Another key challenge is time. It takes considerable effort to maintain port surveillance and protection 24/7. Human resources are limited and existing personnel must be organized into shifts to sustain continuous monitoring.

UxVs are a valuable asset, but they also have limitations, including the need for recharging or repairs. The best approach is to implement a combination of multiple sensors and layered systems, where the weaknesses of one system are compensated for by the strengths of others.

Q2: What do you consider to be the main threats to port security and protection today?
A2: UxVs themselves are not a new threat but rather a new vector. It is important to understand that various actors may use UxVs to threaten a port. Just as UxVs can be a vector for attackers, they can also serve as a vector for defenders.

Q3: What changes could be implemented to mitigate the challenges you mentioned earlier?
A3: UxVs must begin contributing more actively to countering other UxVs. We need to fight technology with technology. Additionally, there is no moral or legal objection to using our UxVs to destroy attacking UxVs.

Q4: What technologies are currently used in the monitoring and protection of port infrastructure? Which are the most used/important?

A4: All sensors are important. The combination of various sensors and technologies significantly enhances monitoring and protection efficiency. Electromagnetic spectrum manipulation is particularly important, for example, frequency jammers. There are now emergency protocols with ANACOM that allow certain frequencies to be jammed when protecting Portuguese critical infrastructure.

Q5: What benefits do you see in the use of UxVs for port protection and how can they be employed?

A5: Technology must be countered with technology. UxVs are excellent tools for neutralizing other UxVs.

Q6: What capabilities should UxVs possess or develop to support port protection?
A6: Greater interoperability is needed (via STANAGs), both between different UxVs and between UxVs and C2 systems.

Q7: What types of UxVs do you consider most relevant?
A7: All of them are important, both underwater and surface types. It is crucial to determine the most effective ways to employ them. There are, for example, two approaches to using UxVs in infrastructure monitoring. Using software to map the port initially and then checking for changes during subsequent patrols. The second approach is having a UxV operate continuously, remapping the port each time as if it were the first pass. It is important to employ all types of UxVs in conjunction with other surveillance sensors as well as with kinetic and non-kinetic countermeasures. We must analyze potential attack vectors and then combine surveillance and protection elements, including UxVs, to neutralize threats.

Q8: What are the main challenges in using UxVs for port protection?
A8: Certain areas are too high-risk for UAV operations. For example, flying UAVs over hydrocarbon tanks, fertilizers, or other hazardous materials is not recommended. To mitigate these risks, it is essential to establish no-fly zones.
Armed UxVs face even more restrictions. It is necessary to carefully analyze and define recommended flight paths for UAVs and, where UAV operation is not viable, identify which alternative systems can be employed to compensate.

Q9: What will be the main benefits of integrating AI?
A9: UxVs and monitoring sensors generate large volumes of data. AI will contribute to better data analysis. It will be interesting to see how AI's decision-making capabilities evolve and to what extent it will be viable to allow AI to make decisions autonomously. One possibility is to require human authorization for AI actions; another is to allow AI to operate without human validation. However, this raises important legal questions that are currently under careful consideration.

Interview characterization

The interview was conducted with Commander Anjinho Mourinha, currently in the transformation and innovation division of *Estado Maior da Armada.* The goal was to better understand the operational benefits, challenges and integration potential of UxVs in the context of Harbour Protection, specifically focusing on the case of Sines Harbour.

Interview Transcription

Q1: What benefits do you identify in the use of UxVs for the defence of Sines Harbour?

A1: The first major benefit is that UxVs are designed to operate in environments that are Dangerous, Dirty and Dull. In the context of port defence, the "Dull" aspect is particularly relevant, as long periods may pass without any threat. However, if the situation escalates, UxVs can also be used to neutralize or destroy threats through kinetic measures. The second advantage lies in surveillance capabilities. UxVs cover all operational domains and port protection missions are inherently multi-domain.

- UGVs can be used for land surveillance, as they can be equipped with cameras and placed in blind spots not covered by fixed surveillance. They can complement or replace foot patrols, being smaller, more discreet and eliminating risk to human operators.
- UAVs offer an aerial view of the port, enabling monitoring of both land and maritime areas. For land-only surveillance, rotary-wing UAVs are ideal—they can follow pre-programmed search patterns and be equipped with EO and IR sensors, making them highly effective at detecting threats at night via thermal signatures. Fixed-wing UAVs cover larger areas, contributing to early threat detection.
- USVs are suitable for surface surveillance and can physically interpose between a threat and the infrastructure. They can also be armed with kinetic response capabilities.
- UUVs are valuable for bottom surveys, used to detect changes on the harbour floor such as mines or explosive devices. Different types exist. Some are designed for mine warfare and bottom mapping, while smaller ones can inspect piers and ship hulls.

Fixed sonars can be used to detect divers and mobile underwater systems can also be deployed. This was tested during the REPMUS exercise. However, current underwater systems are not yet optimized to detect other mobile underwater systems, fixed passive or active sensors are still more effective.

The C2 (Command and Control) of UxVs is a complex issue. It is essential to have an integrated system capable of both transmitting and receiving information. NATO is currently developing this capability through STANAG 4817, which is expected to be widely adopted for port protection. The Harbour Protection Module (HPM) concept is now considered outdated and has been replaced by more modern approaches, such as STANAG 4817, which allows for the integration of UxV C2 systems along with fixed systems like cameras and passive sonars. Previously, the system worked with a "plug and play" model, but now, with UAVs and 5G, it makes much more sense to install a dedicated private 5G modem. If that's not possible, a Wi-Fi network can be used, although it offers less range and security. The less reliant we are on Wi-Fi, the better the cybersecurity. Nevertheless, it remains important to retain internet access for certain operational services.

Q2: What are the greatest challenges related to the use of UxVs in port defence?
A2: The main challenge is tactical in nature, as there is currently no specific operational framework for the use of UxVs in this context. The doctrinal publication ATP-94, which guides tactical operations, needs to be updated to include tactics tailored to these systems. The second major challenge is standardization.

Q3: How can the challenges identified above be addressed?
A3: Through technological standardization, namely via the adoption of STANAG 4817and through tactical standardization, by developing TTPs (Tactics, Techniquesand Procedures) that treat Harbour Protection as an operation in which the integration of manned and unmanned systemsand the concept of Manned-Unmanned Teaming (MUM-T), are recognized as significant force multipliers.

Interview characterization

The interview was conducted with Lieutenants Santos Bica and Rodrigues Marante, currently in unit X31. The objective was to gather insights on the operational advantages of UxVs, the main challenges in their useand the role of Artificial Intelligence (AI) and interoperability in future Harbour Protection frameworks.

Interview Transcription

Q1: What are the main advantages that unmanned systems can provide in the security of infrastructures?

A1: The main advantage of UxVs is their ability to conduct systematic 24/7 surveillance. Depending on weather conditions and how they are deployed, it is possible to keep sensors permanently operational by using multiple UxVs. Unlike human operators, these systems do not get tired, they only require battery replacement, fuel replenishment, or routine maintenance to resume operations.

Q2: What are the main advantages of these systems in Port Protection?
A2: In the port context, UAVs provide a highly valuable third-person perspective, offering a broader understanding of the situational picture. They also enable the inspection of areas that are difficult to access by land, enhancing both the response capability and surveillance of remote port zones. USVs, on the other hand, typically have a greater capacity to carry heavier sensors, providing higher-quality operational data for both surveillance and potential offensive scenarios.

Q3: What are the main challenges in using unmanned vehicles for Port Protection?
A3: One of the main challenges lies in the C2 (Command and Control) of these systems. As soon as more than one UV is deployed, the complexity increases significantly, making interoperability between platforms essential. Exercises such as REPMUS are fundamental for testing and promoting this interoperability. During these exercises, many systems operate in the same geographic and temporal space, generating vast amounts of data that need to be compiled and analysed. In the case of UAVs, certification processes for aerial operations are time-consuming and subject to strict national and European regulations, further complicating the use of these systems.

Moreover, weather conditions greatly affect UAVs, especially smaller Class I UAVs, which limits their operational availability.

Q4: What capabilities should be developed to overcome the challenges previously identified?
A4: NATO is working to address these difficulties through the creation of STANAGs, which aim to foster synergies between manufacturers and operators by standardizing programming languages and common protocols, thereby improving interoperability between systems.

Exercises such as REPMUS are also extremely valuable, as they provide practical opportunities to integrate equipment from different origins and facilitate the compilation and analysis of shared data.

Q5: What types of UxVs are most relevant for Port Protection?
A5: Firstly, quadcopters and hexacopters are very important due to their agility and operational simplicity (typically in the small category <150 kg).

Secondly, surface vehicles offer significant added value because of their larger payload capacity, allowing them to carry more complex and heavier sensors, such as Synthetic Aperture Radar (SAR). Fixed-wing UAVs are better suited for scenarios where the threat level escalates, though their operation is more complex, particularly during take-off and landingand they are generally more expensive, especially military-grade models.

Q6: What will be the benefits of Artificial Intelligence in Port Protection?
A6: AI will greatly enhance the efficiency of data acquisition and analysis performed by UxVs. In terms of autonomy, AI will increase the operational autonomy of UxVs, enabling them to perform navigation, mission planning, target identification, recognitionand attack more autonomously and with greater effectiveness. Ultimately, it may be possible to remove the human operator entirely from certain loops.

Q7: Do you believe UxVs have the potential to become the most effective weapons for neutralizing other UxVs?

A7: So far, soft-kill measures, such as electromagnetic jamming, have proven to be the most effective. However, I believe that in the future these systems will be enhanced and complemented by hard-kill measures, such as directed energy weapons, which are already being developed and tested by several companies and nations.

Interview characterization

The interview was conducted with Lieutenants Santos Bica and Rodrigues Marante, currently in unit X31. The purpose of the interview was to gather insights on the advantages, challengesand technological trends, especially regarding the use of AI and data fusion, for the integration of UxVs in modern Harbour Protection systems.

Interview Transcription

Q1: What are the main advantages that unmanned systems can provide in the security of infrastructures?

A1: The main advantage of UAVs is their ability to provide an aerial perspective, allowing surveillance over large areas with less interference from physical obstacles such as buildings or terrain elements.

Q2: What are the main advantages of these systems in Port Protection?
A2: These systems can be programmed to conduct automatic patrols within defined areas, reducing the need for constant human intervention. If they detect an anomaly, intrusion, or any suspicious event, they can generate real-time alerts for human operators. Specifically, USVs excel in operating within the water areas of the port, where they can perform interception missions against unauthorized vessels. In addition, USVs can be equipped with various systems, communication antennas, cameras, sensorsand loudspeakers, enabling them to perform surveillance, warningsand area denial actions.

Q3: What are the main challenges in using unmanned vehicles for Port Protection?
A3: UxVs in port protection face several challenges. One of the main obstacles is the need to create systems capable of conducting autonomous real-time video analysis,

thereby reducing dependency on human operators. However, the development of effective detection and recognition algorithms is currently limited by the lack of suitable training datasets, especially open-access datasets, for AI model training. Another major challenge is related to the integration and correlation of data and images collected by various platforms (e.g., UAVs, USVsand fixed sensors).

Q4: What capabilities should be developed to overcome the challenges previously identified?
A4: First, a robust technological infrastructure must be developed to support advanced AI systems, particularly for the automatic analysis of images and videos collected by UxVs.

In addition, it is essential to invest in data collection to train AI algorithms. Lastly, it is necessary to promote the development of multisensory data integration and fusion capabilities, enabling the consolidation of information from various types of UxVs and fixed sensors.

Q5: What types of unmanned vehicles are most relevant for Port Protection?
A5: In Port Protection, USVs and UAVs stand out as the most relevant platforms. USVs are particularly effective in the water areas of the port, where they can conduct patrols and interception missions against suspicious vessels. They also offer great flexibility, as they can integrate multiple systems such as sensors, cameras, loudspeakersand communication antennas, allowing for surveillance, deterrenceand area denial actions. UAVs, in turn, have the advantage of operating over both land and water areas, providing a broad aerial view that facilitates the detection of suspicious movements and the monitoring of activities. It is also important to emphasize that port security should adopt a multifaceted approach based on the complementarity of different platforms and sensors. Using a combination of different types of UxVs creates operational redundancies and increases the overall resilience of the protection system.

Q6: What will be the main benefits of integrating Artificial Intelligence in Port Protection?

A6: One of the main benefits is the ability to automate operations that currently require human supervision, such as UAV surveillance missions and real-time image analysis.

By using pre-planned flight paths and AI, it is possible to conduct autonomous aerial patrols, with automatic object detection and classification of suspicious situations.

Q7: Do you believe unmanned vehicles have the potential to become the most effective weapons for neutralizing other unmanned vehicles?

A7: This approach has gained importance mainly due to the high cost of traditional counter-UAV solutions, such as guided missiles, which are often used to neutralize low-cost commercial UAVs. There are already numerous video records demonstrating the effectiveness of such tactics in real combat scenarios.

Interview characterization

The interview was conducted with Commander Vasconcelos de Andrade, the current Harbour Master at Sines The objective was to collect insights on the main security challenges at Sines Harbour, the coordination mechanisms in placeand the potential use of UxVs and AI in port security.

Interview Transcription

Q1: In your experience, what are the main difficulties in maintaining port security? **A1:** I believe that the very size of the port, with all its terminals and support structures (fuel tanks, gas tanks, pipelines, etc.), presents significant challenges for security. It is a large area to monitor and control. Additionally, the maritime area of the port is also a sensitive and extensive zone.

Q2: How does coordination between the *Capitania* and the Port Administration work? **A2:** Coordination on port security and protection takes place through the Port Protection Operations Coordination Centre (CCOPP), which holds regular meetings. There is also a direct communication channel between the Harbour Master (*Capitão do*

Porto) and the Port Facility Security Officer (PFSO) of the Sines Port Administration for day-to-day coordination on security matters. For issues of high importance, there is a direct line between the Harbour Master and the Board of Directors of the Sines Port Administration. The relationship between the entities is excellent. The powers of the Harbour Master are defined in Article 13 of Decree-Law No. 44/2002, of 2 March. The powers of the Port Authority (Port Administration) are defined in Decree-Law No. 46/2002, of 2 March.

Q3: How is the coordination between the *Capitania* and other entities involved in port security conducted?

A3: Through the CCOPP, concerning port security and port activity. The *Capitania* participates in CCOPP meetings. The CCOPP's responsibilities are defined in Article 10 of Decree-Law No. 226/2006, of 15 November.

Q4: What resources are typically shared between the *Capitania* and the Port Administration?

A4: Sometimes, Maritime Police vessels are used to directly support the Sines Port Administration. There is also a sharing of knowledge, which is a valuable asset.

Q5: What additional concerns are raised by the presence of Underwater Infraestructure?

A5: It is certainly a concern, particularly regarding the activity of trawling fishing vessels in the vicinity of the Underwater Infraestructure.

Q6: What resources do you consider most important for monitoring and protecting port infrastructure?

A6: Human presence and CCTV systems available to the security forces. The use of UAVs as a complementary tool is also important.

Q7: What would be the role of the *Capitania* in a military port protection operation?

A7: The *Capitania* would take on the role assigned by the Admiral Director-General of the Maritime Authority and Commander-General of the Maritime Police, specifically in the Maritime Police dimension.

Q8: What benefits do you identify in the use of UxVs in Harbour Protection and Port security?
A8: It is already a reality that some major ports around the world are using such equipment for security and logistics within port facilities. Given the considerable size of Sines Port, human travel takes time, so the simultaneous use of this type of equipment represents a clear added value. The jurisdiction of the Sines Port Administration includes a land area of 6.31 km^2 and a maritime area of 147.5 km^2.

Q9: What capabilities should these vehicles possess or develop to be effective in this context?
A9: They should have the ability to film, detect pollutionand provide high-resolution imagery from high altitudes. They should also be able to detect targets in night conditions (infrared) and film in such conditions. Additionally, they should be capable of measuring air quality through sensors.

Q10: What types of unmanned systems do you consider most relevant for port protection?
A10: While I am not a specialist in unmanned systems, I believe that rotary-wing UAVs are the most suitable due to their versatility and the ability to take off and land from any location. In the future, fully autonomous UAVs that can self-charge through docking stations would be a valuable addition.

Q11: What are the main challenges associated with using these systems?
A11: One challenge is related to data protection. With the current data protection regulations, it is challenging to use this type of equipment. Another challenge is the size of Sines Port, which requires equipment with high endurance to operate for long periods. Locations must also be defined for UAV take-off and landing.

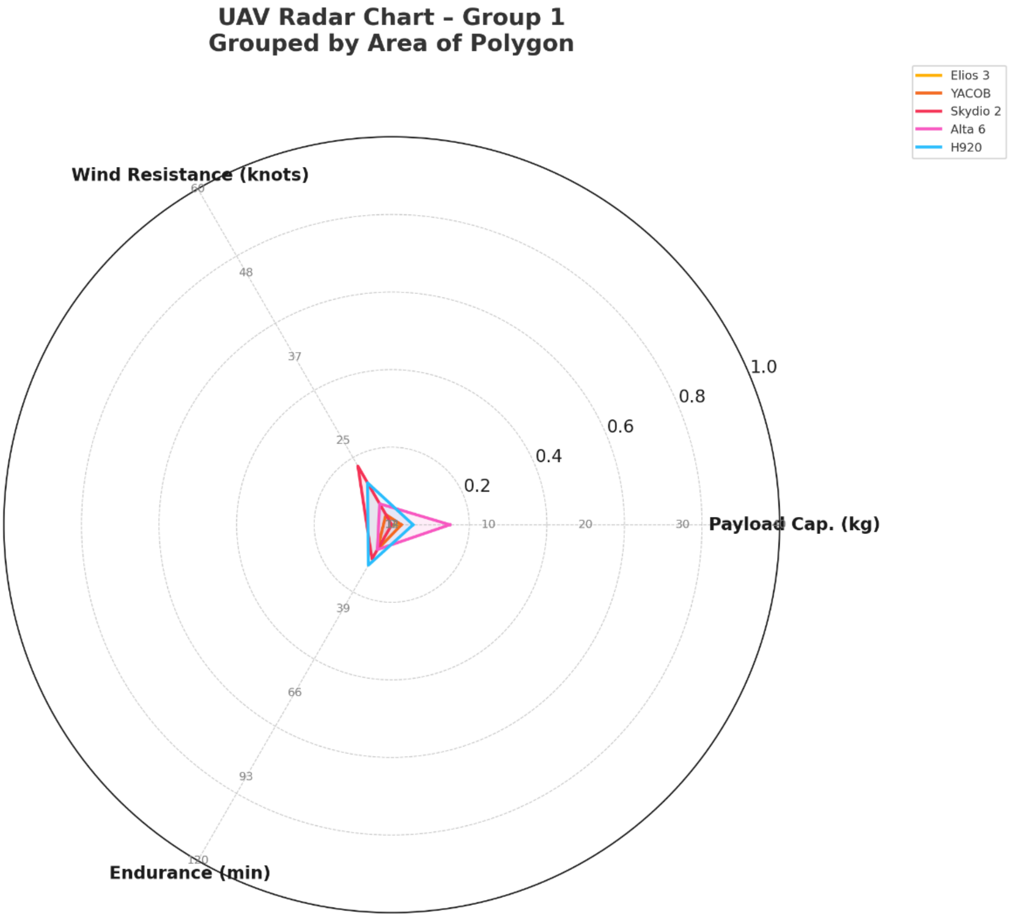
Q12: What capabilities are needed to overcome these challenges?
A12: The capabilities needed relate to the operation of unmanned systems: there must be specific training available to operate these systems without restrictions. There also needs to be an adequate number of operators, given that personnel at *Capitanias*/Maritime Police work in shifts to ensure 24/7 coverage.

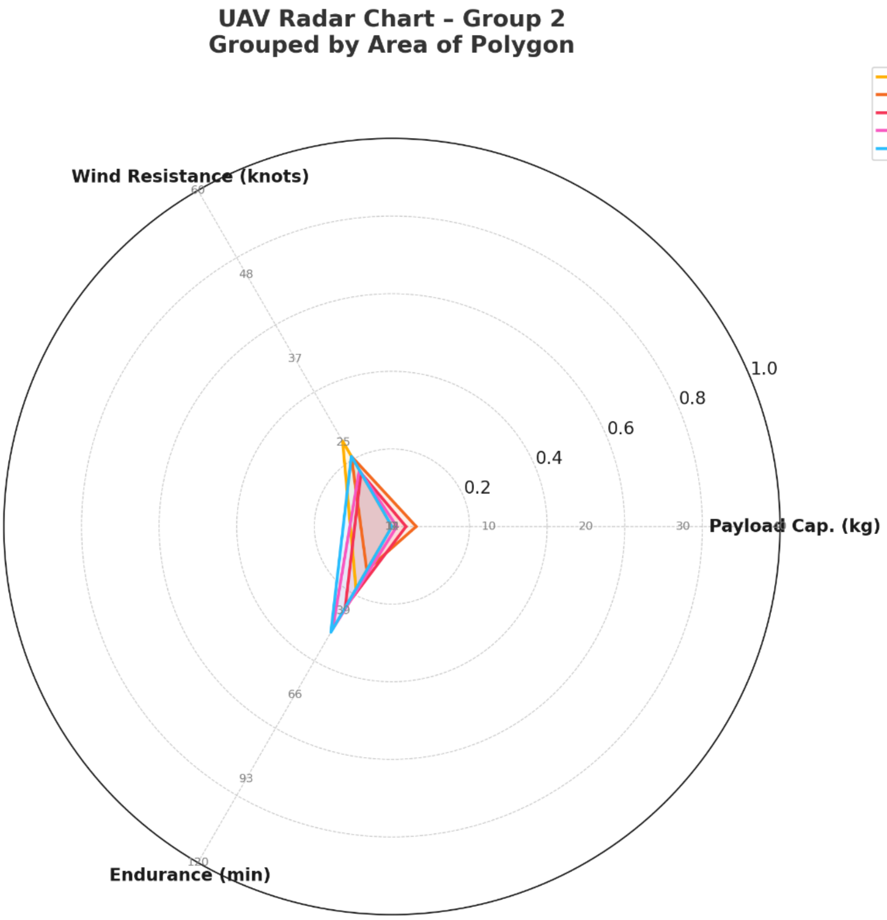
Q13: What are the main benefits you foresee from integrating Artificial Intelligence in port security?

A13: I believe that AI will be beneficial as it can act as a facilitator in identifying targets that may pose a potential risk to safety/security, through the use of algorithms. It may also help detect abnormal situations that deviate from the normal pattern of port activity and issue the appropriate alerts.

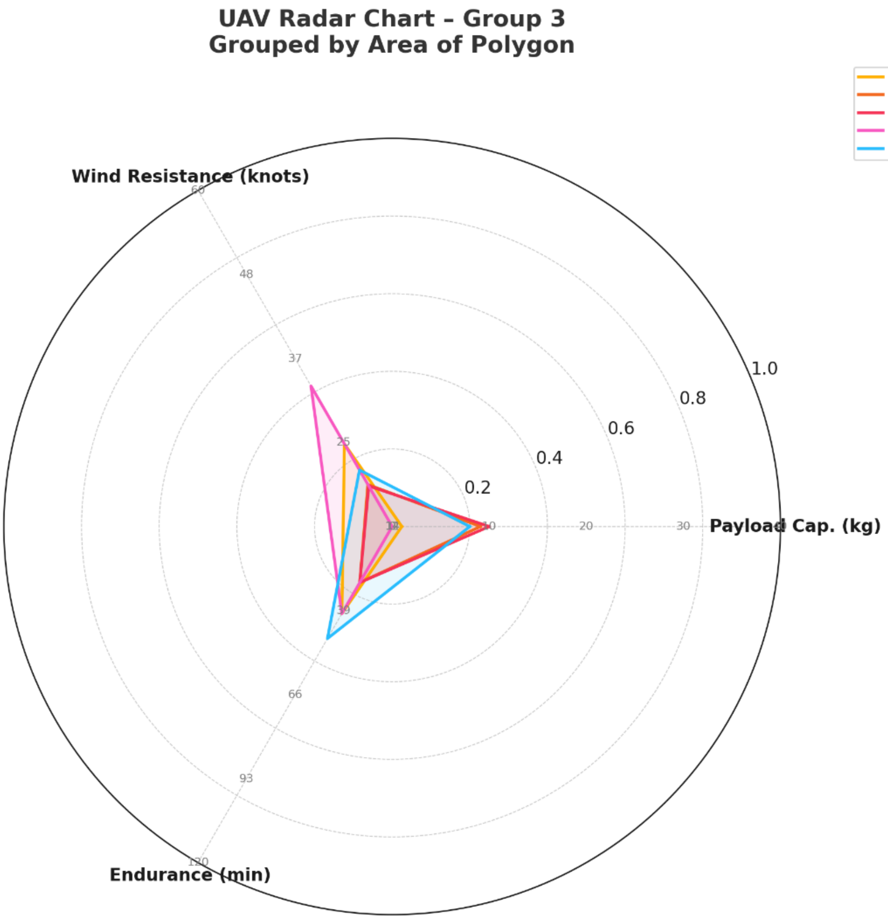
Appendix B- Radar Charts

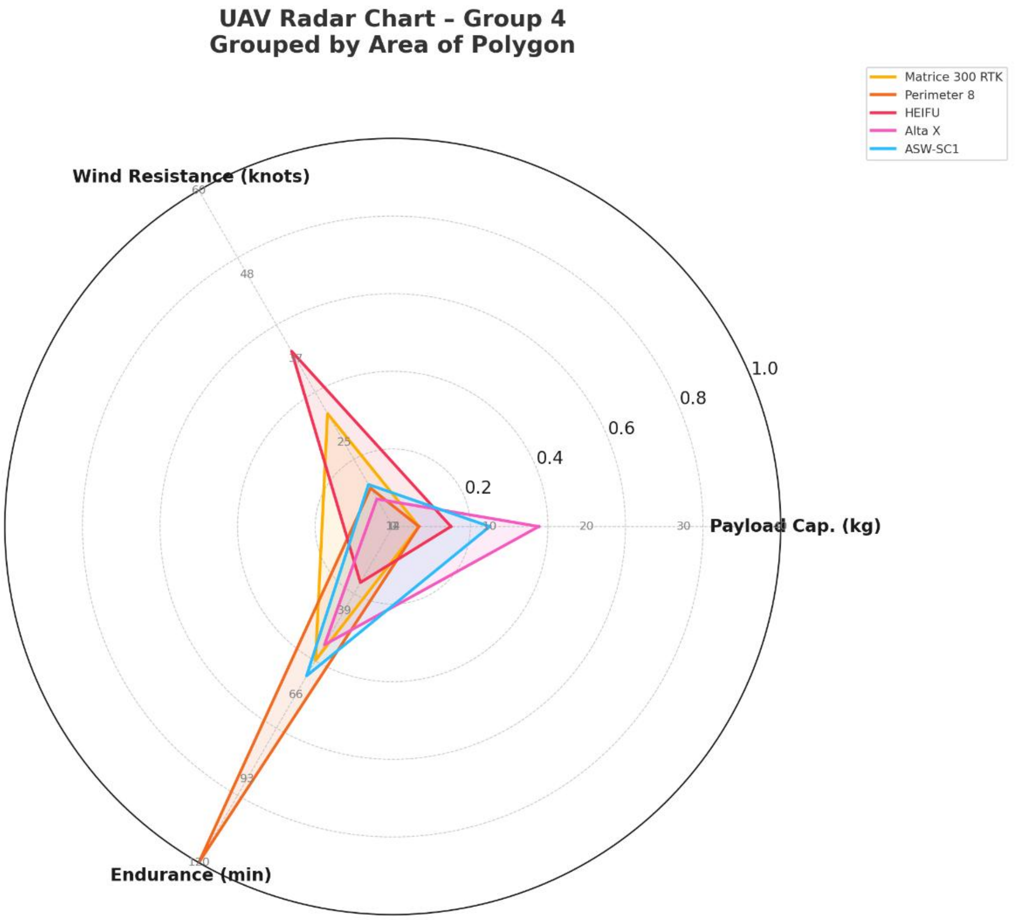
UAV Charts

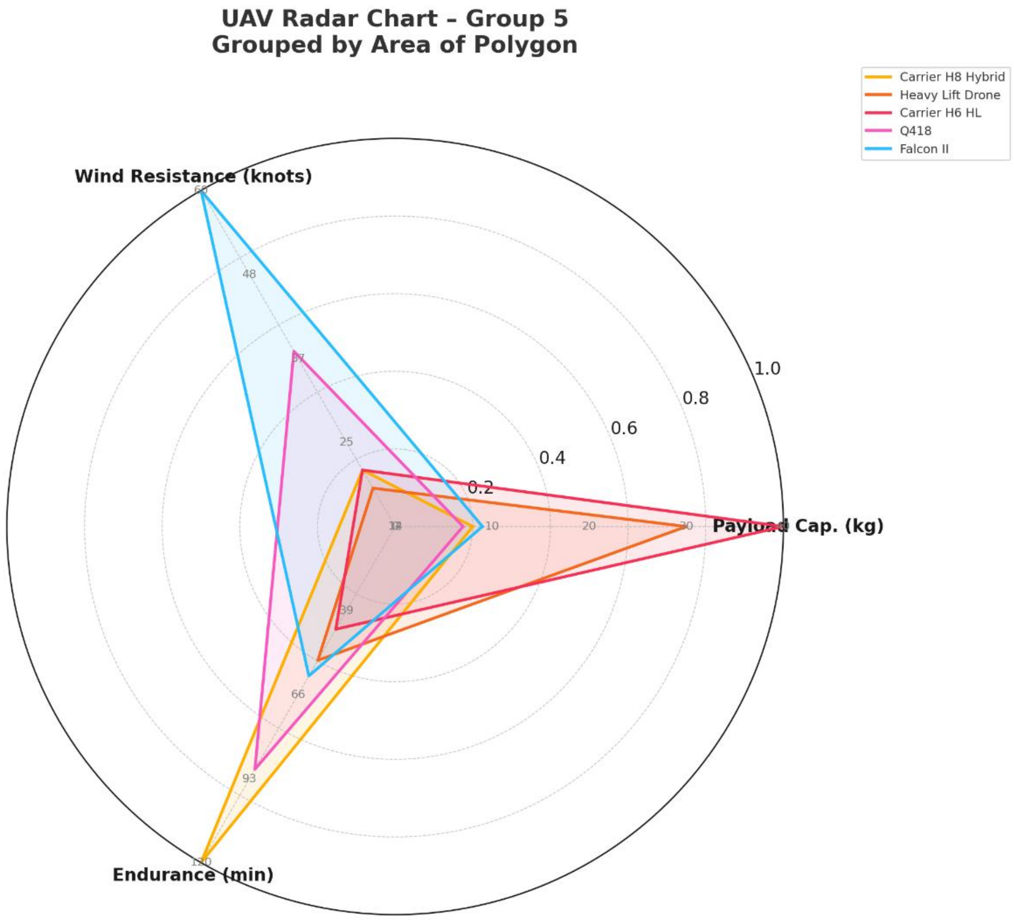




UAV Radar Chart – Group 2
Grouped by Area of Polygon
Parrot ANAFI Ai
Voyager 5
Matrice 200 V2
Quantix Recon
DJI Mavic 3
Wind Resistance (knots)
Payload Cap. (kg)
Endurance (min)
0.2
0.4
0.6
0.8
1.0
10
20
30
25
37
48
60
66
93
120

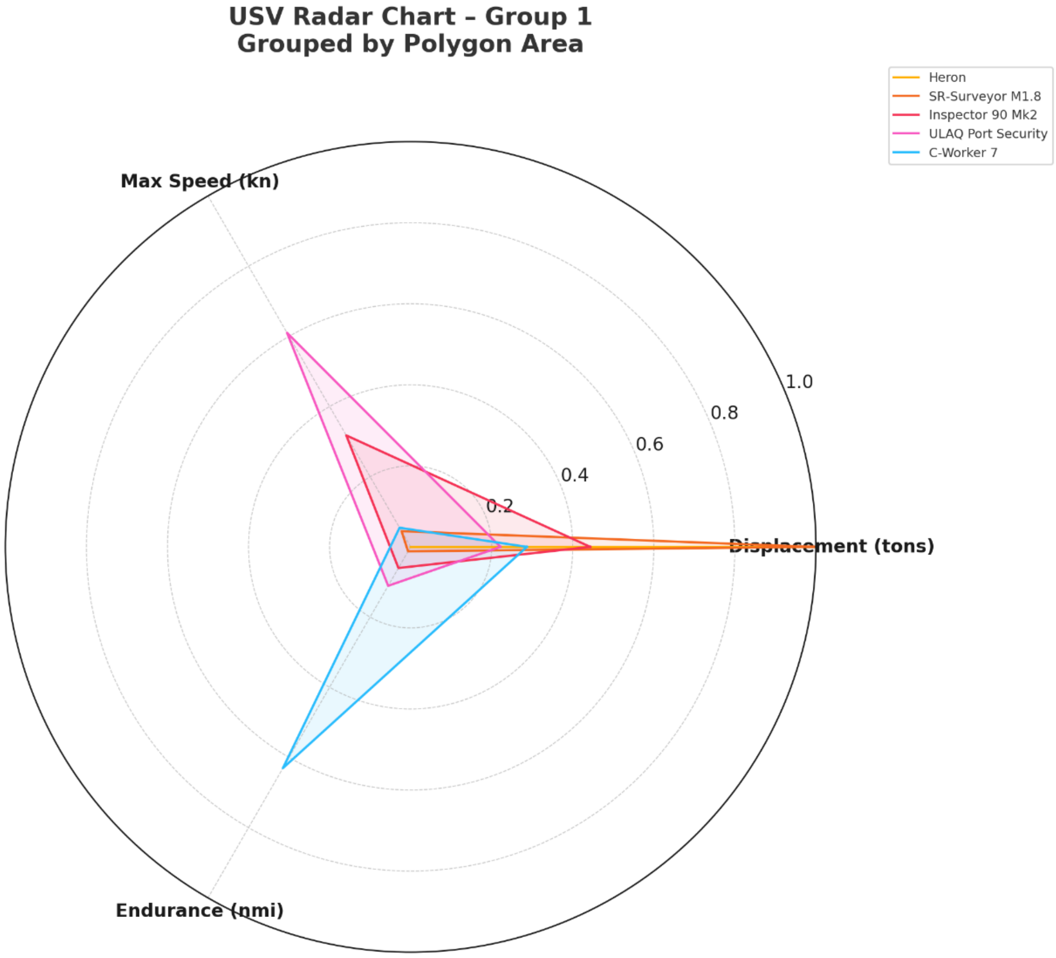

UAV Radar Chart – Group 3
Grouped by Area of Polygon
Optimus 1-EX
Alta 8
PD6B-AW-ARM
Autel EVO II
Carrier H6 Electric
Wind Resistance (knots)
Payload Cap. (kg)
Endurance (min)
0.2
0.4
0.6
0.8
1.0
10
20
30
25
37
48
60
39
66
93
120

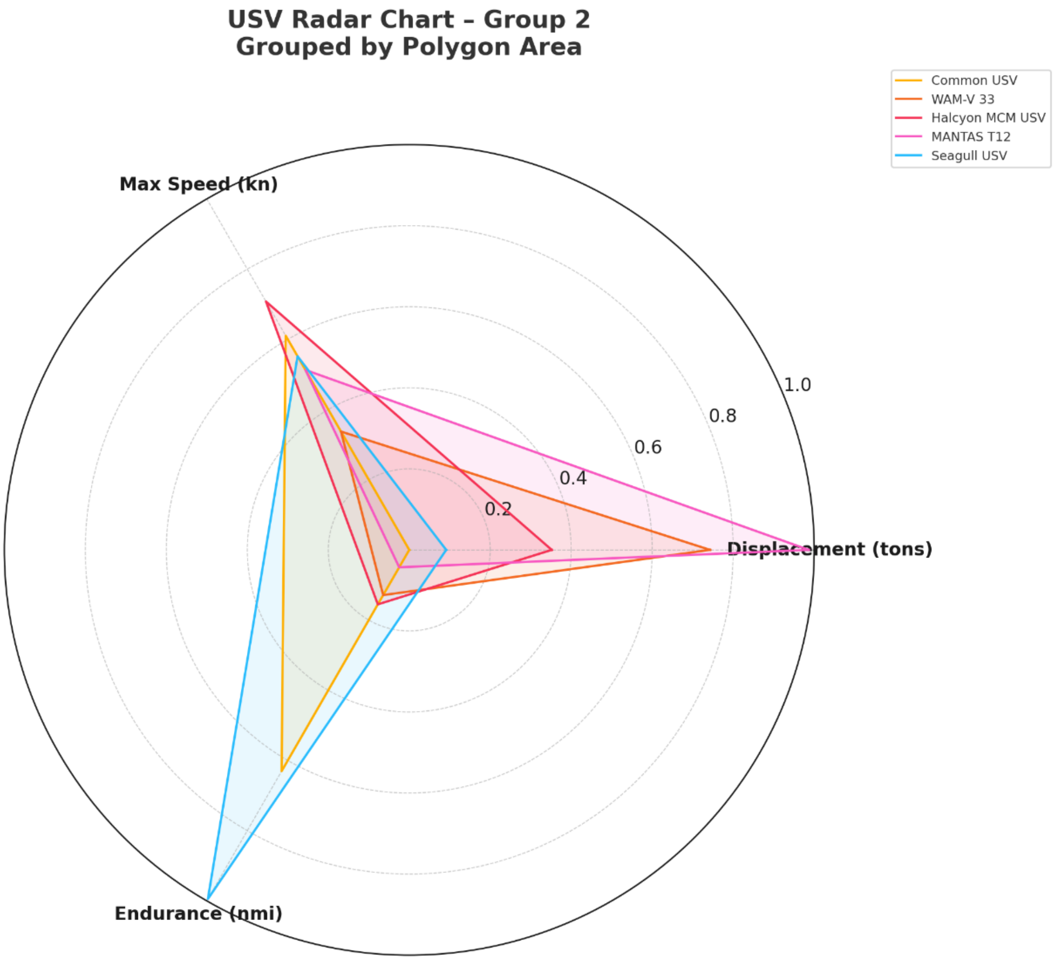

UAV Radar Chart – Group 4
Grouped by Area of Polygon
Matrice 300 RTK
Perimeter 8
HEIFU
Alta X
ASW-SC1
Wind Resistance (knots)
Payload Cap. (kg)
Endurance (min)
0.2
0.4
0.6
0.8
1.0
48
25
10
20
30
39
66
93

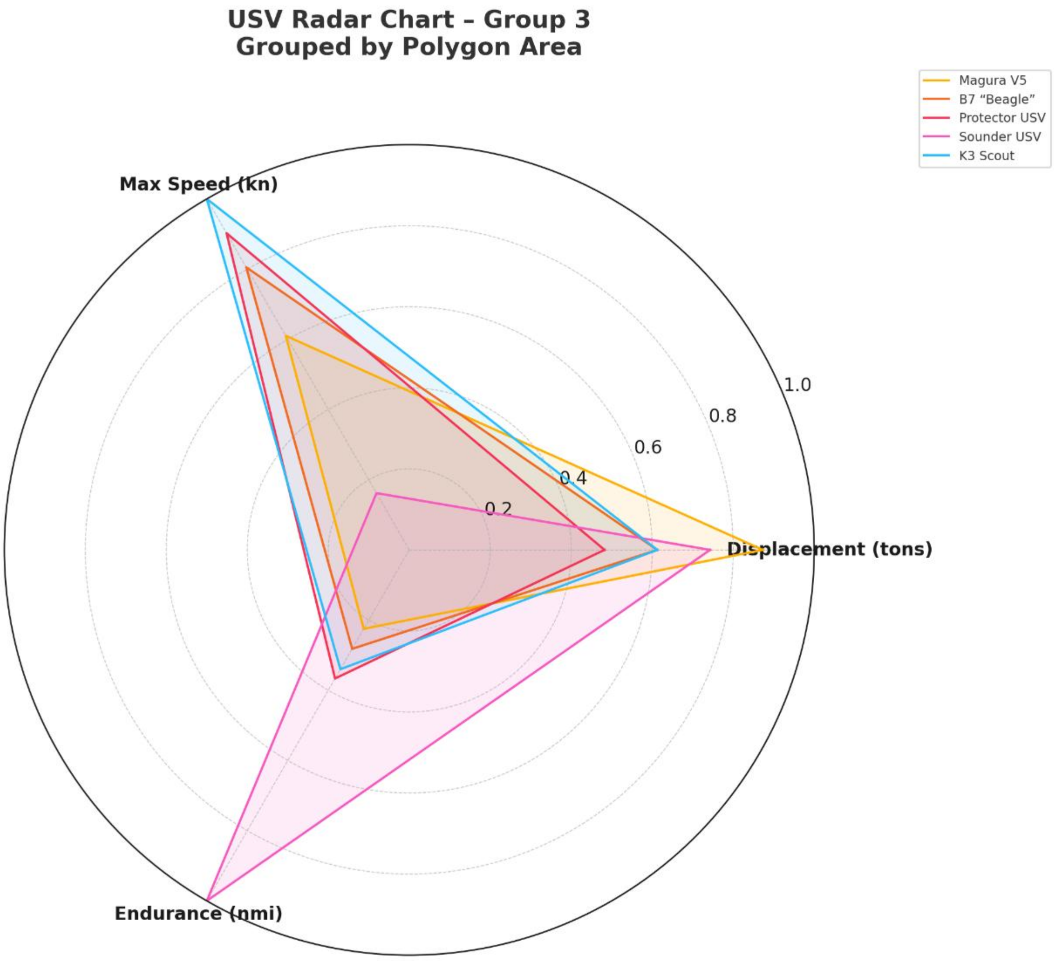


UAV Radar Chart – Group 5
Grouped by Area of Polygon
Carrier H8 Hybrid
Heavy Lift Drone
Carrier H6 HL
Q418
Falcon II
Wind Resistance (knots)
Payload Cap. (kg)
Endurance (min)
0.2
0.4
0.6
0.8
1.0
10
20
30
25
37
48
39
66
93

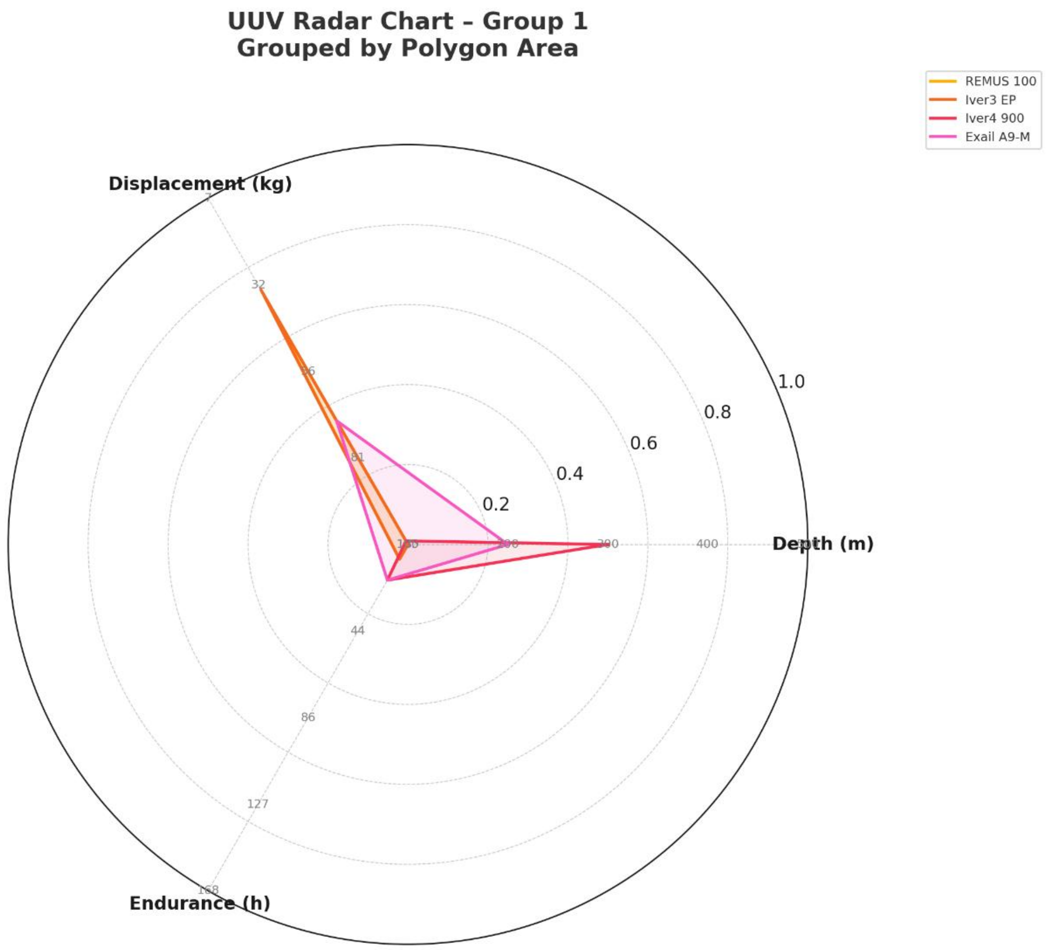
USV Charts

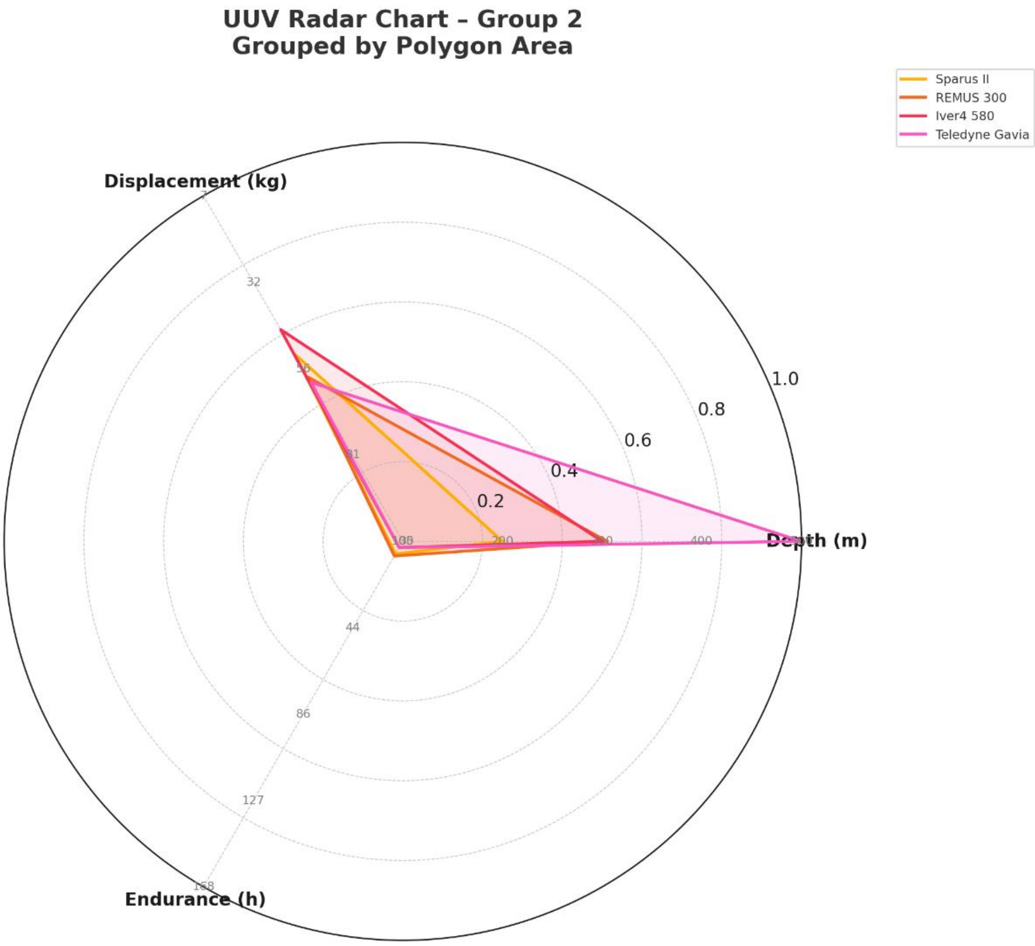

USV Radar Chart – Group 1
Grouped by Polygon Area
Heron
SR-Surveyor M1.8
Inspector 90 Mk2
ULAQ Port Security
C-Worker 7
Max Speed (kn)
Displacement (tons)
Endurance (nmi)
0.2
0.4
0.6
0.8
1.0

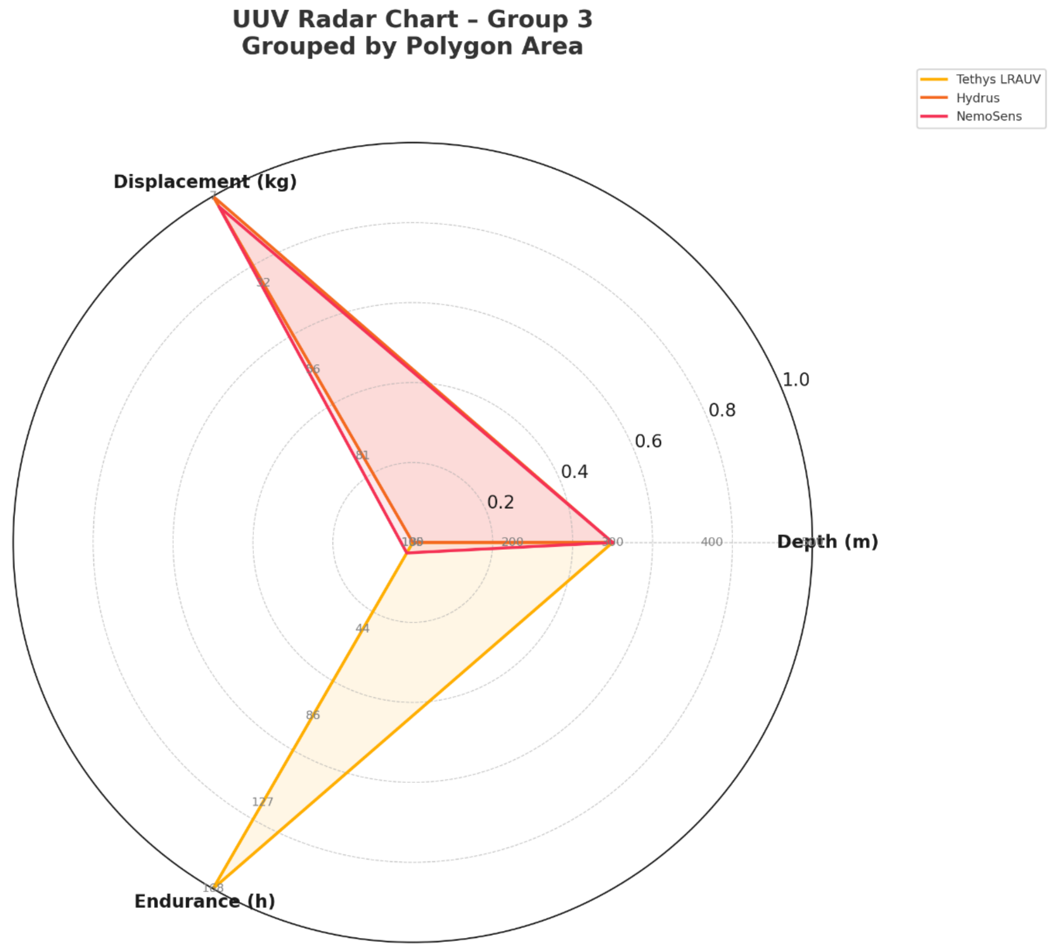

USV Radar Chart – Group 2
Grouped by Polygon Area
Common USV
WAM-V 33
Halcyon MCM USV
MANTAS T12
Seagull USV
Max Speed (kn)
Displacement (tons)
Endurance (nmi)
0.2
0.4
0.6
0.8
1.0


USV Radar Chart – Group 3
Grouped by Polygon Area
Magura V5
B7 "Beagle"
Protector USV
Sounder USV
K3 Scout
Max Speed (kn)
Displacement (tons)
Endurance (nmi)
0.2
0.4
0.6
0.8
1.0

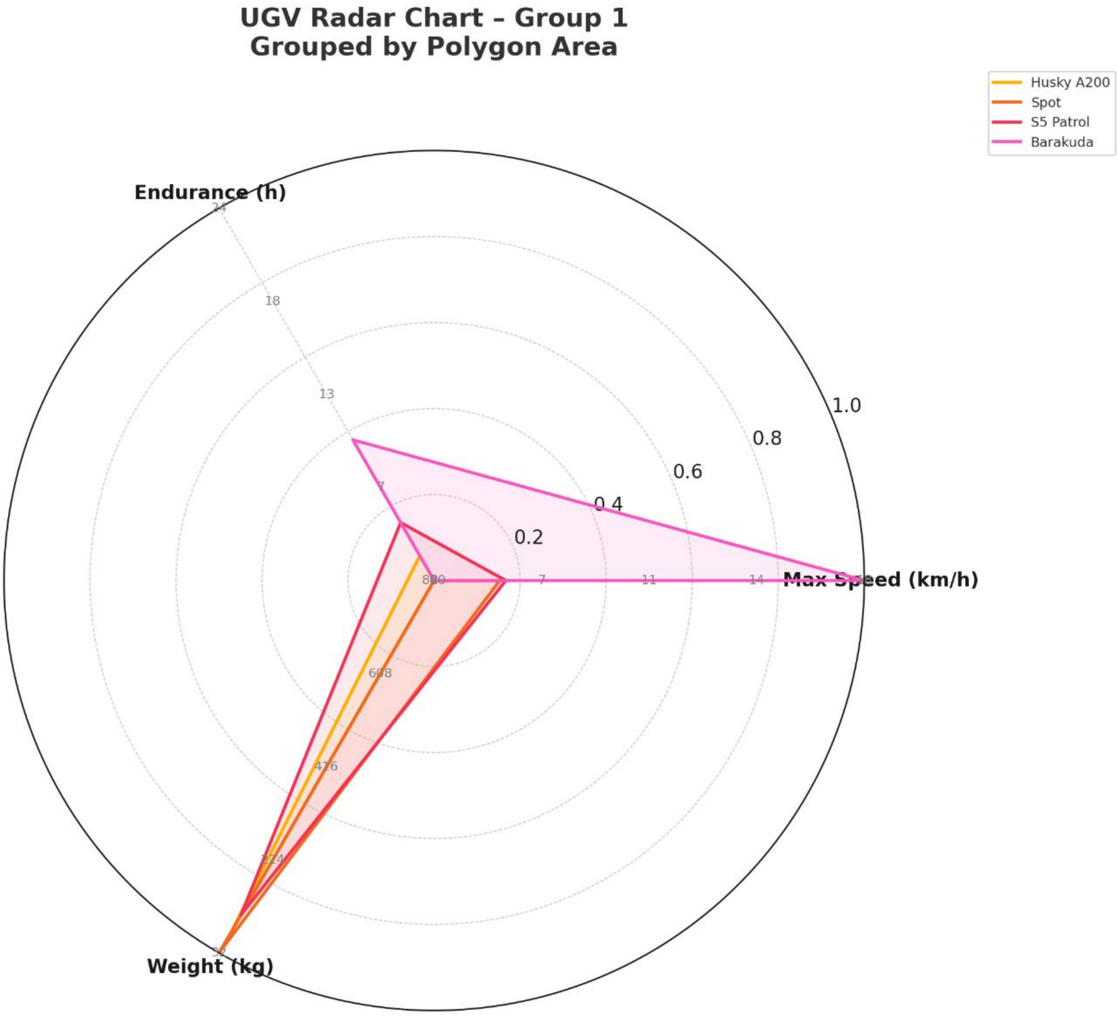
UUV Charts


UUV Radar Chart – Group 1
Grouped by Polygon Area
REMUS 100
Iver3 EP
Iver4 900
Exail A9-M
Displacement (kg)
32
81
Depth (m)
0.2
0.4
0.6
0.8
1.0
400
44
86
127
Endurance (h)

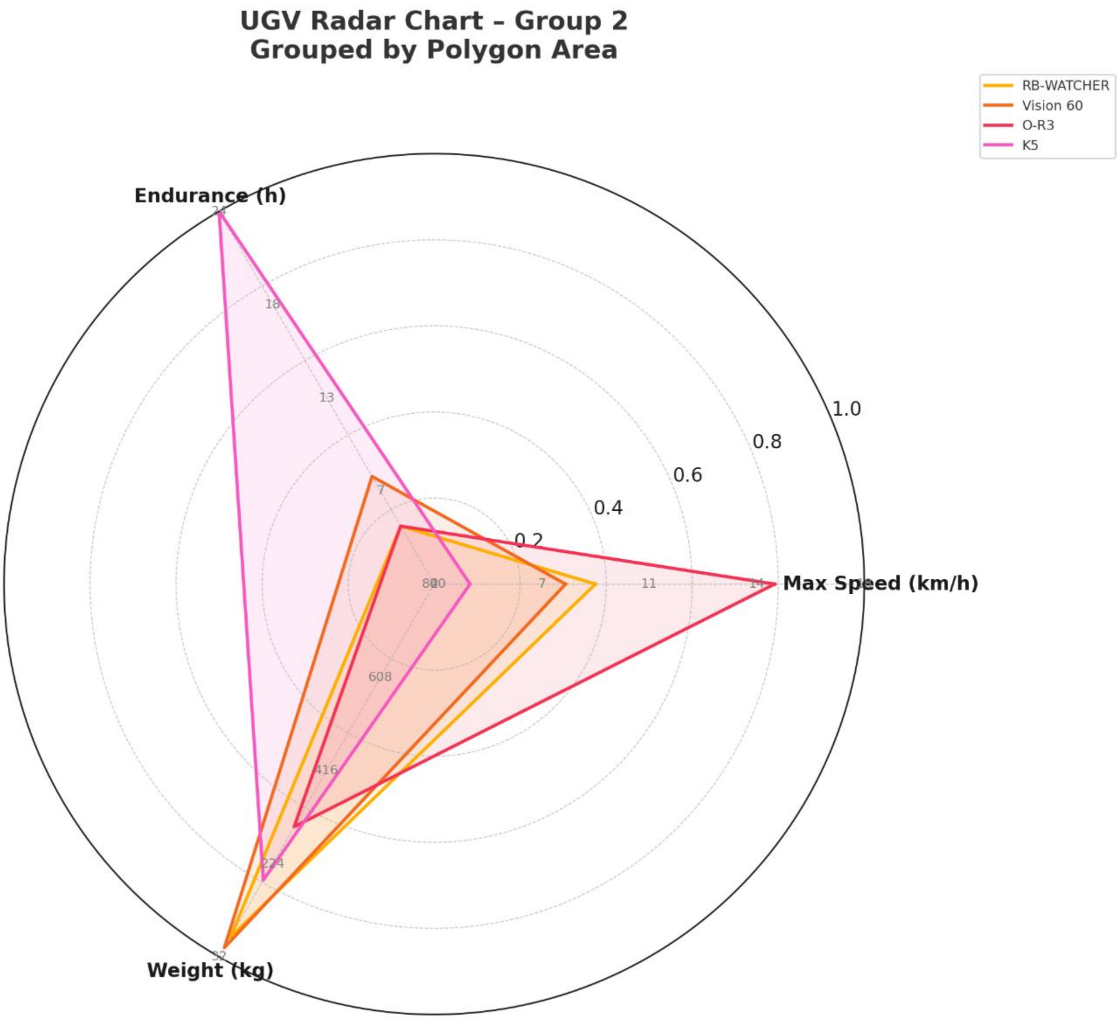

UUV Radar Chart – Group 2
Grouped by Polygon Area
Sparus II
REMUS 300
Iver4 580
Teledyne Gavia
Displacement (kg)
Depth (m)
Endurance (h)
0.2
0.4
0.6
0.8
1.0
32
44
86
127
168
200
400


UUV Radar Chart – Group 3
Grouped by Polygon Area
Tethys LRAUV
Hydrus
NemoSens
Displacement (kg)
Depth (m)
Endurance (h)
0.2
0.4
0.6
0.8
1.0
200
400
44
86
127

UGV Charts



UGV Radar Chart – Group 1
Grouped by Polygon Area
Husky A200
Spot
S5 Patrol
Barakuda
Endurance (h)
18
13
7
Max Speed (km/h)
7
11
14
0.2
0.4
0.6
0.8
1.0
608
416
224
Weight (kg)



UGV Radar Chart – Group 2
Grouped by Polygon Area
RB-WATCHER
Vision 60
O-R3
K5
Endurance (h)
Max Speed (km/h)
Weight (kg)
1.0
0.8
0.6
0.4
0.2

Chart Radar Code

UAV Chart Code

```
import math
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

# --- Load and prepare the data ---
df = pd.read_excel("Class I rotary wing UAVs.xlsx")[
    ['Model', 'MTOW (kg)', 'Payload Cap. (kg)', 'Wind Resistance (knots)', 'Endurance (min)']
].dropna()

df = df.sort_values('MTOW (kg)').head(25).reset_index(drop=True)

# Define metrics (excluding MTOW)
METRICS = ['Payload Cap. (kg)', 'Wind Resistance (knots)', 'Endurance (min)']
RANGES = {m: (df[m].min(), df[m].max()) for m in METRICS}
ANGLES = np.linspace(0, 2 * np.pi, len(METRICS), endpoint=False).tolist() + [0]

# Function to compute polygon area
def polygon_area(row):
    values = [(row[m] - RANGES[m][0]) / (RANGES[m][1] - RANGES[m][0]) for m in METRICS]
    values += values[:1]
    return 0.5 * np.abs(sum(values[i] * values[i+1] * np.sin(ANGLES[i+1] - ANGLES[i]) for i in range(len(values)-1)))

df['Area'] = df.apply(polygon_area, axis=1)
df = df.sort_values('Area').reset_index(drop=True)

GROUP_SIZE = 5
for g in range(math.ceil(len(df) / GROUP_SIZE)):
    subset = df.iloc[g*GROUP_SIZE:(g+1)*GROUP_SIZE]

    fig, ax = plt.subplots(figsize=(10, 10), subplot_kw=dict(polar=True))

    for _, row in subset.iterrows():
        values = [(row[m] - RANGES[m][0]) / (RANGES[m][1] - RANGES[m][0]) for m in METRICS]
        values += values[:1]
        ax.plot(ANGLES, values, label=row['Model'])
        ax.fill(ANGLES, values, alpha=0.10)

    ax.set_ylim(0, 1)
    ax.set_xticks(ANGLES[:-1])
    ax.set_xticklabels(METRICS, fontsize=12, fontweight='bold')

    ax.set_title(f"UAV Radar Chart - Group {g+1}\nGrouped by Polygon Area", y=1.10, fontsize=16, fontweight='bold')
    ax.legend(loc='upper right', bbox_to_anchor=(1.30, 1.10), fontsize='small')
    plt.tight_layout()
    plt.show()
```

USV Chart Code

```
import math
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

df = pd.read_excel("USV_Sines_Port_Security_Standardized.xlsx")[
    ['USV Model', 'Displacement (tons)', 'Max Speed (kn)', 'Endurance (nmi)']
].dropna()

METRICS = ['Displacement (tons)', 'Max Speed (kn)', 'Endurance (nmi)']
RANGES = {
    'Displacement (tons)': (df['Displacement (tons)'].max(), df['Displacement (tons)'].min()),  # inverted
    'Max Speed (kn)': (df['Max Speed (kn)'].min(), df['Max Speed (kn)'].max()),
    'Endurance (nmi)': (df['Endurance (nmi)'].min(), df['Endurance (nmi)'].max())
}
ANGLES = np.linspace(0, 2 * np.pi, len(METRICS), endpoint=False).tolist() + [0]

def polygon_area(row):
    values = [(row[m] - RANGES[m][0]) / (RANGES[m][1] - RANGES[m][0]) for m in METRICS]
    values += values[:1]
    return 0.5 * np.abs(sum(values[i] * values[i+1] * np.sin(ANGLES[i+1] - ANGLES[i]) for i in range(len(values)-1)))

df['Area'] = df.apply(polygon_area, axis=1)
df = df.sort_values('Area').reset_index(drop=True)

GROUP_SIZE = 5
for g in range(math.ceil(len(df) / GROUP_SIZE)):
    subset = df.iloc[g*GROUP_SIZE:(g+1)*GROUP_SIZE]

    fig, ax = plt.subplots(figsize=(10, 10), subplot_kw=dict(polar=True))

    for _, row in subset.iterrows():
        values = [(row[m] - RANGES[m][0]) / (RANGES[m][1] - RANGES[m][0]) for m in METRICS]
        values += values[:1]
        ax.plot(ANGLES, values, label=row['USV Model'])
        ax.fill(ANGLES, values, alpha=0.10)

    ax.set_ylim(0, 1)
    ax.set_xticks(ANGLES[:-1])
    ax.set_xticklabels(METRICS, fontsize=12, fontweight='bold')

    ax.set_title(f"USV Radar Chart – Group {g+1}\nGrouped by Polygon Area", y=1.10, fontsize=16, fontweight='bold')
    ax.legend(loc='upper right', bbox_to_anchor=(1.30, 1.10), fontsize='small')
    plt.tight_layout()
    plt.show()
```

UUV Chart Code

```
import math
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import re

# Helper to extract numbers from strings
def first_num(cell):
    if pd.isna(cell): return np.nan
    match = re.search(r'[-+]?\d*\.?\d+', str(cell).replace(',', '.'))
    return float(match.group()) if match else np.nan

df = pd.read_excel("UUV_models_Sines_Port.xlsx")[
    ['Model', 'Depth Rating (m)', 'Weight (kg)', 'Endurance (h)']
]

for col in ['Depth Rating (m)', 'Weight (kg)', 'Endurance (h)']:
    df[col] = df[col].apply(first_num)

df = df.dropna().reset_index(drop=True)
df = df.rename(columns={
    'Depth Rating (m)': 'Depth (m)',
    'Weight (kg)': 'Displacement (kg)',
    'Endurance (h)': 'Endurance (h)'
})

METRICS = ['Depth (m)', 'Displacement (kg)', 'Endurance (h)']
RANGES = {
    'Depth (m)': (df['Depth (m)'].min(), df['Depth (m)'].max()),
    'Displacement (kg)': (df['Displacement (kg)'].max(), df['Displacement (kg)'].min()),  # inverted
    'Endurance (h)': (df['Endurance (h)'].min(), df['Endurance (h)'].max())
}
ANGLES = np.linspace(0, 2 * np.pi, len(METRICS), endpoint=False).tolist() + [0]

def polygon_area(row):
    values = [(row[m] - RANGES[m][0]) / (RANGES[m][1] - RANGES[m][0]) for m in METRICS]
    values += values[:1]
    return 0.5 * np.abs(sum(values[i] * values[i+1] * np.sin(ANGLES[i+1] - ANGLES[i]) for i in range(len(values)-1)))

df['Area'] = df.apply(polygon_area, axis=1)
df = df.sort_values('Area').reset_index(drop=True)

GROUP_SIZES = [4, 4, len(df) - 8]
start = 0
for idx, size in enumerate(GROUP_SIZES, start=1):
    subset = df.iloc[start:start+size]
    start += size

    fig, ax = plt.subplots(figsize=(10, 10), subplot_kw=dict(polar=True))

    for _, row in subset.iterrows():
        values = [(row[m] - RANGES[m][0]) / (RANGES[m][1] - RANGES[m][0]) for m in METRICS]
        values += values[:1]
        ax.plot(ANGLES, values, label=row['Model'])
        ax.fill(ANGLES, values, alpha=0.10)

    ax.set_ylim(0, 1)
    ax.set_xticks(ANGLES[:-1])
    ax.set_xticklabels(METRICS, fontsize=12, fontweight='bold')

    ax.set_title(f"UUV Radar Chart - Group {idx}\nGrouped by Polygon Area", y=1.10, fontsize=16, fontweight='bold')
    ax.legend(loc='upper right', bbox_to_anchor=(1.30, 1.10), fontsize='small')
    plt.tight_layout()
    plt.show()
```

UGV Chart Code

```
import math
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import re

def first_num(cell):
    if pd.isna(cell): return np.nan
    match = re.search(r'[-+]?\d*\.?\d+', str(cell).replace(',', '.'))
    return float(match.group()) if match else np.nan

df = pd.read_excel("UGV_models_Sines_with_weights.xlsx")
df.columns = [c.replace('\xa0', ' ') for c in df.columns]

df = df[['Model', 'Max Speed (km/h)', 'Endurance (h)', 'Weight (kg)']]
for col in ['Max Speed (km/h)', 'Endurance (h)', 'Weight (kg)']:
    df[col] = df[col].apply(first_num)

df = df.dropna().reset_index(drop=True)

METRICS = ['Max Speed (km/h)', 'Endurance (h)', 'Weight (kg)']
RANGES = {
    'Max Speed (km/h)': (df['Max Speed (km/h)'].min(), df['Max Speed (km/h)'].max()),
    'Endurance (h)': (df['Endurance (h)'].min(), df['Endurance (h)'].max()),
    'Weight (kg)': (df['Weight (kg)'].max(), df['Weight (kg)'].min())  # inverted
}
ANGLES = np.linspace(0, 2 * np.pi, len(METRICS), endpoint=False).tolist() + [0]

def polygon_area(row):
    values = [(row[m] - RANGES[m][0]) / (RANGES[m][1] - RANGES[m][0]) for m in METRICS]
    values += values[:1]
    return 0.5 * np.abs(sum(values[i] * values[i+1] * np.sin(ANGLES[i+1] - ANGLES[i]) for i in range(len(values)-1)))

df['Area'] = df.apply(polygon_area, axis=1)
df = df.sort_values('Area').reset_index(drop=True)

GROUP_SIZE = 4
for g in range(math.ceil(len(df) / GROUP_SIZE)):
    subset = df.iloc[g*GROUP_SIZE:(g+1)*GROUP_SIZE]

    fig, ax = plt.subplots(figsize=(10, 10), subplot_kw=dict(polar=True))

    for _, row in subset.iterrows():
        values = [(row[m] - RANGES[m][0]) / (RANGES[m][1] - RANGES[m][0]) for m in METRICS]
        values += values[:1]
        ax.plot(ANGLES, values, label=row['Model'])
        ax.fill(ANGLES, values, alpha=0.10)

    ax.set_ylim(0, 1)
    ax.set_xticks(ANGLES[:-1])
    ax.set_xticklabels(METRICS, fontsize=12, fontweight='bold')

    ax.set_title(f"UGV Radar Chart - Group {g+1}\nGrouped by Polygon Area", y=1.10, fontsize=16, fontweight='bold')
    ax.legend(loc='upper right', bbox_to_anchor=(1.30, 1.10), fontsize='small')
    plt.tight_layout()
    plt.show()
```

Annexes

Annex A- HPROMS

NR	DESCRIPTION
1	Conduct subsurface search at pier and approaches
2	Maintain surveillance at pier and surroundings areas
3	Escort designated unit from the harbour entrance to the pier
4	Embark vessel protection detachment (VPD) on board designated unit
5	Ensure surveillance and patrolling at sea and/or land by all means available
6	Establish exclusion zone of (xxx) meters around identified critical spot
7	Raise protection of critical spots
8	Establish exclusion zone of (xxx) meters around berth area
9	Establish exclusion zone number (xxx)
10	Deploy floating barriers around designated area
11	Establish passive underwater protection measures (with Best Management Practices e.g. nets, wires)
12	Place security barriers to reduce car speed at HSA entrances
13	Reinforce control of entries to pier/harbour through all access
14	Establish a safe logistic area for material inspection of ships cargo
15	Reinforce security on adjacent areas with means of the host nation
16	Conduct permanent Patrols at sea within HSA
17	Conduct random Patrols at sea within HSA
18	Conduct of / increase hull-inspections of ships in harbour
19	Inspect and identify all civilian sea shipping authorized to operate at HSA
20	All civilian shipping operate within HSA with security team embarked only
21	Conduct security briefing to all shipping entering/leaving the harbour
22	Conduct permanent Patrols on land within HSA /adjacent areas
23	Conduct random Patrols on land within HSA /adjacent areas
24	Reinforce security teams protecting Critical Spots
25	Brief all personnel to be suspicious and inquisitive about strangers and unknown suitcases
26	Protect personnel and service transport in designated area
27	Sweep / Search vehicles, material and unknown personnel
28	Minimize the presence of locals /civilian personnel in defined areas
29	Minimize/restrain leaves from military compound
30	Harden the all/designated area (xxx) with physical barriers/sentries
...	**Spare**
n	Spare