atlantis The Atlantic Testing Platform for Maritime Robotics

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Guidelines for update existing Standards for O&M using robots

RINA-C and INESCTEC

Actions

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Project Coordinator	Approved the updated second version as the final version and sent to the European Commission.	INESC	31.10.2023

Disclaimer

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Acronym	Meaning
ASV	Autonomous Surface Vehicles
AUV	Autonomous Underwater Vehicle
BVLOS	Beyond Visual Line of Sight
COLREG	International Regulations for Preventing Collisions at Sea
EASA	European Union Aviation Safety Agency
FMECA	Failure Mode Effects and Criticality Analysis
GPDR	General Data Protection Regulation
H&S	Health and Safety
IMCA	International Marine Contractors Association
IMO	International Maritime Organization
IMR	Inspection, Maintenance and Repair
ISO	International Organization for Standardisation
LARS	Launch and Recovery System
MASRWG	Maritime Autonomous Systems Regulatory Working Group
MASS	Maritime Autonomous Surface Ships
MAV	Maritime Autonomous Vehicle
MCA	Maritime & Coast Guard Agency
MMO	Marine Management Organisation
NORSOK	Norsk Sokkels Konkurranseposisjon
O&M	Operation and Maintenance
OW	Offshore Wind
OWF	Offshore Wind Farm
PPE	Personal Protective Equipment
RCC	Remote Control Centre
ROV	Remotely Operated Vehicle
SAM	System of the Maritime Authority
SARUMS	Safety and Regulations for European Unmanned Maritime Systems

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SOLAS	International Convention for the Safety of Life At Sea
UAS	Unmanned Aerial Systems
UAV	Unmanned Aerial Vehicle
UMV	Unmanned Maritime Vehicle
UNCLOS	United Nations Convention on the Law of the Sea
USV	Unmanned Surface Vehicles
VLOS	Visual Line of Sight
WFA	WindFloat Atlantic

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1. INTRODUCTION

The O&M of Floating Offshore Wind Farms poses significant technological and economical challenges including asset downtime, operational expenditure (OPEX) incurred, data quality, and fault diagnosis and prognosis.

The O&M activities for Floating Offshore Wind Farms involve inspecting and maintaining components of the wind turbines and their subsystems to prevent and address faults.

O&M activities are typically performed by qualified technicians, often working in extreme conditions and during restricted weather windows. The duration of turbine downtime and hence the lost energy production can be considerable, while the use of crew transfer vessels (CTVs) and service operation vessels (SOVs) also makes up a significant proportion of the offshore wind farm O&M costs.

It has been estimated that the operations and maintenance (O&M) of onshore wind turbines account for about 25–30% of the total lifecycle cost of wind turbines, and in the case of offshore turbines, the costs are even higher, in the range of 30–35% (Stehly T., 2019).

Given the nascent nature of the floating wind energy industry and the lack of established best practices, these operations present significant scope for optimisation and cost reduction.

The FOWT industry can benefit from the technical expertise and innovations developed in the offshore oil and gas (O & G) and fixed wind energy industries. However, the deployment floating platforms requires the development of solutions to reduce the cost and increase safety of installation, operation and maintenance (O & M) and decommissioning related marine activities.

Recent advances in the development of offshore robotics have opened new opportunities for deploying semi or fully autonomous systems for the O&M of offshore wind farms. Incorporating robotic systems offshore can not only improve the assets' reliability but could also reduce costs and mitigate the health and safety (H&S) risks associated with deploying human operators to offshore sites with harsh weather conditions.

Offshore O&M activities for OWF are not yet standardized and technical normative do not yet exist, particularly if we consider the use of robots, whose own regulatory framework is still under construction and very linked to field of application.

In addition, Wind turbines are moving further offshore to deeper waters and are exploiting higher wind speeds in harsher environments. This trend creates additional challenges in the design, installation, operation, maintenance, and decommissioning phases of an offshore wind farm.

Numerous investigations for developing efficient and optimum Floating Offshore Wind Turbine (FOWT) platforms and various innovative design concepts have been evolving in the last few years. Several pilot and demonstration-scale floating wind farms are now operational in different parts of the world. Significant reductions will be required across all key stages in the development of a floating wind farm.

The purpose of this document is to provide an overview about Regulatory framework and the development of standardization guidelines for new O&M methodologies using robotic solutions in offshore wind farms.

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2. OPERATIONS AND MAINTENANCE OF FLOATING OFFSHORE WIND FARM

2.1. Introduction

The O & M activities include performing preventive and corrective maintenance, inspection, surveys, and conducting condition monitoring of various components and assets.

The primary objectives of O&M are to ensure asset availability (limit shutdown) and preserve equipment lifetime, while also taking into consideration the H&S aspects of the employees involved.

Several factors can affect the implementation of O&M strategies for FLOATING OFFSHORE WIND FARM.:

Limited accessibility and dependence on weather windows: The higher values of significant wave height and wind speed, restrict the accessibility of OWT for service vessels and the transfer of personnel from the vessel to the OWT. Offshore access systems with compensated mobile walkways have been widely applied together with service vessels over the past decade, although such devices are still heavy and expensive. If a maintenance task needs to be postponed due to weather issues, a longer waiting period and increased energy loss during downtime will likely occur. Even without considering the effects of weather, OWT maintenance costs are higher than that of equivalent tasks onshore due to the specialized equipment required. In addition, a severe offshore working environment, higher wind speed, wave-induced motions, and structural vibrations result in higher failure rates of OWT components.

Increased loads: turbines are subjected to cyclic loads due to dynamic response of the turbine to wind and wave profiles. Hence, they are prone to more structural damage as compared to their onshore or bottom-fixed counterparts. The sub-systems such as foundation and mooring lines will also be subjected to harsher wave conditions which may influence the individual component's lifecycle. Consequently, the inspection and maintenance activities need to be considered more often for these turbines.

O&M costs: While the fixed O&M cost of a FOWF can be predetermined, the variable costs associated with transferring personnel and equipment to the offshore sites are subjected to the availability of weather windows, the type and duration of repair, and the significant wave height. This brings about a corresponding increase in the costs associated with leasing of CTVs and SOVs. Furthermore, the risks associated with safety and well-being are higher at these locations, and as such, the insurance costs are dearer. These factors culminate in an overall higher OPEX for the wind farm.

A successful maintenance strategy aims to maximize economic benefit, extend component life, reduce the number of emergency repairs, reduce overtime costs, and relieve the work stress of unpredictable failures. Maintenance strategies are typically classified as corrective (reactive) maintenance, proactive maintenance, and opportunistic maintenance based on when maintenance is conducted.

In general, maintenance can be divided as follows:

Preventive maintenance that is performed to mitigate the occurrence of a component or system failure in the future.

Preventive Maintenance can be further classified as follows:

a) Calendar based: a fixed number of inspections or repairs per a specified interval of time, conducted by the operator irrespective of the damage state of the components or system.
b) Condition based: a repair or replacement is conducted based on the observed health of the component or system.

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Corrective maintenance relies on the repair or replacement of a component or system when the damage, failure or failure has already occurred.

Predicting failures before they occur through robust condition monitoring approaches can lead to a significant reduction in O&M costs. These approaches are based on analysis of specific measurements and aspects of operations such as fatigue analysis, strain measurement, thermal and acoustic data.

Recent advances in sensors, data analysis and improvements in machine learning algorithms have opened new opportunities for integrated and in-depth systems analysis, where different types of data can facilitate informed and reliable decision-making.

Below is indicated possible applicability of On Condition Maintenance strategy respect the main component of OWT.

	NACELLE	TOWER	BLADE	BEARINGS	SHAFT	GEARBOX	GENERATOR	MOORING LINE	ANCHOR SYSTEM	CABLE	FLOATER PLATFORM
VIBRATION ANALYSIS	X		X	X	X	X	X			X	
TORSIONAL VIBRATION					X	X					
OIL ANALYSIS				X		X	X				
STRAIN MEASUREMENT		X	X					X		X	X
TEMPERATURE	X			X		X	X				
THERMOGRAPHY	X		X	X	X	X	X				
VISUAL INSPECTION	X	X	X	X		X	X	X	X	X	X
RADIOGRAPHIC INSPECTION		X	X								X

Table 1 - Monitoring and analysis methods applied to different component

Operations and maintenance of the floating offshore wind farm include performing preventive and corrective maintenance, inspection, surveys, and condition monitoring of various components and activities (turbine system, floater, electrical system, mooring and anchoring system...). Such activities are typically included in the scope of O&M contracts for wind farm operators with the aim of maintaining the asset after its installation and during the entire operational phase.

The floating wind industry is still in its infancy, as compared with bottom-fixed, and these activities may be adapted as lessons are learned from more installations. These activities are associated with not only maintaining the wind turbine generator but also the floating platforms, mooring lines, anchors, and dynamic cables. For instance, surveys need to be conducted to inspect the condition of catenary moorings and drag anchors. Moorings are raised to the surface for a detailed inspection.

Furthermore, dynamic cables require regular visual inspection of bending stiffeners, transition joints, buoyancy modules, and marine growth.

Floating platforms are designed to withstand weather conditions without failure throughout the life of the turbine; however, as with any other offshore structure, dynamic sea conditions can cause cracks to occur.

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2.2.Operation & Maintenance using Robotic Technology in O&G sector

As far as the challenge of oil and gas assets operations are becoming more complex, themes such as health, safety, security and environmental standards that apply in operations are more stringent. Robotics addresses the mobility element of the challenge, reducing safety exposure for our people, our contractors and suppliers, and automating data collection for advanced analytics tools to provide proactive leak and corrosion detection.

Technical advances in recent years have made robotic systems more cost-effective. Internet of Things brings internet connectivity to everyday objects and devices, essentially allowing robots to become mobile sensors collecting data and training machine learning models. Increased processing power, better batteries and improved sensor technologies have all had roles in this trend. Today, robotics is a fast-moving field with exciting developments linked to the wider trends in digitalization.

Robotics, by default, offers improved maintenance capabilities to oil and gas activities. Broadly speaking, robotic deployment tends to be unmanned, and either autonomous or remotely operated. Unmanned aircraft systems (UAS) or simply drones, help in performing inspection, repair, and maintenance (IRM) tasks over wide areas in a short span, especially those which are not easily reachable, such as a flare stack or an offshore platform.

Similarly, autonomous underwater vehicles (AUVs) or remotely operated vehicles (ROVs) have become essential in undertaking subsea infrastructure maintenance activities. Another robotic technology, crawler robots, is being used for performing maintenance activities in constrained areas that may be otherwise inaccessible to humans.

Main applications are relevant to:

- Fugitive emission, Leak detection and emission control – unmanned aircraft system
- Confined space inspections (tank, vessel…) – indoor unmanned aircraft system
- Visual integrity inspections (flare, submerged asset, installations at the loading bays) – UAS, indoor UAS, AUV

Digital technologies offer new options for detecting emission in oil &gas operation.
Emission sources are being targeted through a range of innovation technologies: such as imaging camera, sniffer robots and drone mounted sensors.

Traditionally, drones have been used as a specialty tool to complete an explicit task, but a shift is now occurring where drones are becoming embedded into operations as a preferred way of working. They offer a cost effective and safe way to rapidly gather imagery of out of reach spaces and large geographic areas.
For example, at Shell’s Deer Park refinery, the tank farm is inspected by drones to collect data as opposed to inspectors physically visiting the tanks. The surveillance robotics team is looking to build upon these types of initiatives by doing this kind of repetitive data collection activity across wide areas of a facility (ShellEnergy).

In the past, human divers performed dangerous underwater maintenance and construction work. As the industry moved to deeper waters, more than 150 meters from the surface, humans could no longer deal with the conditions, and remotely operated vehicles – ROVs – became fundamental.

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There are still advances to be made: for instance, removing tethers and making ROVs autonomous and able to operate for long periods without human interaction. Autonomous underwater vehicles (AUVs) are used in surveillance/inspection of the seabed and subsea equipment, such as pipelines, risers, wells, pumps, etc.

Over the years, as ROVs have had their capabilities extended to enable them to handle more complex operations, and they have become indispensable tools for conducting safe activities in deep water.
Marine Robotics are enabling Shell to change the concept of operations for all offshore facilities, including traditional oil and gas as well as offshore wind and carbon capture and storage facilities.

Several standards and guidelines are already in force in O&G sector but none of them regulates the use of robotic technology for the execution of activities starting from the design and validation development phase.

To highlight the high potential of robotics inspection, the provided picture (Fig 1) depicts a confined space, and it was captured during a visual inspection conducted with the aid of an indoor aeronautical drone. This innovative approach eliminated the need for human personnel to enter confined space, thereby minimizing associated risks. The primary purpose of this inspection was to assess the structural integrity of the confined space. Special emphasis was placed on examining the welds within this environment, with a focus on evaluating their current condition. Additionally, the inspection aimed to identify any signs of localized or generalized oxidation, which could potentially compromise the integrity of the structure.

The use of advanced technology not only ensured the safety of personnel but also allowed for a thorough and comprehensive examination of the confined space, providing valuable insights into its structural health and the state of its welds. Such inspections are crucial for maintaining the safety and reliability of the structure in question.

Figure 1 - Example of a visual inspection made by an indoor aeronautical drone

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In Fig 2 instead, it is depicted a visual inspection of a refinery torch, a critical component in the facility. This inspection was conducted using an aeronautical drone, demonstrating a forward-looking approach to safety and efficiency. The utilization of this drone technology effectively eliminated the need for personnel to perform the inspection using lifting equipment and working at heights. Moreover, it ensured that the refinery could continue its operations without interruption during the inspection process.

The primary objective of this inspection was to assess the condition of the flare tip, a vital element in the refinery's safety and pollution control measures. Specific attention was given to evaluating the extent of wear on the flare tip, examining any deformations within its internal steel structure, and assessing the integrity of the refractory material lining its interior. This inspection methodology not only prioritized safety by avoiding risky work at height but also ensured the ongoing functionality of the refinery. By proactively identifying any issues with the flare tip, maintenance and repairs could be scheduled as needed, contributing to the overall safety, environmental compliance, and operational efficiency of the refinery.

Figure 2 - Example of a visual inspection of a refinery torch

Figure n. 3 offers instead a glimpse into a visual inspection conducted within the internal tunnel of a power plant, a critical infrastructure component responsible for housing the water required for cooling the system. This inspection employed the use of an amphibious drone, showcasing an innovative approach that effectively eliminated the need for personnel to enter the confined space. This approach greatly mitigated associated risks. The primary objective of this inspection was to assess the extent of erosion affecting the tunnel's structural integrity. Special attention was also given to identifying any obstructions within the tunnel that could potentially impede the smooth flow of water, thereby jeopardizing the cooling process.

By utilizing an amphibious drone, this inspection not only ensured the safety of personnel but also facilitated a comprehensive evaluation of the tunnel's condition. This proactive approach is crucial for maintaining the efficiency and reliability of the power plant's cooling system, preventing potential issues related to erosion and blockages, and ultimately contributing to the plant's operational efficiency and safety.

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Figure 3 - Example of a visual inspection of a tunnel in a power plant

A further example of robotic inspection is reported by the picture in Fig 4, a snapshot from a visual inspection conducted within a chimney located inside a refinery. This inspection was executed using an aeronautical drone, demonstrating a safety-conscious approach that effectively removed the need for workers to perform inspection tasks at heights, often requiring lifting equipment. The primary goal of this inspection was to assess the overall structural integrity of the chimney. Specifically, it involved an evaluation of the condition of the chimney's mantle and an examination of the metal structures such as stairs and walkways. A critical aspect of this assessment was the careful scrutiny for any deformations or anomalies present on these structural components.

By employing an aeronautical drone for this inspection, safety hazards associated with working at heights were significantly reduced, and a thorough examination of the chimney and its associated structures was made possible. This proactive approach to maintenance and safety ensures that any issues related to the integrity of the chimney and its support structures are identified promptly, contributing to the safety and continued reliable operation of the refinery.

Figure 4 - Example of a visual inspection conducted in a refinery chimney

In the section below, the most important standards for subsea tests conditions are reported:

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AODC 035	Code of practice for the safe use of electricity underwater
ISO 13628	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 1: General requirements and recommendations Petroleum and natural gas industries – Design and operation of subsea production systems – Part 8: Remotely Operated Vehicle (ROV) interfaces on subsea production systems
ISO 14224:2016	Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment
ISO 19901-7	Petroleum and natural gas industries – Specific requirements for offshore structures – Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units
UNI EN ISO 9712:2012	Non-destructive testing — Qualification and certification of NDT personnel
UNI EN ISO 9223:2012	Corrosion of metals and alloys — Corrosivity of atmospheres — Classification, determination, and estimation
UNI EN 13018:2016	Non-destructive testing - Visual testing - General principles
UNI EN 13927:2006	Non-destructive testing - Visual testing - Equipment
NORSOK	NORSOK R-002 Lifting equipment NORSOK R-003 Safe use of lifting equipment NORSOK U-101 Diving respiratory equipment NORSOK U-102 Remotely operated vehicle (ROV) services NORSOK U-103 Petroleum reated manned underwater operations inshore NORSOK Z-008 Risk based maintenance and consequence classification NORSOK Z-013 Risk and emergency preparedness assessment
DNV	DNV-RP-E307 Dynamic Positioning System DNV-OS-F101 Submarine Pipeline Systems DNV RP F103 Cathodic Protection of Submarine Pipelines by Galvanic Anodes
IMO-International Maritime Organization	IMO 808E Code of safety for diving systems (resolution A.536(13) as amended by resolution A.831(19)) and any further amendments. As printed in ISBN 978-92-801-14324 (Sales number IMO 808E, London: IMO,1997) or later edition
EASA	EASA - European Union Aviation Safety Agency, “Easy Access Rules for Unmanned Aircraft Systems (Regulations (EU) 2019/947 and (EU) 2019/945),” EASA, 2020.
NBH IK-2708	The Norwegian Board of Health IK-2708. Norwegian guidelines for medical examination of occupational divers. (Statens helsetilsyns veiledningsserie; vol 2000;1-00. Oslo, 2000 or any later edition)

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IMCA	IMCA R 001	Plastic spherical air-filled fishing buoys
	IMCA R 002	Requirements for IMCA-approved ROV introductory training courses
	IMCA R 004	Guidance for the safe and efficient operation of remotely operated vehicles
	IMCA R 005	Guidance on safety procedures for isolation of ROV high voltage equipment (above 1kV)
	IMCA R 006	ROV audit guidance document
	IMCA R 007	IMCA ROV services contracting principles
	IMCA R 008	Terms and conditions for ROV support services
	IMCA R 009	ROV Mobilisation
	IMCA R 010	Guidance on module outlines for ROV-related training courses
	IMCA R 011	The initial and periodic examination, testing and certification of ROV launch and recovery systems
	IMCA R 013	Contract for the provision of ROV, support vessel and associated work
	IMCA R 015	Code of practice for the safe use of electricity under water
	IMCA R 016	Diver and ROV based concrete mattress handling, deployment, installation, repositioning and decommissioning
	IMCA R 017	Contract for the provision of ROV, support vessel and associated work
	IMCA R 019	Understanding biodegradable lubricants: An introduction to 'green' oil in hydraulic systems offshore
	IMCA R 020	Remotely operated vehicle intervention during diving operations
	IMCA R 021	Guidance for remotely operated vehicle load testing and inspection
	IMCA R 022	Guidelines for the shared use of sensors for ROV and survey purposes
	IMCA R 023	AUV Audit Guidance Document
	IMCA C 005	Guidance on competence assurance and assessment: Remote Systems & ROV Division

In addition to international standard mentioned before, Oil Companies have already developed internal procedure that define the execution of maintenance activity using robots. As example:

Saudi Aramco References

- SAEP-80 Safety Procedure for Mini-copter UAV Operations at Saudi Aramco Industrial Sites
- SAEP-81 External Inspection of Industrial Assets using Unmanned Aerial Vehicles

ENI

- 23046.SLI.OFF.FUN External Survey of Submerged Risers
- 23006.SLI.OFF.FUN Functional Specification for Positioning
- 23035.SLI.OFF.FUN Functional Specification for External Survey of Pipelines in the Offshore Areas
- 23036.SLI.OFF.FUN Functional Specification for External Survey of Pipelines in the Near Shore Areas
- 20311.VAR.COR.SDS Underwater Inspections of Cathodic Protection Systems
- 27956.PLI.COR.SDS Guideline for Monitoring of Onshore Pipeline
- MOD.OFF.SLI.608 Technical Data Sheet for Bathymetric Data
- MOD.OFF.SLI.609 Technical Data Sheet for Events Data
- MOD.OFF.SLI.610 Technical Data Sheet for Videos Data
- MOD.OFF.SLI.611 Technical Data Sheet for Images Data

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2.3. Operation & Maintenance using Robotic Technology widely used in Industrial/Energy applications

Fig 5 below represents a valuable tool used for identifying structural defects in wind turbines following visual inspections conducted with aeronautical drones. This approach to remote inspection has gained prominence due to its speed, efficiency, and, most importantly, the significant reduction in risks for workers who would otherwise have to conduct these inspections in potentially hazardous conditions.

The effectiveness of the tool hinges on the initial inspection, which must be carried out using cutting-edge technologies and well-defined procedures. This meticulous approach is essential to ensure that the tool, powered by machine learning algorithms, functions accurately. The tool relies on high-quality data collected through robust methodology during the inspection, enabling it to accurately detect anomalies present on the wind turbine structure.

It becomes evident that the success of the inspection and the proper functioning of the tool are interdependent. A key factor in this equation is the competence and training of personnel responsible for the drone-based inspection of wind turbine blades (Fig 6). These personnel need to be well-versed in the methodologies required for conducting precise and reliable inspections. Their expertise ensures that the data collected meets the necessary standards for training machine learning algorithms, ultimately leading to more effective defect detection and safer wind farm operations.

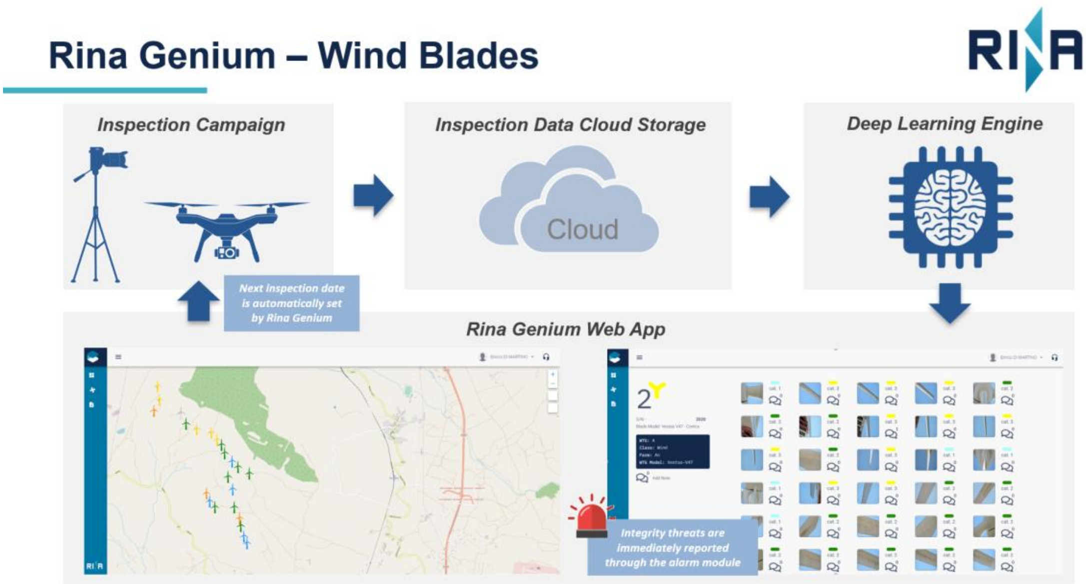

Figure 5 - RINA Genium tool

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Figure 6 - Images taken from a visual inspection of the blades of an offshore wind turbine

An important and well-known industry application for drones is the gas leaks inspections, which represents a cutting-edge and technologically advanced system. This system enables precise detection of methane concentrations along pipeline routes. The process begins with remotely assigning the task to the drone, specifying the pipeline route. The drone takes off from a take-off and landing station, specially adapted for self-wireless charging. It then proceeds to fly along the designated pipeline route while employing a high-sensitivity detector based on tunable diode laser absorption spectroscopy (TDLAS) to identify methane concentrations over the pipeline.

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At regular intervals, the drone accurately marks measurement points with coordinates, parts per million (ppm) readings, measurement height, captures photos, and gathers other pertinent data. These results are transmitted to the operator in real-time. Importantly, the drone autonomously calculates the safe distance it can cover while maintaining enough charged power to return to its docking station. Once recharged, the drone can seamlessly resume its measurements from any unfinished location.

Specifications for the methane detector include:

- High-sensitivity detection of methane (CH_4) and methane-containing gases with a gimbal for measurement stabilization, all based on TDLAS.
- Ability to detect methane concentrations as low as 1 ppm·m (with detection limits ranging from 1 to 500,000 ppm·m).
- High patrol speed of approximately 10 m/s during inspections.
- Capability to identify even the faintest traces of natural gas from altitudes ranging from 0.5 to 100 meters.
- Accurate geographic positioning of the measurement beam.
- Connectivity options, including internet, Bluetooth, or Wi-Fi.
- Water and dust resistance.
- Automated documentation of pipeline inspections and real-time reporting with an accuracy of ±10%.
- Self-calibration with an integrated reference cell.

Specifications for the UAV Drone include:

- Extended flight time, ideally at least 40 minutes.
- Maximum horizontal speed of up to 20 m/s.
- Autonomous flight routed using ArcGIS format layers, with remote control capabilities and the option to switch to manual control.
- Ability to identify and avoid obstacles such as trees, shrubs, and power lines.
- Capability for long-distance flights, enabling automatic landings at predefined areas in pipeline facilities with wirelessly self-charging stations or alternatives.
- Precise geographic positioning of the drone.
- Water and dust resistance.

General system specifications encompass:

- Integration capabilities with Pipeline Integrity Management System (PIMS) and other internal information systems, including ArcGIS.
- Cyber threat detection and identification of high-priority threats.
- Fully integrated Full HD camera with gimbal stabilization for enhanced video recording and photography, supporting interactive panoramic viewing of photographs along the pipeline route in ArcGIS.

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- A photo analysis system that tracks the inspected route, marking coordinates of gas leaks, areas where the pipeline is exposed to the air, and any unauthorized activities.
- Completion of drone equipment, including detection, inspection, data processing, storage, etc., after simulations, customization, and testing, with final assignment to AB Amber Grid.

- **Hybrid Drone for long range missions**
- **Extended flight time(up to 2h)**
- **Extended operational range BVLOS, (up to 50 Km)**
- **4G/5G connection, cloud dataset**
- **Remote mission control**
- **Limited OpEx**
- **Autorization support by italdrone**
- **Fixed wing with vertical take off and landing**

Figure 7 - An example of hybrid drone system operated

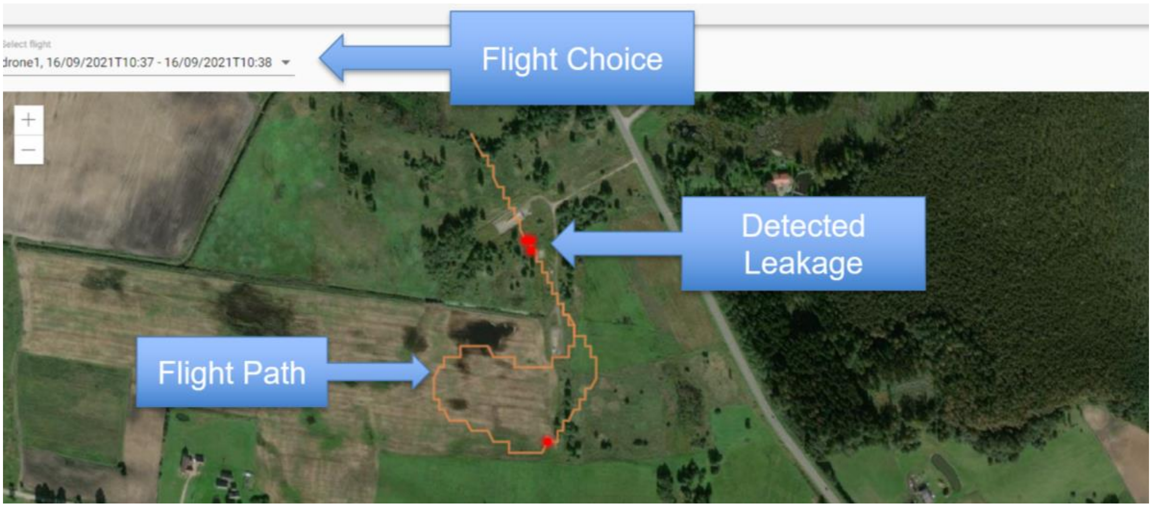

Figure 8 - Example of a Gas Leaked Detection performed by RINA using a robotic drone

Robotic applications have revolutionized various sectors, offering innovative solutions in site visits, inspection, asset integrity assessment, due diligence, environmental surveys, and offshore activities. Here's a description of the potential applications of robots and drones in these fields:

- Site Visit:

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Robots and drones are instrumental in site visits, especially in hazardous or hard-to-reach areas. They can provide real-time data and imagery, aiding engineers, architects, and construction professionals in surveying construction sites, archaeological digs, or disaster-stricken areas. Their ability to capture high-resolution images and videos allows for precise documentation and remote monitoring.

- Inspection:
  The inspection industry benefits greatly from robotics. Drones equipped with specialized sensors and cameras can inspect infrastructure such as bridges, pipelines, and power lines. Submersible ROVs (Remotely Operated Vehicles) are used for underwater inspections. These robots reduce human risk and provide more accurate data for maintenance and safety assessments.

- Asset Integrity Assessment:
  For industries dealing with critical infrastructure, like oil and gas, robots are invaluable for asset integrity assessment. Crawling robots can navigate through pipes and tanks to inspect for corrosion, leaks, or structural issues. Drones can perform aerial inspections of large facilities, providing a comprehensive view of assets and potential vulnerabilities.

- Due Diligence:
  In due diligence processes, robots and drones help streamline data collection and risk assessment. They can perform property surveys, capturing detailed images and 3D models. This data aids investors, real estate professionals, and insurance companies in making informed decisions about acquisitions, property valuations, and risk assessments.

- Environmental Survey:
  Robots and drones are essential tools for environmental surveys, enabling scientists and researchers to collect data in remote and sensitive ecosystems. Drones equipped with specialized sensors can monitor air and water quality, track wildlife populations, and assess the impact of climate change. Submersible ROVs play a crucial role in exploring the depths of the ocean and studying marine ecosystems.

- Offshore Activities:
  Offshore industries, such as offshore drilling and renewable energy production, rely on robots and drones for a wide range of tasks. Subsea ROVs are used for underwater maintenance and repairs on oil rigs and wind turbines. Drones monitor offshore installations, ensuring their safe and efficient operation. Autonomous surface vessels (ASVs) help with oceanographic research and data collection in remote offshore locations.

In conclusion, robots and drones have transformed site visits, inspections, asset integrity assessments, due diligence processes, environmental surveys, and offshore activities across various industries. Their ability to access remote or hazardous environments, collect precise data, and improve safety measures has made them indispensable tools in modern operations and decision-making processes.

2.4. Components and Systems Identification

For new application like Floating offshore wind turbine in floating configuration the analysis should proceed by identifying all systems and sub-systems. It should continue by identifying all weaknesses in each of these systems and analyse how each identified weakness is managed.

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The main components of Floating offshore wind turbine can be grouped in systems:

Code	System	Components:	Component Code
S-1	Rotor System	Blade	BL
		Hub	HB
		Pitch System	PS

Table 2 - Components for Rotor system

Code	System	Components:	Component Code
S-2	Drive Nacelle System	Shaft	SH
		Generator	GE
		Gearbox	GB
		Electrical and Controller System	E&C

Table 3 - Components for Drive Nacelle System

Code	System	Components:	Component Code
S-3	Yaw System	Yaw system	YS

Table 4 - Components for Yawn system

Code	System	Components:	Component Code
S-4	Floater Platform	Tower	TO
		Mechanical Support, Ladders..	MS
		Knee braces; beams, v-braces and k-joints; Columns Water entrapment plate (Above/Below water)	FP

Table 5 - Components for Floater Platform system

Code	System	Components:	Component Code
S-5	Mooring & Anchor system	Platform Mooring Connectors	PMC
		Chains	CH
		Anchors	AN

Table 6 - Components for Mooring & Anchor system

Code	System	Components:	Component Code
S-6	Cable system	Array cables	AC
		Export cable	EC
		Protection systems of cables: Bend stiffener	PC

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		buoyancy modules **Uraduct** **Touchdown protections**	

Table 7 - Components for Cable system

2.5. Failure modes and effects analysis

Whenever the function of an item of equipment or system requires it to work in an environment in which any failure has the potential to have a catastrophic effect, it is responsible design practice to carry out an FMEA as part of an operations and maintenance strategy. Consequently, several people, organisations, bodies, are very interested in the findings of an FMEA.
The objective of an FMEA is to identify the potential design and process failures which will cause the system under analysis to fail to perform its intended function.
An FMEA provides a systematic method for identifying modes of failure together with their effects on the item or process, both locally and globally.

The main FMEA steps are:

- Failure Modes Identification & Selection;
- Failure Effects Analysis;
- Detection Methods;
- Failure Patterns Analysis.

2.5.1. Failure Modes Identification & Selection

A failure mode is a single event, which causes equipment functional failure. The description shall contain proper detail for it to be possible to select an appropriate failure management policy.

The floating technology requires frequent maintenance, and such a procedure's difficulty involves a considerable amount of associated costs.

Due to the severe working conditions the possibility to consider a large volume of damages of blades, gearboxes, mooring systems, and other parts of floating wind turbines can increase the failure rate and economic losses can be effectively reduced through fault detection and risk or failure analysis of floating wind turbine systems.

Analyse failures of each element and their impact on each system can be the first step to define the maintenance strategy. Since the rotor and drivetrain rotate, and the structures are exposed to waves, the failure rates are frequently caused by wear and fatigue during operation, and some failures are considered to happen randomly without explicit trends and predictions.

Identification and selection of failure modes to be analysed shall be based on:

- Probability of occurrence;
- Level of details;
- Consequences at equipment level.

Typical sources of failure mode information are:

  - Owner technical historical record/database;
  - Supplier data;
  - International recognized databanks;

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- Collection of reliability and maintenance data for equipment;

The progressive population of these databases, due to the increase of offshore wind installations in floating configuration, will allow a targeted identification of reliable data associated with identified failure modes.

Based on Reliability data a proper Maintenance strategy can be developed.

The identification of failure modes is a fundamental step because depending on this identification the reliable data can be collected.

The number of installations is growing significantly, and this will allow a greater availability of data.

For a careful analysis it is necessary to make the data collection as homogeneous as possible (clear definition of failure modes) to use without ambiguity, the experiences gained.

Reliability data connected to FM provide fundamental guidance for condition-based maintenance implementation and benefit optimal operating and maintenance (O&M) strategy planning.

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2.5.2. Failure Effects Analysis

Failure effects describes what happens if a failure mode occurs without specific task is done to anticipate, prevent or detect the failure.

Failure effects statements, used to assess the consequences of each failure mode, shall provide the basic information needed to decide what failure management policies shall be implemented to avoid, eliminate, or minimize consequences.

Local effects refer to the effects of the failure mode on the element under consideration. The consequences of each possible failure on the output of the item will be described. The purpose of identifying the local effects is to provide a basis for judgement when evaluating existing alternative provisions or devising recommended corrective actions. In certain instances, there may not be a local effect beyond the failure mode itself.

Some failure modes can affect:

- Output
- Product Quality
- Customer service

A set of standardized system/unit effects as follows:

System/Unit Effect	System/unit Definition
PRO - RED	Production Reduction
PRO - S/D	Production Shutdown
NONE	No immediate failure consequence

Some failure modes may threaten:

- Safety
- Health
- Environment

Some failure modes may have an impact in:

- Operating Cost (for instance by increasing energy consumption)

Other failure modes may have a simultaneous impact on more than one of the categories mentioned above.

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2.5.3. Detection Methods

Early detection of a failure or imminent failure can allow operators, maintainers, users and others to intervene and reduce either the likelihood of adverse effects or their consequences.

This is the method or activity by which a failure is discovered. This information is vitally important when evaluating the effect of maintenance, e.g. to distinguish between failures discovered by a planned action (inspection, preventive maintenance) or by chance (casual observation). Categories of detection methods are identified in the following table (refer to API Standard 689/ISO 14224) (ISO 14224 Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment):

#	Code	Detection Method	Explanation	Activity
1	**PREV**	Periodic Preventive Maintenance	Failure discovered during preventive service, replacement or overhaul of an item when executing the preventive maintenance programme	Scheduled activities
2	**TEST**	Functional Testing	Failure discovered by activating an intended function and comparing the response against a predefined standard. This is one typical method for detecting hidden failures.	
3	**INSP**	Inspection	Failure discovered during planned inspection, e.g. visual inspection, non-destructive testing	
4	**PCM**	Periodic Condition Monitoring	Failures revealed during a planned, scheduled condition monitoring of a predefined failure mode, either manually or automatically, e.g. thermography, vibration measuring, oil analysis, sampling	
5	**CCM**	Continuous Condition Monitoring	Failures revealed during a continuous condition monitoring of a predefined failure mode	Continuous monitoring
6	**INT**	Production Interference	Failure discovered by production upset, reduction, etc.	
7	**OBC**	Casual Observation	Casual observation during routine or casual operator checks, mainly by senses (noise, smell, smoke, leakage, appearance etc.)	Casual occurrences
8	**COR**	Corrective Maintenance	Failure observed during corrective maintenance	
9	**DEM**	On Demand	Failure discovered during an on-demand attempt to activate an equipment unit (e.g. safety valve fails to close on ESD-signal, fail to start a gas turbine on demand, etc.)	
10	**COM**	Combination	Combination of the above several methods	Other
11	**OTH**	Other	Other observation method	
12	**UNK**	Unkown	Observation method unknown or not specified	

Table 8 - Detection methods categories for a failure

Notes

1. Condition monitoring implies use of specific equipment and/or algorithms to monitor the condition of the equipment with respect to predefined failure modes. Condition monitoring (CM) can be further divided into:
   a. Periodic CM: periodic condition monitoring includes techniques such as thermography, off-line vibration measuring, oil analyses, calibration checks and sampling;
   b. Continuous CM: continuous instrumental surveillance of process parameters and equipment condition, e.g. temperature, pressure, flow, RPM, to detect abnormal operating conditions.

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2.5.4. Failure Patterns Analysis

One of the most important factors that affects the selection of any failure management policy is the relationship between age (or exposure to stress) and failure. There are six sets of ways (Dominant Failure Patterns) in which the conditional probability of failure varies as an item gets older.

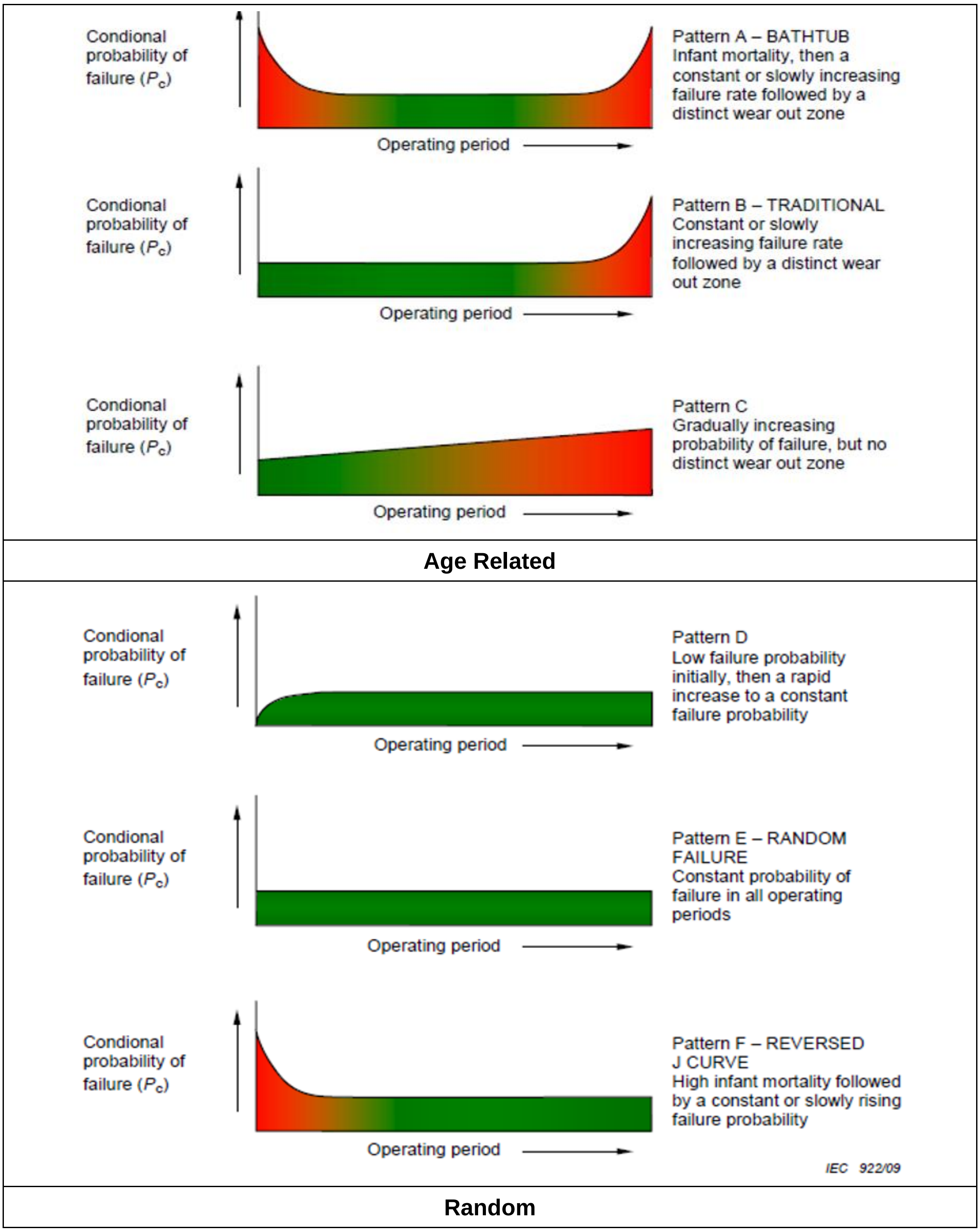

Figure 9 - Dominant Failure Patterns (IEC 922/09)

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The failure management selection process shall consider that the conditional probability of some failure modes will:

- Increase with age (or exposure to stress);
- Not change with age (or exposure to stress);
- Decrease with age (or exposure to stress).

The list below summarizes the Conditional Probability vs Operating Period

- Patterns A (Bathtub Curve) and B (Traditional view) both display a point at which there is a rapid increase in the conditional probability of failure (sometimes called a "wear-out zone").
- Pattern C (Slow Aging) shows a steady increase in the probability of failure, but no distinct wear-out zone.
- Pattern D (Best New) shows low conditional probability of failure when the item is new or just out of the shop, then a rapid increase to a constant or very slowly increasing level.
- Pattern E (Constant Random Failure) shows a constant conditional probability of failure at all ages (random failure).
- Pattern F (Worst New) starts with high infant mortality, dropping to a constant or very slowly decreasing conditional probability of failure.

In general, age-related failure patterns (A, B and C) are commonly associated with direct wear fatigue or corrosion.

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2.5.5. Failure Modes for Floating Wind Offshore

2.5.5.1. Failure Modes for Rotor System components

Identification of FMs is performed at component level.

In this section, they will be indicated the FMs related to Rotor System. The major failure modes of these components are listed below:

Component	Failure Modes
BLADE	BLADES CRACKS DELAMINATION SURFACE WEAR FATIGUE LIGHTINING STRIKES PROTECTION DEVICE FAILURE HIGH VIBRATION UNSTEADY PERFORMANCE
ROTOR	AERODYNAMIC ASYMMETRY
PITCH SYSTEM	HYDRAULIC SYSTEM FAILURE ASYMMETRY IN PITCH ANGLE (WRONG PITCH ANGLE) ABNORMAL VIBRATION PREMATURE ACTIVATION LIMIT SWITCH FAILURE

Table 9 - Common FMs for Rotor system components

FM mode selected for this system can be identified as Age Related FMs due to wear fatigue or corrosion. Electrical component and control component FM can be identified as Random FM.

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2.5.5.2. Failure Modes for Drive Nacelle System components

Identification of FMs is performed at component level.

In this section, they will be indicated FMs related to Drive Nacelle System. The major failure modes of these components are listed below:

Component	Failure Modes
SHAFT	SHAFT WEAR DEFORMATION ABNORMAL VIBRATION
GENERATOR	ROTOR AND STATOR FAILURE BEARING WEAR OVERHEATING LUBRICATION FAILURE STRUCTURAL DEFICIENCY ABNORMAL VIBRATION ABNORMAL SIGNALS ABNORMAL INSTRUMENT READING FAIL TO SYNCHRONIZE FAIL TO START ON DEMANDS WINDING FAILURE SENSOR FAILURE LEAKAGE
GEARBOX	BEARING WEAR ABNORMAL VIBRATION ABNORMAL TEMPERATURE CORROSION WEAR LUBRICATION FAILURE
ELECTRICAL AND CONTROLLER SYSTEM	ELECTRIC COMPONENTS FAILURE CONTROLLER FAILURE SENSORS FAILURE

Table 10 - Common FMs for Drive Nacelle System components

This system is the most critical system due to the presence of Generator and Gearbox components. In addition, many sensor can be installed to monitor components' performances.

Mechanical subcomponent failure modes can be identified as Age Related FMs due to wear or fatigue; corrosion is not expected.

Electrical component and control component FM can be identified as Random FM.

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2.5.5.3. Failure Modes for Yaw System components

Identification of FMs is performed at component level.

In this section, they will be indicated FMs related to Yaw System. The major failure modes of these components are listed below:

Component	Failure Modes
YAW SYSTEM	HYDRAULIC SYSTEM FAILURE ABNORMAL VIBRATION ERRATIC ALIGNMENT YAW CONTROL SYSTEM FAILURE

Table 11 - Common FMs for Yaw system components

Hydraulic System Failure, Abnormal Vibration, Erratic Alignment can be identified as Age Related FMs due to wear or fatigue; corrosion is not expected.

Electrical component and control component FM can be identified as Random FM.

2.5.5.4. Failure Modes for Floater Platform System components

Identification of FMs, is performed at component level.

In this section, they will be indicated FMs related to Floater Platform System components. The major failure modes of these components are listed below:

Component	Failure Modes
TOWER	STRUCTURAL DEFICIENCY BOLT CONNECTION FAILURE ABNORMAL VIBRATION LOSS OF INTEGRITY (LOSS of COATING/CORROSION) FATIGUE (FLANGE BOLT AND WELD AREA)
MECHANICAL SUPPORT, LADDERS..	STRUCTURAL DEFICIENCY CORROSION FATIGUE (FLANGE BOLT AND WELD AREA)
KNEE BRACES; BEAMS, V-BRACES AND K-JOINTS; COLUMNS WATER ENTRAPMENT PLATE (ABOVE/BELOW WATER LEVEL)	STRUCTURAL DEFICIENCY LOSS OF INTEGRITY (LOSS of COATING/CORROSION) FATIGUE (FLANGE BOLT AND WELD AREA) CATHODIC PROTECTION FAILURE

Table 12 - FMs for Floater Platform System components.

FM mode selected for this system can be identified as Age Related FMs due to wear fatigue or corrosion.

Electrical component and control component are not included in this system.

2.5.5.5. Failure Modes for Mooring & Anchor system components

Identification of FMs is performed at component level.

In this section, they will be indicated FMs related to Mooring & Anchor system components. The major failure modes of these components are listed below:

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Component	Failure Modes
MOORING LINES	ABNORMAL VIBRATION MOORING LINES BREAKDOWN (WEAR/ FATIGUE/ CORROSION)
ANCHORS	ANCHOR FAILURE

Table 13 - FMs for Mooring & Anchoring system components

Anchor Failure can be identified as Age Related FMs due to wear, erosion.

Abnormal Vibration, Breakdown are generated in a complex dynamic system, they can be identified mainly as Random Failure due to collision or unexpected events; wear/ fatigue/ corrosion can be also considered.

2.5.5.6. Failure Modes for Cable system components

Identification of FMs is performed at component level.

In this section, they will be indicated FMs related to Cable system components. The major failure modes of these components are listed below:

Component	Failure Modes
ARRAY CABLES	ABNORMAL VIBRATION CABLE INSULATION FAILURE BREAKDOWN
EXPORT CABLE	ABNORMAL VIBRATION CABLE INSULATION FAILURE BREAKDOWN
CABLE PROTECTION DEVICE	CABLE PROTECTION DEVICE FAILURE

Table 14 - FMs for Cable system components

Deterioration and Cable Insulation Failure can be identified as Age Related FMs due to wear, erosion.

Abnormal Vibration, Breakdown, Cable Protection Device Failure are generated in a complex dynamic system, they can be identified mainly as Random Failure due to collision or unexpected events.

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2.6.Failure Management Policies

There are several options available for the failure management policies, namely:

- Condition Monitoring
- Scheduled Restoration & Scheduled Replacement
- Failure-Finding
- Run to Failure
- Combination of Tasks

2.6.1. Condition Monitoring (or On-Condition Task)

Condition Monitoring (or On-Condition Task) tasks are designed to detect degradation as functional failure is approached. They are continuous or periodic tasks to evaluate the condition of an item in operation against pre-set parameters to monitor its deterioration. It may consist of inspection tasks, which are an examination of an item against a specific standard.

Most failure modes do not occur instantaneously. In such cases, it is often possible to detect that the items concerned are in the final stages of deterioration before they reach the failed state.

This evidence of imminent failure is known as a **potential failure**, which is defined as an identifiable condition that indicates a functional failure is either about to occur or is in the process of occurring. If this condition can be detected, it may be possible to prevent the item from failing completely and/or avoid the consequences of the failure mode.

The potential failure exhibits a condition or several conditions that give warning of the failure mode under consideration. Such conditions may include noise, vibration, temperature changes, lubricating oil consumption or degradation of performance.

What happens in the final stages of the failure process is resumed by the P-F curve. This shows how a failure starts, deteriorates to the point at which it can be detected (P) and then, if it is not detected and corrected, continues to deteriorate, usually at an accelerating rate, until it reaches the point of functional failure (F).
To evaluate the interval for a condition monitoring task it is necessary to determine the time between potential and functional failure.
Knowledge of the initial condition and the deterioration rate is helpful in predicting when the potential failure and functional failure are likely to occur. This will assist in determining when the initial condition monitoring task should start.

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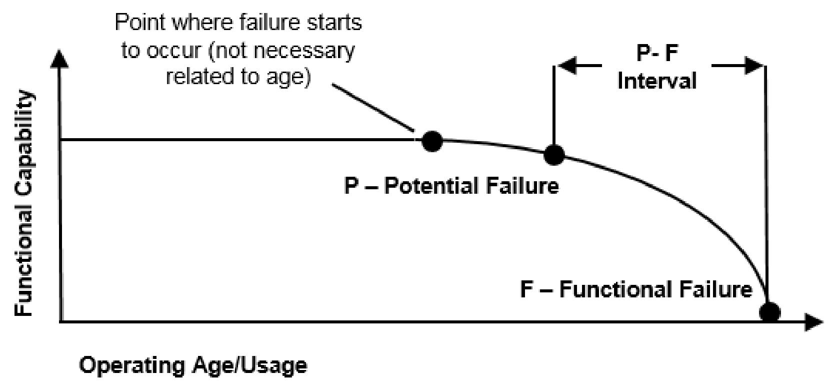

P-F Curve

Figure 10 - Potential failure curve

If a potential failure is detected between point P and point F, this is the point at which it may be possible to act to prevent the functional failure and/or to avoid its consequences: whether it is possible to take meaningful action depends on how quickly the functional failure occurs, as discussed later. Knowledge of the initial condition and the deterioration rate is helpful in predicting when the potential failure and functional failure are likely to occur.

The P-F interval (also known as the warning period) governs how often on-condition tasks must be done. To detect the potential failure before it becomes a functional failure, the interval between checks must be less than the P-F interval.

On-Condition tasks are applicable on both random failures and age-related failures because they are preceded by warning period.

Anyway, in case of random failures On-Condition tasks must begin as soon as the item is put into service.

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2.6.2. Scheduled Restoration & Scheduled Replacement

Scheduled restoration entails taking periodic action to restore the capability of an item at or before a specified interval (age limit), regardless of its condition at the time, to a level that provides a tolerable probability of survival to the end of another specified interval (which need not be the same as the initial interval).
It is the work necessary to return the item to a specific standard. Since restoration may vary from cleaning to the replacement of multiple parts, the scope of each assigned restoration task must be specified: it usually entails either servicing & lubrication, remanufacturing a single component or overhauling an entire assembly.

Servicing and Lubrication (S&L) are tasks which tend to focus on checking oil levels, changing complete oil inventories (small reservoirs), checking the operation of central lubrication systems, greasing and carrying out activities that exercise equipment but do not require it to be removed from service or taken off-line.

Scheduled replacement means discarding an item or component at or before a specified age limit, regardless of its condition at the time. This is done with the principle that replacing an old component with a new one will restore the original resistance to failure: it consists in the removal of an item, with a specific working life limit, by replacing with a new one, that meets all the required performance standards. Scheduled replacement tasks are normally applied to so-called “single-cell parts” such as cartridges, safe-life structural members, etc.

In case of age-related failure modes, it is possible to identify the age at which wear-out begins or when the wear-out is not more tolerable. The scheduled restoration or scheduled discard task must be done in advance than this age.
In other words, the frequency of a scheduled restoration or scheduled discard task is governed by the age at which the item or component shows a rapid increase in the conditional probability of failure.

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2.6.3. Failure-Finding Tasks

Failure-finding tasks are useful to determine whether an item is able to fulfill its intended function: they are only applicable to hidden failures and only if an explicit task can be identified to detect the functional failure.
A failure-finding task can either be an inspection, function test or a partial function test to determine whether an item would still perform its required function if demanded. Failure-finding is relevant where functions are normally not required, for example in the case of redundancy or safety functions that are only seldom activated.

2.6.4. Run to Failure or No Preventive Maintenance

In case of evident / hidden (single or multiple) failures that do not affect health, safety and environment, the most cost-effective failure management policy might simply be to allow the failures to occur and then take appropriate steps to repair them. In other words, “run to failure” is only valid if:

- A suitable scheduled task cannot be found for a hidden failure, and the associated multiple failure does not have safety or environmental consequences,
- A cost-effective proactive task cannot be found for failures with operational or non-operational consequences.

2.6.5. Combination of Tasks

If a failure mode or a multiple failure could affect safety or the environment and no scheduled task can be found that on its own reduces the risk of failure to a tolerably low level, it is sometimes possible that a combination of tasks (usually from two different task categories, such as an on-condition task and a scheduled task), might reduce the risk of the failure mode to the tolerable level.

When considering such combinations, care must be taken to ensure that each task on its own will satisfy the technical feasibility criteria appropriate to that kind of task, and that each task is carried out at the frequency appropriate for that task.
Care must also be taken to ensure that the two tasks combined will in fact reduce the consequences to a tolerable level.

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2.7. Periodic Inspection

The following Table summarizes the main components subjected to planned periodic inspections.

The indicated intervals are recommendations from deliverable developed during Atlantis project: *"D1.1 - Showcase assessments and technical requirements for IMR robotics"*.

Component	Concerns	Maintenance Task	Interval
Blades	Blades Defect	Visual Inspection	3Y (1)
Tower	Weld defects Bolts on flanges connection Surface treatment defects	Visual Inspection	Same of blades
Drive Train Inspection	Structural integrity, coating, corrosion, leakage, vibration diagnostics, oil level, function control, noise, etc.	Visual Inspection Functional Verification	1Y
Condition control	Structural integrity, grease and oil condition, function of pitch, etc.	Visual Inspection Functional Verification	2Y
Floater	Structural integrity (above/below) Weld defects (above/below) Bolts on flanges connection Surface treatment defects (above) Excessive marine growth on subsea structures (below)	Visual Inspection Cleaning (if necessary)	1Y (2)
Mooring Line	fatigue cracks of load bearing elements and abrasion damage	Structural Integrity Cleaning (if necessary)	1Y (2)
Dynamic Cables	Abrasion damage Failure of accessories Stresses, wear, and fatigue Excessive marine growth	Structural Integrity Cleaning (if necessary)	1Y (2)

Table 15 - Intervals recommended for planned periodic inspections

(1) manufacturers perform inspections with drones annually
(2) Interval can be extended to 5Y

Detailed check lists are developed in Attachment 1-2.

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2.8. Logistics

Wind turbines and offshore substations are accessed by technicians through a wide range of conceivable equipment and techniques (J. Philips, 2013).

The main factors that influence the suitability of the offshore logistics solution are:

- Weather and sea-state
- Safety Requirements
- Regulatory Requirements
- Cost (of retaining and using a service)
    - Personnel carrying capacity
    - Equipment payload
- Response time (a function of speed)

The optimal strategy for the operation and maintenance of an offshore wind project is determined by various factors such as:

- Weather and sea-state
- Distance from onshore facilities
- Number, size, and reliability of turbines
- Offshore substation design

The distance between the turbines and onshore facilities is a main driving factor in the cost of Operation and Maintenance of offshore wind, next to number and reliability of wind turbines and thus it becomes a primary consideration in the estimation of the most cost-effective approach to O&M.

Since better wind conditions are observed at higher distances, a shift from strategies optimized for near-shore sites to strategies optimized for distant offshore wind sites is imminent.

The different means to access offshore turbines are tried, tested and well understood workboats and less well-established helicopter services with each having its own pros and cons. Workboats on one hand are relatively inexpensive, and have a large carrying capacity, but response times are slow, and operation depends on sea conditions. Helicopters on the other hand have very short response time and sea conditions doesn't affect its operations (although poor visibility can impact accessibility) but are expensive and have lower passenger capacity. The safety and regulatory aspects of both approaches are yet to be fully explored for O&G applications.

2.8.1. Planning

Lately, an increasing interest gained in issues related to mission planning in relation to climate conditions: the main goal is to maximize the operational window and safety during offshore operations. Recent tools combine wave measurements, weather forecasts, and navigation data like speed, course, RPM and the voyage plan, with ship characteristics, loading conditions, and motion sensor measurements.

This facilitates continuous monitoring as well as simulation and forecasting of the ship responses and performance. Warnings can be generated for possible hazards and their consequences.

One of these OCTOPUS is developed by ABB during ATLANTIS project to improve the planning of O&M operations for a safer and more efficient robotic-based operations and increasing the operational availability of the support vessels.

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2.9.HSE

One of the vital aspects in offshore wind farm operations is the Health, Safety and Environment (HSE). A careful management of the following challenges is necessary to mitigate the unique challenges offshore wind industry faces:

- Harsh weather conditions
- Long distances from shore
- Complex machinery

As demands for clean energy is ever growing, so does the offshore wind industry and thus role of HSE in its operations become increasingly crucial. In addition, providing a high level of safety and sustainability which is needed for the right operations of an offshore wind farm, HSE activities also play a critical role in:

- Developing and implementing safety procedures and protocols
- Training workers and promoting a culture of safety
- Monitoring and evaluating offshore wind farm operations
- Emergency response planning and execution

Regular training sessions are conducted to equip workers with latest technologies, thus maintaining a strict safety standard and reducing risk of accidents. Careful monitoring of offshore wind operations and its monitoring are other crucial roles.

To identify potential risks, recommend corrective actions and ensure compliance with health, safety and environmental standards, regular inspections and audits are carried out.

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3. ROBOTICS FOR O&M OF FOWF

Significant research is currently being conducted in the development of efficient and optimal floating wind turbines. To decrease the costs associated with installation, O & M and decommissioning operations, many innovative designs, procedures, and technologies along with established best practices are required.

Some aspects can be adopted from the O & G industry, however, the unique nature of FOWTs requires dedicated research and development.

A significant increase in the adoption of robotics in the oil and gas sector has been witnessed in recent years. This has been motivated by the advanced automation capabilities provided by the modern robots along with a reduction in the number of manhours needed in the rigs.

Robotic systems offer various opportunities to significantly change the nature of the offshore operations, ranging from efficiently execution of repetitive tasks to attaining continuous and high-resolution data. Furthermore, the potential financial advantages and H&S-related benefits for the personnel onboard at offshore installations necessitate the need to minimize the manual human intervention.

In recent years, the concept of remote inspection in industrial processes has also been gaining traction, whereby unmanned aerial vehicles (UAVs) and remotely operated vehicles (ROVs) are being utilized to access the machines and sites that are otherwise difficult or dangerous for humans to operate in. Prototype systems have been developed and tested for fault detection in pipelines, subsea survey, and repairs, and more recently for wind turbine inspections.

Applicability of robotic solution shall be based on certain requirements to successfully complete their mission given the FOWF-related site constraints. These requirements are as follows:

- **Mobility:** Mobility pertains to the motion of the robot in unstructured environments under difficult operating conditions and at speeds that allow for efficient acquisition of inspection data. For instance, the thruster technology of a subsea robot should be reliable and controllable where it should be able to do the required task in an efficient manner while also minimizing the possibility of a crash into the asset. For subsea robots, the propulsive efficiency remains a challenge. Simultaneously, the operational range of subsea robots also needs to increase to be useful for longer duration underwater monitoring activities. The design optimization on these two fronts has improved in recent years. Moreover the weather limitation can be evaluated (wind speed, significant wave heights, visibility, mean currents).
- **Sensing capabilities**: Another important requirement is the sensing capability of the robot. The sensors not only aid in navigation and control of the robot itself but also determine its operational capability in terms of conducting the remote or in-situ inspection of the asset, attaining feature-rich information, and performing non-destructive testing (NDT). Here, it is also important to assess the functionality of the sensors with respect to their operation in dynamic wind and wave conditions such as during foggy weather and in turbid sea water.
- **Size and weight:** An important aspect of the offshore robots is their cumulative size and weight. The size of the robot should be large enough to accommodate the resident sensors and actuators/manipulators. Although keeping the robot small and light is desirable, it is also crucial to maximize the payload for various diagnostic instruments while maintaining ample power storage. This has ramifications in terms of power requirements and operational endurance of the mission. Hence, the cumulative weight of the robotic structure and its payload should be within the specified bounds where a trade-off has to be made between the operational requirements of

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the robot and weight bearing capacity of the entire system. Furthermore, country-specific regulatory considerations exist for the particular sizes and weights of unmanned aerial systems.

- **Level of autonomy:** The level of autonomy of the robot describes the automation capability of the robot. The objective for an autonomous operation is to achieve the missions as assigned by its human operator(s) through the designated human-robot interaction mechanism. While the state of the art includes remote operation of UAVs and tethered control of subsea robots under human supervision, the focus has increasing been moving towards highly autonomous robotic systems. These robots are capable to carry out asset inspection for extended duration of time and without active human intervention. Such systems need to acquire data, store it on their onboard computer, and send it to the onshore control system. Moreover, it is likely that the autonomy will be tuned for different scenarios. For example, transit out to the windfarm could be heavily automated but an inspection task may require more approval or input from a remote operator.

3.1. Climbing robots

In general, human operators with rope-access to the wind turbine conduct O&M tasks such as cleaning blades and inspecting structural defects in windy, high, and harsh environments. It is envisaged that a climbing robotic mechanism could replace some of these O&M tasks, improving efficiency in the process while also addressing the H&S aspects. In literature, different types of climbing robots are discussed based upon their design specification and functional requirements.

The definition of climbing robots is restricted to be the machines that can move vertically or around the tower and blades of a wind turbine. The robot's access to the entire circumference of the tower and to the surface of the blade is imperative as it would determine the range of the O&M tasks that could be conducted. Based on their locomotion ability, climbing robots can be classified into the following two types:

- Legged locomotion: The key benefit of legged climbing robots is that they are highly adaptable to the surface structure, can clear obstacles and steps, and they can move from ground to wall with ease. In literature, various robots can be found with different number of legs and for different degrees of freedom. However, in terms of a smooth gait control, many degrees of freedom contribute to a complicated mechanical structure and the associated control system. Consequently, the weight and torques are also increased.
- Wheeled or chain-driven locomotion: In case of a relatively smooth surface, climbing robots based on wheels and chains are used. The quick and continuous movement, as well as a simpler mechanical structure and control design, are significant advantages of wheeled or chain-driven robots. However, since these robots are unable to manage large steps or obstacles, they are less adaptable to varying surface characteristics and are limited to specific use-cases.

Significant research is currently being conducted to explore the possibility to blade cleaning and conduct NDT for tower and blades.

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3.2. Unmanned aerial vehicles

While relatively fewer studies have focused on climbing robots for O&M, aerial robots are gaining increased interest for conducting inspection and other remote sensing applications ranging from surveillance and infrastructure inspection to data acquisition, and aerial mapping.

The automated inspection of energy assets based on UAVs have gained significant attention in recent years. For instance, dust on solar panels in a large-scale solar farm can affect the power generation. In this case, UAVs can be utilized to monitor the condition of the solar panels.

Another use of UAVs in power systems that has been studied is automatic meter reading along with the inspection of damage to the transmission lines.
In the case of FOWFs, a mature commercial offering is available where UAVs fitted with data acquisition technology are used to scan the surface of the turbine tower and blades. Advancements in UAV technology have led to increased automation of the task, reducing the onus on the pilot to manually manoeuvre the UAV. The data are then recorded and wirelessly transmitted back to the onshore control station. Post-processing is done to acquire imaging details, acoustic emissions, and the sensor measurements.

Main benefits of using UAVs to inspect FOWF assets include:

- a more frequent and spatially larger access to the wind farm in a shorter interval of time,
- the possibility to mount a variety of imaging and acoustic sensors onto the UAV for feature-rich data acquisition,
- the improvement in H&S aspects regarding manned access to the FOWFs.

Nevertheless, certain aspects of the UAV motion need to be considered such as the range and endurance of the aircraft along with spatially covering the maximum area within a shorter interval of time. In case of a fixed-wing aircraft, the minimum turning radius restriction needs to be accounted for when considering flight paths with many curvatures. While most UAVs can adapt to variable weather environments, the offshore conditions such as strong winds need to be considered before the flight of the UAV.

The factors affecting a UAV's payload limitation primarily include its design weight, onboard power storage unit, and the type of sensing equipment. The heavier the sensing equipment will be, the more thrust would be needed by the UAV, and hence, the power requirements would increase.

Moreover, UAVs must maintain communication with the operators and in some cases, with the control station. A swarm of UAVs with BVLOS capability has the benefit in terms of an efficient control and larger swept area. Furthermore, the acquired data need to be stored onboard and then transmitted to the control station. Here, sufficient data storage and transmission bandwidth need to be considered. Other connectivity challenges such as obstacle avoidance, GPS denial, and signal fading also need to be considered. Recent research has benefitted from the advancements in machine learning algorithms for autonomous navigation and guidance of UAVs. This is complemented using imagery sensors such as LIDAR to acquire feature-rich data and send it to the onshore computers.

UAVs can be used to detect the cracks on wind turbine blades based on image data acquisition. It is pertinent to mention that the environmental conditions such as foggy and rainy weather can cause problems in the imaging, resulting in reduced usability and a limited detection of faults.

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3.3.Subsea robots

Recent advancements in subsea survey and inspection technology have allowed more detailed studies of the oceans and underwater structures.
Marine scientists and companies also have access to a wide range of underwater technologies, which are increasingly being used for a variety of purposes. However, owing to the increased offshore developments with varied scientific requirements, deep sea research remains expensive in terms of logistics and personnel requirements. Subsea technology is routinely used by the offshore oil and gas, and renewable energy industries for inspection, monitoring, and maintenance of assets in areas that are otherwise inaccessible to the marine personnel.

In recent years, ROVs are increasingly being used at windfarms for conducting O&M activities along with de-risking offshore operations. The industry is developing new technologies for both underwater and topside applications to minimize the O&M costs and manpower requirements while also improving the safety and reliability aspects.

For the case of a FOWF, two primary applications for ROVs pertaining to O&M are cited:

- export/array cable surveys and repairs
- structural Inspection

While the uptake of ROVs for inspection and monitoring has seen progress in recent times, significant challenges impede their full-scale exploitation in offshore sites. ROVs have very limited autonomy and must be tethered to the surface to receive power and be controlled from a technician. Higher operating costs for battery power and acquisition of trained technicians are stumbling blocks.

On the other hand, autonomous underwater vehicles (AUVs), self-propelled underwater robotic systems powered and piloted by an on-board power source and computer, provide benefits in terms of higher mission capabilities, such as autonomous mapping and inspection of subsea structures.
The drawbacks include limited operational range and increased on-board power requirements in case of longer duration missions. Both types of these subsea robots have attracted research and development efforts.
ROVs are classified into different types based upon their operational capabilities, as shown in Table 16.

Class	Description	O&M activity
I	Observation ROVs	Visual survey
II	Observation ROVs with payload option	Visual survey and light intervention
III	Work-class vehicles	Heavier payload with manipulators
IV	Towed and tracked vehicles	Cable burial, marine grow removal
V	AUVs	Autonomous inspection, spatial mapping

Table 16 - Classification of ROVs

Classes I and II constitute observation vehicles with the ability to mount various sensors such as SONAR, high-definition camera, and lights.
Class III is work-class vehicles with the ability to mount small manipulators in addition to more advanced sensors.
Class IV vehicles are pulled through the water by a surface craft. These are heavier vehicles and are normally designed to carry out a specific underwater task such as burial of cables.

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Class V includes AUVs that are untethered, have higher autonomy and manoeuvrability, and can carry out mapping tasks for a longer duration of time.

Aspects related to portability need to be considered as the deployment and recovery of sophisticated ROVs can be manually challenging and expensive. In terms of ROVs for FOWF, it is pertinent to mention that a vast majority of these systems would be deployed in shallow water along with experiencing rough wave and tidal conditions as opposed to deeper waters where the disturbances are minimal.

3.4.Autonomous surface vessels

Autonomous surface vessels (ASVs), also known as unmanned surface vessels (USVs), have been the focus of significant research in recent years. While the use of CTVs and SOVs bring flexibility in terms of payload and personnel capacity, their dependence on weather windows and higher leasing costs makes their use for longer duration of time less than optimal. With the anticipated construction of wind farms farther from the coast, a considerable reduction in O&M vessel costs could be possible by eliminating the need for large inspection vessels.

While the use of ASVs in defence and security domain has seen significant development, their usage in offshore wind energy operations is still nascent. The use of ASVs has benefits in terms of conducting marine O&M for extended duration of time and without the need for enhanced crew deployment.

ASVs typically utilize catamaran hulls for higher stability and have a modular design, whereby different types of payloads can be mounted based on the specific mission requirements. It is important to consider the varying degrees of autonomy for the ASVs and their effects on the O&M activities and task allocation.

ASVs have demonstrated their ability to conduct mapping and obtain accurate models of the terrain above and below the sea level. This is done by combining laser scanning data with bathymetric data and then geo-referencing both data sets. In this way, a 3D model synchronized with temporal and spatial characteristics information is generated. Furthermore, ASVs have high manoeuvrability, can mount sensors of different types and weight, and they have higher communication bandwidth which are pivotal in conducting large-scale bathymetry and surveying. Finally, removing the human operator from the offshore vessels allows to enhance human safety on the command-and-control operational framework in the offshore environment. ASVs also pose significant challenges in terms of their use in the wind industry owing to larger distances to the FOWFs and limited weather window availability.

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3.5. Application of robotics for key FOWF-specific O&M activities

A categorization of robotics-based O&M is shown in Table 17. The feasibility for a selection of O&M activities is highlighted in terms of low, medium, and high.

Low feasibility refers to systems being in nascent stages of development, while the medium feasibility refers to systems that have been validated in scenarios representative of the actual FOWFs. High feasibility pertains to systems already in use with the future potential of upscaling the technology along with enhancing their usability in the FOWF domain. It is observed that the UAV- and ROV-based systems are more commercially developed and can conduct a range of tasks while the use of ASVs is relatively nascent and subject to extensive regulatory requirements.

O&M activity	Robotic system	Type of data acquired Typical payload	Feasibility
Blade Inspection	UAV	Photogrammetry, video Assessment and thermographic camera	High - UAVs widely used in industrial applications, high TRL
	Climbing Robots	Ultrasonic imaging, NDT	Low - mounting and control remains challenging, low TRL for wide-scale adoption
Tower inspection	Climbing Robots	Photogrammetry, Ultrasonic sensors	Medium - benefits in terms of fatigue testing, grout and structural health monitoring
	UAVs	Visual and thermal Imaging	Medium - 3D scanning of the tower cross-section
Nacelle O&M	Resident Robots	Grippers, visual imaging	Low - resident systems inside the nacelle can perform minor inspections Medium - UAVs can do external surveys, deploy small payload to assist personnel
Bathymetry mapping	ROV	Sonar	High - widely used in marine operations
	ASV	SONAR, GPS/IMU for Autonomous Navigation	Low - challenging in terms of large-scale command and navigation of ASVs
Inspection of array/ export cables	ROV, AUV	Camera, grippers	High - increased usage of ROVs for fault detection and fatigue inspection in sub-components
Burial of export cables	ROV	Camera, grippers	High - burial of cables is done using work-class ROVs, inspection of defects and fatigue in sub-components
Marine growth on subsea structures	ROV	SONAR, video Assessment	High - widely used in marine operations
Metocean survey	ROV	Camera, lights	Medium - widely used in marine operations, marine regulations need to be taken into account
Transport of components	ASV	Data link, battery-powered	Low - deployment of higher autonomy level ASVs are subject to marine regulations and zone approvals, advanced navigation requirements for fleet control and coordination

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Offshore operations center	ASV	Data Link, Battery-Powered	Low - autonomous mother vessels can deploy UAVs and ROVs, limited applications due to navigation and data communication requirements

Table 17 – Application of robotics for key FOWF-specific O&M activities

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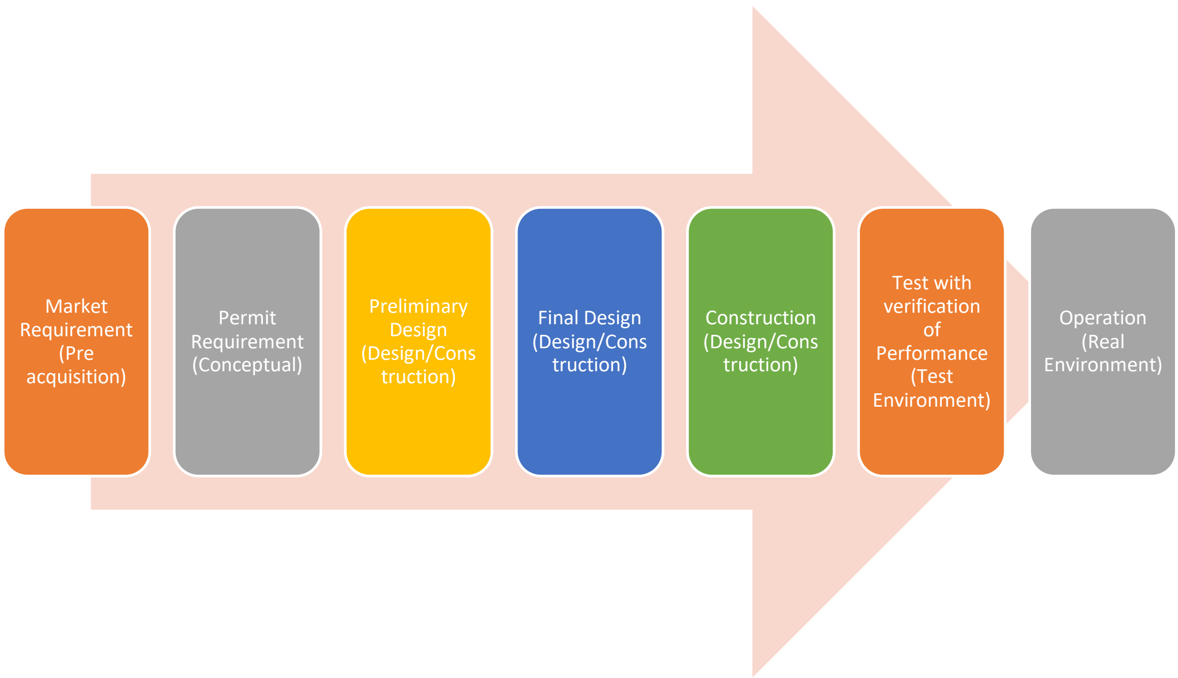
4. Technology Assessment

4.1. Introduction

Technology development can be defined in many ways. It can be the development and demonstration of new or unproven technologies, expanding existing technologies to new users, or can also be the combination of existing technologies to achieve a specific goal. An early recognition of technology development in the project life cycle is essential so that it allows the project to establish a credible technical scope, schedule, and cost baseline.

A review of how technology development activities can be brought to an appropriate level of maturity is shown in the chart below:



A roadmap is usually created to assist the technology development pathway for its successful implementation. Identification of needs and requirements of a system or components and its associated risks is the first step of a technology development program. This serves as the input to the design phase.

The second step involves selecting equipment which meets or most closely meets the functional requirements. To achieve this, existing equipment are utilized to their full potential, but in cases where the environment is hazardous, adaptation of commercial technologies is needed.

Initial assumptions relative to system and process performance are verified through small scale and proof-of-concept testing. After comparisons with initial input parameters and review, refinements are applied if necessary to be in line with project requirements. Technology development program plans are modified consistent with the test results.

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Performance verification is implemented in the design and construction phases. After the selection of a product or equipment to perform a specific task, its verification against the design requirements is done to ensure its complete capability in the operating environment.

Performance of the process or equipment on both the component level and from an integrated system perspective is ensured by Verification. The different levels may include checking that operation parameters are within the operating envelope of supporting systems (eg: power, feed, rate etc.) and meeting the physical expectations of the equipment, examining properties of material produced against set standards.

Once the verification activities are carried out, a full-scale testing is done to assess the durability and reliability of the process and/or equipment. To demonstrate process conditions over extended periods, integrated runs which involve combining components, systems or processes are performed. This testing opens the doors for further process optimization, if necessary and is a testament to the reliability of equipment in long-term remote operations and production of quality end products within the safety limits.

Technology development comes along with the risk related to first-of-kind applications.

4.2. Technology Readiness Assessment

“A TRA is a systematic, metric-based process and accompanying report that assesses the maturity of certain technologies used in systems” (NasaGov). The TRA is an assessment of how far technology development has proceeded based upon documented evidence. It is more of a review process than a pass/fail test which is to ensure that critical technologies reflected in the project design have been developed to work as intended before initiating construction expenses. TRAs are conducted by technically qualified personnel who are independent of the project. A TRA can:

- Identify the gaps in testing & demonstration
- Identify immature or unproven technologies that might result in increased project risk
- Provide the information about future steps needed to reach the readiness level required

Process can be described by the following steps:

- Identifying the Technology components/assembly (novelty or applied in different environment).
- Assessing the Technology Readiness Level (TRL). TRL indicates the maturity level of a given technology, as defined in Table. The TRL scale ranges from 1 (basic principle observed) through 9 (total system used successfully in project operations). TRL is not an indication of the quality of technology implementation in the design. Testing should be done in the proper environment and the technology tested should be of an appropriate scale and fidelity.
- Developing a Plan (TMP), if the TRL level does not meet the expectation.

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Technology Readiness Level Definitions

TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported.	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experi-mental results validating predictions of key parameters.
4	Component and/or breadboard validation in laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component and/or breadboard validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.
6	System/sub-system model or prototype demonstration in an operational environment.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.
7	System prototype demonstration in an operational environment.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test performance demonstrating agreement with analytical predictions.
8	Actual system completed and "flight qualified" through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	Documented test performance verifying analytical predictions.
9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results.

Table 18 - Technology Readiness Level Definitions [6]

4.3.Role of Coastal Test Centre

Even though there have been significant improvements in new and existing robotic technologies, their testing and validation are not catching up at the same pace. Due to a lack of testing and demonstration in a realistic environment, there is a lack of trust among end-users and asset owners which hinders the mass uptake in current IMR practices. Lack of testing is due to mainly three reasons:

(1) Lack of safe testing environments which emulate realistic conditions.
(2) Reluctancy from end-users to provide access to real environments comes with a risk of damage to existing assets (eg: offshore scenarios where conditions are adverse compared to onshore scenarios).
(3) Lack of a recognized and transversal metric that quantifies the benefits of robotic technologies as well as their operational safety. This can demand a large amount of resources from end-users thus reducing the motivation.

The ATLANTIS Test Centre is developed with ambitions to promote the uptake of robotic technology for the O&M of the offshore wind sector and to facilitate developments in the field of maritime robotics. This

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pilot infrastructure can demonstrate key enabling robotic technologies for inspection and maintenance of offshore wind farms.

Other than bridging the gap between laboratory tests and real offshore environments, new technology testing which will lead to increased impact of the validation of robotic technologies and promoting the adoption of these technologies by the OW sector are the main purposes of the Test Centre.

To achieve this objective, the testing, validation, and demonstration activities taking place in the Test Centre are expected to:

- Contribute to the increased end-user trust in robotic technology
- Motivate changes in the existing legal and regulatory framework that constrict the use of these technologies
- Incentivize robotic developments

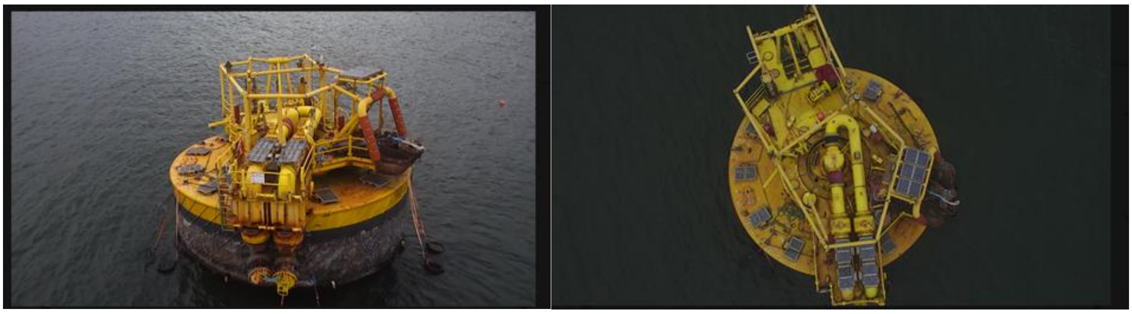

Figure 11 - ATLANTIS Test Centre

The Coastal testbed of the ATLANTIS Test Centre (Fig 11) is equipped with a floating structure that simulates an offshore floating structure of an offshore floating wind turbine. The floating structure installed is a decommissioned Catenary Anchor Leg Mooring (CALM) buoy, that provided support to the loading and discharging of liquid product cargo to/from tankers, near onshore or production fields.

Figure 12 - View of the ATLANTIS Coastal Test Bed

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4.4 Technology Qualification

4.4.1 Certification and trust in robotic technologies

Access to Test platforms is not always easily accessible. Several factors must be considered such as the representativeness of the platform with respect to the features to be tested, the time window respect the technology development plan, and not least the costs.

Further factors like the lack of standard metrics to evaluate the functionalities shall be considered. In some cases, the validation obtained through the involvement of Certification Companies may represent an alternative.

4.4.2 Purpose

According to what have been already developed and experienced by RINA, the usual path for the validation of a new technology is taken into consideration (Qual.). Novel technology is generally not adequately covered by established codes and procedures. Novel technology may therefore be required to be qualified through an approach herein denominated Technology Qualification (TQ). TQ is the process of verification that the novel technology meets the specified requirements for its intended service, through a systematic and documented process of qualification that will include examination of the design, engineering analyses and testing programs.

Engineering systems may comprise known and novel technology. The TQ process is aimed at identifying the novel elements and novel application of known technology, on which to focus the qualification program.

TQ is to be based on specified safety, availability and reliability criteria, boundary conditions and interface requirements defined in the TQ basis.
TQ should be consistent with the following general philosophy:

- The TQ process is to be based on a systematic approach.
- A risk assessment is to be conducted to identify, rank and control failure modes affecting the fitness for service of the novel technology.
- Engineering analyses can be used to demonstrate that the design fulfils the specified requirements for its intended service.
- Measurements and tests are to be used to document that the novel technology fulfils the specified requirements for its intended service.

Alternative methods to demonstrate the fitness for service may be used if they are supported by proper justification. An example is the case when the novel technology is constituted by, or includes, software.

The result of TQ is an official statement, supported by appropriate documentation, of fitness for service consistent with the TQ basis. The statement may be in the form of a certificate, class notation or other equivalent document which is issued following the evaluation of the supporting evidence (drawings, technical reports, applicable rules and standards etc.), the survey for construction, installation and commissioning. The statement will confirm that the novel technology meets the specified requirements for its intended service.

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4.4.3 Qualification Process

The qualification of novel technology is a systematic process consisting of various steps:

- Definition of Qualification Basis
- Technology Assessment
- Selection of Qualification Methods
- Data collection (analysis and testing)
- Functionality assessment.

4.4.3.1 Qualification Basis

The purpose of the qualification basis is, in the possible absence of fully relevant codes and procedures, to define the objectives of the novel technology, the fulfilment of which is to be proved through the TQ process.

The qualification basis will be used as the input for the TQ process, through the establishment of criteria to be shared by the stakeholders (i.e. at least the Contractor and the Owner) and the third party. It should include at least the following key items:

- Description of the technology to be qualified with the system boundaries defining the scope of the TQ
- Operational conditions and limitations
- Functional requirements
- Safety, reliability, availability and maintainability criteria
- Codes and standards.

They will be used as the basis for establishing the design, manufacturing and installation specifications, the test and maintenance policy throughout the lifecycle.

4.4.3.2 Technology Assessment

The purpose of the Technology Assessment is to divide the technology into manageable elements in order to assess those elements that involve aspects of novel technology and identify the key challenges and uncertainties. The Technology Assessment should include the following issues:

- division of the technology into manageable elements (i.e. subsystems and components, processes or operations, manufacturing, installation etc.)
- assessment of the technology elements with respect to novelty (see Table 1)
- identification of the main challenges and uncertainties related to the novel technology aspects.

The level of detail in the subdivision of the technology should be appropriate to focus on the novel or uncertain aspects that subsequently will be subjected to risk assessment.

Technology is to be classified according to its degree of novelty:

Application Area	Technology		
	Proven	Limited field history	New or unproven
Known	1	2	3
New	2	3	4

Table 19 - Technology elements with respect of novelty

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This classification implies the following:

1) No new technical uncertainties
2) New technical uncertainties
3) New technical challenges
4) Demanding new technical challenges.

This classification applies to the totality of the applied technology as well as each separate part, function and subsystem forming it. It is used to highlight the points of concern due to limited field history.
Technology in Class 1 is proven technology where proven methods for qualification, tests, calculations and analysis can be used. Technology defined as Class 2 to 4 is defined as novel technology, and for this reason it is likely that no recognized standard for the design exists or is fully applicable; thus, such technology is to be qualified according to the procedure described in the following section. The distinction between 2, 3 and 4 makes it possible to focus on the area of concern.

4.4.3.3 Qualification Methods

The objective of this step is to select methods that adequately address the key issues of the technology subject to qualification. Such methods will likely consist of a proper combination of engineering analyses and test programs, aimed at increasing confidence in the novel technology and reducing the uncertainties. The selected qualification methods will become mandatory for the TQ process.
A prominent aspect of the engineering analyses is the risk assessment process, which is mandatory in the framework of the TQ process.

4.4.3.4 Risk Assessment Process

A risk assessment of the novel technology is to be conducted according to the techniques dealt with in the applicable standards. 'Risk' in this context is related to the events that may affect the fitness for service of the novel technology, with the proper attention to the interfaces with the proven technology.

In general, the study will be aimed at the following objectives:

- evaluation of the design and operational procedures
- assessment of the safety and operability of the novel technology
- determination of regulatory compliance (certification, classification).

The study is to be endorsed by the various stakeholders in the project and approved by the third party.
It is recommended that the study should be subdivided into the following main tasks:

- Hazard identification
- Risk assessment against the defined acceptance criteria and interfaces
- Definition of risk control options
- Documentation of the study.

These tasks are detailed in the following.
1) Hazard identification: this task aims at identifying and screening hazards with the potential to threaten the safety of personnel, the integrity of the system, the environment and the efficiency of the service provided. The hazard identification is to include all normal and emergency operations. A typical, but not necessarily exhaustive, list of hazards includes:

  - Extreme weather

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- Collision
- Dropped objects
- Extreme temperatures
- Fire/explosion
- Release of flammable or toxic gas
- Release of cryogenic liquids or gases
- Rollover
- Loss of stability
- Failures in station keeping systems
- Loss of electrical power supply
- Failures in process systems
- Failures in cargo systems.

It is recommended that the hazard identification should be conducted with a view to screening out hazards that are trivial or of minor significance, by means of a qualitative or semi-quantitative approach: a quantitative approach is premature in this phase and in any case reliability data are not usually available for novel applications.

2) Risk assessment: it is the combination of probability and severity of the consequences relevant to each significant failure mode, at the level of detail relevant for the development phases. The risks from the significant hazards selected from the above task are to be assessed and considered together to show the relative contribution of different hazards to the total risk. The acceptance criteria (for safety, availability, reliability, downtime etc.), the proposed risk assessment methodologies and the tools to be used should be agreed among the stakeholders at the beginning of the project. It is recommended that the third party should be involved early in the risk assessment process, and its participation ensured in the main tasks with the purpose of monitoring and validating the various steps.
When the novelty of the technology simply consists in a deviation from the applicable prescriptive codes, the safety criteria should be based on the spirit and nature of the codes. Therefore, it is to be demonstrated that the novel technology provides a level of safety equivalent to a standard design resulting from the direct application of the codes.
The risk assessment carried out for the purpose of TQ should be based on recognized techniques as far as possible. In the quantitative analysis, particular attention is to be given to the proper treatment of uncertainties.

3) Risk control definition: options can be preventive, mitigative or a combination of the two. Risk reduction is to be based on the ALARP principle. A typical hierarchical approach to risk reduction is:

- Minimization of hazards inherent in the design
- Prevention
- Detection
- Control
- Mitigation of consequences
- Escape, Evacuation and Rescue.

4) Document production: the whole process consisting of tasks 1 to 3 above is to be properly documented and reviewed when necessary. It is to include, as a minimum, the specified criteria, the minutes of the hazard identification sessions, tables and graphs obtained from software tools, the treatment of uncertainties and the list of the risk control options along with their rationale and any other additional material to support the conclusions of the study.
Attachment 4A/B Example of Risk assessment are proposed for UAV/Underwater.

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4.4.3.5 Data Collection (Analyses and Testing)

The objective of this phase is to collect the results of the selected qualification activities.
Supporting evidence of the design, construction, operations and maintenance of the novel technology in its lifetime is to be provided. Means of catering for confidentiality issues are to be agreed on among the stakeholders.

The typical documentation, as far as applicable, to be provided in this phase is listed in the following.

- Design criteria
- Applicable normative framework
- Detail drawings
- Technical specification
- Manufacturing and installation
- Material specifications and certificates
- Operating manuals
- Test and maintenance procedures
- Engineering analyses
- Risk assessment reports.

4.4.3.6 Functionality Assessment

The objective of this phase is to obtain confirmation that the functional requirements and the safety, reliability, availability and maintainability criteria are fulfilled, by providing evidence of the results of the relevant TQ activities.

4.4.4 Deliverables

As supporting evidence of the TQ, the following technical reports are to be issued.

1) Technology Assessment Report
   This report is to detail the tasks 'qualification basis' and 'Technology Assessment'.
2) Technology Qualification Plan
   This report is to detail the task 'qualification methods', which is to include full details of the risk assessment performed on the novel technology.
3) Technology Qualification Report
   This report is to detail the tasks 'data collection' and 'functionality assessment'.

A different organization of deliverables can be adopted upon agreement among the stakeholders and the third party.
The deliverables are to be verified, commented on, and approved by the third party upon closure of all comments. A prominent aspect of the engineering analyses is the risk assessment process, which is mandatory in the framework of the TQ process.

4.4.5 Certificates

Once TQ deliverables have been approved and the technology has been found fit for service, the relevant certificate is to be issued.

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4.4.6 ATLS Technological Certification

The certification of robotic technology obtained at the Coastal Test Center of Atlantis can be achieved by certification scheme named "ATLS Technological Certification".
This scheme is based on "Technology Qualification" applied to Coastal Test Center of Atlantis and it includes following steps:

- Authorizations
- Check of safety procedures
- Check of Deployment and Recovery
- Verification of insurance and liability documentation
- IMR activity validation
- Verification of collected data

This certification scheme has been developed in the context of Atlantis Project and can be applied to Technology Developers interested in offshore IMR activities.

4.5 Training

In addition, specific Training Program can be developed. An example of training course is presented below:

- Introduction to UAV Inspections
- Environmental Impacts
- Local Regulations
- Emergency and Safety procedures
- Crew Composition and requirements
- Type of sensors and payload
- Thermal Inspections
- UAV Inspections Techniques
- Captured Data Properties
- Sensor and camera Settings
- Analysis of asset to be inspected
- Shut-down Requirements
- Preflight Phase
- Utilizing Preflight Checklists [see attachment]
- Evaluating Forecast Weather
- Determining Takeoff/Landing Points
- In Flight Assessment Checklist [see attachment]
- Evaluating Weather conditions
- Identifying Hazards [see attachment]
- Data Storage
- Post processing activity

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4.6KPI Philosophy and Application Strategy

According to: ISO 14224 the following main steps can be performed:

- KPI Development
- KPI Measurement
- Corrective Action Execution

Develop KPIs for improvement.

In the areas where improvement is desired, KPIs should be developed. Each KPI should have a targeted performance level. The KPI and target should, where possible, be specific, measurable, achievable (but require stretch), realistic and time-based (i.e. they can track performance improvement over time). The frequency at which the KPI is measured is determined by a realistic expectation of the amount of time required for any corrective action to have an impact on the performance level. Thus, if there is no willingness to measure and analyze the parameters when there is no change from one measurement to the next, but it is necessary to balance this against not measuring often enough, resulting in the situation that parameters can be out of control for long periods. In addition, it is necessary to consider the time, cost and resources needed to develop, maintain and manage the KPIs, as this also determines how many robust KPIs can be used.

- Measure KPI

The KPI should be measured and reported, where possible, within existing systems. In addition to measuring the KPI, it is necessary to compare the result against the target and to identify any causes for deviations.

- Take corrective action

The causes for deviations should be addressed and corrective actions performed, and the process should be repeated many times.

Often KPI can be defined as an indicator calculated between 0 and 1 and some of deviation ranges can be identified.

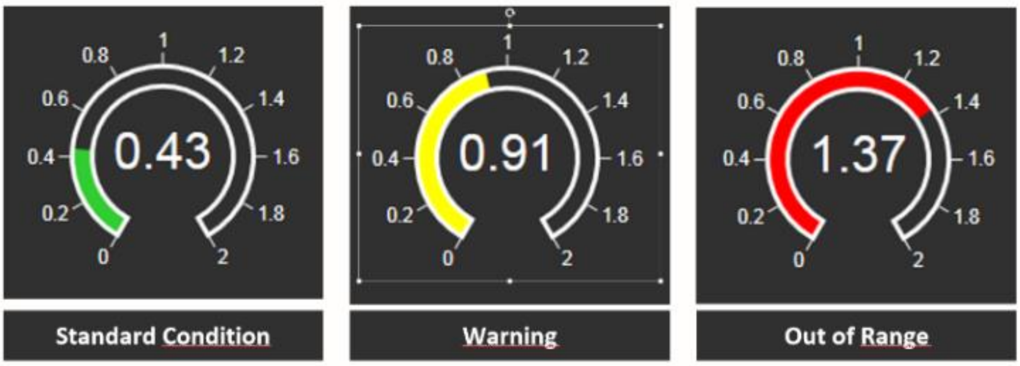

Figure 13 - KPI indicator

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Training

Competency Assessment
(Number of Individuals Who Successfully Complete a Planned Training Session on the First Try) / (Total Number of Individual Training Sessions with Completion Assessment Planned for that time period)
Definition Successful Completion: A passing grade on an exam or competency assessment for which there is no requirement to repeat/redo the training, exam, competency assessment or any part thereof. Training Session with Completion Assessment: A planned PSM training session for which there is a required demonstration of knowledge or skill through an examination or competency assessment.
Target Value Target value to be defined on yearly basis
Recording Frequency Yearly

Failure to follow procedures/safe working practices
(Number of safety critical tasks observed where all steps of the relevant safe working procedure were not followed / Total number of safety critical tasks observed) x 100%
Target Value Target value to be defined on yearly basis
Recording Frequency Yearly

Procedures Current & Accurate
(Number of procedures reviewed/updated per year / Total number of procedures required to be reviewed/updated during the measurement period) x 100%.
Target Value Target value to be defined on yearly basis
Recording Frequency Yearly

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Procedures Clear, Concise & Include Required Content
(Number of procedures reviewed for content / Total number of procedures) x 100%.
Target Value Target value to be defined on yearly basis
Recording Frequency Yearly

Number of Inspection conducted by Rob.Tech Pilot
Definition Number of Inspections conducted by Rob.Tech Pilot is a KPI that measures the total number Inspections conducted by Rob.Tech Pilot within a specific time period.
Advantages Evaluate if the pilot has the necessary knowledge and skills to perform Maintenance and Inspection activity
How to calculate N° inspection performed/Yearly <1; 1 N° inspection performed/Yearly >1<3; 2 N° inspection performed/Yearly >3; 3 KPI= N° inspection performed/3
Target Value Target value to be defined on yearly basis
Recording Frequency Yearly

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Operation

Launch/Recovery Failure
Definition Launch/Recovery Failure measures the Launch/Recovery activity failed.
Advantages Evaluate efficiency of inspection Launch/Recovery procedures.
How to calculate Launch/Recovery failed <1; 1 Launch/Recovery failed >1<3; 2 Inspection Time >3; 3 KPI= Launch/Recovery failed /3
Target Value Target value to be defined on year basis
Recording Frequency Mission basis

Weather condition Limitation vs. Robotic tech. max allow. value
Definition Weather condition limitation exceeding acceptable values.
Advantages Evaluate technology limitation respect Weather condition
How to calculate Visibility Wind speed Sea state KPI= N° inspection aborted due to loss of visibility (exceeding Robotic tech. max allow. value)/N total inspection performed KPI= N° inspection aborted due to wind speed (exceeding Robotic tech. max allow. value)/N total inspection performed KPI= N° inspection aborted due to Sea State (exceeding Robotic tech. max allow. value)/N total inspection performed
Target Value Target value to be defined on year basis
Recording Frequency Mission basis

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Loss of charge (battery)
Definition Loss of charge during inspection leading to recovery procedure.
Advantages Evaluate efficiency of inspection and allows comparison with different payload/maintenance task
How to calculate KPI= N° inspection aborted due to loss of charge/N total inspection performed
Target Value Target value to be defined on year basis
Recording Frequency Mission basis

Loss of control
Definition Loss of control during inspection leading to recovery procedure.
Advantages Evaluate Control efficiency of inspection
How to calculate KPI= N° inspection aborted due to loss of control/N total inspection performed
Target Value Target value to be defined on year basis
Recording Frequency Mission basis

Average Inspection activity time
Definition Average Inspection activity time measures the average time used to perform an inspection activity
Advantages Evaluate efficiency of inspection and allows comparison with different techniques/methodologies
How to calculate Inspection Time <1h; 1

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Inspection Time >1h<3h; 2 Inspection Time >3h; 3 KPI= N° inspection performed/3
Target Value Target value to be defined on hours basis
Recording Frequency Mission basis

Logistic

Logistic Weather condition Limitation
Definition Weather condition limitation exceeding Logistic acceptable values.
Advantages Evaluate Logistic availability respect Weather condition
How to calculate Visibility Wind speed Sea state KPI= N° inspection aborted due to visibility/N total inspection performed KPI= N° inspection aborted due to wind speed/N total inspection performed KPI= N° inspection aborted due to Sea State /N total inspection performed
Target Value Target value to be defined on year basis
Recording Frequency Mission basis

Data collection

Quality Data Acceptance
Definition Data captured during Inspection activity
Advantages Evaluate quality of inspection and allows comparison with different techniques
How to calculate % of discarded data Vs Total data acquired

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Target Value Target value to be defined on mission basis
Recording Frequency Mission basis

Additional KPI can be defined during Robotic Technology development can be measured in Test Platform to obtain performance evaluation or to monitor Robotic technology development.

Performance evaluation

Cathodic Protection Measure
Definition Measure of Cathodic Protection Vs. Value set
Advantages Evaluate quality of Measure
How to calculate % of accuracy vs. Value set Measure ±5%; 1 Measure >5%<10%; 2 Measure >10%; 3 KPI= Value Measured+deviation/3
Target Value Target value to be defined on mission basis
Recording Frequency Mission basis

Cleaning
Definition Measure of Cleaning Task Vs. Value set (cm2)
Advantages Evaluate quality of Measure
How to calculate % of execution vs. Value set Value of execution <50%; 1 Value of execution >50%<80%; 2 Value of execution >80%; 3

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KPI= Value of execution /3
Target Value Target value to be defined on mission basis
Recording Frequency Mission basis

Performance evaluation-Data quality

Surface defect Identification
Definition Identification of surface defect on pre-fixed component
Advantages Evaluate quality of inspection
How to calculate Identification of surface defect based on data acquired. Calculation can be based on quantitative (dimensions of defect) or qualitative (identification Y/N) procedures
Target Value Target value to be defined on mission basis
Recording Frequency Mission basis

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5. Conclusions

The deliverable has considered existing regulations and standards related directly to the O & G sector and robotic technologies applied in this field, with the aim of identifying how inspection and maintenance operations are regulated. No applicable standards have been identified and the present guideline aims to promote the use of robotic technology towards all stakeholders involved in the chain: end users, robotic technology developers, research centers and engineering consultancy companies.

Offshore O&M activities are not yet standardized and technical normative do not yet exist, particularly if we consider the use of robots, whose own regulatory framework is still under construction and very linked to field of application.

The proposed guideline not only addresses traditional maintenance issues but offers a point of interest for future uses of robotic technology in the field of inspection and maintenance. Today the main use is based on visual inspections, non-destructive tests, cleaning, small measurements, and limited maintenance activities.

In addition to significant benefits in the technical field, shall be emphasized the benefits that is possible to obtain in HSE field.

The rapid increase of offshore wind can facilitate the use of robotics to limit exposure in harsh environments.

Research and development play a leading role; the development of accessible platforms to validate market solutions can help reduce the gap generated using robotics whose maturity is gradually increasing for inspection and maintenance activities in the wind offshore field.

Equally interesting is the path identified that involves the involvement of certification companies. The proposed methodological approach allows to have a complete and impartial vision of the steps to be performed against a request for technological qualification.

The proposed approach can be adopted in different sectors, due to several experiences gained by RINA in the marine sector.

In the ATLANTIS EU funded project there was no opportunity to start a qualification process towards robotic technology developers: it requires time and huge effort, but it is important to stress how the current guidelines may pose the basis for a future development of such standards.

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6. Attachment

6.1.Attachment 1- Check List-Maintenance Activities for Turbine

Blades	Check surface damage
	Check delamination
	Check protective film and erosion at the leading edge
	Check corrosion cracks
	Check structural discontinuities
	Check Condition of the lightning protection system
	Check Pre-tensioning of bolts
	Check Blade sealing to hub
	Check Blade adjusting device (if any)
	Infrared thermographic analysis (when required)
Tower	Check surface damage
	Check structural discontinuities
	Check corrosion cracks
	Check Condition of the lightning protection system
	Check torque of bolts on flanges connection (each section of the tower)
	Check Platform: Surface damage, corrosion cracks, structural discontinuities Visual Inspection
	Check Ladder Assembly: Surface damage, corrosion cracks, structural discontinuities
	Check Safety equipment: Visual Inspection
	External cleaning
	Infrared thermographic analysis (when required)
Drive Train	Structural integrity Inspection
	Coating Inspection
	Corrosion Inspection
	Leakage Inspection
	Vibration Diagnostics
	Sample oil & oil analysis lubricating system (gearbox / generator) Degradation and contamination
	Function control
	Noise Check
	Structural integrity Inspection
	Monitoring system calibration and functional test

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	Thermographic inspection (electrical components: generator and transformers) to detect loose connections, insulation problems, or load imbalances.
	Mechanical component inspection and test
	Electrical component inspection and test
	Rotor balance and pitch angle inspection
	Endoscope inspection (if required)

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6.2.Attachment 2-Check List- Maintenance Activities for BoP

Floating Structure (Above Sea Level)	Check/ Re-torque bolt connection between the platform and the tower
	Check integrity of primary structure
	Check integrity of coating
	Check walkway and laydown area support, grating, handrails, stairs to tower;
	Check equipment foundations, especially davit crane;
	Check vents and sounds
	Check on-deck manhole and hatch access ways;
	Check electrical cables, cable trays and instrumentation
	Check outside hull (columns, upper main beam, V-braces), including the corrosion protection status;
	Check Machinery rooms, including access to the platforms, primary structure, corrosion protection status, ladders, handrails and equipment and systems;
	Check Void compartments, including bulkheads, decks and stiffening, vents and sounds, manholes, and any secondary structure;
	Check Keel plates and lower main beams
	Check pipe racks, pipe supports, piping and valves;
	Check Electrical and instrumentation cables, cable trays
	Check Safety equipment.
	External cleaning
	Access equipment such as ladders, stairways, fall protection, anchors, and railings
	Visual inspection for damage detection on lightning receptors, and resident sensors' installation
	Structural health monitoring system / Dynamic Loads Monitoring (instrument)
Floating Structure (Below Sea Level)	Check significant deformation (misshapen) or fracture of structures
	Check mechanical damage caused by collisions or falling objects
	Check leaks
	Check eccessive marine growth
	Check condition of anodes
	Check presence of foreign bodies
	Check extensive corrosion of submerged parts
	Check significant amounts of scale

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	Check condition of column shell; knee braces; lower main beams, V-braces and K-joints; water entrapment plate (below sea water level)
	External cleaning
	Inspection of welds and NDT measurements

Cables Protection Systems	Monitored/visually inspected: Cables position
	Monitored/visually inspected: touchdown protections
	Monitored/visually inspected: bend stiffeners
	Monitored/visually inspected: buoyancy modules including straps, bolts and nuts
	Monitored/visually inspected: Monitor cable-protection accessories.(Bend stiffener and Uraduct are the most common)
	Monitored/visually inspected: condition of the outer sheath of the cable
	Cleaning with water jet and brush for excessive marine growth (if necessary)
	NDT for integrity control and damage monitoring (if necessary)

Export cable and Array cable	Bathymetric survey to inspect conditions of the seabed and scour protection, where applicable, around the base of the foundations.
	Bathymetric survey to determine the presence of significant deterioration of cables
	Diver inspection, where a diver is deployed to swim along the cable to both visually and physically inspect the cable on the seabed
	Sonar mosaicing
	External cleaning for marine growth (if necessary)
	Inspection using 3D imaging sonar as the cable is laid in position.

Anchoring system	Visual Inspection (Anchoring system): PMCs - Platform Mooring Connectors
	Visual Inspection (Anchoring system): Chains
	Visual Inspection (Anchoring system): Clump & accesories
	Visual Inspection (Anchoring system): Anchors

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	External cleaning for marine growth (if required)
	Marine growth thickness and twist measurement along the mooring lines and cables. (if required)
	NDT measurement (if required)

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6.3.Attachment 3-Check List Functionality- Robotic Inspection

PRE FLIGHT

- ☐ CHECK WEATHER CONDITION
- ☐ NOTIFY TO REMOTE SURVEILLANCE UNIT START/END OF THE INSPECTION WORKS.
- ☐ KEEP A FIRST AID KIT
- ☐ BREAFING PRE-FLIGHT WITH OTHER TEAM MEMBERS
- ☐ VISUAL INSPECTION / CONTROL OF STRESS ZONES / PROPELLERS (CHECK CONDITIONS)
- ☐ CHECK INSTALLATION MICRO SD CARD
- ☐ CHECK BATTERY INSTALLATION (CHECK FULL CHARGE)
- ☐ CHECK THE PLANNED ROUTE
- ☐ FLIGHT MODE SWITCH (ON DESIRED POSITION)
- ☐ REMOTE CONTROL BATTERY (CHECK FULL CHARGE)
- ☐ SWITCHING ON REMOTE CONTROL/(ERROR CHECKING)
- ☐ SELECT CAMERA ICON AND SET
- ☐ CHECK SPACE ON SD CARD (POSSIBLY FORMAT)
- ☐ CONTROL OF POSSIBLE EXTERNAL INTERFERENCE
- ☐ CHECK SIGNAL LOSS ACTION (RETURN TO HOME/ LAND/ HOVER - INDOR)
- ☐ CHECK RE-ENTRY POINT
- ☐ HOME POINT CHECK (TAKE-OFF POINT)
- ☐ CHECK FOR ACTIVE SENSORS
- ☐ TAKE-OFF LOCATION (FREE AND SAFE TAKE-OFF)
- ☐ NOTIFY ALL TEAM MEMBERS "READY FOR TAKE-OFF"
- ☐ ENGINE
- ☐ START RECORDING
- ☐ TAKE-OFF

IN FLIGHT

- ☐ CONTROL CHECK (DIFFERENT DIRECTIONS)
- ☐ CHECK FOR ACTIVE SENSORS
- ☐ CHECK VIDEO RECORDING
- ☐ CHECK INSPECTION ROUTE
- ☐ CHECK BATTERY AND SIGNAL LEVEL (AFTER 5 MIN)
- ☐ CHECK BATTERY AND SIGNAL LEVEL (AFTER 10 MIN)
- ☐ CHECK BATTERY AND SIGNAL LEVEL (AFTER 15 MIN)
- ☐ CHECK BATTERY AND SIGNAL LEVEL (EVERY 5 MIN TO THE END OF MISSION)
- ☐ CHCK WETHER CONDITION
- ☐ CHECK RETURN ROUTE

POST FLIGHT

- ☐ SWITCH OFF UAV
- ☐ SWITCH OFF OF ALL ACCESORIES
- ☐ SWITCH OFF OF REMOTE CONTROL
- ☐ VISUAL INSPECTION / CONTROL OF STRESS ZONES / PROPELLERS (CHECK CONDITIONS)
- ☐ REMOVAL SD
- ☐ CONTROL SD

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PRE INSPECTION

- [ ] CHECK WEATHER CONDITION
- [ ] NOTIFY TO REMOTE SURVEILLANCE UNIT START/END OF THE INSPECTION WORKS.
- [ ] KEEP A FIRST AID KIT
- [ ] BREAFING PRE-INSPECTION WITH OTHER TEAM MEMBERS
- [ ] VISUAL INSPECTION ALL COMPONENTS
- [ ] CHECK INSTALLATION MICRO SD CARD
- [ ] CHECK BATTERY INSTALLATION (CHECK FULL CHARGE)
- [ ] CHECK THE PLANNED ROUTE (OBSTACLES; INTENFERENCES)
- [ ] CHECK OPERATIONAL DEPTH
- [ ] SELECT CONTROL MODE (ON DESIRED POSITION)
- [ ] REMOTE CONTROL BATTERY (CHECK FULL CHARGE)
- [ ] SWITCHING DESIDERATA CONTROL MODE/(ERROR CHECKING)
- [ ] SELECT CAMERA ICON AND SET
- [ ] CHECK LIGHT NAVIGATION & CAMERA
- [ ] CHECK SPACE ON SD CARD (POSSIBLY FORMAT)
- [ ] CHECK SIGNAL LOSS ACTION (RETURN TO HOME)
- [ ] CHECK RE-ENTRY POINT
- [ ] HOME POINT CHECK
- [ ] CHECK FOR ACTIVE SENSORS/INSTRUMENTATION
- [ ] FUNCTION TESTING PRIOR TO USE
- [ ] UMBILICAL/TETHER CABLES (IF ANY)
- [ ] NOTIFY ALL TEAM MEMBERS "READY FOR INSPECTION"
- [ ] LAUNCH PROCEDURES
- [ ] START RECORDING

INSPECTION

- [ ] CONTROL CHECK (DIFFERENT DIRECTIONS)
- [ ] CHECK FOR ACTIVE SENSORS
- [ ] CHECK VIDEO RECORDING
- [ ] CHECK INSPECTION ROUTE
- [ ] CHECK OPERATING DATA (POSITION, DEPTH, SPEED)
- [ ] CHECK BATTERY AND SIGNAL LEVEL (AFTER 5 MIN)
- [ ] CHECK BATTERY AND SIGNAL LEVEL (AFTER 10 MIN)
- [ ] CHECK BATTERY AND SIGNAL LEVEL (AFTER 15 MIN)
- [ ] CHECK BATTERY AND SIGNAL LEVEL (EVERY 5 MIN TO THE END OF MISSION)
- [ ] CHECK WEATHER CONDITION (CURRENT VELOCITY,VISIBILITY, MAXIMUM OPERATING WAVE HEIGHT)
- [ ] CHECK RETURN ROUTE
- [ ] RECOVERY PROCEDURE

POST INSPECTION

- [ ] SWITCH OFF AUV
- [ ] SWITCH OFF OF ALL ACCESORIES
- [ ] SWITCH OFF OF REMOTE CONTROL
- [ ] VISUAL INSPECTION ALL COMPONENTS
- [ ] POST-DIVE CHECKS TO IDENTIFY DAMAGE/MAINTENANCE TASK ON AUV/ROV.
- [ ] REMOVAL SD
- [ ] CONTROL SD
- [ ] CHECK THAT ALL DATA ARE DOWNLOADED AND STORED APPROPRIATELY

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6.4. Attachment 4A-Risk Assessment-UAV

Maintenance task can be performed by Robotic Tech	Hazard		Initial risk (pre-mitigation)			Control measures	Residual risk (post-mitigation)
	Hazard description	Hazard effect	Severity [Note1]	Likelihood [Note2]	Risk category	Description of control Measures	Risk category
Authorizations	Missing documentation	Authorization denied Inspection activity delayed (Asset cannot be inspected)	2	2	LOW	Check completeness by using check list Observance time for authorization	LOW
Tecnology Risk Assesment	Missing Trials Tests (Limited Knowledge of application Area, Limited Knowledge of Technology)	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed	MEDIUM
Representativeness of the test platform vs. Weather Conditions	Inspection activity are not validated under Harsh Weather conditions	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Tests can be required by Owner considering weather conditions near to real Environment	MEDIUM
Representativeness of the test platform vs. Asset Complexity	demostrative asset not representative for complexity	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Tests can be required by Owner	MEDIUM
Representativeness of the test platform vs. Multiple Interaction	Multiple Interaction	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Test can be required	MEDIUM
Check safety procedures	Safety procedures not identified/tested	Loss of control Phisical Damage to Robotic Asset Phisical Damage to inspected asset Asset loss/ Collision	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Test can be required	MEDIUM
Deployment	Deployment procedures not identified/tested	Asset loss/ Collision	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Test can be required	MEDIUM
Non-Disclosure Agreement (NDA)Signed	Missing documentation	Authorization denied Inspection activity delayed (Asset cannot be inspected)	2	2	LOW	Check completeness by using check list Observance time	LOW
Flight authorizations	Missing documentation	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	2	MEDIUM	Check completeness by using check list Observance time for authorization	LOW
Risk analysis	Hazard identification not completed/ not performed	Possible impact due to missing hazard identification	4	2	MEDIUM	Check list to map applicable potential hazard	LOW
Verification of insurance and liability documentation ; pilots certificates	Expired documentation	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	2	MEDIUM	Check completeness by using check list Internal QA/QC procedure to assure validity of insurance and certification	LOW
Calibration and test (before starting)	Control Failure Function Failure	Loss of control Phisical Damage to UAV Phisical Damage to inspected asset Asset loss/ Collision	4	3	MEDIUM	Perform Calibration and check before starting (Internal QA/QC procedure) UAV shall be tested and checked according to supplier's guidelines	LOW
Check safety procedures	Safety procedures not respected	Loss of control Phisical Damage to UAV Phisical	4	3	MEDIUM	Check safety Requirements Preparation of emergency plan UAV shall be checked and tested before the start of mission.	LOW

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		Damage to inspected asset Asset loss/ Collision				Check that control is only allowed to qualified personnel (Internal QA/QC procedure)	
Verification of weather conditions (before starting)	Adverse Weather	Inspection postponed	4	3	MEDIUM	Weather forecast monitoring before the mission	LOW
Transfer to opeational area	Loss of equipment Collision	Asset loss/damaged	2	2	LOW	Training and sea survival course PPE to be used Personnel to comply to Vessel procedure and vessel crew instructions during any transfer Equipment segregation area Qualified personnel operating	LOW
Verification of weather conditions (before deployment and during the mission)	Adverse Weather	Inspection postponed	4	3	MEDIUM	Weather forecast monitoring before the deployment and during the mission	LOW
Deployment	Deployment Failure	Asset loss/ Collision	2	2	LOW	Observation of safety distances and operative procedures (no lifting equipment is involved)	LOW
Achievement of operational area	Control Failure Function Failure	Loss of control Phisical Damage to UAV Phisical Damage to inspected asset Asset loss/ Collision	4	3	MEDIUM	Observation of safety distances	LOW
Start of operations Inspection activity	Functional failure Adverse Weather Pilot error	Loss of control Phisical Damage to UAV Phisical Damage to inspected asset Asset loss/ Collision	4	3	MEDIUM	Perform Weather monitoring before (forecast) and during the mission Observation of operating area UAV shall be checked and tested before the start of mission. Check that control is only allowed to qualified personnel (Internal QA/QC procedure)	LOW
Start of operations Inspection activity	Comunication/control Failure	Loss of control Phisical Damage to UAV Phisical Damage to inspected asset Asset loss/ Collision	4	3	MEDIUM	UAV shall be checked and tested before the start of mission. Check that control is only allowed to qualified personnel (Internal QA/QC procedure)	LOW
Asset recovery	Recovery Failure	Asset loss/ Collision	2	2	LOW	Observation of safety distances and operative procedures Monitor weather condition (no lifting equipment is involved)	LOW
Verification of collected data	Errors in data collection	Data storage not available	2	2	LOW	Control of data collection devices	LOW
Data storage and sharing	Data storage failed Files corrupted	Data storage not available	2	2	LOW	Backup	LOW

Note1

- Catastrophic (5)
- Substantial (4)
- Significant (3)
- Minor (2)
- Negligible (1)

Note2

- Rare (1)
- Remote (2)
- Occasional (3)
- Frequent (4)
- Almost certain (5)

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6.5.Attachment 4B-Risk Assessment-Underwater

Maintenance task can be performed by Robotic Tech	Hazard		Initial risk (pre-mitigation)			Control measures	Residual risk (post-mitigation)
	Hazard description	Hazard effect	Severity [Note1]	Likelihood [Note2]	Risk category	Description of control Measures	Risk category
Authorizations	Missing documentation	Authorization denied Inspection activity delayed (Asset cannot be inspected)	2	2	LOW	Check completeness by using check list Observance time for authorization	LOW
Tecnology Risk Assesment	Missing Trials Tests (Limited Knowledge of application Area, Limited Knowledge of Technology)	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed	MEDIUM
Representativeness of the test platform vs. Weather Conditions	Inspection activity are not validated under Harsh Weather conditions	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Tests can be required by Owner considering weather conditions near to real Environment	MEDIUM
Representativeness of the test platform vs. Asset Complexity	demostrative asset not representative for complexity	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Tests can be required by Owner	MEDIUM
Representativeness of the test platform vs. Multiple Interaction	Multiple Interaction	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Test can be required	MEDIUM
Check safety procedures	Safety procedures not identified/tested	Loss of control Phisical Damage to Robotic Asset Phisical Damage to inspected asset Asset loss/ Collision	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Test can be required	MEDIUM
Deployment	Deployment procedures not identified/tested	Asset loss/ Collision	4	4	MEDIUM	Successful test performed at test platform Implementation recommendations from tests performed Additional Test can be required	MEDIUM
Non-Disclosure Agreement (NDA)Signed	Missing documentation	Authorization denied Inspection activity delayed (Asset cannot be inspected)	2	2	LOW	Check completeness by using check list Observance time	LOW
Authorizations	Missing documentation	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	2	MEDIUM	Check completeness by using check list Observance time for authorization	LOW
Risk analysis	Hazard identification not completed/ not performed	Possible impact due to missing hazard identification	4	2	MEDIUM	Check list to map applicable potential hazard	LOW
Verification of insurance and liability documentation	Expired documentation	Authorization denied Inspection activity delayed (Asset cannot be inspected)	4	2	MEDIUM	Check completeness by using check list Internal QA/QC procedure to assure validity of insurance and certification	LOW
Calibration and test (before starting)	Control Failure Function Failure	Loss of control Phisical Damage to AUV/ROV Phisical Damage to inspected asset Asset loss/ Collision	4	3	MEDIUM	Perform Calibration and check before starting (Internal QA/QC procedure) AUV shall be tested and checked according to supplier's guidelines	LOW
Check safety procedures	Safety procedures not respected	Loss of control Phisical Damage to UAV	4	3	MEDIUM	Check safety Requirements Preparation of emergency plan UAV shall be checked and tested	LOW

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		Phisical Damage to inspected asset Asset loss/ Collision				before the start of mission. Check that control is only allowed to qualified personnel (Internal QA/QC procedure)	
Verification of weather/ocean conditions (before to start)	Adverse Weather	Inspection postponed	4	3	MEDIUM	Weather forecast monitoring before the mission	LOW
Transfer to opeational area	Loss of equipment Collision	Asset loss/damaged	2	2	LOW	Training and sea survival course PPE to be used Personnel to comply to Vessel procedure and vessel crew instructions during any transfer Equipment segregation area Qualified personnel operating	LOW
Deployment	Deployment Failure	Asset loss/ Collision	4	2	MEDIUM	Application of lifting procedure Observation of safety distances and operative procedures & weather conditions (lifting equipment can be involved)	LOW
Achievement of operational area	Control Failure Function Failure	Loss of control Phisical Damage to AUV/ROV Phisical Damage to inspected asset Asset loss/ Collision	4	3	MEDIUM	Observation of safety distances Observation PLANNED ROUTES	LOW
Start of operations Inspection activity	Functional failure Adverse Weather Pilot error	Loss of control Phisical Damage to AUV/ROV Phisical Damage to inspected asset Asset loss/ Collision	4	3	MEDIUM	Perform Weather monitoring Observation of operating area AUV/ROV shall be checked and tested before the start of mission. Check that control is only allowed to qualified personnel (Internal QA/QC procedure)	LOW
Start of operations Inspection activity	Comunication/con trol Failure	Loss of control Phisical Damage to AUV/ROV Phisical Damage to inspected asset Asset loss/ Collision	4	3	MEDIUM	AUV/ROV shall be checked and tested before the start of mission. Check that control is only allowed to qualified personnel (Internal QA/QC procedure)	LOW
Asset recovery	Recovery Failure	Asset loss/ Collision	4	3	MEDIUM	Application of lifting procedure Observation of safety distances and operative procedures Monitor weather condition (lifting equipment is involved)	LOW
Verification of collected data	Errors in data collection	Data storage not available	2	2	LOW	Control of data collection devices	LOW
Data storage and sharing	Data storage failed Files corrupted	Data storage not available	2	2	LOW	Backup	LOW

Note1

- Catastrophic (5)
- Substantial (4)
- Significant (3)
- Minor (2)
- Negligible (1)

Note2

- Rare (1)
- Remote (2)
- Occasional (3)
- Frequent (4)
- Almost certain (5)

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