EUROPEAN DEFENCE AGENCY

EU Preparatory Action on Defence Research (PADR)

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Technological demonstrator for enhanced situational awareness in a naval environment

Project acronym: OCEAN2020

Project full title: "Open Cooperation for European mAritime awareNess 2020"

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OCEAN2020

D6.5.2: Roadmap Report for Future Research and Capability Development

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ANNEXES

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1 INTRODUCTION

1.1 Scope

Beside and taking benefit from technical development done during OCEAN2020 project, this document provides recommendations for further activities to support the project aims. These activities may include planning for capability development, the development of European Union (EU) industrial capabilities or the development of scientific research.

In addition to the partners' knowledge, all these aspects take into account experience gathered during the OCEAN2020 development and, especially, during the simulated and live demonstration trials.

1.2 Overview

The scope of this document is addressed throughout two main parts. The first deals mainly with the technical side of the development by introducing several sets of recommendations after providing a summary of the applied process in the OCEAN2020 project with an analysis to identify the areas of strength and opportunity. In this framework, recommendations were elicited for requirement analysis, system architecture upgrading, modelling activities, subsystems upgrading and system integration enhancements.

This part also introduces a planning for capability development at national and EU levels. The milestones are proposed by considering OCEAN2020 capability needs that are in the scope of the 2018 EDA capability development plan.

The second part of this document concerns both of the technical and the business side of the development. Mainly based on technology building blocks (TBBs) and considering maritime defence purposes, the proposed enhancements in this part, go further than the improvements that have been presented on the framework of the OCEAN2020 reference architecture. Recommendations are then given for developing European industrial capabilities in different fields such as unmanned platforms, sensors & effectors, communication, command & control and information technology areas. The involvement of scientific research institutes is also addressed in this part after analysing research needs that can be related to unmanned systems.

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1.3 Document structure

The document structure is the following:

- Recommendations for further activities
- Planning for capability development,
- Development of EU industrial capabilities,
- Development of scientific research.

1.4 Glossary

1.4.1 Acronyms

ACD	Amplitude Change Detection
ACO	Ant Colony Optimization
AI	Artificial Intelligence
AIOP	Artificial Intelligence Operations
AMMOD	Automated Man Made Object Detection
AR	Augmented Reality
ASW	Anti-submarine warfare
CACOC	Chaotic Ant Colony Optimization to Coverage
CapTech	Capability Technology Areas
CAS	complex adaptive systems
CC	Cloud Computing
CCD	Coherent Change Detection
CDP	Capability Development Plan
COP	Common Operational Picture
CT	Communication Technology
DAA	Detect and Avoid
EDF	European Defence Fund
EU	European Union
EUMC	European Union Military Committee
EUMS	European Union Military Staff

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HRI	human-robot interaction
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronic Engineers
IoT	Internet of Things
ISR	Intelligence, surveillance, and reconnaissance
IT	Information Technology
JTRS	Joint Tactical Radio System
LoA	Level of Ambition
MBSE	Model Based Systems Engineering
MCM	Mine Counter Measures
MCCM	Mine Counter-Counter Measures
MMCM	Maritime Mine Counter Measures
MOC	Maritime Operations Centre
MOD	Ministry of Defence
MVP	Minimum Viable Product
MW	Maritime Warfare
NAF	NATO Architectural Framework
NATO	North Atlantic Treaty Organization
NCBR	National Centre for Research and Development
NCC	Network Centric Communications
OCEAN	Open Cooperation for European mAritime awareNess
OSINT	Open Source Intelligence
OW&AS	Obstacle Warning and Avoidance Systems
PADR	Preparatory Action on Defence Research
PON-N	Polish Navy
RDP	Requirements Demonstration Plan
RMP	Recognised Maritime Picture
SCC	Strategic Context Cases
SD-WAN	Software-defined Wide Area Network

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SLOC	Sea Lines Of Communication
SOA	Service Orientated Architecture
SOC	Security Operations Center
SSHUM	Structures and Systems Health and Usage Monitoring
UAV	Unmanned Air Vehicles
UMS	Unmanned Maritime System
USV	Unmanned Surface Vehicles
UUV	Unmanned Underwater Vehicles
UxS	Unmanned Systems where the domain is not specified.
VR	Virtual Reality
WAN	Wide Area Network
WBS	Work Breakdown Structure
WSM	Water Space Management

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1.4.2 Definitions

- *Active learning: In active learning, the artificial intelligence is given the opportunity to query results for specific input data on the basis of pre-defined questions that are considered significant. Usually, the algorithm itself selects questions with high relevance.*
- *Bistatic RADAR: A bistatic RADAR is a RADAR system for which the transmitter and the receiver are located at considerably different positions with respect to the distances of expected targets.*
- *Capability: capability is the ability to perform action(s) to achieve objective(s) / effect(s) under specified standards and conditions.*
- *C3: Command, Control and Communications are the key to managing the battle space and exploiting information superiority as enablers of all other operational and support missions. Effective C3 assures situational awareness and provides the ability to control the forces at all levels of command.*
- *CMS: Combat Management Systems are at the heart of naval vessels. Combat Management Systems integrate all the ship's sensors and information of other parties for real time situational awareness. They manage all Combat System sensors and weapons and provide planning and decision aids for the conduct of warship missions.*
- *EC: the European Commission is an institution of the European Union responsible for proposing legislation, implementing decisions, upholding the EU treaties and managing the day-to-day business of the EU.*
- *EDA: the European Defence Agency is an agency of the European Union that promotes and facilitates integration between Member States within the EU's Common Security and Defence Policy.*
- *Grazing angle: The grazing angle is defined as the angle on a certain ground location between the transmitter line of sight to the respective ground location point and its tangential ground location plane.*
- *ISAR: Inverse Synthetic Aperture RADAR. A RADAR which builds up an aperture by coherently aggregating RADAR echoes from a ground scene under consecutively different aspect angles is called Synthetic Aperture RADAR. If the target changes its aspect angle by moving or turning over a certain short period of time with respect to the RADAR's look angle, a so-called Inverse Synthetic Aperture is built up.*
- *MOC: The Maritime Operation Center provides a framework from which Navy commanders exercise C2at the operational level. Command and control entails both the processes (planning, directing, coordinating, and controlling forces and operations) and systems (personnel, equipment, communications, facilities, and procedures employed by commander) as they relate to the exercise of authority and direction over assigned or attached forces and organizations. The MOC exists to streamline the operational cycle and to provide a structure for quickly and*

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effectively establishing support for an operational level maritime commander. The MOC is an extension of the commander; its sole function is command support, and its authority is delegated to it by the commander. The span of control a commander can effectively exercise is finite. At the operational level, the commander normally delegates the authority to plan and execute tactical missions to subordinate task force or task group commanders. This enables the commander and his MOC to focus attention on the operational level and empowers subordinate commanders to employ their forces to support the commander's intent.

- *Monostatic RADAR: A monostatic RADAR is a system for which the transmitter and receiver are located at the same position.*
- *OCEAN2020 market end product: made of several components: EU MOC, component to provide situation awareness to National MOC, component to collect and process UxS data at tactical command centre, UxS assets that are able to communicate with EU MOC / National MOC or tactical command centre, Mission sensors and effectors fitted on UxS assets.*
- *PADR: The Preparatory Action on Defence Research is a concrete step aimed at assessing and demonstrating the added-value of EU supported defence research and technology (R&T). The relevant results are expected to further deepen European defence cooperation, addressing capability shortfalls, and to strengthen European defence stakeholders. The European Commission launched the PADR with a view of developing a future European Defence Research Programme as part of the EU's next Multiannual Financial Framework.*
- *Sea states: The sea state is the numerical description of the ocean-surface roughness. It is defined by multiple numbers of the "one-third wave heights" where the wave heights are defined as the "significant" heights of the average peak-to-trough of the waves.*
- *Supervised learning: The artificial intelligence learns on the basis of given input and output pairs. In this case, a programmer provides the appropriate values for a particular input. The aim is to train the system in the context of successive calculations with different inputs and outputs and to establish connections.*
- *Swell angle: The swell angle is the look angle relative to the "swell" of the sea waves. With constant winds it is usually the same look angle relative to the wind direction.*
- *UAV: An unmanned aerial vehicle, commonly known as a drone, is an aircraft without a human pilot aboard. UAVs are a component of an unmanned aircraft system (UAS); which include a UAV, a ground-based controller, and a system of communications between the two. The flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator (Remotely Piloted Aircraft System) autonomously by on-board computers.[*
- *USV: Unmanned surface vehicles (USV) or autonomous surface vehicles (ASV) are vehicles that operate on the surface of the water (watercraft) without a crew. Using a small USV in parallel to traditional survey vessels as a 'force-multiplier' can double*

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survey coverage and reduce time on-site. Military applications for USVs include powered seaborne targets and mine-hunting. Operational USVs may have offensive capability.

- *UUV: Unmanned underwater vehicles, sometimes known as underwater drones, are any vehicles that are able to operate underwater without a human occupant. These vehicles may be divided into two categories, remotely operated underwater vehicles (ROVs), which are controlled by a remote human operator, and autonomous underwater vehicles (AUVs), which operate independently of direct human input. The latter category would constitute a kind of robot.*
- *Unsupervised learning: In unsupervised learning, artificial intelligence learns without predefined target values and without rewards. It is mainly used for learning segmentation (clustering). The machine tries to structure and sort the data entered according to certain characteristics. For example, a machine could (very simply) learn that coins of different colours can be sorted according to the characteristic "colour" in order to structure them.*

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A1.	GA 801697	PADR-US-01-2017 – Grant Agreement 801697 OCEAN2020 – ANNEX I – PART B – Description of the Action

2.2 Reference documents

Ref.	Identification	Title
R1.	NATO Lessons Learnt Handbook	Joint Analysis and Lessons Learned Centre, The NATO Lessons Learned Handbook, NATO, Third Edition, 2016
R2.	Architecture Processes	IEEE, "IEEE42010 - Enterprise, Systems and Software - Architecture Processes," 2016.
R3.	Concept Selection Method	S. Pugh, "Concept selection: a method that works," in *Review of design methodology, International Conference on Engineering Design*, Rome, 1981.
R4.	System Life Cycle	EEE, "IEEE 15288 - Systems and Software Engineering - System Life Cycle Processes," 2015.
R5.	NAF V4	NATO Architecture Capability Team, "NATO Architecture Framework Version 4," NATO Consultation, Command and Control Board, Brussels, Belgium, 2018.
R6.	DSEEP Guidance	IEEE, "IEEE Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP)," *IEEE Std 1730-2010 (Revision of IEEE Std 1516.3-2003)* , pp. 1-79, 2011.
R7.	CD&E Handbook	NATO, "NATO Concept Development and Experimentation (CD&E) Handbook," Allied Command Transformation, 2018.
R8.	EDA1	2018 EU Capability Development priorities
R9.	EDA2	Adapted version Naval Manoeuvrability – edition 28.06.2019
R10.	EDA3	Adapted version Underwater control contributing to resilience at sea – edition 28.06.2019
R11.	Reference Architecture	D2.1-A1 : Reference Architecture Annex 1 of « Overarching Design »

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Ref.	Identification	Title
R12.	PESCO	https://pesco.europa.eu/
R13.	ETID 2015	MINISDEF - Estrategia de Tecnología e Innovación para la Defensa (ETID 2015)
R14.		http://www.ieee.es/Galerias/fichero/docs_opinion/2018/DIEEEO32-2018_Coop-Estrcut-Perman_UE_SegyDef_BeatrizCozar.pdf
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R17.	EDA4	Exploring Europe's capability requirements for 2035 and beyond - Insights from the 2018 update of the long-term strand of the Capability Development Plan
R18.	Erskine	Architectural work for Modelling and Simulation combining the NATO Architecture Framework and C3 Taxonomy
R19.	D2.1	OCEAN2020 - D2.1 Overarching Design
R20.	Joint Operations	US Army, Joint Operations. Joint Publication 3-0, Incorporating change 1, Joint Chiefs of staff Washington DC, USA, 2018.
R21.	D2.13	OCEAN2020 - D2.13 MOC Integration Design Guidelines
R22.	D2.2	OCEAN2020 - D2.2 Data Fusion Analysis Report
R23.	D2.3	OCEAN2020 - D2.3 Video Analysis Report
R24.	D2.4	OCEAN2020 - D2.4 Decision Support Analysis Report
R25.	D2.6	OCEAN2020 - D2.6 Electromagnetic Engineering Design
R26.	D2.7	OCEAN2020 - D2.7 Security Design Report
R27.	D3.12	OCEAN2020 – Simulated Trial Report
R28.	D3.10	OCEAN2020 – D3.10 Simulated Trial Plan
R29.	D3.8	OCEAN2020 – D3.8 Systems Simulation Design Description
R30.	MDO	https://newsletter.aptie.es/c/q2w9n/4j8dmgzj/qjbqrfszinu
R31.	D2.12	OCEAN2020 – D2.12 Specification of selected Space Assets

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R33.	D6.3.1	Mediterranean Sea Trial Result Evaluation Report
R34.	CESEDEN	D. T. 04/2019 Artificial intelligence, automation and robotics (AIA&R) in the military
R35.		Program of Technical Modernization of the Polish Armed Forces for the years 2021-2035
R36.		The Operational Program Preventing (Counter) Threats at Sea
R37.		Polish Strategic Concept of Maritime Security(2017 edition)
R38.	ALFUS (a)	Autonomy Levels for Unmanned Systems (ALFUS), Hui-Min Huang (ALFUS Working Group, SAE AS4D Committee), https://www.nist.gov/sites/default/files/documents/el/isd/ks/ALFUS-BG.pdf
R39.	ALFUS (b)	Specifying autonomy levels for unmanned systems: interim report, Hui-Min Huang et al, SPIE conference, 2004, https://ws680.nist.gov/publication/get_pdf.cfm?pub_id=822502
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R41.	ACO	E. Kuiper and S. Nadjm-Tehrani. Mobility models for UAV group reconnaissance applications. In: 2006 International Conference on Wireless and Mobile Communications (ICWMC'06). Institute of Electrical & Electronics Engineers (IEEE), jul 2006.
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R47.	Aliman et al. (b)	Aliman N-M. et al. (2020) Error-Correction for AI Safety. In: Goertzel B., Panov A., Potapov A., Yampolskiy R. (eds) Artificial General Intelligence. AGI 2020. Lecture Notes in Computer Science, vol 12177. Springer.
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3 EXPLOITATION

3.1 Recommendations for further activities

3.1.1 Methodology

To provide recommendations across the full range of OCEAN2020 activities, a methodology is proposed that starts with a review of the processes applied and the activities completed throughout the OCEAN2020 project up to the generation of this report. The aim of this review is to provide a framework around which the strengths and weaknesses of each activity can be observed and discussed in context. The three key steps to execute this review methodology are presented below:

I. Provide a summary of the process applied in the OCEAN2020 project.
II. Identify potential areas of strength observed within the application of the process.
III. Identify potential areas of opportunity observed within the application of the process.

The completion of these three key activities will then facilitate the generation of subject specific recommendations to inform future activities. This methodology is based on the principles found in the NATO Lessons Learnt Handbook [R1], which may be used to provide further detail around the identification of relevant observations within the executed process.

The further activities as part of the overall exploitation task will address those parts, which will increase most the benefits of the current outcomes of the project.

Based on the knowledge generated during the project execution, additional required activities in the following areas will be identified and an initial outline of the needed work will be described:

- Requirements analysis
- System architecture upgrading
- Further modelling activities
- Upgrading of subsystems
- Enhancements of system integration
- Additional live demonstrations
- Further research regarding
    - autonomous behaviour of unmanned systems operating as a squad
    - methods of artificial intelligence for decision support
    - methods of artificial intelligence for situational awareness improvement and situational prediction
    - algorithms of fusion of data from unmanned systems

The activities relating to Requirements analysis, System architecture upgrading, further modelling activities, upgrading of subsystems, system integration, and additional live

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demonstrations are addressed in the following sub-sections of this section. The further research activities are addressed in section 4.2.2.

3.1.2 Recommendations for Requirement Analysis

3.1.2.1 Summary of the Applied OCEAN2020 Requirements Analysis Process

The OCEAN2020 requirements analysis process was completed as part of OCEAN2020's Work-Package 1 (WP1) and was completed within the first six months of the project. Building upon standardised requirements analysis processes, such as the IEEE Systems and Software Engineering Architecture Process [R2], the work is described from the perspective of three distinct tiers:

- **Governance** – High-level guidance and activities for the planning, execution and reporting of the requirements analysis tasks.
- **Management** – The process for planning, running and monitoring the development of the tasks according to the direction provided by the governance.
- **Description and Evaluation** – Activities and toolsets required to execute the tasks.

3.1.2.1.1 Governance Approaches Applied to OCEAN2020 Requirements Analysis

At a governance level, the completed work was structured in accordance with the Grant Agreement, with the all of the Requirement Analysis tasks preceding System Design (WP2) and subsequent work package tasks, such as Technology Development, System Integration and Trial Planning. An overview of the logical governance structure within WP1, developed following an analysis of the Grant Agreement, is provided in Figure 1. Within this structure, two main areas of requirements analysis were identified.

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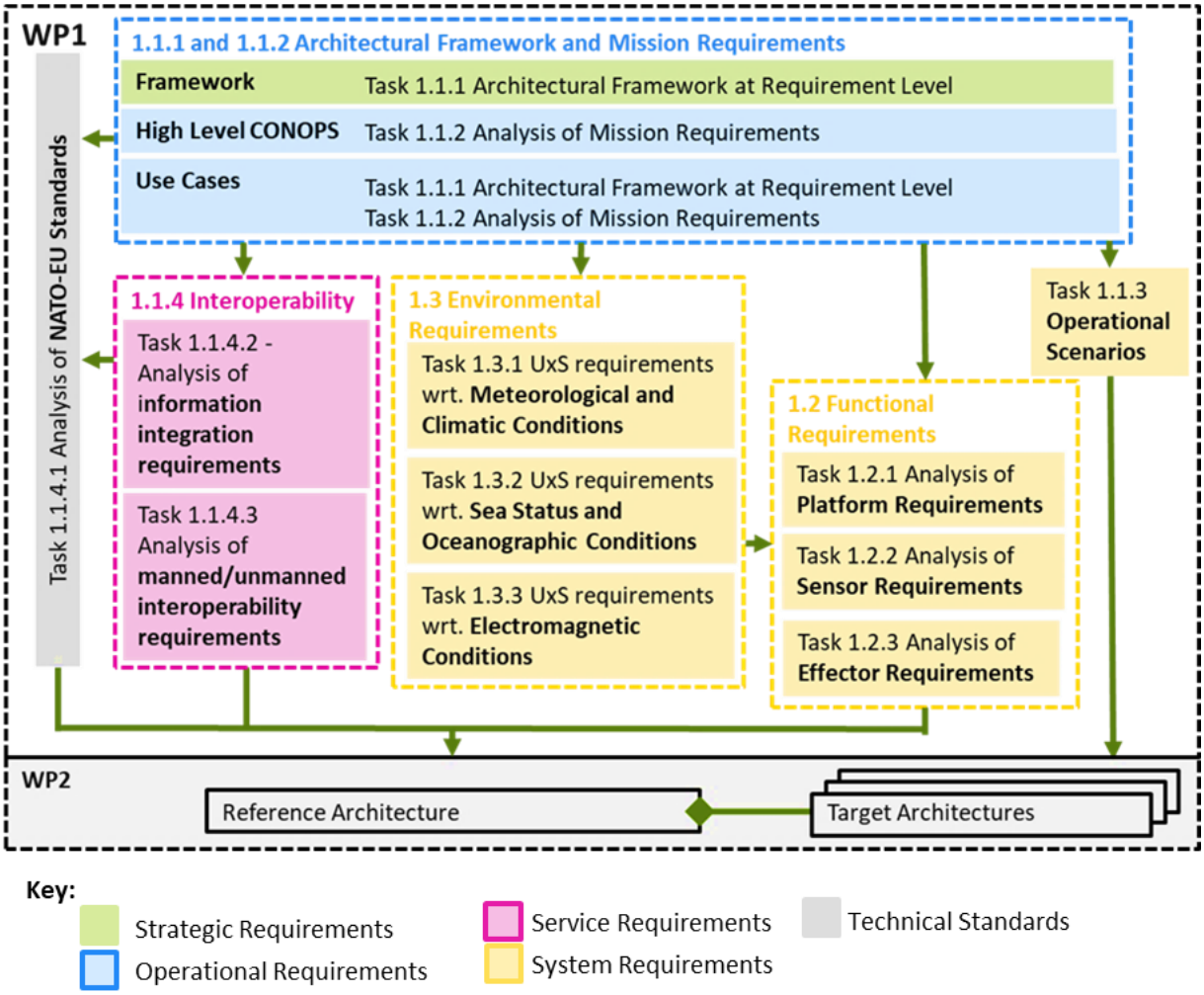

Figure 1 – NATO Architectural Framework (NAF) Dependency Diagram of the Derived Requirements Analysis Governance Structure

The first was the elicitation and analysis of the strategic and operational requirements, generated as part of the work to create a Framework, CONOPS and Use Cases. These initial outputs articulated the high-level goals, capabilities, scenario areas and information flows that would be used to define the areas of interest throughout the requirements analysis tasks. The second main area of work created the service and system requirements required to specify interoperability, environmental functional needs.

As planned, the generation of all WP1 outputs were completed and finalised within the first six months of the OCEAN2020 project with the outputs allowing work to proceed in the generation of the reference and target architectures as part of the project's WP2.

Throughout each of these tasks, related standards were identified, analysed and recorded, with references made from the requirement set where required. To support discussions

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between the stakeholders and validate requirement sets, a set of relevant operational scenarios were also generated and maintained.

3.1.2.1.2 Management Approaches Applied to OCEAN2020 Requirements Analysis

At the management level, a Pugh Analysis based selection method [R3] was utilised to identify the most suitable approach to planning, running and monitoring the execution of the WP1 tasks within the consortium. The process selected to guide the work was the Institute of Electrical and Electronics Engineers (IEEE) System Life Cycle Process [R4]. Specifically, a key element emphasised in the application of the IEEE process was the adoption of iterative and recursive requirement elicitation and analysis techniques.

This processes shares the approach of agile development activities, where initial actions are taken to identify a minimum viable product (MVP) set of requirements that cover the complete system with a basic level of complexity. These requirements then form a baseline set of the requirements that can be reviewed, discussed and added to develop complexity and completeness in the required areas. A schematic providing and overview of this approach can be seen in Figure 2.

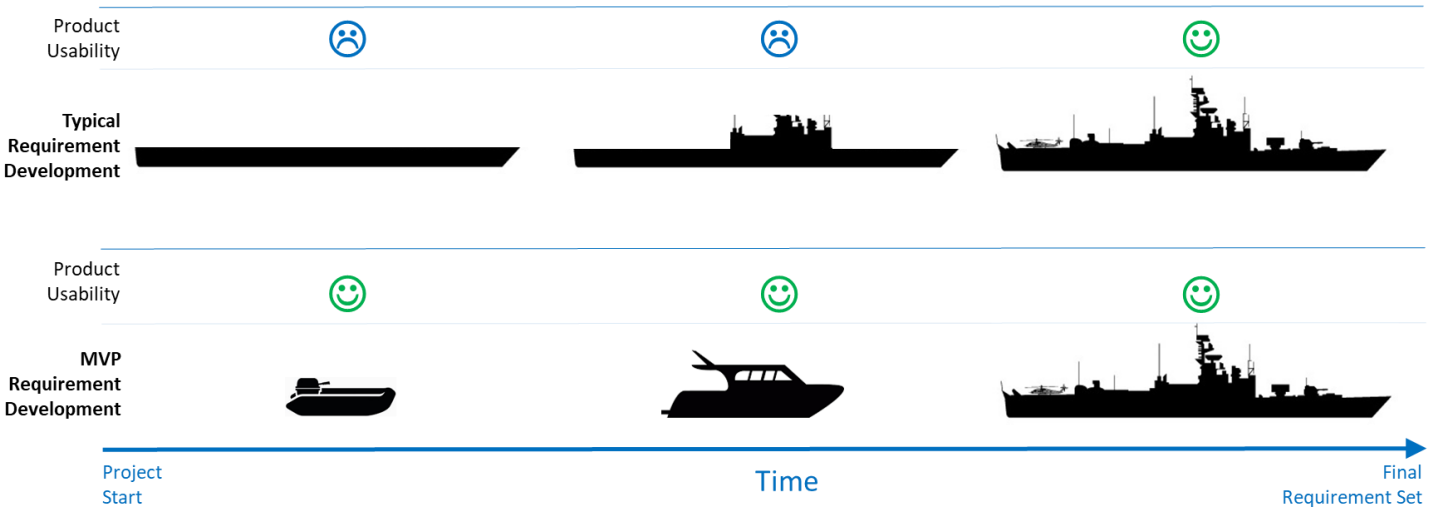

Figure 2 - Comparison of typical and MVP requirements coverage throughout the elicitation process.

The practical application of requirement elicitation, analysis, problem resolution, prioritisation and feedback were repeated throughout a high-paced series of workshops with a wide range of project stakeholders. Within each of the workshops summarised in Figure 3, one iteration of the process to elicit requirements, prioritise them, identify conflicts and validate the updated requirement set was made.

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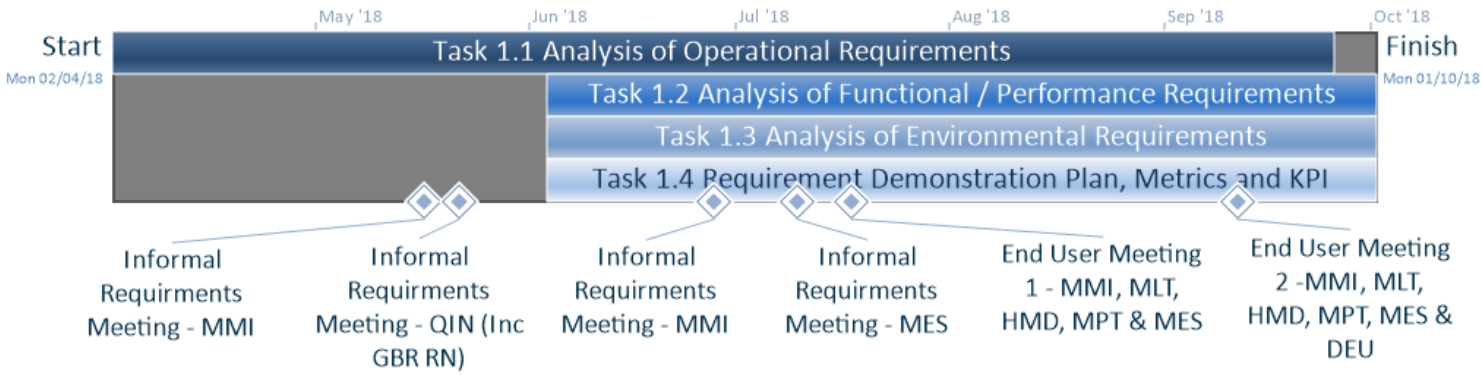

Figure 3 – Overview of the End User requirements analysis events held throughout the execution of WP1.

3.1.2.1.3 Description Approaches Applied in OCEAN2020 Requirements Analysis

To facilitate the application of the IEEE based management process among all areas of WP1, several tailored toolsets and approaches were developed and utilised at the Description level. A Model Based Systems Engineering (MBSE) approach allowed a central requirement set to be communicated via a variety of conceptual model views, with each view being implemented by following guidance from the NATO Architectural Framework (NAF) [R5] toolset. Within the NAF toolset, particular emphasis was placed on views that supported the conceptual analysis of requirements within the operational community with requirement elicitation activities focussed around the use of NAF Logical Concept Views to describe scenarios and Logical Activity views to link the requirements to architectural elements for the subsequent review and verification activities.

The key outputs of the activities included not only the required deliverable documentation, but also an Enterprise Architecture and a database of requirements. Within these outputs, the Enterprise Architecture providing the linkage between each of the project elements and the related requirements with a series of NAF conceptual models and a repository of workshop outputs and requirement rationale. The database of requirements provided a baseline reviewed of requirements that informed the project Requirements Demonstration Plan (RDP). Each of these outputs was passed to each of the subsequent work package owners which, in turn, were further elaborated to support the project across many specialised areas. One example of this can be seen in the further requirements analysis activities executed as part of the IEEE Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP) [R6] to support modelling and simulation in WP3. Each of the resulting deliverables were unclassified, with annexes containing restricted information where required.

3.1.2.2 Conclusions and Recommendations - Potential areas of strength observed within the applied process

Through the execution of the requirements analysis activities described within this document, a range of challenges were identified and overcome, presenting the opportunity to observe

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potential areas of strength within the actions taken. One key theme throughout the identified challenges may be the concept of multi-community integration, brought about by both the wide scope of the multi-domain, multi-discipline project as well as the organisational complexity of a project that involves stakeholders from different backgrounds from across Europe. These challenges were successfully met by actions taken across each of the levels of the architecture process.

Within the Description layer, the utilisation of the NAF toolset to support MBSE conceptual modelling activities and provide a series of tailored views to each stakeholder was understood to have provided a significant benefit. Beyond the clarity provided by communicating with logical diagrams, the discussions required to collaboratively discuss, model and analyse each of the requirement areas allowed the elicitation of not just requirements but also their priority and the rationale for their inclusion.

The use of the MVP approach to rapidly develop a complete requirement set allowed the scope and boundaries of the project to be identified, articulated and agreed by all stakeholders in the first few weeks of the project. The remainder of the effort in the requirements analysis phase could then be spent identifying and eliciting further detail in the areas that were of either high innovation or high end user need through iterative and incremental processes.

The successful application of this iterative and incremental requirements elicitation and analysis management process can be inferred from three indicators: The high the number of requirements analysis workshops held, the wide range of stakeholders present and the number of discussion points covered at each. By balancing the presence of the End Users with representatives from the project's system providers and partners from subsequent work packages, the resulting discussions and requirements analysis outputs iterated towards a consensus of identified requirement sets that were both operationally relevant and demanding, while being technically feasible and achievable within the scope of the OCEAN2020 project.

Finally, by utilising the structure of the work package to provide governance across each of the requirement analysis areas, the resulting requirement was well aligned with the objectives of the grant agreement. With reference to the final deliverables from WP1, the successful adoption of each of the items and their use to drive the progress of each of the subsequent work packages has been observed. Examples include the use of the Enterprise Architecture to structure the system design activities in WP2 as well as the use of the requirements database and populated Requirements Demonstration Plan to facilitate the possibility to utilise DSEEP guidance within WP3. Further, the creation of an unclassified core requirement set, with classified annexes where required, has aided the dissemination of the complete requirement set throughout subsequent project activities.

3.1.2.3 Conclusions and Recommendations - Potential areas of opportunity observed within the applied process

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Observations have been made that may be used to identify areas of opportunity to support future requirements analysis activities. One such observation is the restriction placed on the requirements analysis process by the inferred need to complete all WP1 activities before the execution of the systems design in WP2. Conversely, standardised architecture development processes, such as those from the IEEE, recommend that requirements analysis should continue throughout the design processes of a project. This approach commonly brings two key benefits. The first is that, while the analysis of an initial requirement set is vital to allow the progress of subsequent design activities, the continued maintenance of this requirement set is encouraged. The rationale behind this approach is that, even with the best-reviewed requirement sets, during the design phase further trade-offs and discussions between the stakeholders will inevitably be required. Further, as all parties required in the design and demonstration of the project elements continue to increase their knowledge about the problems to be addressed and the capabilities of the solutions provided, new requirement areas may emerge. In each of these cases, the on-going review, refinement and update of the requirement set will provide the ability to properly inform the decisions made and provide the tools required to capture the rationale for use in future activities. The second key benefit is that, by implementing an iterative approach, initial requirement sets are likely to be available very early in the project. These early requirements sets are valuable in their ability to bring forward the execution of the system design and development activities that, in OCEAN2020, were executed as part of WP2 and WP3 after the completion of WP1.

A further observation is that the outputs required by the adopted governance structure did not fit clearly with any of the standardised processes considered, leading to assumptions having to be made to tailor the standardised approach to achieve the content of each of the requirement areas. Due to this task specific tailoring, the fidelity level of each of the requirements areas was not necessarily aligned. To better align the fidelity of the requirement sets across the project, the selected IEEE management process recommends a structured approach to the identification of system actors, elements and requirements as governance steps before commencing the requirements analysis process. An overview of these steps is provided in Figure 4.

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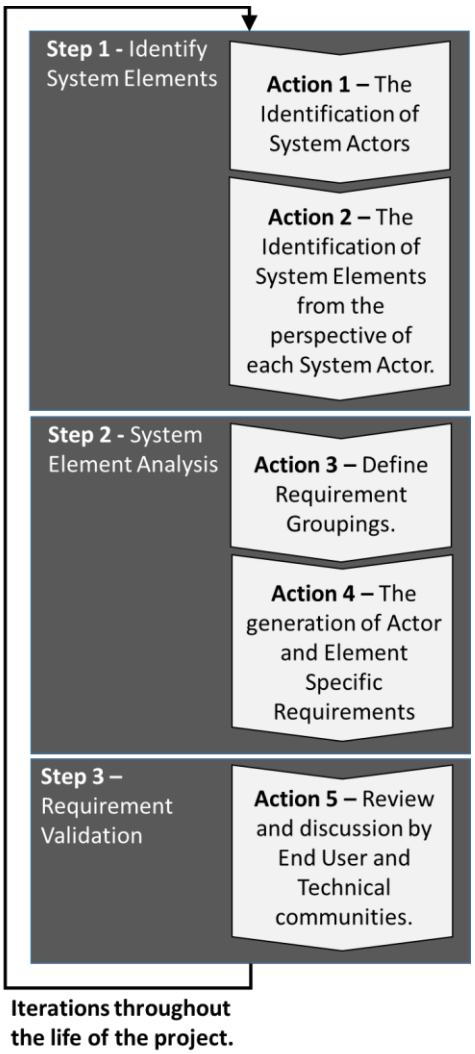

Figure 4 – Summary of a structured approach to the identification of project requirement areas.

One opportunity to better support the execution of standardised requirements analysis processes, such as the one shown in Figure 4, is for the process stages and their outputs to be considered and aligned during the generation of the project's Work Breakdown Structure (WBS). While further investigation may be required, this approach could simplify task allocations by enabling the reuse of standardised and centrally referenced guidance among consortium members, while simultaneously incorporating industry best practice to encourage the creation of high quality and reusable requirement sets.

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3.1.2.4 *Conclusions and recommendations for requirements analysis – A bullet point list of key findings*

With the aim of building upon the detailed observations and discussion presented in sections 3.1.2.1, 3.1.2.2 and 3.1.2.3, the following recommendations to support future requirements analysis activities are suggested:

- *Governance level recommendations* - Further focus should be placed on iterative requirements analysis efforts throughout the project lifecycle, not just the first few months of the project. Continued spirals of requirements analysis activities are expected to increase the completeness of the requirement set and the quality of the resulting solutions. Further, this approach may enable the acceleration and early starting of design and development activities in future projects.

- *Governance level recommendations* - The alignment of the expected outputs against commonly used requirements analysis standards could allow a more rapid and efficient start-up in complex, multi-domain project consortia. This alignment to standardised guidance may also improve the quality and completeness of delivered documents towards the end of the planned activities.

- *Management level recommendations* – The MVP approach to requirements development allows the complete scope of the project to be understood, communicated and agreed by all stakeholders in the first weeks of the project. Once defined, efforts can effectively and efficiently used to develop the maturity of key requirement areas using agile and iterative methodologies.

- *Management level recommendations* – The ability to generate sharable unclassified deliverables with restricted information contained within separate annexes increased the share-ability and impact of the requirement set. This approach could be considered a best practice and should be considered in future multi-stakeholder programs.

- *Description level recommendations* - Further investigation should be made into the application and refinement of MBSE approaches in support of multi-national, multi-domain projects. Specifically, the use of NAF as a concept modelling toolset provides an established baseline of views and approaches that can be used to remove barriers between communities and increase the completeness and quality of future requirement sets.

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3.1.3 Recommendations for System Architecture upgrading

3.1.3.1 General considerations

The recommendations related to the upgrading of system architecture presented at the moment of writing this document are based upon the following inputs:

1) The design delivered at the first part of the project cycle, which provides a proposed architecture and also a body of guidelines and capabilities that serve not only as a basis for the deployment of the live demonstrations, but also as a project takeaway and a reference for future developments
2) A summary of lessons learned from the specific live exercises that took place in November 2019 during the Mediterranean Demonstration campaign
3) A set of direct recommendations obtained from the elicited experience in the points above, which are related to the Target Architectures

The figure below summarizes the process of elaboration of recommendations.

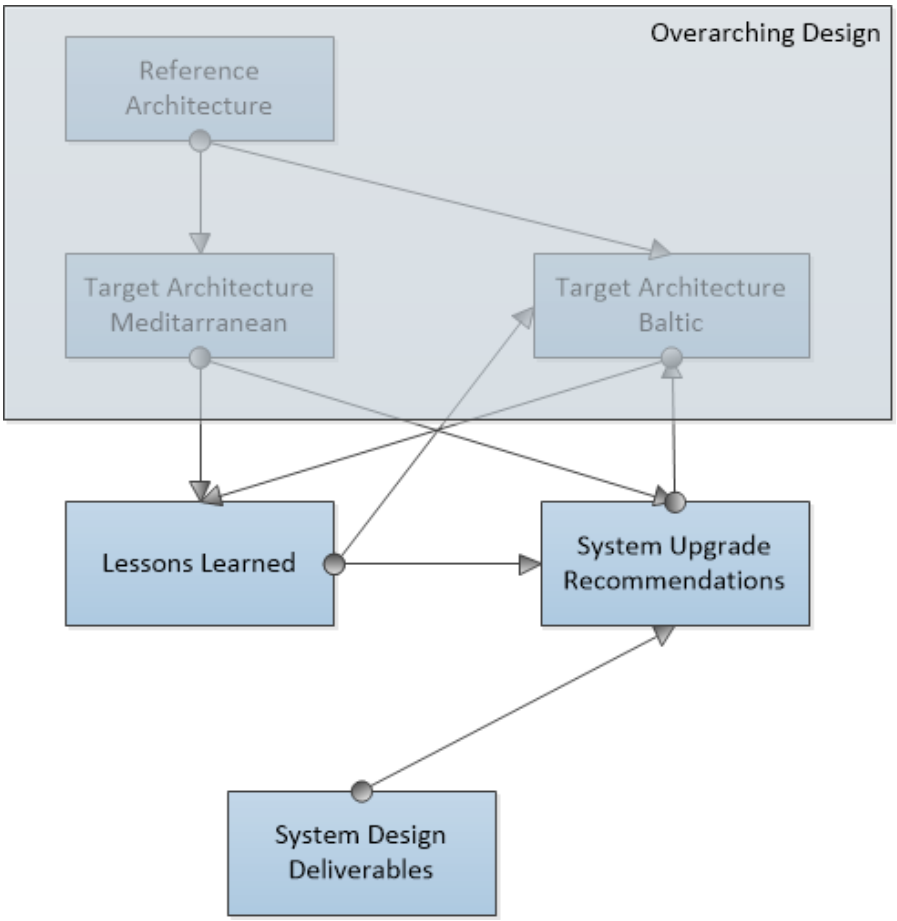

Figure 5 – Process of elaboration of recommendations

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3.1.3.2 OCEAN2020 System Design Framework

The overarching architecture of the OCEAN2020 is based on the NATO Architecture Framework [R5]. An overarching architecture is a description of the desired configuration of a C3 system necessary to meet the organisation's medium to long-term (up to 15 years) requirements (see e.g. Erskine, [R18]). Consequently, the OCEAN2020 is by definition already providing guidelines and recommendations within the documentation contained in the System Design deliveries, and with this object in mind, these documents should be approached.

Reference architecture is an implementation-independent perspective that captures operational business processes, information products, user requirements, interface specifications and logical architectural patterns. The Reference Architecture proposed by OCEAN2020 is given in [R11].

The proposed Reference Architecture is focused on the Maritime Domain, according to the OCEAN2020 mandate and scope. However it has been noted the need to take into account the interrelation between domains that cannot be ignored in the implementation of joint international operations [R30]. This is particularly the case for the consideration of the Cyber domain and the Space domain. Future updates of the architecture might take this approach into account.

Cyberspace is defined in Joint Operations [R20] as "a global domain within the information environment. It consists of the interdependent network of information technology infrastructures and resident data, including the Internet, telecommunications networks, computer systems, and embedded processors and controllers".

In fact, specific aspects related to the Cyberspace domain are addressed in the deliverable D2.7 Security Design [R26]. Here, particularly the functionality of the Security Operations Center is proposed. The SOC is not part of the current OCEAN2020 architecture. However the presence of such entity for purposes of cyber security is highly necessary and required to be a subject of future approaches.

An equivalent discussion can be considered for the Spatial Domain, which is not part of the OCEAN2020 scope. However the *Satellite imagery integration* is specifically identified as a capability within the OCEAN2020 overarching design, and at design level the space assets that have participated in the Mediterranean Demonstration are described in the deliverable *D.12 Specification of selected Space Assets* [R31] The Demonstration of November 2019 has already demonstrated the importance of this domain within the naval operations, not only for providing the required communications at sea but also as a source of information for the construction of the maritime picture.

A target architecture is derived from the related reference architecture and specifies the design at a sufficient detail to direct the acquisition and integration of components to achieve a desired capability [R18]. The Target Architectures for the Mediterranean and Baltic Sea

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demonstrations are provided in the corresponding annexes of the OCEAN2020 deliverable *D2.1 Overarching Design* [R19].

The deliverable *D2.13: MOC Integration Design Guidelines* [R21] targets to set an outline for the development and implementation of future MOC systems. Main aspects addressed in this deliverable are the following: design of tasking and planning, integration of data/images and information fusion, RMP enhancement, behaviour analysis and design of external interfaces.

The list below provides the reference to other design documentation that introduces guidelines for the development of the different systems involved in the project:

- D2.2 Data Fusion Analysis Report [R22]
- D2.3 Video Analysis Report [R23]
- D2.4 Decision Support Analysis Report [R24]
- D2.6 Electromagnetic Engineering Design [R25]
- D2.7 Security Design Report [R26]

3.1.3.3 Summary of lessons learned during the implementation of the Mediterranean Sea demonstration

During the execution of the Mediterranean Sea demonstration, a set of problems or points for improvement in the system architecture were identified

A first evaluation of lessons learned from the demonstration can be obtained from the deliverable *D6.3.1: Mediterranean Sea Trial Result Evaluation Report [R33]. Chapter 5 in this document provides lessons learnt on the following areas:*

- Lessons learnt on trial organisation and execution
- Lessons learnt at operational level
- Lessons learnt at technical level

Particularly the lessons at technical level can be used as a source for elicitation of recommendations for upgrading the system architecture.

In addition to these, some considerations obtained from the demonstration are provided in the following paragraphs. These are particularly relevant for the contents of the proposed upgrades described in the next section.

Use of norms and standards

During the exercise, three main standards were used for the information exchange between the MOC and the various assets deployed (including CTG). These standards were STANAG 4609 for sending video, STANAG 4676 for sending detection and tracks information and STANAG 4586 for sending assets and vessels telemetry.

These standards have enough capacity to cover the operational needs of information exchange. However, the standards and norms are designed to give global coverage to a generic

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type of problem or need. For their application to specific problems, they usually require adaptation or common interpretation among the entities that will use them for information exchange.

For example, some fields of the information to be exchanged may be marked in the standard as optional and yet in their application to a specific environment they should be used as mandatory.

Also, in some cases it is necessary to give a specific content to a generic field, such as the id of a track. For application in some environments it will be enough to fill in this field with a number. However, in other fields it must be filled with a sequence of characters or predefined code between the entities that are going to communicate (for example, "ID_source-ID_track").

The same type of adaptations may be necessary in the case that it is necessary to communicate two entities by means of a standard that marks one of the fields as mandatory, but whose information is not available. In this case, values such as "unknown" or "not available" are usually used.

During the initial tests carried out for the Mediterranean demonstration, the need to mark a series of rules for the use of the protocols (STANAG 4609 Video, STANAG 4676 Tracks and STANAG 4586 Telemetry) was detected for the correct interpretation of the information between the different entities that communicate.

To give an example, during the tests it became necessary to communicate AIS tracks using STANAG 4609. An AIS track has three possible identifier types: MMSI, IMO and CALL SIGN. In this case it was necessary to establish a commonly used rule that the MMSI field would always be used in the track id field for AIS tracks.

Also, in the case of the use of STANAG 4586 for video it was necessary to deactivate some validations at the time of receiving the information, since the standard establishes a set of obligatory fields that during the tests were not present.

The situation described refers to the practical implementation of the interface modules of the application handling the data within the specific instance of the Mediterranean demonstration, and represents a typical situation for this kind of system deployments. In this case the implementation of STANAG 4676 to include AIS tracks information, and STANAG 4609 for video were necessary to be adapted.

Communication channels and alternative routes

Sending information from UxV to MOC required the use of communications channels with limited available bandwidth, sensitive link establishment or high latency time.

The possibility of a communication channel presenting problems or failures was high, so it was necessary to establish contingency plans to mitigate as much as possible the loss of communication.

Static configuration of information providers and consumers

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The process of deploying the systems and their configuration and preparation for the execution of the Mediterranean Sea demonstration was one of the most time-consuming tasks. It was necessary to know in advance which sources of information each system would provide, as well as the systems that would consume such information.

This meant that the configuration of the systems was a critical element and lacked flexibility.

Establishing alternative communication channels to mitigate the effect of a failure or breakdown in the main communication channel was a time-consuming task during the execution of the exercise.

Video formats

During the Mediterranean Sea demonstration, video was sent between the different systems using the MP4 / H.264 format, along with the metadata set specified by the STANAG 4609 standard.

During the demonstration, priority was given to the reception of real time video with the highest possible quality, meaning a very high frame rate and high image resolution. However, due to the communication channels used for video transmission, the video did not always arrive with the expected quality. This problem was usually caused by some instability in the radio communication channels (satellite communication, VHF) through which the video signal had to pass and which caused cuts in communications, decrease in the available bandwidth or increase the transmission latency.

3.1.3.4 Recommendation for System Architecture upgrading

The recommendations below relate to the following generic systems, as defined in the Reference Architecture:

- MOC: the specific systems depend on the different architecture implemented in the particular MOC (for example National and EU MOC). These can be identified in the Target Architectures and the particular MOC implementations. The system affected are those that implement the functions of *Information Exchange* and *Build and Present RMP*
- Unmanned System: Unmanned Vehicle, Unmanned Control Station.
- Naval vessel: CMS, tactical datalink

According to the problems and points of improvement found during the MOC implementation of the Mediterranean Sea demonstration, the following improvements are proposed:

Use of norms and standards

The different norms and standards define a framework for the information exchange between the different systems. However, there is a need to develop agreed specifications for the use and implementation based on the real needs of information exchange between the systems.

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In many cases, the standards and norms are designed to define the information exchange between systems in a very generic and unspecialized way. This allows the standard or norm to be used in many different environments.

However, when the standard or norm is used in a very specific environment, it is necessary to define common and agreed set of use rules that specify de details of use of the standard or norm, optimizing and clarifying the use.

This specification may not be unique if the application of the standard or norm is made in different environments within the same scope, as explained in section 3.1.3.3 above (Use of norms and standards)

Static configuration of information providers and consumers

The static or manual configuration of the available sources at any time in the systems interconnection is a great waste of time and resources.

To improve this aspect of interoperability between systems, it would be necessary to establish a communication procedure by which the different systems could publish or announce the information sources that are available at any given time, as well as the details of these sources, including formats and security restrictions if any.

Also, if an information source has alternative communication channels for contingency purposes, this contingency configuration should also be shared with the potential consumers. In this way, if during the operation it is necessary to use the contingency communication channels, the change of channel would be totally transparent for the operator and the loss of information in the process of changing the contingency channel would be minimal.

Before the execution of the Mediterranean Demo it was necessary to establish a complete list of the different sources of data available during the demo, as well as the set of consumers who would receive such information. With the tables of producers and consumers, the configuration of all the network architecture was defined and applied to the main communications node. The main advantage was the possibility of validating the different communications paths before the demo. But it also had as a disadvantage the rigidity when implementing changes in the transmission between transmitter and receiver.

If during the demo it was necessary to incorporate the information from a sensor or system not foreseen before the demo (a situation that can appear in the real execution of missions), it would have been very complicated to implement the necessary changes.

In the case of the Baltic demo, the architecture proposed allows to ask the system what information is available in real time and to subscribe to the information flows available at any time. The advantage is flexibility and adaptability. The disadvantage is that the protocol used to carry out all this communication is not based on standards, but on an ad-hoc developed protocol.

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Video formats

Video in MP4 / H.264 format sent through networks with low bandwidth or with unstable links causes the video sent to have a very low quality.

Depending on the needs of the mission being executed, it would be important to define what the main need for video reception is.

If the main need is focused on the details of the image, a configuration based on sending full consecutive frames would be the most appropriate (for example, the use of MJPEG). However, the use of this type of format would cause the loss of continuity in the movement of the video. Full frames with all the details would be received but there would be a long time between the frame refresh depending on the available bandwidth.

On the other hand, if the needs of the operation imply the need to have detail focused on movement and action, the use of formats such as H.264 would be more appropriate, taking into account the nature of the communications systems on which the information will circulate for the configuration of the encoding.

3.1.4 Recommendations for further Modelling activities

3.1.4.1 Summary of the OCEAN2020 Modelling Activities

One perspective on the modelling activities within the OCEAN2020 project made be taken by considering the flow of requirements from the strategic requirement sets, discussed in 3.1.2, through to the developments made as part of the Modelling and Simulation (M&S) activities in WP3. Within this context, conceptual modelling activities took place throughout WP1. Supported NAF guidance, the aim of this modelling was to mitigate any cultural and communication barriers that may exist within the consortium and to develop a common understanding of the project scope, architectural design and technical solutions. This activity resulted in an agreed requirement set and an Enterprise Architecture that could guide the technical development and integration activities as well as a Requirements Development Plan (RDP) that could be used to guide the activities of WP3. Indeed, these resources were used as inputs to subsequent modelling and simulation activities.

Within WP3 in the following domains modelling has been conducted:

- Modelling of UxS deployment, specifically autonomous behaviour of aerial, surface and underwater unmanned systems as well as their swarming behaviour.
- Modelling of flexible sensor suites.
- Communication and electromagnetic modelling to simulate controls and data exchanges over a network of unmanned and manned systems, and ashore centres, especially in the electromagnetic conditions of a contested environment
- Modelling of Electronic Protection Measures to ensure resilience of radio/satellite communication in contested environment.

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- Modelling the effects of meteorological and climatic conditions, sea state and oceanographic conditions on UAS/USS/UUS launch and recovery.

Each of the models described have been developed within a network of specialist industrial and research centres located throughout Europe. In order to contribute the specialist knowledge available within each centre into a single simulation capability, a distributed simulation architecture has been developed. Information can be exchanged between the distributed simulation laboratories in real time, allowing the evolution of a scenario to be run based on the outputs from each model. Further, areas of particular interest can be investigated in detail with off-line high fidelity models. The information obtained from these investigations can be used to inform the parameters and outputs of the system models. A detailed description of the simulation capabilities developed within the project are provided in the Systems Simulation Design Description [R29].

Guided by the guidance provided in the IEEE Distributed Simulation Engineering and Execution Process (DSEEP) [1], shown in Figure 6, the mutual understanding gained in WP1 was further analysed to identify the Needs and Objectives for a series of three simulated trials, staring with a first trial in support of the Med Sea live demonstration.

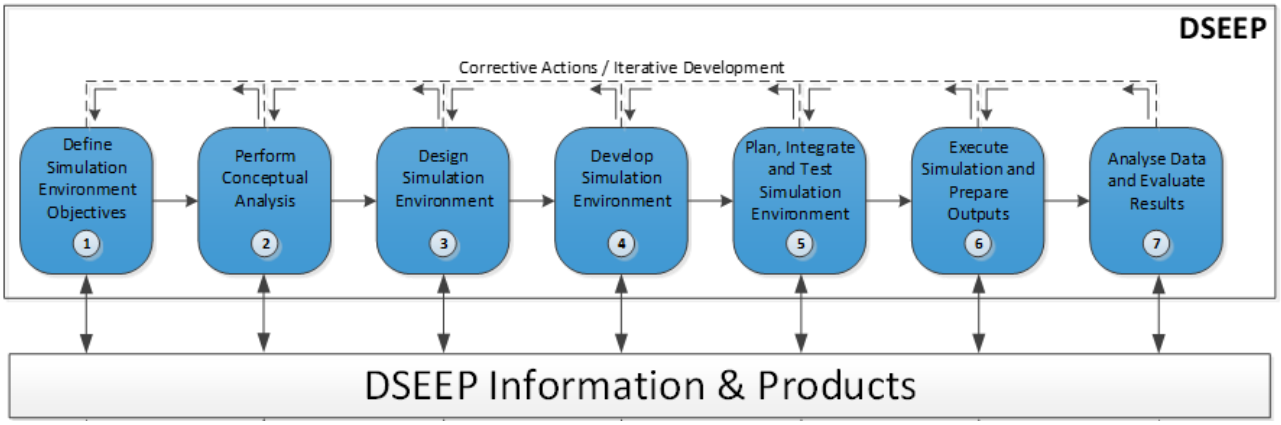

Figure 6 – Seven steps of the DSEEP process

The analysis within the first step of DSEEP identified four central needs of modelling and simulation activates:

- De-Risking – *Will the live trials work*
- Complementing – *Will the architecture work in complex conditions? How? What if…?*
- Integration – *How to assess new technologies developed for the project?*
- Demonstrate – *Based on the content of the RDP*

These needs drove the subsequent activities of detailed conceptual modelling to support the development of a simulation capability that would be used in the series of simulated trials. At this level, conceptual models were generated to represent key elements of the capability such as platform kinematics, sensor capabilities and environmental conditions; an example output from this process is shown in Figure 7.

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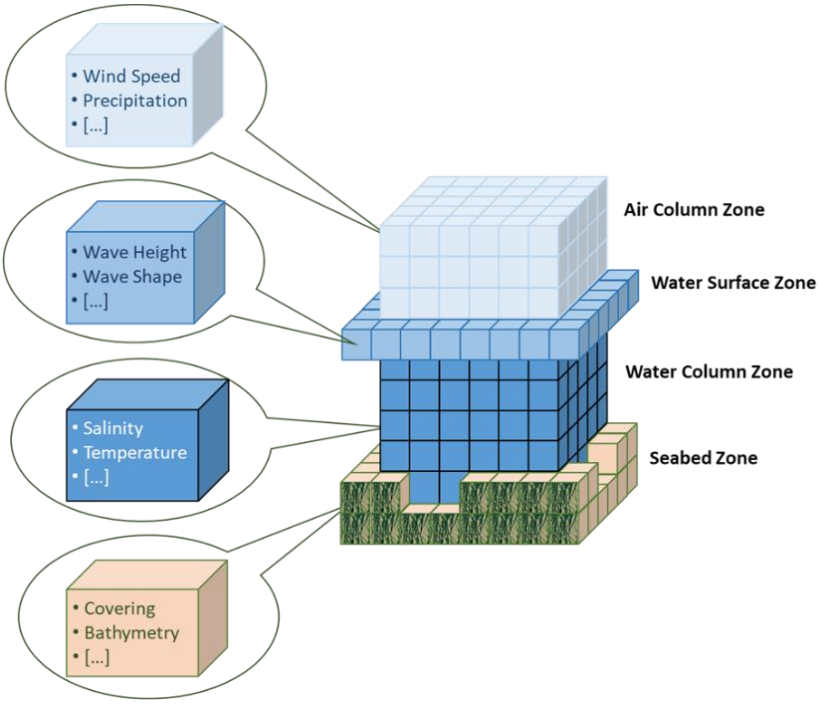

Figure 7 – Conceptual model of the simulation capabilities environmental conditions

Continuing through the DSEEP steps, these conceptual modelling activities supported the cooperation and collaboration of WP3 partners to generate a distributed simulation capability that was demonstrated in the first simulated trial. Combining expertise from a variety of research institutes and industrial partners across Europe, this simulation capability was able to further assist the validation of the complete OCEAN2020 system with technical partners, end users and project sponsors.

3.1.4.2 Potential areas of strength observed within the Modelling Activities

During the execution of WP3 activities described in 3.1.4.1, modelling covered a range of activities from conceptual modelling with the aim of identifying operational concepts and their related requirements to the development of computer-based models that allow users to experiment with components of the OCEAN2020 system.

As described in section 3.1.2 of this report, the use of conceptual modelling resulted in a shared and understood enterprise architecture and requirements set contained in the RDP. It was observed that each of these WP1 deliverables could be used as inputs to the DSEEP process of WP3. Particular synergies were found in the re-use of conceptual models generated as part of WP1 that were further elaborated as part of DSEEP steps 2 and 3 before providing an input for the development of the computer based simulation capability.

The resulting M&S capability was demonstrated in the first simulated trial, reported in [R27]. It was observed that this trial encouraged the technical community to demonstrate the

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operation of system components, which can be difficult to articulate across communities. One such example of this can be found in the work of the underwater data fusion modelling, where multiple system interactions generate contact location errors that are subsequently filtered, quantified and communicated into the command and control (C2) system. The ability to articulate the operation of each of these system elements, along with the final data produced, encouraged further communication among end users and project sponsors which, in turn, is expected to enable the benefits of the technology to be realised.

Further cases and examples of the use of M&S to support the cross-community collaboration within the project can be found in the Systems Simulation Design Description [R29].

3.1.4.3 Potential areas of opportunity observed within the Modelling Activities

The process to link the outputs of WP1 to the work of WP3 has demonstrated the ability for modelling to connect communities with the aim of identifying and resolving a range of challenges. One observation is that the use of a more structured approach to the identification of areas of interest and the use of modelling to drive developments could increase the impact of these activities. One suitable approach may be the application of Concept Development and Experimentation (CD&E) [R7] principles that, supported by increasing the fidelity of conceptual models, encourages the iterative development of operational concepts into detailed models and requirement sets. A further observation is that, as recommended by DSEEP, the continued interaction of stakeholders such .as end users and project sponsors will further increase the relevance and value of all modelling activities. These activities can be supported with a range of verification, validation and accreditation (VV&A) activities.

The simulated trials described in the Simulation Trial Plan [R28], focuses on the four modelling and simulation objectives presented in section 3.1.4.1 of this document:

- De-risking
- Complimenting
- Integration
- Demonstration

Interaction with stakeholders is a key component in each of these objectives. To ensure that this interaction is maximised, Simulated Simulation Design Documentation [R29], utilises the DSEEP [R6] process to structure and support stakeholder interaction

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3.1.4.4 *Final summary of the identified modelling activity conclusions and recommendations*

Following the discussion of the key modelling activities, from the perspective of WP3, the following recommendations may be offered:

- Further investigation should be made into identifying the potential of processes that encourage conceptual modelling as part of the requirements development, such as the DSEEP process, across a variety of project areas.

- Further investigation should be made into the quality improvements and project synergies provided by the alignment of conceptual modelling activities that support strategic, operational and systems requirements development and the subsequent conceptual modelling activities of the DSEEP guidance [R1]. One such approach may be found in the NATO CD&E methodology [R7].

- To improve the value of all modelling activities, further consideration should be given to continuous and iterative verification, validation and accreditation (VV&A) by all required stakeholders, including end users and project sponsors.

- Further emphasis should be placed on the use of computer based modelling and simulation activities to explore, articulate and identify the applications and benefits of emerging technologies throughout the project.

- Even if promising results have been achieved and are expected to be produced within the next period of OCEAN2020, additional research effort is needed in all the above-mentioned domains (modelling of UxS deployment, modelling of flexible sensor suites, communication and electro-magnetic modelling, modelling of Electronic Protection Measures, modelling the effects of meteorological and climatic conditions, sea state and oceanographic conditions on UAS/USS/UUS launch and recovery).

3.1.5 Recommendations for upgrading of Subsystems

Conducting effective reconnaissance missions, at present and in the future, will require systematic improvement and development of systems. Particularly, in the field of gathering essential information aimed at achieving operational tasks. The modernization of systems will include the replacement of sensors (detectors) on new one, having higher working parameters and advanced processing, arrangements of the data handling and display, as well as the data transmission.

These subsystems should be open to modifications and updates, according to the highest standards, in order to provide their optimal usage. They should be considered in the role of

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effective system of decision-making (Decision Support System), based on elements of the artificial intelligence. Due to the growing requirements in this area, it is essential to gradually implement new techniques and technology.

Development of surveillance and reconnaissance systems for the purposes of MSA (Maritime Situational Awareness) is closely connected with widespread usage of unmanned platforms of different types and applications, such as UAV, USV and UUV.

Concept of subsystems designated to gather information should be based on the assumption that all basic tasks will be executed by the group of air, surface and underwater unmanned vehicles, optimized structurally and based on modular elements. As a goal, unmanned platforms should be based on similar functional modules, standardized under the agreed common technical concept. Their dimensions and mass should be limited only by technical possibility of European Industry and usability for the effective performance of recommended tasks.

Building of new systems should be realized in accordance with European and NATO standards. Inside areas non covering multinational norms, national norms should be applicable. The update of defensive norms and standards should be led systematically with reference to conducted modernization works.

3.1.5.1 Maritime Operational Centres

As specified in the OCEAN2020 MOC definition (see Overarching Design [R19]): “The MOC is an extension of the commander; its sole function is command support, and its authority is delegated to it by the commander”. How the creation of a system based on data processing can help the role of the Commander is described for example in CESEDEN [R34].

The MOC capabilities demonstrated in the scope of the OCEAN2020 relate among other to the following Joint Functions (See Joint Operations [R20]): Command and Control, Information and Intelligence. Particularly, “the information function encompasses the management and application of information and its deliberate integration with other joint functions to change or maintain perceptions, attitudes, and other elements that drive desired behaviours and to support human and automated decision making” and “the intelligence function supports this understanding with analysis of the Operational Environment […] to help commanders and staffs understand and map friendly, neutral, and threat networks.”

Related to the above, the MOC system upgrades suggest to converge to a data centric system instead of a sensor centric one: this means that the capabilities of real time analysis and processing of big amounts of data, that have been made available over the last two decades, might facilitate a systemic creation of knowledge, from diverse and heterogeneous sources, and replacing previous MOC concepts based on modular and independent sources of information.

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Equally, the human based appraisal of the operational environment, subjected to the natural limitations of the human brain and tendency to decision bias, is to be supported and corrected through automated, knowledge based appraisal of the operational environment founded on historical data and statistical inference. A high level review list of these potential capabilities is also given in CESEDEN [R34]. Specific examples of these techniques are provided in the project documentation that is specified in the section 3.1.3.2 *OCEAN2020 System Design Framework* above, such as video analysis, data fusion, decision support and behaviour analysis.

Considering aspects related with MOC, it seems that training concept is inseparable link between gaining knowledge and increasing the competences of the operators. OCEAN2020 documentation includes, an idea of the European training centre was also described. It was proposed to build its competences, based on 3 values: Interoperability, Complexity and Innovation [R60].

The mission of the presented European Training Centre would be conducting training and learning for the operational level commands and the Commands of the Maritime Component of the European Union and its Member States, in order to prepare the Staff personnel for the most effective implementation of tasks and conducting operations in the three-dimensional sea space in times of peace, crisis and armed conflict. The Centre also could act as a common platform, integrating the National Training Centres to enable training tasks to be carried out in the various National Training Centres in a joint and coordinated manner.

What is more, it should supports innovation and development, because strong R&D relations with university units and other research centres. There is a Distributed EU-M&S-Experimentation Laboratory (EMSX Lab) for which first actions have been taken. In addition, the PESCO project 'Integrated European Joint Training and Simulation Centre (EUROSIM)' aims to establish a tactical and simulation hub. Future projects should build on these efforts, as can be seen in the EDIDP SVTE Call for Simulation.

3.1.5.2 Upgrading Command and Control System C4I (network centric)

3.1.5.2.1 Advanced Control Station for UxS

Modern command centres should be characterized by high level of flexibility, regarding operator positions architecture and consistency in terms of the current chain of command.

Considering tactical level of command, we should easily separate a single operator level of command which refers to UxS operator and a group of operators' level of command which refers to the CMS structure. Moreover, to cover all aspects of tactical command positions, we are obliged to include a specific type of C2 which is Commander Task Group (CTG).

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The classic approach presented on the diagram below, shows a basic common example of organization structure, wherein CTG should collect information from UxSs and CMSs and after appropriate analysis transfer to MOC in near-to-real time.

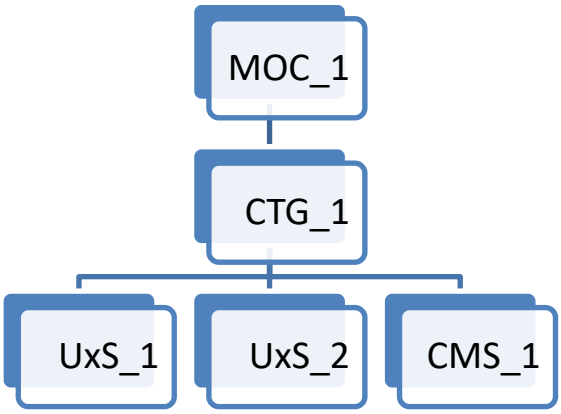

Figure 8 – CTG placing in organization structure

Advanced command and control systems (e.g. CTG) should be evolved to be able to manage not only platforms and sensor subsystems on-board, but to be able to incorporate a single UxS operator into their structure. Also operator's position will be equipped with Human-centred display technology, essential for effective work within the established Control Station.

This approach demands the particular technology solutions and applications dedicated also to the operator of UxS to create Advanced Operator Position.

Recommendation for Advanced Operator Position (in case of a single UxS):

- Improved synthetic video with 3D graphics and moving maps;
- 270° horizon Field-of-View (FOV) on multiple wide-screen graphical overlays;
- High-definition (HD) video;
- Fused, multi-source data (e.g. Link 16) into a Common Operational Picture (COP) on a single display;
- Easy to switch between automated "point and click" or manual "hands on" during flight operations;
- Ergonometric design;
- Touch-screen technology;
- Ergonomic seating for increased comfort and design;
- Increases manning efficiency with intuitive controls and data displays;
- Design validated by anthropometric/ergonomic expert from Scientific National Institute;
- Compliance with MIL-STD-1472 and other human factor standards.

On the picture below, the idea of proposed solutions is presented.

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Figure 9 – Example of AOP [1]

The Advanced Operator Position (AOP), understanding as advanced GCS, designed for collecting information's from different unmanned platforms (UxVs) and sensors. The presented approach should offer significantly improved situational awareness and reduced pilot workload. Innovations have to be directed on intuitive interfaces that are designed to make potentially hazardous situations easier to identify and to generally improve the decision-making process.

Using this highly automated GCS, the operator's role will become more supervisory in nature. In response, a new interface paradigm is required for effective supervisory control of multiple UxVs by a single operator. It is also important to ensure that the operator has adequate means to first observe and then direct the automation's functioning in order to be responsive to changes in the mission, vehicle status, or operational environment.

3.1.5.2.2 Advanced Communication between platforms and command stations -Tactical Radio Links Development

Research and Development initiatives should be focused on interim and long-term networked communication solutions that can be integrated into existing and future Unmanned Aerial, Surface and Subsurface Platforms.

[1] https://gaasimedia.wordpress.com/photo-library/ground-control-stations/

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Network Centric Communications extends line-of-sight - Communication System ought to be developed to enhance long-range reporting and data transfer. Communication pods on-board UAV could provide an aerial gateway for airborne and ground communications networks systems. Network Centric Communications (NCC) should consist of the best mix of Joint Tactical Radio System (JTRS), software defined radios, tactical data links, for example Link 16 system for UAV or Link 22 NILE for USV. For long range data transfer, SATCOM satellites should be used. Referring to Baltic see Demo Trials SATCOM should support information dominance, reliability, secure communication and enhancement of situational awareness.

NCC Required Features:

- Delivers persistent communications coverage;
- Provides range extension for aerial/ground networks;
- Bridges JTRS and other tactical waveforms;
- Provides full participation on Link 16 network;
- Digitally connects tactical edge users to sensor information;
- Communication between all elements line of sight;
- Quick-reaction capable.

3.1.5.3 Upgrading UxS

Recommendation for future development of unmanned platform should be based on full modularity and additional following factors:

- Interoperability with subsystems;
- Maintainability (easy to repair, open for preservation);
- Extensibility (possible for the enlargement and susceptible to the modernization);
- Composability (open for fast reconfiguration and interchange working modules);
- Reusability (possible for the repeated application).

To point out a difference between modularity and composability, it should be told that composability allows reconfiguring to required mission. Other side, modularity function means using only to one function or task.

New generation platforms (UxS) should be characterized by widely comprehended autonomy and possibility of independent work based on advanced deck steering systems. They have to possess ability of autonomous beginning of surveillance or reconnaissance mission (landing, launching and recovery from water). They should ensure tactical abilities of the long-term patrolling of recommended area and transfer data or image from this area to the CTG in the near-to-real time. The advanced structure of communication systems should allow data transfer between different cooperative platforms. UUVs have to cope with additional difficulties regarding communication due to the lack of radio transmission through the water.

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Although the ROVs are wire-linked with a surface asset (a ship or an USV) and data can be transmitted in real-time, it is not the case of AUVs that can transfer their data only when at surface, or using close-range underwater links with a ship or a subsea structure. Even when at surface, as the vehicle is low on water (slightly buoyant), the waves can downgrade or cut the link with the CMS. As a consequence, UUVs' autonomous level of decision is foreseen to be improved (see table hereafter). This implies an improvement of on board computing power (CPU, GPU or quantum computing), and a step increase in on board autonomous processing turning sensor data into actionable information, e.g. data quality, environmental sampling (currents, thermocline, communication channel conditions for example) and sea bottom characterisation (seabed type, clutter density). The autonomous decision making engine then must make use of all the information to ensure mission success.

Underwater communications are limited in range and bandwidth and vary widely with environmental conditions. An improvement in underwater communications is required for two principal reasons: communications between vehicles to enable collaborative autonomy and communications back to an operator for improved human-AI teaming. These two topics of course are fundamental to the take up of autonomous of the horizon squads of autonomous vehicles and require much more development and improvement. In particular, the issue of trust between humans and UUVs when there is limited communication and latency in updates of the mission.

Finally, due to the lack of GPS underwater, target location accuracy can be a significant issue for re-location and re-acquisition. The topic of underwater navigation is of utmost importance and requires significant improvement. This will become of particular consequence for covert missions.

Technologically advanced derivative of the proven unmanned platforms should characterise following attributes:

Table 3.1-1 – UxS upgrade attributes

UAV	USV	UUV
- Increased endurance - High level of autonomy - Unprecedented reliability - **Increased manoeuvrability** - D**esigned based on low visibility/signature technology** - Open, modular architecture supports integration of few payloads simultaneously, with capacity for growth - Redundant controls - Easy transportable by typical air and navy assets - Heterogeneous multilevel swarm capability with high-level data fusion		

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UAV	USV	UUV
- Real or near real time of data transfer - Satellite communications - Controlled by assigned Ground or Maritime Control Station		- High data storage capacity - Controlled by assigned Maritime Control Station - Improved Human-AI teaming
- Automatic take-off and landing launching and recovering -reduces pilot workload	- Automatic launching and recovered from water	- Reconnaissance mission recovery from water - Improved underwater navigation - Increased dedicated on board computing capability - Autonomously measure environment conditions and elaborate self-diagnosis: ○ set-up own sensors & payload (e.g. range of sonars, cameras, weapons) ○ adapt mission plan to optimize performance (e.g. adjust line spacing for optimum area coverage, update position accuracy, charge battery and resume mission) -
- Common Data Link (CDL) line-of-sight communications/air data relay communications;	- Common Data Link (CDL) line-of-sight communications	- high flow data transmission, through a communication relay (UAV or USV)
- De-icing system on board UAV especially MALE or HALE class		

3.1.5.4 Upgrading Sensors

Multi-mode New Generation (NG) RADAR and widely used NG RADAR passive SAR-type on-board aerial unmanned platform and micro LiDAR (Light Detection and Ranging) will be highly recommended as future surveillance sensor. Passive Synthetic Aperture RADAR (PSAR),

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Inversed Synthetic Aperture RADAR (ISAR) and Low Probability Intercept RADAR (LPIR) should be deployed on small aerial platforms.

Spotlight modes are designed to provide high-resolution photographic-quality imagery through clouds, rain, dust, smoke and fog. Subtle changes in the scene need to be detected by overlaying two images taken at different times. Coherent Change Detection (CCD), Amplitude Change Detection (ACD), and Automated Man Made Object Detection (AMMOD) algorithms rapidly highlight the differences between the first and second SAR image, providing an excellent imagery analysis tool.

Detection modes like Maritime Wide Area Search (MWAS) mode allow to detect ship and boat traffic in various sea state conditions. NG RADARs providing maritime detection modes often include integrated AIS (Automated Identification System). However, the tracks resulting from detection modes are not fused with AIS data to produce a new RADAR output. Data fusion is often performed out of the RADAR by the sensor integrator.

Also, RADAR data are not directly outputted with a standard format. The integrator is still in charge of data conversion to meet relevant standard requirements. NG RADARs should then offer the possibility to provide standardized output data (e.g. STANAG 4545 or 7023 for spotlight imaging modes and STANAG 4607 for detection modes).

Concerning EO/IR sensors, in recent years, much useful insight from biological vision systems are used in the development of new concepts of next generation military infrared imaging systems. Developing of the new technology would support the progress of this kind innovative optical imaging system included: variable acuity fovea FPA and imaging system with wide field of view, high resolution and fast frame rate based on this kind of FPA Agile detection and discrimination infrared system employing super resolution processing technology, subpixel imaging system (example: nano-cell) based on the animal retinal visual mechanism. Furthermore, adaptive coded aperture visible/infrared imaging system should base on pinhole imaging visual mechanism and on hybrid lens.

Recommendation for sensors upgrading can be summarized as follow:

- Enhancing NG RADAR and LiDAR integration on small UAVs;
- Developing the use of CCD, ACD and AMMOD algorithms to process high resolution imagery RADAR outputs;
- Providing fused data when using detection modes with AIS;
- Providing output data in a standard format;
- Enhancing IR sensors capabilities on the basis of biological vision.

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3.1.5.5 *Synthetic from Multisensors Picture, (Display) -Target Location Accuracy - Future Development.*

The Target Location Accuracy (TLA) program will provide enhanced video and targeting capabilities to the war fighter. Key elements of the program include real-time display of target coordinates with target location error, digital data archiving, and image mosaicking and post processing with advanced data exploitation tools.

Significant upgrades to current (UAV and USV systems) multispectral targeting systems will provide significant improvements in video imagery and targeting accuracy. Through the use of differential Global Positioning System (GPS), a newly designed eye-safe laser rangefinder and enhanced data exploitation tools, real-time, precision 3D coordinates are available for every image frame (Single Aim point Centre Pixel – SACP). Further upgrades will offer real-time, precision 3D coordinates for every pixel of every image frame.

TLA program should provide new capabilities to almost any mission. In conjunction with Search and Rescue (SAR), the ability to rapidly provide very accurate locations of victims to rescuers can mean the difference in survival. Additionally, it will allow the rapid location and isolation of targets of interest. Finally, these improvements will enable the war fighter to find, track, identify, and engage targets faster and with better accuracy than ever before. TLA will offer accuracy and timeliness that will improve mission success in surveillance operation.

Requisite features:

- Real-time, precision 3D coordinates for static and moving targets;
- Constant update of the sensors accuracy–every position includes accuracy measurements (i.e. target location error);
- Improved eye-safe laser rangefinder allows for operation in any environment;
- Will improve effectiveness of data exploitation tools–better mapping, mosaicking and data archive/retrieval;
- Growth path with precision 3D coordinates for every pixel of every image frame (SPI-3D).

3.1.6 Recommendations for enhancements of Systems Integration

When considering complex Decision Support Systems that integrate UxV assets, the definition of a “System of Systems” naturally emerges: multiple, dispersed, independent systems in context as part of a larger, more complex system.

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Heterogeneous technologies, coming from many domains have to be integrated in a complete and effective operational system. When the system is multi-national, building systems are normally produced by different manufacturers from various countries, following specific production processes and rules that generate an escalation effect on the complexity of the integration phase.

3.1.6.1 Norms and standards

The engineering approach to the integration is mainly based on interfaces agreement among all parties and on the choice of common standard references. With the term interfaces, they have to be intended in every layer of the ISO-OSI model: from physical, to application data.

Technologies out of R&D projects are often realized without structured standardization processes, since the need of realizing a prototype system on the field often require an agile, unrestricted and easy-to-adjust approach.

During prototyping trials and tests, shortcuts (customizations, proprietary data sets, incomplete procedures, simplifications, laboratory solutions, etc.) are adopted to reach the expected goals. This approach is usually required to minimize development re-workings and to keep system structures as simple and flexible as possible. On the other hand, when the time comes to integrate the system into a larger system of systems, the “results achieved through flexibility” may become obstacles.

The main recommendation, therefore, is to design systems with standard inputs and standard outputs since the early phases of the design. As it may sound obvious and self-evident, in the defence system many standards exist from nation to nation and even in standardization process of multi-national organizations (e.g. NATO) many different applicable rule set choices can be adopted.

Agreeing the reference standards, when designing a system of systems, may require a bigger initial effort in the early definition phase, but it will provide tangible benefits during the integration phase.

Many European funded R&D projects have already tackled different aspects of the defence systems. Standardization for many aspects of the design and integration are still unaddressed and they are being decided (or proposed) throughout the design definition phase of every single starting project.

In principles, it is expected that any following project start from previous agreed set of references, while different actors involved in R&D have often changed, completely or partially, the rule set. This is one of the main axes of improvement of the process of the multi-national cooperation projects: a library of EU reference standards must be adopted in order to avoid dispersion and lack of interoperability among projects. By providing a solid rule set will prevent multiplication of tools used in the same domain.

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In the frame of Ocean2020, as a defence project consortium, many NATO defence standards, data structures, norms and agreements have been adopted, since they are reference for many of the countries contributing to the project.

To achieve the goal of an EU defence system, a standardization rule set has to be marked as a critical priority.

3.1.6.2 On-board Systems Integration

The lessons learned during Ocean2020 Mediterranean Sea Demonstration integration, mainly concerned the coexistence of new experimental equipment with legacy platforms and systems. Integrating prototypes of unmanned vehicles on board of in-service warships is an activity that requires more significant working on board, the higher the level of integration that is aimed for.

Just to provide some reference numbers, on board of each Italian FREMM frigate for the integration of Unmanned Helicopters HERO and SOLO were added:

- 13 antennas
- around 5000m of cables and wires
- 1 rack with electronic equipment
- 3 consoles (2x24” and 55” monitor)

As result, for UxS on-board integration, a detailed program of the modifications and of the required times must be arranged and tightly followed:

- Preparatory studies,
- Detailed changes design,
- Timely and effective procurement of the equipment
- Allocation of working time slots in the schedule of the operating units
- Coordination with all involved entities (industrial and military)

Another installation aspect to be taken in consideration is the allocation of working spaces inside the technical/operational rooms and on the topside. An operational unit has its on-board spaces already full and adding some big/huge infrastructure (like a shelter, rack, unmanned station, etc.) can require some considerable effort.

From a technical point of view, the coexistence between experimental technologies and legacy ones is another set of constraints to be carefully designed since the beginning.

Technology on board of warships which are in service since years cannot have the capabilities and the capacities to manage last generation and/or state-of-the-art components. For example, emitting sources to be installed on the top side of the warship may induce heavy limitations on older devices which can be more sensitive to electromagnetic interferences.

Other interferences that limit the installation on board are related to safety of equipment and personnel. Guns blasting areas, UxV safe storage and movement, fuel handling and storage,

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just to make some few examples, are environmental constraints that must be taken into maximum consideration when designing the integration of unmanned vehicle on a naval platform.

3.1.6.3 Land-based Systems Integration

Two categories of integration are to be foreseen at land based facilities:

- operations centre control room
- unmanned ground control and recover station

When considering the land installation of a system components in a base spaces on the ground, safety and security procedures are the principal and most evident constraints, which must be taken in due consideration.

Designing an operation control centre, the main integration challenges arise when the system has to ensure interoperability with legacy command support and planning systems. The design must take into account networking limitations like routing among nets at different classification levels, virtualization of software (new or existing), bandwidth limitation for information (especially if satellite links are involved), and different data standards. These typical obstacles must be accurately designed and overcome during all the phases of the project. A dedicated test campaign to verify exchanges with legacy systems has to be planned.

At Maritime Operation Centre it is very important to provide some synthetic dedicated outputs of the systems on the battle space (both in terms of system data and visual presentation), because the decisional level requires a more synthetic level of information with respect to the tactical one. Detailed information available on board of the warship must be elaborate to extract more synthetic situation awareness.

When the UxV must be operated from a harbour dock, from an airfield or from another land facility, all the limitations highlighted for the naval integration of the unmanned are still valid. They can be more easily mitigated, because on the land there is availability of larger areas than on a warship and alternative solutions can be easily arranged. Nevertheless the safety of equipment and personnel still plays a really important role and they must be carefully addressed in every phase of the project.

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3.2 Recommendations for Capability Development

3.2.1 Methodology

This section, dealing with recommendations for capability development, is addressed in two steps.

The basis considered is the 2018 EDA capability development plan. It is completed with OCEAN2020 project outputs.

The first step is dedicated to the collection of capability needs relative to the OCEAN2020 end product or its component from work achieved in other OCEAN2020 work packages and information collected from each national procurement agency. In the following section, results are presented by grouping similar capability needs (if any).

The second step is dedicated to definition of capability development milestones to fulfil the capability needs identified in first step. Beyond available milestone defined in EDA capability development plan, the milestones take into account capability need timeline and knowledge of OCEAN2020 partners in development. The results are grouped by similar capabilities (if any) and associated to a timeline.

3.2.2 Identification of Capability Development axis

3.2.2.1 EU Capability development plan

At European level, capability development axis are identified through the capability development plan produced by EDA in close cooperation with its Member States and with the active contributions of the EU Military Committee (EUMC) and the European Union Military Staff (EUMS), that is updated regularly. The last one available is the 2018 revision. Agreed priorities for EU capability development are reported in EU Capability development priorities [R8], derived from the capability development plan. It includes also Strategic Context Cases (SCC) and landscapes the priorities and designs work program.

Amongst the 11 priorities given in the 2018 EU Capability development priorities [R8], two are of main interest for OCEAN2020 scope. Limiting them to what should be used in an OCEAN2020 system, the resulting capabilities are:

- Priority “Naval manoeuvrability” [R9]
    - Enhancing Maritime situational awareness, with optimize use of the existing capacities :
        - Create the so-called ‘bubble approach” as MARSUR like comparable to regional agreement around Europe
        - Promote a regional connecting hub implementation
        - Ensure a MARSUR like architecture and CONOPS as the only EU information sharing military network

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And new capabilities:

- Establish connectivity with cross sectoral EU MSA and existing EU networks;
- Implement cross sectoral Standard Operational Procedures
- Integrate additional sensors such as :long range RADAR, UAVs ESM and EO/IR capable supported by an efficient C2-C3 architecture
- Integration of permanent coverage ensured by High altitude flying assets
- Integration of new space assets like nano-and-micro SAR satellites and high-altitude pseudo satellites (HAPS).

- Surface superiority module, clarifies future capability needs:
  - Long-range anti-ship/access denial capabilities
  - Use of unmanned, automated systems, with long endurance at sea
  - Improve survivability of naval assets
  - Capability to detect and defeat low observability air, surface and underwater targets

  with following approach:

  - Develop procedures/standards to avoid collisions of unmanned systems
  - Improve unmanned systems effectiveness
  - Harmonize requirements for futures unmanned systems
  - Develop the common design of a long-range unmanned platforms
  - Develop a collective approach for common design of standardized deployable systems
  - Develop cooperation in the EU shipbuilding sector
- Power projection module, clarifies future capability needs:
  - Improvement of long-range logistics support
  - Naval aviation capabilities
  - Force protection capabilities

  with following approach:

  - Increase efficiency of logistic systems through new technologies
  - Develop new weapon systems to increase force protection
  - Develop advances early warning system to improve the RMP and readiness to improve forces interoperability.
  - Improve the effectiveness of replenishment at sea (RAS) through automated and more secured systems.
  - Develop self-defence (hard and soft kill) and stealth capabilities
  - Implement launch/recovery system for naval aviation
  - Increase platform availability through new multinational programmes

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- Priority “Underwater control contributing to resilience at sea” [R10]
  - Improve Mine warfare with following approach:
    - Develop an EU CONOPS for new generation MMCM
    - Use dedicated unmanned systems (surface and sub-surface)
    - Launch a MMCM standardization initiative for new generation
    - Improve sensor performance for manned and dedicated unmanned underwater systems
    - Adopt standard to merge and evaluate data between legacy systems and unmanned systems
    - Improve the coordination in mission and water space management (WSM), including with non-military users (interoperability)
    - Develop UW communication standards notably for swarm operations
    - Develop self-learning (AI based) capability for autonomous MMCM systems
    - Improve integration of autonomous MMCM UxVs into swarm operations
    - Develop UMS capabilities able to detect electronic MCCM, and have and adaptive behaviour
    - Develop common standardized UMS platforms, to be equipped with different sensors fitted for MW, ASW and ISR.
  - Enhance Anti-submarine warfare with following approach:
    - Establish a flexible underwater surveillance system (digital barrier)
    - Develop a common data base and populate with environmental data
    - Introduce the use of multi-statics in operational sensor systems
    - Apply AI to data analysis and classification
    - Develop ASW unmanned vehicles
    - Improve the interoperability of existing mission/WSM system usable by all European navies
    - Develop hard-kill solution to counter smart torpedo
    - Establish a network of ASW at EU level
    - Integrate automated systems into the network
    - Establish a balanced mix between remote and autonomous systems

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3.2.2.2 Ocean2020 Capability Framework

3.2.2.2.1 Capability Taxonomy

The Reference Architecture [R11] proposed by OCEAN2020 provides a generic solution that enables many capabilities. Thereto, functions are defined that together allow demonstrating the full set of capabilities. The three major operational goals with their associated capabilities are summarized in the table below:

Table 3.2-2 – Operational goals and capabilities

Operational goals	Capabilities	
Integral operational tasking/planning.	Automated resource allocation and tasking / Flexible asset integration.	Heterogeneous UxS assets.
		Manned/unmanned assets.
RMP construction at (EU) MOC level.	Combine data into common RMP.	Behaviour analysis.
		Data visualization.
		Data/sensor fusion.
		Satellite imagery integration.
		Video analysis
	Secure data exchange (between MOCs).	(Near) real time data exchange.
		Integrated secure network between participating MOCs.
		Protection measures for classified data exchange.
Operational tasking at lower levels (e.g. naval vessel, unmanned vehicles).	UxS control and operation	Remote control
		Automatic UxS deployment and retrieval up to sea state 5.
		NATO interoperability (STANAGs).
		Robust control in contested environment.
		Robust control in severe environmental conditions.
		UxS autonomy.
	Mission planning for heterogeneous assets.	Automated mission planning for heterogeneous assets.
		Automated replanning and execution.
	Compile and maintain (local) RMP.	Exchange RMP data with MOCs.
		Secure data exchange (between assets).
		Data visualization.
		Data/sensor fusion.

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3.2.2.2.2 OCEAN2020 System Requirements aspects

Considering the wide spectrum of issues related directly to the capability development, the right connection to the requirement from WP1 should be presented.

EU Capability development priorities are the main interest for OCEAN2020 scope.

The concept to support process of analysing and optimizing the delivery of military capabilities in line with EU intents:

- Provision of unmanned systems like UAS, USS, and UUS operated alongside other unmanned and manned systems from multiple nations;
- Provision of data sharing capabilities and a secure network for data sharing between nations MOCs/CMSs and with the EU MOC;
- Provision of an EU Maritime Operation Centre (MOC), capable of commanding an EU-led military maritime operation;
- Provision of enhanced interoperability with NATO to be able to collaborate in future conflicts.

3.2.2.2.3 OCEAN2020 Generic System Approach

The purpose of the system overview is to give a top-down breakdown of systems and functionalities. Furthermore, it shows how the functions and systems relate to each other.

In the diagram below, the system context diagram of the OCEAN2020 system-of-systems is given. It depicts the boundary between the OCEAN2020 system and its environment. Out of the closed box the diagram shows the main elements the system interacts with, e.g., civil and NATO partners and systems, as well as the maritime environment and any adversaries.

The main interacting entities of the OCEAN2020 itself are shown in the closed box: the MOC, naval vessel and unmanned vehicles.

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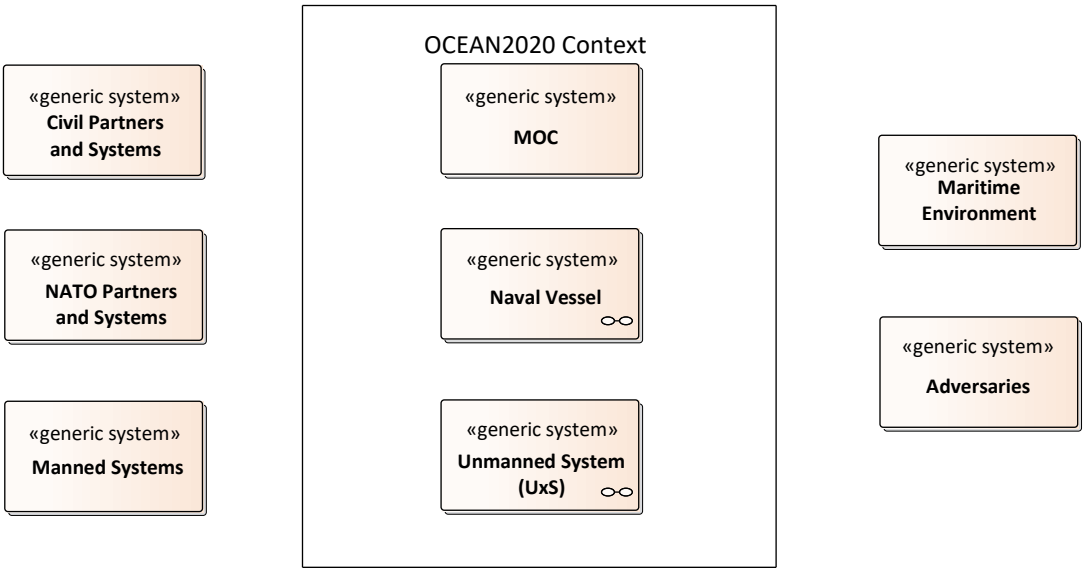

Figure 10 – OCEAN2020 Generic System

The precise definitions of these entities are given in the list below.

- Unmanned Systems (UxS): The x can stand for: Aerial, Surface or Underwater.
- MOC: Maritime Operations Centre which can be at national or EU level. A, typically land-based, facility to plan and coordinate maritime operations.
- Naval Vessel: A seagoing, typically manned, watercraft. Several types exist :
    - Mine Countermeasures Vessel
    - Patrol Vessel
    - Submarine
    - Task Force Command Vessel

  The Combat Management System (CMS) is integrated on Surface Naval Vessels.

Therefore, from a point of view of the capability analysis development, the approach presented here should be focused in these entities above. The precise definitions are given in [R11].

The relation between the approaches for capability development for the EDA Roadmap and the OCEAN2020 is summarized in the following tables.

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Table 3.2-3 – EDA roadmap – Naval manoeuvrability vs OSCEAN2020 capabilities

EU capability development - Naval Maneuvrability		OCEAN2020	
Domain	**Capabilities**	**Generic Systems**	**Capabilities**
Maritime Situational awareness	• Create a "bubble-approach" to regional agreements in EU	EU MOC; National MOCs	Plan, execute and control integrated maritime ISTAR operations with mixed manned/unmanned assets in contested environments; Integrated operational tasking by single mission management team.
	• Promote a regional collecting HUB implementation	EU MOC: Exchange RMP data with MOCs;	NATO Interoperability
	• Ensure a MARSUR like architecture and CONOPS	EU MOC; National MOCs;	Compile and maintain common RMP at MOC level; Integrate secure network between participating MOCs
	• Establish connectivity with cross-sectoral EU MSA and existing EU networks	EU MOC; National MOCs	Secure data exchange (between MOCs).
	• Implement cross-sectoral SOPs	EU MOC; National MOCs; Secure Data Exchange	Integrated secure network between participating MOCs. Protection measures for classified data exchange.
	• Integrate additional sensors	Unmanned Vehicles	Unmanned assets integration.
	• Support the launch of space assets		Satellite imagery integration.
	• Support a global EU MSA arrangement	EU MOC	Compile and maintain common RMP at MOC level; Integrate secure network between participating MOCs; Integrated operational

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EU capability development - Naval Maneuvrability		OCEAN2020	
Domain	**Capabilities**	**Generic Systems**	**Capabilities**
			tasking by single mission management team.
Surface Superiority	• Develop procedures/standards to avoid collisions of unmanned systems	Unmanned Systems	Integral Operational tasking and planning; Operational Tasking; NATO interoperability; Automated sense and avoid
	• Improve unmanned systems effectiveness	Unmanned Systems	Integral Operational tasking and planning; Operational Tasking; Secure data exchange between assets
	• Harmonize requirements for future unmanned systems	Unmanned Systems	Operational Tasking
	• Develop the common design of a long-range unmanned platform	Unmanned Systems	Operational Tasking
	• Develop a collective approach for common design of standardized deployable systems	Unmanned Systems; Naval vessels	Operational Tasking
	• Develop cooperation in the EU shipbuilding sector	Naval vessels	
Power Projection	• Increase logistic systems efficiency	Unmanned Systems; Naval vessels	Plan, execute and control an operational tasking (OPTASK) with UxS assets.
	• Apply Energy Conservation Measures		
	• Develop new weapon systems	Develop new effectors	
	• Develop advanced early warning system	MOCs; Unmanned Vehicles; Naval vessels	RMP construction at (EU) MOC level
	• Improve the effectiveness of replenishment at sea (RAS) through automated and more secured systems	Improve Unmanned Vehicles with automated/autonomous capability	

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EU capability development - Naval Maneuvrability		OCEAN2020	
Domain	**Capabilities**	**Generic Systems**	**Capabilities**
	• Develop R&D projects		
	• Implement/launch recovery system for naval aviation	Unmanned Systems; Naval vessels	Operational Tasking
	• Launch multinational procurement programmes	MOCs; Naval Vessels; Unmanned Systems	Operational Tasking

Table 3.2-4 – EDA roadmap – Underwater Control vs OSCEAN2020 capabilities

EU capability development - Underwater Control		OCEAN2020	
Domain	**Capabilities**	**Generic Systems**	**Capabilities**
Mine Warfare	• Develop an EU CONOPS for MMCM	MOCs; Naval Vessels; Unmanned Systems	Integral Operational tasking and planning; Operational Tasking
	• Launch a MMCM standardization initiative	MCM Vessel; Unmanned Underwater Systems	Integral Operational tasking and planning; Operational Tasking
	• Improve sensor performance for underwater systems	Unmanned Underwater Systems	Data/sensor fusion.
	• Adopt standards for data	MOCs; Naval Vessels; Unmanned Systems	Exchange RMP data with MOCs; Secure data exchange (between assets); Protection measures for classified data exchange; Data visualization.
	• Improve interoperability of missions & WSM systems	MCM Vessel; Unmanned Underwater Systems	Integral Operational tasking and planning; Operational Tasking
	• Develop/apply advanced tech solutions to detect/counter mines	MCM Vessel; Unmanned Underwater Systems	Data visualization; Data/sensor fusion; Video analysis.

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EU capability development - Underwater Control		OCEAN2020	
Domain	**Capabilities**	**Generic Systems**	**Capabilities**
	• Continue compliance with counter mine diving standards		
	• Develop covert communications cap & standards	MCM Vessel; Unmanned Underwater Systems	Exchange RMP data with MOCs; Secure data exchange (between assets); Protection measures for classified data exchange
	• Develop UMS capabilities	MCM Vessel; Unmanned Underwater Systems	Integral Operational tasking and planning; Operational Tasking
	• Develop UW communication standards	MCM Vessel; Unmanned Underwater Systems	Exchange RMP data with MOCs; Secure data exchange (between assets); Protection measures for classified data exchange
	• Develop self-learning cap for autonomous MMCM systems	Unmanned Underwater Systems	UxS autonomy; Adaptive behaviour; Local SA (without man in the loop); Automated sensor processing; Automated sense and avoid (anti-collision).
	• Improve integration of autonomous MMCM UxVs	MCM Vessel; Unmanned Underwater Systems	Integrated secure network between assets; UxS control via satellite or naval platform.
	• Develop UMS capabilities	MCM Vessel; Unmanned Underwater Systems	Exchange RMP data with MOCs; Secure data exchange (between assets); Protection measures for classified data exchange; Data visualization.

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EU capability development - Underwater Control		OCEAN2020	
Domain	**Capabilities**	**Generic Systems**	**Capabilities**
	• Develop common standardized UMS platforms	MCM Vessel; Unmanned Underwater Systems	Integral Operational tasking and planning; Operational Tasking
Anti-submarine Warfare	• Establish a flexible underwater surveillance system		Implement use of Unmanned Underwater Systems
	• Develop a common database		
	• Introduce the use of multistatics		
	• Test and develop digital barrier system		
	• Apply AI to data analysis and classification		
	• Develop ASW unmanned vehicles	Unmanned Underwater Systems	
	• Improve interoperability of missions and WSM systems		
	• Develop hard-kill solution vs smart torpedoes		
	• Establish an ASW network at EU level	EU MOC; National MOCs;	Develop network connecting EU MOC and National MOC
	• Integrate automated systems to the network	unmanned systems	
	• Establish a balanced mix between remoted and autonomous systems	ROV and unmanned autonomous systems	

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3.2.2.2.4 EU National capability development

3.2.2.2.4.1 The Spanish Strategy of Technology and Innovation for Defence (ETID)

At Spanish National level the later efforts oriented to reinforce the capabilities in Defence are been focused within the framework of the PESCO [R12, R16] (Permanent Structured Cooperation). In fact, Spain was one of the main sponsors of the agreement, together with Italy, France and Germany [R14]

A national strategy of Technology and Innovation of Defence (ETID, [R13]) was defined and issued in 2015, which in principle is still a reference in the area, although the necessity of its actualization and review has been already recognized [R15], in order to adapt it to the European context and improve the institutional support to the sector. In fact the new planning cycle initiated in 2019 contemplates a long term planning scenario up to 2015, so that the ETID is to be upgraded taking into account the envisaged capabilities needed for this period [Acami, R32].

The Defence Technology and Innovation Strategy (ETID) is an initiative derived from the MINISDEF R&D policy that aims to provide technological guidance and promote coordination between the different actors, both internal and external to the Department, involved in the development of technology linked to the current and future needs of the FAS.

The Annex I of the ETID included a list of Technological Goals, in order to be a guide both for investments in R + D + I of the Ministry and for the national technological and industrial base. For its implementation, the ETID contemplated several actions to put into practice the guidelines of the Defence R & D & I Policy.

The ETID recommended specific attention to new initiatives promoted by the EU linked to dual technologies or specifically addressed to defence, “due to the important benefits that can be derived from them”.

The Annex I of the ETID provided a Technology Analysis wherein a number of technological areas were proposed for development. These areas are as follows:

1. Weapons and ammunition: technology and advanced weapon capabilities, support to weapon and ammunition life cycle
2. Sensors and Electronic systems: RADAR, EOS, acoustic sensors, sensor data processing, Electronic Warfare
3. Platforms: common technologies, ground stations. Land, naval and aerospatial platforms.
4. Combatiente: systems, human factors
5. NRBQe: counter IEDs, NRBQe defence
6. C4I: information systems, tactical communications, training systems, securisation of information and communications

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According to this summary, it is evident that several lines of development reflected in the Annex I of the ETID (namely sections 2, 3 and 6) are directly related to the capabilities identified in the OCEAN2020 Reference Architecture, and involved in the project demonstrations. As an example, a specific sub-section for naval unmanned vehicles is contemplated under section 3 Platforms.

The Technological Goals from the Annex I of the ETID (MTs for their acronym in Spanish) that are related to the EDA Roadmap and OCEAN2020 capabilities or Generic Systems are listed below:

- MT 1.1.1: energy materials with improved performance
- MT 1.1.2: effectiveness and efficiency of ammunition, weapons and weapons systems
- MT 1.3.1: non-lethal weapons
- MT 1.3.2: directed energy weapons
- MT 2.2.2: SAR / MTI systems
- MT 2.2.5: Advanced RADARs for air defence and surveillance and space monitoring
- MT 2.3.1: EO / IR Sensors and Night Vision Systems
- MT 2.4.1: Atmospheric and underwater sonars
- MT 3.4.1: New generation naval platforms
- MT 3.4.2: Power generation and propulsion systems for naval platforms
- MT 3.4.3: Unmanned naval vehicles
- MT 3.5.1: New generation of aerial platforms
- MT 3.5.2: Military RPAS Class II and Class I
- MT 3.5.3: Integrated and modular systems for avionics
- MT 3.5.4: Propulsion systems for aerial platforms
- MT 3.5.5: Integration of RPAS in non-segregated airspace
- MT 3.5.6: Small satellites
- MT 6.1.1: C2 functionalities for information superiority
- MT 6.1.2: Big data for C4I functionalities
- MT 6.1.3: Smart techniques for decision support systems
- MT 6.1.4: Information gathering and development of military intelligence
- MT 6.2.3: Federated tactical deployable networks in coalition
- MT 6.2.4: Dynamic communication networks to support sensor networks

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MT 6.2.5: Data links and new digital tactical links

MT 6.5.1: Cyber defence - Automation of actions against cyber-attacks

MT 6.5.2: Cyber defence - Intelligence and decrease of enemy's cyber mobility

MT 6.5.3: Encryption systems

MT 6.5.4: Multi-level systems

Now the mapping of the approaches for capability development for the EDA Roadmap, OCEAN2020 and the ETID is summarized in the table below.

Table 3.2-5 – EDA roadmap – Naval manoeuvrability vs OSCEAN2020 capabilities vs ETID

EU capability development - Naval Maneuvrability		OCEAN2020	ETID
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (MTs)**
Maritime Situational awareness	• Create a "bubble-approach" to regional agreements in EU	Network connecting EU MOC and National MOCs.	
	• Promote a regional collecting HUB implementation	Exchange RMP data with MOCs (EU and National); Implement NATO Interoperability for other data	
	• Ensure a MARSUR like architecture and CONOPS	Integrate secure network between participating MOCs (EU MOC, National MOCs)	MT 6.2.3
	• Establish connectivity with cross-sectoral EU MSA and existing EU networks	Network connecting EU MOC and National MOCs.	
	• Implement cross-sectoral SOPs	Implement secure Data Exchange between EU MOC and National MOCs	MT 6.5.x
	• Integrate additional sensors	Implement additional sensor to Unmanned Vehicle and additional Unmanned vehicles	MT 2.2.5; MT 2.2.2; MT 2.3.1; MT 2.4.1
	• Support the launch of space assets		MT 3.5.6
	• Support a global EU MSA arrangement	Development of an EU MOC	

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EU capability development - Naval Maneuvrability		OCEAN2020	ETID
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (MTs)**
Surface Superiority	• Develop procedures/standards to avoid collisions of unmanned systems	Integral Operational tasking and planning; Operational Tasking; NATO interoperability; Automated sense and avoid	MT 3.5.5
	• Improve unmanned systems effectiveness	Integral Operational tasking and planning; Operational Tasking; Secure data exchange between assets	MT 3.4.1; MT 3.4.2; MT 3.4.3; MT 6.2.4; MT 6.2.5
	• Harmonize requirements for future unmanned systems	Unified Operational Tasking	
	• Develop the common design of a long-range unmanned platform	Develop Unmanned Vehicles	MT 3.5.1; MT 3.5.2; MT 3.5.3; MT 3.5.4
	• Develop a collective approach for common design of standardized deployable systems	Develop new Unmanned Vehicles and Naval vessels following same approach	
	• Develop cooperation in the EU shipbuilding sector	Naval vessels	
Power Projection	• Increase logistic systems efficiency		
	• Apply Energy Conservation Measures		
	• Develop new weapon systems	Develop new effectors	MT 1.1.x; MT 1.3.x
	• Develop advanced early warning system	Develop RMP construction at (EU) MOC level	MT 6.1.x
	• Improve the effectiveness of replenishment at sea (RAS) through automated and more secured systems	Improve Unmanned Vehicles with automated/autonomous capability	
	• Develop R&D projects		

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EU capability development - Naval Maneuvrability		OCEAN2020	ETID
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (MTs)**
	• Implement/launch recovery system for naval aviation	Unmanned Vehicles; Naval vessels	
	• Launch multinational procurement programmes	MOCs; Naval Vessels; Unmanned Vehicles	

Table 3.2-6 – EDA roadmap – Underwater Control vs OSCEAN2020 capabilities vs ETID

EU capability development - Underwater Control		OCEAN2020	ETID
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (MTs)**
Mine Warfare	• Develop an EU CONOPS for MMCM	Integral Operational tasking and planning; Operational Tasking	
	• Launch a MMCM standardization initiative	MCM Vessel; Unmanned Underwater Systems	
	• Improve sensor performance for underwater systems	Improve sensor of Unmanned Underwater Systems	MT 2.4.1
	• Adopt standards for data		
	• Improve interoperability of missions & WSM systems	Implement interoperability between MCM Vessel; Unmanned Underwater Systems	MT 3.4.3
	• Develop/apply advanced tech solutions to detect/counter mines	MCM Vessel; Unmanned Underwater Systems	
	• Continue compliance with counter mine diving standards		

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	EU capability development - Underwater Control	OCEAN2020	ETID
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (MTs)**
	• Develop covert communications cap & standards		
	• Develop UMS capabilities	Develop MCM Vessel; Unmanned Underwater Systems	
	• Develop UW communication standards	Develop MCM Vessel; Unmanned Underwater Systems	
	• Develop self-learning cap for autonomous MMCM systems	Develop autonomous Unmanned Underwater Systems	
	• Improve integration of autonomous MMCM UxVs	MCM Vessel; Unmanned Underwater Systems	
	• Develop UMS capabilities	MCM Vessel; Unmanned Underwater Systems	
	• Develop common standardized UMS platforms	Develop standardized MCM Vessel; Unmanned Underwater Systems	

3.2.2.2.4.2 The Polish Strategy of Technology and Innovation for Defence

The Polish defence strategy focuses on active participation in both building own defence capabilities and strengthening the security system at the European Union level as well as in the global dimension.

The National Centre for Research and Development (NCBR) is significantly supporting institution for creating Polish Strategy of Technology and Innovation for Defence. NCBR in cooperation with the Ministry of National Defence and Ministry of Internal Affairs takes actions related to scientific research and studies for the purposes of national defence and security. In the calls for proposals centred on specific research areas, companies that are the most likely to increase the national security are selected. The purpose of implemented programs and projects is not only to increase opportunities for Polish scientific and industrial entities, but also to strive for a technological independence by creation of Polish know-how in critical technologies for national defence and security.

This strategy, in addition to the implementation of national programs, assumes broad cooperation for building defence capabilities in the framework of international bilateral and multilateral cooperation. In addition, it includes active participation in initiatives

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and programs undertaken by the EU under EDA or The Permanent Structured Cooperation (PESCO) activities.

Bearing in mind that the OCEAN2020 project is dedicated to activities implemented in the maritime domain, the main assumption of the Technology Development Strategy and innovation is presented in the aspect of developing the Polish Navy's capabilities.

The main directions of Polish technology development strategy and implementation of defence innovation are contained in Program of Technical Modernization of the Polish Armed Forces for the years 2021-2035[2]. The above document is the basis for tasks related to the development of the Navy as part of the Polish Armed Forces.

Based on that, key areas of Polish Navy (POL-N) development were defined in the Operational Program Preventing (Counter) Threats at Sea[3].

Future development tasks related to "Ocean 2020 area" are oriented to implementation new generation reconnaissance systems and surveillance equipment.

One of the main principles of planning the development of the Polish Navy, indicated in the Polish Strategic Concept of Maritime Security (2017 edition)[4] is network-centricity. Network-centricity is understood as the rational and effective use of resources by commands and staffs, consisting in the distribution of current and reliable situational information. The main assumption of increasing efficiency of activities should be the network structure of all components, i.e. decision centres, platforms, sensors and effectors. This is to ensure, despite a large centring, obtaining a time and space synchronized situational awareness of all network participants. The above document indicates the continuation of the development of command systems for which the minimum level of ambition (LoA) is to implement systems in the medium and long term that meet the full C4I (including ISTAR) standards.

Gathering the information from maritime domain is crucial for surveillance system at every level of command (tactical, operational and strategic). Moreover, the possibility to share the information between military and non-military information systems is perceived as the most valuable solution to receive the most completed Common Operational Picture (COP). The principles of sharing the information must be established to ensure the right security regulations in aspect of information clauses. Realizing that, the capability for building complex MSA, is an indispensable for effective monitoring of the maritime situation in Polish jurisdiction areas and early detection of military and non-military threats, Polish Navy concept includes a wide integration of available and future reconnaissance elements and systems. It will be possibly based on building a system (in accordance with EU and NATO standards) with an open architecture and taking into account the possibilities of implementing or integrating innovative technologies.

[2] Original title: Program Modernizacji Technicznej Sił Zbrojnych na lata 2021-2035 (uwzględniający przedsięwzięcia realizowane w 2020 roku

[3] Original title: Program Operacyjny Zwalczanie Zagrożeń na Morzu.

[4] Original title: Strategiczna Koncepcja Bezpieczeństwa Morskiego Rzeczypospolitej Polskiej (2017)

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Considering the national maritime command system as a main source for sharing the information between other (national and foreign) system, the defined elements of architecture needed to be implemented are:

- IT network centric systems;
- Communications network centric systems;
- Cyber protection solutions;
- Network-centric interoperability;
- Provision of network services.

Such a complex solution should not have been limited to the stationary infrastructure.

First of all, due to the specificity of the modern approach to all types of operations, which is characterized by high mobility of armed forces, it should include naval component (ships and ground component assets) as well as elements of the command system (staffs and commands of all levels of command).

In addition, bearing in mind that the navy is a flexible instrument used both in monitoring the current situation and rapid response anywhere in the world, an effective, efficient and near real time exchange of information is necessary for the proper command and tasking process.

The Polish Navy, realizing alliance obligations under the NATO alliance, as well as taking part in the EU's activities for security, delegates ships, naval air assets and command and staff components to alliance operations.

With the above in mind, the Polish Navy is focused to meet the requirements and standards ensuring its interoperability (compatibility) for both national and allied operations.

The way the Polish Navy meets these requirements is a high engagement to develop and modernize existing C2 systems and, in the long term perspective, to build and develop the established LoA new C4I (ISTAR) systems.

The extensive use of innovating technologies in the area of communication, acquisition, collection, processing and analysis of data in the process of integration of elements of the future command system, will allow achieving the established LoA. In practice, this refers to the integration of stationary and mobile elements of reconnaissance systems, ship platforms and in particular unmanned systems, due to their diversity in types and environment of operation, as well as the synergy of its swarm use.

Such systems, to ensure the exchange of the orders, reports, information from data bases, operational data regarding the Recognize Maritime Picture (RMP) and efficient MSA as a part of COP should be supported by crypto links, IT Networks connection, satellite communication mobile “ad hoc” data transmission communication network or channels.

At present and in the short term, the Polish Navy is focused on developing the capacity to use UUV / UUS. This applies to a significant extent in the MCM area, an example of which is the new generation of the on-going MINEHUNTERs construction program. The use of UUVs should

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be considered not only as collecting data for MCM activities (data for the Mine Warfare Data Centre), but also as building a comprehensive picture of the underwater situation (seabed and water space volume) to ensure safety of navigation.

In addition, the Navy intends the use of both UAV / UAS and USS / USV in medium- and long-term development plans. This indicated plans are taking into account their implementation as part of planed shipbuilding programs for new combat and patrol vessels, as well as the development of elements dedicated to shore units. It should be emphasized that these solutions constitute critical elements of the possibilities of the future ISR system, as well as for conducting anti-surface (ASuW) and antisubmarine warfare (ASW).

Taking into account the increasing autonomy, UxS / UxV will be able to carry out tasks throughout the maritime responsibility zone, and most importantly they will constitute a flexible tool for operations in territorial waters (classified as mostly littoral waters).

The synergy of the use of ship platforms UxS supported by elements of the surveillance and monitoring system will allow ensuring an appropriate level of security on Sea Lines Of Communication (SLOC), in certain sea areas, harbours and other maritime critical infrastructure objects.

This approach shows that only complex solutions consisting of various types of unmanned systems disposing suits of sensors in conjunction with stationary infrastructures provide the right level of protection.

Looking at the presented objectives in terms of the time factor, it was found that the majority from a technological point of view would be achievable in the short term (by 2024). However, taking into account the effective and dynamic development of new innovative technologies and the cost-to-effect ratio, the capability development process should adapt the principle of open system architecture, which is included in the plans of the Polish Navy.

This approach facilitates software updates, hardware modernization as well as system expansion with new modules in the medium and long term (up to 2030-2035).

Looking at the presented objectives in aspect of time factor, it is identified that most of them from the technological point of view would be achievable in short term period (until 2024).

The list below presents Technological areas in general propose for development:

1. Sensors and Electronic systems: RADAR, EOS, acoustic sensors, sensor data processing, Electronic Warfare.
2. Platforms or technologies, ground stations: UAV, USV, UUV.
3. Counter IED and UIED (Underwater Improvised Explosive Device).
4. C4I: information systems, tactical communications, training systems, protection of information and communications.

The Technological Goals (TG Poland) that are related to the EDA Roadmap and OCEAN2020 are listed below:

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TG 1: SAR / MTI systems – Synthetic Aperture RADAR with Multi Target Indicator;
TG 2: Advanced RADARs for air defence and surveillance and space monitoring;
TG 3: EO / IR Sensors and Night Vision Systems;
TG 4: Atmospheric and underwater sonars;
TG 5: New generation naval platforms;
TG 6: Unmanned naval vehicles;
TG 7: New generation UAV, USV, UUV equipped with modular equipment;
TG 8: Small satellites (micro satellites);
TG 9: C2 functionalities for information superiority;
TG 10: Big data for C4I functionalities;
TG 11: Smart techniques for decision support systems;
TG 12: Information gathering and development of military intelligence;
TG 13: Dynamic communication networks to support sensor networks;
TG 14: Data links and new digital tactical links;
TG 15: Cyber defence - Automation of actions against cyber-attacks;
TG 16: Cyber defence - Intelligence and decrease of enemy's cyber mobility.

Now the mapping of the approaches for capability development for the EDA Roadmap, OCEAN2020 and the Polish Navy Development is summarized in the table below:

Table 3.2-7 – EDA roadmap – Naval manoeuvrability vs OSCEAN2020 capabilities vs Polish Development TGs

EU capability development - Naval Manoeuvrability		OCEAN2020	Polish Development
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (TGs)**
Maritime Situational Awareness	• Create a "bubble-approach" to regional agreements in EU	Network connecting EU MOC and National MOCs.	TG 15: TG 16:
	• Promote a regional collecting HUB implementation	Exchange RMP data with MOCs (EU and National); Implement NATO Interoperability for other data	TG 15:
	• Ensure a MARSUR like architecture and CONOPS	Integrate secure network between participating MOCs (EU MOC, National MOCs)	TG 9:
	• Establish connectivity with cross-sectoral EU MSA and existing EU networks	Network connecting EU MOC and National MOCs.	TG 11: TG 12: TG 13:

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	EU capability development - Naval Manoeuvrability	OCEAN2020	Polish Development
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (TGs)**
	• Implement cross-sectoral SOPs	Implement secure Data Exchange between EU MOC and National MOCs	TG 15: TG 16:
	• Integrate additional sensors	Implement additional sensor to Unmanned Vehicle and additional Unmanned vehicles	TG 1: TG 2: TG 3: TG 4:
	• Support the launch of space assets		TG 8:
	• Support a global EU MSA arrangement	Development of an EU MOC	TG 8: TG 9: TG 10: TG 11:
Surface Superiority	• Develop procedures/standards to avoid collisions of unmanned systems	Integral Operational tasking and planning; Operational Tasking; NATO interoperability; Automated sense and avoid	TG 11: TG 12: TG 13: TG 14:
	• Improve unmanned systems effectiveness	Integral Operational tasking and planning; Operational Tasking; Secure data exchange between assets	TG 6: TG 7: TG 13: TG 14:
	• Harmonize requirements for future unmanned systems	Unified Operational Tasking	TG 6: TG 7:
	• Develop the common design of a long-range unmanned platform	Develop Unmanned Vehicles	TG 6: TG 7: TG 14:
	• Develop a collective approach for common design of standardized deployable systems	Develop new Unmanned Vehicles and Naval vessels following same approach	TG 5: TG 6: TG 7:
	• Develop cooperation in the EU shipbuilding sector	Naval vessels	TG 5: TG 6: TG 7:
Power Projection	• Increase logistic systems efficiency		
	• Apply Energy Conservation Measures		
	• Develop new weapon systems	Develop new effectors	

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EU capability development - Naval Manoeuvrability		OCEAN2020	Polish Development
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (TGs)**
	• Develop advanced early warning system	Develop RMP construction at (EU) MOC level	TG 9: TG 10: TG 11: TG 12:
	• Improve the effectiveness of replenishment at sea (RAS) through automated and more secured systems	Improve Unmanned Vehicles with automated/autonomous capability	TG 5: TG 6: TG 7: TG 15:
	• Develop R&D projects		
	• Implement/launch recovery system for naval aviation	Unmanned Vehicles; Naval vessels	TG 5: TG 6:
	• Launch multinational procurement programmes	MOCs; Naval Vessels; Unmanned Vehicles	TG 5: TG 6:

Table 3.2-8 – EDA roadmap – Underwater Control vs OSCEAN2020 capabilities vs Polish Development TGs

EU capability development – Underwater Control		OCEAN2020	Polish Development
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (TGs)**
Mine Warfare	• Develop an EU CONOPS for MMCM	Integral Operational tasking and planning; Operational Tasking	TG 9: TG 11: TG 12:
	• Launch a MMCM standardization initiative	MCM Vessel; Unmanned Underwater Systems	TG 5: TG 6: TG 7:
	• Improve sensor performance for underwater systems	Improve sensor of Unmanned Underwater Systems	TG 4: TG 5: TG 6: TG 7:

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	EU capability development – Underwater Control	OCEAN2020	Polish Development
Domain	**Capabilities**	**Capabilities and/or Generic Systems**	**Technological Goals (TGs)**
	• Adapt standards for data		TG 10:
	• Improve interoperability of missions & WSM systems	Implement interoperability between MCM Vessel; Unmanned Underwater Systems	TG 5: TG 6:
	• Develop/apply advanced tech solutions to detect/counter mines	MCM Vessel; Unmanned Underwater Systems	TG 4: TG 5: TG 6:
	• Continue compliance with counter mine diving standards		
	• Develop covert communications cap & standards		TG 14: TG 15:
	• Develop UMS capabilities	Develop MCM Vessel; Unmanned Underwater Systems	TG 3: TG 5: TG 6: TG 7:
	• Develop UW communication standards	Develop MCM Vessel; Unmanned Underwater Systems	TG 5: TG 6: TG 13: TG 14:
	• Develop self-learning cap for autonomous MMCM systems	Develop autonomous Unmanned Underwater Systems	TG 5: TG 6: TG 7:
	• Improve integration of autonomous MMCM UxVs	MCM Vessel; Unmanned Underwater Systems	TG 5: TG 6: TG 9: TG 11: TG 12: TG 14:
	• Develop UMS capabilities	MCM Vessel; Unmanned Underwater Systems	TG 5: TG 6: TG 7:
	• Develop common standardized UMS platforms	Develop standardized MCM Vessel; Unmanned Underwater Systems	TG 5: TG 6: TG 7:

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3.2.3 Hypothesis of capability development milestones

Based on Strategic Context Cases Naval Manoeuvrability [R9] and Underwater control [R10], three horizons are proposed:

- Short term : until 2024
- Medium term : 2025-2034
- Long term : Beyond 2034

Table 3.2-9 – Capability development milestones – Naval Manoeuvrability

	Until 2024	2025-2034	Beyond 2034
Maritime Situational awareness	• Create a "bubble-approach" to regional agreements in EU	• Establish connectivity with cross-sectoral EU MSA and existing EU networks	• Integrate additional sensors
	• Promote a regional collecting HUB implementation	• Implement cross-sectoral SOPs	• Support the launch of space assets
	• Ensure a MARSUR like architecture and CONOPS		• Support a global EU MSA arrangement
Surface Superiority	• Develop procedures/standards to avoid collisions of unmanned systems	• Harmonize requirements for future unmanned systems	• Develop a collective approach for common design of standardized deployable systems
	• Improve unmanned systems effectiveness	• Develop the common design of a long-range unmanned platform	• Develop cooperation in the EU shipbuilding sector
Power Projection	• Increase logistic systems efficiency	• Develop advanced early warning system	• Develop R&D projects
	• Apply Energy Conservation Measures	• Improve the effectiveness of replenishment at sea (RAS) through automated and more secured systems	• Implement/launch recovery system for naval aviation
	• Develop new weapon systems		• Launch multinational procurement programmes

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Table 3.2-10 – Capability development milestones – Underwater control

	Until 2024	2025-2034	Beyond 2034
Mine Warfare	• Develop an EU CONOPS for MMCM	• Improve interoperability of missions & WSM systems	• Develop UW communication standards
	• Launch a MMCM standardization initiative	• Develop/apply advanced tech solutions to detect/counter mines	• Develop self-learning cap for autonomous MMCM systems
	• Improve sensor performance for underwater systems	• Continue compliance with counter mine diving standards	• Improve integration of autonomous MMCM UxVs
	• Adopt standards for data	• Develop covert communications cap & standards	• Develop UMS capabilities
		• Develop UMS capabilities	• Develop common standardized UMS platforms
Anti-submarine Warfare	• Establish a flexible underwater surveillance system	• Test and develop digital barrier system	• Establish an ASW network at EU level
	• Develop a common database	• Apply AI to data analysis and classification	• Integrate automated systems to the network
	• Introduce the use of multistatics	• Develop ASW unmanned vehicles	• Establish a balanced mix between remote and autonomous systems
		• Improve interoperability of missions and WSM systems	
		• Develop hard-kill solution vs smart torpedoes	

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4 PROPOSED PLANNING FOR RESEARCH AND CAPABILITY DEVELOPMENT

4.1 Proposed planning for capability development

4.1.1 Methodology

Building a common vision of Development of EU Industrial Capabilities should be a result of shared understanding of development needs arising from potential threats. Such increased situational awareness at sea makes it possible to plan and implement actions in the national aspect, determining the potential and demand of national economies.

The chart presented below gives the framework that can be used to ensure the capability development in the industrial economic context.

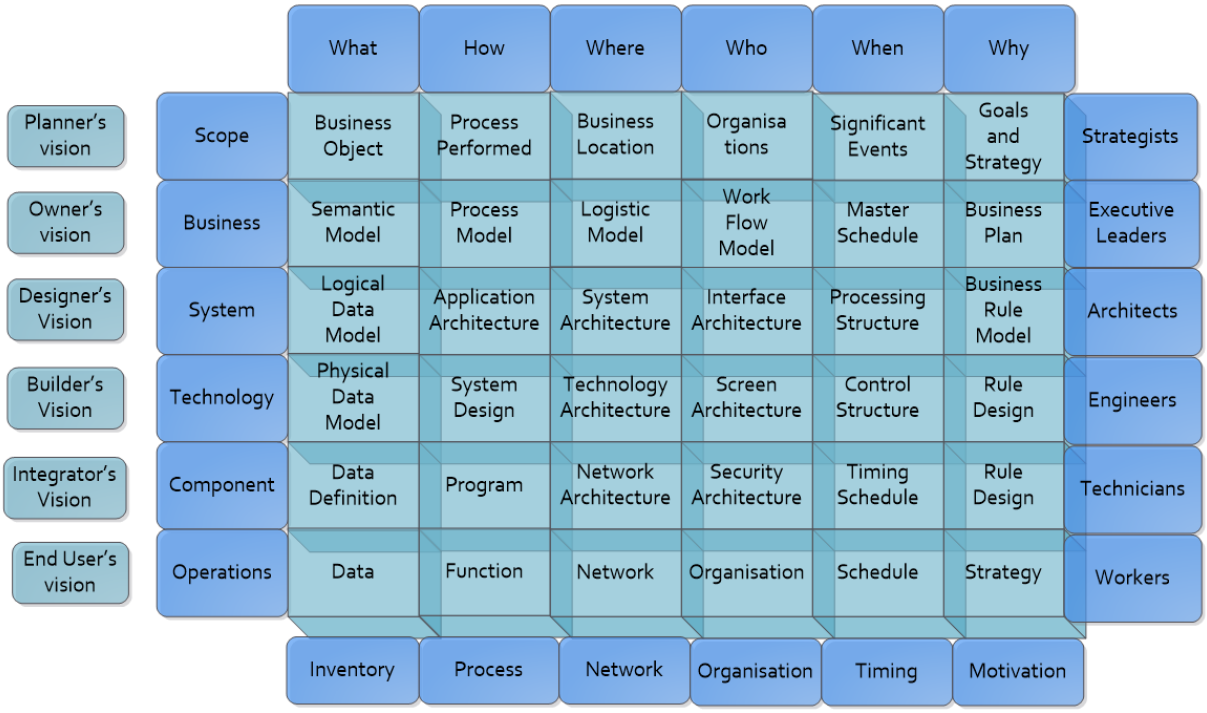

Figure 11 – Enterprise framework

The challenge is to integrate all sources of information obtained from manned and unmanned systems, their assessment (analysis) and their integration to the RMP (Recognize Maritime Picture) to provide necessary and reliable information in MOC, national centres and transmitted to the appropriate EU management level.

Having the right data and conclusions, it is possible to integrate the activities of individual national economies, enabling the achievement of a common goal. This integration, followed

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by its evaluation, should lead to build and increase the EU's economic potential in the field of defence.

First, a roadmap is presented based on CapTech and OCEAN2020 capability development plan. Then, the following areas are detailed for industrial capability developments:

- UxS Platforms,
- UxS Sensors & Effectors,
- Communication
- Command and Control
- Information Technology

4.1.2 Roadmap

OCEAN2020 achievements will contribute to increase the capabilities of the European Defence Industry, its potential and competitiveness on the global market. This kind of project also enhances the cooperation and systems interoperability between EU members.

Execution of a model and potential changes allows specifying all the projects proceeding in indicated area, as well as profitability assessment. Moreover, it gives opportunity to point out a goal that will be used to build a roadmap and, in the future, the path of EU economic potential development.

In general, a roadmap allows achieving main benefits:

- Creating more fluent communication about how EU economic development is perceived.
- Defining, as an assistant, product's and company's strategy. Through predictions of development, it is possible to present when and how targets will be achieved. Roadmap makes it easier to plan and assure resources, including budget in declared period.
- Supporting clients in coordination of production, marketing and disposal activities.
- Facilitating of effective projects and products management and assisting with synchronizing various products development.

For better understanding, each element included in the annex is described in the dedicated document **Annex D6.5.2-A1.**

4.1.3 Development of EU industrial capabilities in UxS Platforms area

The proposed development of EU industrial capability in UxS platforms area is based on Capability Technology Areas (Captech) and OCEAN2020 partners' knowledge. In particular, the following content is based on some Technology Building Blocks (TBBs) of selected CapTechs that identify specific R&T areas that would be beneficial for the development of UxV related defence capabilities included in the CDP.

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With regard to Naval and Air platforms, the necessary development of the following capabilities related to UxS platforms have been identified and divided among short- medium- and long-term achievable platforms.

In the short-term, the developments identified to occur can be divided in two macro categories, the first deals with autonomy and the second with platform and operation security:

For platform behaviour and autonomy:

- Sub-system autonomous – this development would allow the sub-systems to support manned platforms (machine assists human). As an example, for UAS some flight phases like take-off, landing and Taxiing could be autonomously performed. In order to reach this goal the development of a system architecture for autonomy is foreseen;
- Development of navigation in GNSS denied environment - GNSS navigation signals can be highly degraded or denied in cases of particular environment conformations, i.e. urban canyons, indoor environment, forests. In case GNSS signal is lost, a multi sensor navigation system should be activated in order to limit the impact of a lost GNSS signal to the operation of the unmanned system;
- Development of Detect and Avoid (DAA) solution - These solutions would be applied to both the air and sea domain;
- Integration of new SATCOM to platforms,
- Development of a 4D planning space through the development of mission specific parts and flight segments in space and time;
- Development of an autonomous air-to-air refuelling process to support manned or unmanned platform;

For platform and operation security:

- Development and integration of platform real-time (self-)diagnostics, health monitoring and fault prognostics - These sensors would permit a rapid detection of possible damages to the platform, through the use of AI, Big data and Deep Data algorithms;
- Development of Digital Twin for Structures and Systems Health and Usage Monitoring (SSHUM) to enable a further development of multi-level digital-twin for UAVs;
- Development of new blast, fragments and fire resistant structures – the resistance of USV to possible combined weapon effects might be ensured through the usage of new material for the structure of the platform (e.g. smart composite materials);
- Reduction of signature – a reduced platforms' signature can be relevant for the completion of the mission. Due to the new availability of networked ground sensors, looking towards the future it might be worth investing in new stealth concepts which could increase survivability capabilities;
- Metrics definition for dynamic change of levels of control/autonomy – the development of the system allows, for security issues, the direct signalling of changes that may affect the autonomy and control of cooperative naval systems (UMS and

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UxV). Such a system would indicate when a task should be transferred by human to the unmanned system and vice-versa;

- Enhanced Crash resistance – through an increased usage of specific materials and structures able to absorb energy in the event of a crash;
- Development of high-speed USV solutions operable in all Sea States.

In a mid-term view, the CapTech identify the following developments that can be divided in the same two categories identified for the short term developments.

For platform behaviour and autonomy:

- Development of partial autonomous systems – with this level of autonomy, the role of the operator behind unmanned platforms shift from a man-in-the-loop to a man-on-the-loop role: flight planning and real time re-planning (based on machine learning and task oriented inputs);
- Multi- mode flight control systems – these systems would be particularly suited for Optionally Piloted Vehicles (OPV) that could shift from manned/piloted to fully autonomous aircraft with no modifications to the avionics systems;
- Development of automatic ship deck landing systems for UAV, for a new fully automatic upper-modes for ship deck landing;
- Integration of effective obstacle warning and avoidance systems (OW&AS) through sensors and databases that allow the creation of a digital representation of the environment;
- Development of long endurance capabilities - the enhancement of this characteristic could be exploited, i.e. via low drag configurations, aerodynamic drag reduction technologies;
- Development of automated autorotation flight controller for RUAS, its relevance lies in the fact that autorotation becomes a necessity in the event of an engine failure, a transmission failure, or a tail rotor loss;
- Development of precise autonomous launch and recovery system from naval and airborne platforms;
- Development of configurable autonomy architecture on board of the unmanned platform;
- Development of methods for certifiable Artificial Intelligence solutions with intelligent software performing the high-level decision-making functions normally performed by human pilots;

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For platform and operation security:

- Development of defensive protection suite – sensors and countermeasures like chaff, flare or DIRCM (Directional Infrared Counter Measures) should be mounted on large MALE UAVs. This would increase their employability and defensive capacity in adverse scenarios;
- Increased "expendability" of unmanned platforms – as an example, intermediary class UAVs could be employed in swarm and, if necessary, constitute an air decoy in case of electronic warfare;

For power management:

- Integration of directed-energy weapons (e.g. Laser, microwave) into platform and increased supply of electric energy for future aerial platforms;
- Exploit the benefits of hybrid electrical propulsion – this could include the integration of solar cells to increase duration deployment. Also resorting to fuel cell and batteries to supply small surveillance UAV, or developing a hybrid Turbo shaft (mechanical main rotor and electric generator).

In the long term, full autonomy for UxV should be reached. In this framework, the operator would have an out-of-the-loop role. Nonetheless, full autonomy should also be complemented by:

- Integration of multispectral & broadband stealth and high performances capabilities on UxV for long range operations in contested environments (stealth, Artificial Intelligence, secured and discrete datalinks);
- Low cost multispectral (RADAR, IR, visual & aural) and broadband (RADAR: VHF to Ka band) stealth capacities.

4.1.4 Development of EU industrial capabilities in UxS Sensor and Effector areas

Getting the most relevant information from the environment strongly depends on sensors quality and characteristics. Sensors are the main data providers that allow UxV evolving safely and efficiently in their direct environment. They are also the main data generators for ISTAR operations that contribute to build the recognized maritime picture. Effectors allow UxS to directly or indirectly act on external elements, for example by designating or neutralizing a threat. This is why Sensors & Effectors capability development is a key issue to ensure UxS effective involvement in defence operations.

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Based on OCEAN2020 partners' knowledge and CapTech result, the following development recommendations are identified for UxV sensor:

At short-term:

General recommendations:

- Integration of AIS and GNSS receiver to all sensors (EOS, RADAR,..) to ease detection and fusion for UAV and USV;
- Design and realization of sensors to best mitigate self-noise, to optimize the integration of operational sensors and to optimize their performances;

For maritime RADAR applications:

- Development of a consistent sea clutter model which takes into account different grazing angles, frequencies, swell angles, sea states (potentially differentiated in wave height and wind speed), sensor beam widths and sensor resolutions as well as the platforms velocities (in case of coherent processing). This requires a representative number of data acquired during several flight trials followed by specific data evaluations. Such a consistent sea clutter model could improve detection capabilities and reduce false alarms in general over a wide range of model parameters.
- Development of bistatic RADAR set-ups with state-of-the art RADAR sensors for small and medium size sea target detection. This detection can be performed by using one sensor fixed (e.g. the transmitter) on a vessel and the other sensor (e.g. the receiver) mounted on a flying platform or vice versa. Such a set-up provides more flexibilities in terms of sea clutter reduction with respect to target detection than conceivable in monostatic operations.
- Development of machine learning and/or deep learning network approaches for classification of monostatic maritime ISAR images to enhance the maritime situational awareness.

At mid-term:

General recommendations:

- Development of capability to work in a GPS Denied Environment for UAV and USV;
- Automatic detection and classification at EOS sensor level for UAV and USV;
- Proximity sensor integration for sense and avoid function for UAV and USV;
- Autonomous payload-management;
- Laser effector against UAS and USS swarm.

For maritime RADAR applications:

The capabilities introduced for the short-term could be further developed in the following manner:

- Bistatic sea target detection of small and medium size vessels with two flying airborne sensors which could also alternate transmission and reception mode;

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- Bistatic ISAR imaging experiments, extended with two flying airborne sensors;
- Classification of bistatic maritime ISAR images via machine learning and deep learning networks to be continued.

4.1.5 Development of EU industrial capabilities in Communication area

Communication technology (CT) is a basic element of any command & control system, regardless of its size, because the key is the need for constant and fast communication with partners, cooperating forces, remote units and subunits. Every year, we observe new trends in this area. As technologies mature, new and existing ones combine, evolve and commingle to form new opportunities. CT is considered to be a subset of information and communications technology (ICT).

Based on OCEAN2020 partners' knowledge and CapTech result, the following development recommendations are identified for the Communication area:

At short-term:

- Development of secure, wideband communication solutions between UxS and MOCs – software defined communication solutions for long range distances;
- Development of secure, wideband communication solutions between UxSs – short range distances;
- Increasing the use of Software-defined Wide Area Network (SD-WAN) – It is an application of software-defined networking technology that simplifies WAN (Wide Area Network) management by decoupling network hardware from control mechanisms. Conventional network architectures were not built for the demands of a cloud-first workplace, and SD-WAN enables easier access to cloud applications for geographically-distributed platforms manned and unmanned. It allows enterprises to build higher-performance WANs using lower-cost commercial Internet access. SD-WANs are also quicker to establish and reconfigure, since the network becomes a logical layer, compared to all the overhead and latency of implementing a traditional hard-wired physical network.

At mid-term:

- Development of secure, cognitive communication solutions between UxS and MOCs – long range distances;
- Development of secure, cognitive communication solutions for UxSs – short range distances;
- Using 5G & 6G mobile network - Implementing 5G and 6G across the world will bring higher broadband speeds along with more reliable wireless and mobile networks. This will ultimately allow a greater level of automation and technological proliferation into cities and remote areas. The high data transfer speeds of these networks would significantly increase communication capability of autonomous platforms as they would be able to get real-time data from the entire environment. These networks will

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also permit to UxV a high amount secured data transmission to land stations after completing the mission.

At long term:

- Advanced secure, wideband communication solutions for UxS swarm activities.
- Advanced secure, wideband communication solutions between MOCs and UxS swarm.

These goals could be achieved by increasing and extending the use of 5G & 6G technologies.

4.1.6 Development of EU industrial capabilities in Command and Control area

Command and Control Technology is the concept involving the development, maintenance, and use of computer systems, software, and networks for the processing and distribution of data in Command and Control (C2) Systems used both for MOCs and UxSs. This technology is a specialized version of information and communication technologies (ICT). And in this context, below information should be treated.

Based on OCEAN2020 partners' knowledge and CapTech result, the following development recommendations are identified for the Command and Control area:

At short-term:

- Development of National MOC and Integrated Border Management System using the UxS solutions;
- First step of integration of secure network between participating MOCs and UxSs;
- Developing the use of secure cloud services to increase data storage and computing power capabilities without direct active management by the user. Command and Control Systems that have adopted cloud services experience improved time to reaction (making them more effective), increased efficiency and, when done correctly, realize reductions in IT spend. Cloud services also enable faster access to infrastructure, greater scalability and higher availability.

At mid-term:

- Integration of secure network between participating MOCs and UxSs;
- Partially networked EU MOC and national MOC;
- Development of *Artificial Intelligence Operations* (AIOps) - It is a new category of IT operations tools, created primarily to deal with the challenges associated with operating the next generation of IT infrastructure. The core appeal of AIOps is its use of algorithms and machine learning to automate tasks and processes that have traditionally required human intervention. This technology should significantly improve UxS command and control by increasing efficiency and autonomy.

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At long-term:

- Fully networked EU MOC and national MOC;
- Advanced MOC's command and control system used for all domains;
- Developing the use of Autonomous Things Technology - This technology presents a high interest for UxV swarms Command and Control solutions. The real value achieved by autonomous things is that they are able to capture and send information and seamlessly transfer it via networks to cooperating systems where these data can be automatically analysed and actions taken.

4.1.7 Development of EU industrial capabilities in Information Technology area

Information Technology (IT) is the concept involving the development, maintenance, and use of computer systems, software, and networks for the processing and distribution of data. IT is considered to be a subset of information and communications technology (ICT). The IT definition consists of three categories: techniques for processing, the application of statistical and mathematical methods to decision-making, and the simulation of higher-order thinking through computer programs. Several products or services within an economy are associated with information technology, including computer hardware, software, electronics, semiconductors, internet, telecom equipment, and e-commerce.

Based on OCEAN2020 partners' knowledge and CapTech result, the following development recommendations are identified for the Information Technology area:

At short-term:

- Development of secure on-board UxS systems solutions using advanced AI technology;
- Developing the use of Machine Learning (ML) by starting with supervised learning - On the one hand, ML algorithms are responsible for recognizing patterns and on the other hand, they can generate solutions. This will increase UxS autonomy and enhance the RMP by supplying relevant processed data.

At mid-term:

- First step in building the IT for multi-domain C2 for swarms (AI swarm technology);
- Enhancing ML algorithm by introducing unsupervised learning and active learning.

At long term:

- Advanced solutions for UxS swarm activities – for supporting the new way to command and synchronize operations;
- Developing the use of Internet of Things (IoT) in parallel with Autonomous Things Technology introduced in the previous section - IoT is a system of interrelated computing devices, platforms, objects or humans that are provided with unique

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identifiers. IoT allows data transfer over a network without requiring human-to-human or human-to-computer interaction. It uses any communications channel, including wired and wireless. This technology should be particularly relevant for UxS swarms management.

4.2 Proposed planning for Scientific Research

4.2.1 Methodology

The following methodology has been used to identify needs for scientific research and in a second step to develop the research roadmap involving scientific research institutes:

1) Identify the technology building blocks (TBB) defined in EDA's Strategic Research Agendas (SRA)
2) Identify the gaps between OCEAN2020 provided results and the articulated needs in the SRAs/TBBs
3) Identify which of the gaps from above can be filled by research connected to OCEAN2020 (NOT all TBBs are related to the OCEAN2020 topics) and thus are scientific research needs which may be covered by OCEAN2020 partners
4) Describe the identified research needs

4.2.2 Identification of Scientific Research needs

Based on the methodology described above, the following research needs have been identified and are described:

a) Research regarding autonomous behaviour of unmanned systems
b) Research regarding methods of artificial intelligence for decision support
c) Research regarding methods of artificial intelligence for situational awareness improvement and situational prediction
d) Research regarding algorithms of fusion of data from unmanned systems

These researches needs address the following TBBs:

a) TBB 04 "Autonomous and automated GNC and decision making techniques for manned and unmanned systems" of CapTech Guidance, Navigation, and Control
b) TBB 2 "AI and Big Data for Decision Making Support" of CapTech Simulation
c) TBB 7 "Information Process Enhancement by using AI and Big Data" of CapTech Information
d) TBB 1 "Management and Processing Information from Heterogeneous Sources" of CapTech Information

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4.2.2.1 *Research regarding autonomous behaviour of unmanned systems operating as a squad*

Autonomy is a characteristic of mobile unmanned systems that is often considered desirable.

Autonomy has been variously defined as:

- A system's ability to sense, comprehend, predict, communicate, plan, make decisions, and take sequential actions to achieve its goals as determined through interaction with humans and between units that compose the autonomous system
- A set of properties characterizing a system including perception and automated, in-situ sensor processing, intelligent control, cooperation between humans and machines, and scalable collaboration. Different communities focus on different properties: user groups, roboticists, machine learning practitioners and cognitive scientists.
- An Unmanned Systems (UMSs) own ability of sensing, perceiving, analyzing, communicating, planning, decision-making, and acting, to achieve its goals as assigned by its human operator(s) through designed human-robot interaction (HRI). Autonomy is characterized into levels by factors including mission complexity, environmental difficulty, and level of HRI to accomplish the mission [R38], [R39]

Until now, autonomous behaviour of unmanned assets has been addressed from a single asset perspective. Some additional work addressed the behaviour of multiple unmanned assets acting as a swarm. The modelled swarming behaviour has the objective to ensure the complete surveillance of an area by a set of unmanned assets. The mostly used technique is the pheromone-based technique. One of the prominent methods is the Ant Colony Optimization method (ACO) introduced by Dorigo [R40].

When the UxV swarm needs to cover a specific area for surveillance purposes, an adapted ACO algorithm may be used [R41]. This algorithm, developed for UAVs, uses repulsive pheromones to guide the UAVs over the area they have to cover. The UAVs share a map of virtual pheromones that indicate recently visited areas when high pheromone concentrations are present. The UAVs then have a higher probability to move to the least recently visited areas. Additional analysis is needed to ensure that this algorithm may be transferred also to other unmanned vehicles than aerial ones, e. g. USVs, and exhibits the same behaviour.

For military applications like surveillance, target detection or target tracking, the UxVs mobility behaviour must be as unpredictable as possible for an enemy to prevent their tracking by adversarial tracking systems. Since the above mentioned adapted ACO method uses a random process, the requirement that the UxVs mobility behaviour shall be unpredictable is fulfilled.

However, the UxV swarm operator still needs to be able to forecast the UxVs paths. A solution might be to change the random process of the ACO algorithm to a chaotic dynamical system.

A chaotic dynamic is the solution to a deterministic system with the property that the solution is bounded and sensitive to initial conditions, and consequently, unpredictable on a long-term. A Chaotic Ant Colony Optimization to Coverage (CACOC) algorithm that combines an Ant

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Colony Optimization approach (ACO) with a chaotic dynamical system has been introduced by Rosalie et al [R41]. The algorithm has been developed within the ASIMUT project [R43]. Its implementation and validation in a larger simulated trial or a live trial is needed.

However, additional methods for coordinating the unmanned assets swarm are needed in order to enable also other mission of the swarm, especially an autonomous behaviour of unmanned systems operating as a squad, i. e. different members of the unmanned assets squad have assigned different tasks and the members of the squad cooperate in an intelligent way to fulfil the task or mission assigned to the squad as a whole.

Autonomy of unmanned systems is a broad research field and may concern the platform's observation system, its decision-making system or both. Basically, any autonomy problem can be defined as the system's own decision of how to distribute tasks between the squad members in time to reach a common goal.

In order to reach this goal of unmanned systems operating as a squad, a couple of problems must be solved and thus, further research is needed:

- Solving the task allocation problem in multi unmanned vehicles systems. Usage of multiple unmanned aerial vehicles or unmanned surface vehicles to perform cooperative tasks is a promising concept for future autonomous military systems.
- Automatic re-tasking of the whole group of unmanned assets as well as single systems when the contact with a platform/sensor (the unmanned vehicle) is lost
- Automatic reconfiguration of the squad
- Architectures for command and control as well as management of heterogeneous groups/swarms of unmanned vehicles
- Cooperation schemes between autonomous unmanned vehicles operating as a squad
- Improved intelligence of autonomous unmanned vehicles. Beside ubiquitous stochastic methods for artificial intelligence, also deterministic artificial intelligence shall be researched.
- Explainable Artificial Intelligence for unmanned vehicles. An explainable intelligence model gives the logic behind the decisions an unmanned vehicle makes when it is on a predefined mission and chooses to deviate from its designated path.

The most common technique used for tasks distribution in a squad is that of hierarchical task networks, i.e. a systematic mapping of the difference between the initial and goal state of the system into tasks and sub-tasks [R44, R45]. Using this technique, it does not make any difference if the system functionalities are on the same platform or distributed over several platforms, if we neglect communications issues.

One of the most difficult challenges with autonomous squads lies in the design of the autonomy, i.e. how to design a system that can correctly perform tasks without human intervention. This requires the merger of systems modelling and artificial intelligence, an emerging and fast-growing research area that has become known as runtime (i.e. real-time) complex adaptive systems design (CAS). With CAS, the purpose is to define a goal function

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(user expectation of the system) that seamlessly maps onto the system functionality and to include as many algorithms per functional component as possible. This allows the system to select between a multitude of reconfigurations and hence to optimize on the goal function in real-time by far surpassing human performance and human decision making. This type of autonomy is known as level-1 autonomy or level-1 intelligence, i.e. the system obeys a goal function specified by a human [R46, R47].

Going one step further is to include the engineering milestones into the system design. Hence, the user requirements review, the concept readiness review, the design readiness review and the integration review, have all become part of the system's design. This is made possible because autonomous systems are software critical, i.e. they heavily rely on software components. Obviously, this is what is at least required for industry to start embracing the building of autonomous systems.

Finally, additional research is needed on how to test the intelligence of autonomous unmanned systems. Unmanned systems cannot be tested using methodologies developed for testing manned systems. Autonomous unmanned systems differ from manned systems, not only in the position of the system's operator, but also in their role in the decision process. There is a need for a methodology that completely tests this decision process without biasing the system to a default "human" solution. For this to happen in the future means that the system should be able to support "self-verification" of the system requirements and "self-validation" of the user requirements, i.e. to signal a mismatch between the system design and the goal function. This is referred to as level-2 autonomy or level-2 intelligence [R46, R47].

The final step in autonomy, is to formalize ethical human behavior. If this can be accomplished in the distant future, then the system will not only be able to signal a mismatch between the system design and the goal function, but also to correct the goal function according to human standards. This is referred to as "artificial intelligence safety", level-3 autonomy or level-3 intelligence [R44, R45].

4.2.2.2 Research regarding methods of artificial intelligence for decision support

A decision support system which builds on methods of artificial intelligence is called an intelligent decision support system. The goal of such a system is to learn from past experience, fuse ambiguous or contradicting information in a reasonable way, react somewhat consistent in prior unencountered situations by using reasoning systems for solving problems, and prioritising the different elements in a situation.

A support system should be expected to encompass

- intelligent tools for sensor (and platform) planning and control
- multi-sensor, multi-platform data fusion of heterogeneous information
- analysis of correlations in the data and assessment of current trends in the mission environment

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Therefore, there are a couple of fields which need further research to capture the knowledge:

- Domain specific models and ontologies for representing the mission environment accurately
- Deep learning and the challenge of small amount of data supporting the intended missions
- Reasoning by using rules, case-based reasoning, and adapting the underlying databases to learn about new environments
- Probabilistic models like Dynamic Bayesian networks or Markov Random Fields
- Source quality and reliability estimation and integration
- Integration of new data sources (e.g. OSINT for verifying civil activities)
- Big Data analytics for anomaly detection and situation analysis
- Further integration of UxV in the decision support capabilities
- Explainable and transparent AI systems through visualization and special methods and algorithms for giving inside into black box models

Domain specific models and ontologies

While there are already attempts from different directions to formulate a cohesive model, the question here arises, how to connect these models and how well these models are able to actually represent not only the mission environment at the moment but also for future use. Some of these models for maritime data with civil and military background are e.g. MARSUR[5], EUCISE2020[6], the S-100 IHO Universal Hydrographic Data Model[7], and Ontologies and Vocabularies used in BigDataOcean[8]. Furthermore, different STANAGs can be used to represent the available information and share it with partners, e.g. STANAG 4676 is used during the Sim trials in OCEAN2020 for sharing track related data between entities.

Machine Learning, deep learning, challenge of small amount of data, and explainability

While traditional artificial intelligence-based systems like expert systems utilize the available information and experience of experts to identify critical situations, machine learning systems are data-driven. This implies, that in order to function well, data regarding the problem at hand must be available. This is especially true for deep learning systems due to the number of free parameters in the models.

While for civil applications like face detection (e.g. DeepFace developed by Facebook [R52]) huge amount of (sometimes even labelled) data is available, this is often not true for non-civil applications and more general critical situations. Therefore, for future research, the question

[5] https://www.eda.europa.eu/docs/eda-factsheets/marsur-factsheet-v2_09102012_cs5_bleu

[6] http://www.eucise2020.eu/

[7] http://s100.iho.int/S100/home/s100-introduction

[8] http://www.bigdataocean.eu/

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of handling little training data is crucial. One possibility is the use of transfer learning [R53]. This method reuses already trained neural network for new application domains. The idea is, that some of the needed functionality for a neural network to work on different datasets will stay the same. Thus, by moving to another domain, only the additional needed knowledge needs to be learned, which should result in less data needed.

Another point in utilizing machine learning methods in general is the problem of explainability. Especially in mission critical situations, it is important to be able to understand the results of these methods in order for a human operator to actually make the right decision. In order to generate explainable machine learning models, methods like LIME [R54] or SHAP [R55] were introduced. While these can be seen as a starting point, another challenge is to make these explanations available to an operator in an intuitive way [R56],[R57].

Rule-based systems, case-based reasoning, probabilistic models and other expert systems

While the before mentioned machine learning methods are data-driven, the second group of AI-Systems[9] are knowledge based expert systems. These methods tackle to problems, firstly to represent knowledge and secondly to reason with it. By e.g. utilizing vocabularies and ontologies, the information about the mission environment can be encoded in a machine-readable format. This is then the foundation for reasoning methods [R58][R59]. Gaps can be seen here in the development of the knowledge representation e.g. in form of domain knowledge graphs, extraction of information, etc.

For both, reasoning systems and machine learning system another important issue is the integration of uncertainty aspects together with source quality and reliability estimations. This is a crucial point for creating reliable and explainable results.

Integration of new data sources

In order to verify civil activities, other sources beside the conventional radar, etc. can be used. This includes especially OSINT information. By analysing different sources, like e.g. introduced in the MARISA project[10], it is possible to link vessel behaviour as recognised by the conventional sources in conjunction with machine-learning and reasoning systems to validate e.g. civil activities.

4.2.2.3 Research regarding methods of artificial intelligence for situational awareness improvement and situational prediction

For increasing situational awareness, the points mentioned in the prior section are crucial as well. In addition, an emphasis should be put on the intuitive usage of the system, the different available data sources and an easy to learn approach for interacting with the system. Further,

[9] https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=56341

[10] https://cordis.europa.eu/project/id/740698/results

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easy and transparent sharing capabilities and explainability functions for possible AI techniques used are highly recommended for strengthening the situational awareness.

For situational prediction, highly sophisticated algorithms should be placed into use. The aim is, to integrate all the available information in order to make solid predictions. This can be achieved by either using more classical approach of statistical models like Kalman filters (and its extensions) or Markov Chain Monte Carlo based filters; or by utilizing the prediction capabilities of recurrent neural networks. In order to better understand a situation and the possible unfolding scenarios, an operator might want to change certain parameters in the prediction in order to better grasp the whole situation.

4.2.2.4 Research regarding algorithms of fusion of data from unmanned systems

The fusion of data from unmanned systems concerns aspects on different levels including low-level sensor data fusion as well as higher-level fusion, e.g. information fusion. The low-level sensor data fusion is nowadays often part of the UxS carrying the sensor(s). Here, it can be implemented directly on the (unmanned) asset itself, e.g. for the fusion of sensor data from different modalities such as RADAR and EO data, or it can be implemented in the ground control station of an asset. For this kind of fusion, the following research needs can be stated.

The data received from UxS is then subject to high-lever fusion processes. These fusion processes take part at the object level, were sensor data has already been abstracted so far as to represent observed objects. At the object level, object detections have to be aggregated to tracks and those tracks (e.g., from different assets) then have to be correlated to form consistent system tracks.

Tracking is the process of associating a detection with one out of a number of tracks (different targets). Using a dynamic model (e.g. a Kalman filter), the estimated velocities of the targets are used to predict their positions at the timing of the detection. Next, the detection is associated to the track with the smallest difference between the detection and the predicted position. Because prediction errors grow with time, a track is interrupted after a while and a new track is started for the same vessel.

If the detections come from a single sensor, the association process is referred to as sensor level tracking. All detection are input to the tracking system and assigned to the available tracks. With unmanned systems, there are multiple sensors onboard of multiple platforms. Although this slightly complicates the tracking problem because different sensors have different data rates and measurement errors, the same sensor-level tracking methods can be performed which is then referred to as central-level tracking. All detections from different sensors are input to the same tracking process. This has the advantage that all available position and velocity information are used in the tracking process (without averaging or filtering) which gives the most accurate results, i.e. the least false associations and false tracks. The disadvantage is that all detections have to be transmitted to a central point which requires bandwidth. Examples of central-level tracking methods can be found in [R48].

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To avoid the bandwidth problem at the expense of accuracy, track-level fusion can be used instead of sensor-level fusion. Detections are associated with tracks on a single platform after which the tracks (e.g. as spline parameters) are transmitted to a central point and fused (with similarity measures). Track-level fusion methods include e.g. cross-covariance track fusion and covariance-intersection track fusion [R48].

Perhaps the most challenging problem with tracking of targets with unmanned systems is the lack of track continuity. Sensors onboard of unmanned systems usually have a limited field of view. This means that “snap shots” are collected of the tracks, i.e. pieces of track with large gaps in between. This obviously makes the use of a dynamic model in the tracking system impossible, i.e. it is impossible to predict the vessel position if time gaps are too large. In these cases, very sophisticated tracking algorithms have to be used which combine dynamic tracking with reasoning on the target features. Not surprisingly, most of the latest research goes in this direction. A well-known method is to include vessel features like vessel size or optical signatures with the detections in the tracking process. These features are then used to assist the association of tracks of the same target if the dynamics are not accurate enough or completely fail. This can be done by directly associating the detection with one of the tracks or, as is usually done, to reduce the number of track associations (pruning of the observation space). Tracking then becomes more of a classification problem [R49, R50, R51]. Another popular method is to reason on information or latent variables, i.e. variables that cannot be observed but have to be inferred from observations. For example, if it cannot be decided dynamically to which track a detection has to be assigned, information of the presence of vessel lanes, harbors, fishing areas, or vessel behavior like loitering or certain types of fishing behavior may help the tracking process. Tracking now goes beyond classification and becomes more of a reasoning problem [R49, R50, R51].

At the same time, metadata attached to detections or tracks has to be fused, for example, information regarding the type of observed vessel (classification). A further fusion process at an even higher-level is friend-or-foe identification and threat assessment. Research needs addressing this higher-level fusion now arise for example at the fusion of different classification values, as e.g. provided by different assets. Special consideration has to be given to the fact that different data formats and standards can be used by different assets, resulting, for example, in different classification systems (regarding the employed terms to define vessel classes).

Once a system has created consistent system tracks, these tracks (as part of its RMP) have to be shared with other actors (task units, MOC, etc.). Here, further research is needed regarding the organization of update procedures in such a distributed environment. Questions such as “Who is allowed to publish which kind of RMP/track updates?”, “How and when is updated information integrated into a local RMP?” or “How to prevent a cyclic information flow?” need sophisticated answers.

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4.2.3 Elaboration of research roadmap involving Scientific Research Institutes

For elaborating the research roadmap involving scientific research institutes, the following methodology is used:

- Identify where in the Research Window of the European Defence Fund, the respective national MOD research development plans or NATO Science and Technology Organization activities the scientific and research competencies of the respective institute may produce additional value.

  This should be done per competence (e. g. environmental modelling competencies, competencies with regard to autonomous underwater vehicles, etc.)

- Map these possibilities to the overall Research Strategy of the respective institute
- Identify those Work Programs and Calls laid out in them, which are in line with the overall Research Strategy and thus may lead to a successful cooperation with other partners and application for funding.
- Set-up the cooperation, develop a proposal for answering the respective Call, and submit it to the respective funding authority.

4.2.3.1 General research roadmaps of the involved scientific institutes

Multinational capability development at EDA covers the whole life-cycle of a project, from research and development and definition of common standards and requirements to design planning, industrial development and procurement of new defence equipment [EDA Annual Report 2018].

The 2018 Capability Development Plan prioritises military capabilities that need to be addressed and developed by Member States and underpins the identification of cooperative activities [EDA Fact sheet: Capability Development Plan, June 2018]. One of these cooperative activities is the European Defence Fund (EDF).

The upcoming EDF has two dimensions, a research dimension (also called Research Window) and a capability dimension (also called Capability Window). The European defence research programme under the EU's Multiannual Financial Framework 2021 – 2027 is expected to start in 2021 (this year).

As soon as the EDF Work Program will be published (expected spring 2021), each research institute will analyse it, identify the actions and topics which match with its Research Strategy, identify which of its competencies may best contribute to the topics of the action, seek for partners with matching research interest and complementary competencies, set-up a cooperation scheme, and finally develop a proposal and submit it to EDA.

For the 2021 EDF Work Program the cooperation scheme with partners will be set-up by mid-2021. Submission of proposals is expected to happen in November 2021, and start of projects in late 2022.

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4.2.3.2 *Research roadmaps of the involved scientific institutes regarding autonomous mobile Systems*

Regarding their technical competencies, the scientific institutes will further develop their knowledge of

Collaborative autonomy and manoeuvring of UxVs, squads and swarms	2021 and beyond
Resilient communication between autonomous vehicles, including resilient communication for underwater and over the horizon operations	2022 and beyond
Sonar data processing, sonar imagery exploitation:	2022 and 2023
System architectures of cooperative UxS	2022
Automated mission and task management for heterogeneous, multi-domain UxVs, squads and swarms, i.e. tasking, re-tasking, asset configuration, execution and exploitation	2021 and beyond
Run-time validation and verification of autonomous behaviour	2022 and beyond
Fusion algorithms for improved situation awareness using a network of manned and unmanned systems	2021 and beyond
Robust platform navigation and timing solution (in a GPS denied environment)	2021 and beyond

Regarding products and solutions to be developed:

ROS toolbox for autonomy	2022
Improving USV Water Strider and UUV DEDAVE	2022 and beyond
Improving Control Station for USV Water Strider	2022 and beyond
Improving and extending MCM mission and task management software	2021 and beyond
Improving experimental CMS functionalities for integration of UxV operations	2021 and beyond
Improving development environment for experimental CMS functionalities	2021 - 2023
Improving simulation environment for autonomy (now ROS and GAZEBO based)	2021 - 2023

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The knowledge and solutions developed are intended to address the domain/market "Unmanned Warrior" from 2023 on and beyond.

Activities aim to support the integration of unmanned systems on board of future naval ships with reduced manning and the appropriate automation level and decision support. Joint development of functionalities is addressed within the golden triangle of government, industry and research institutes.

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