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BEST PRACTICE GUIDE

Unmanned maritime systems handling, operations, design and regulations

EDITION 2022 - PUBLIC

BEST PRACTICE GUIDE FOR UNMANNED MARITIME SYSTEMS HANDLING, OPERATIONS, DESIGN AND REGULATIONS
SARUMS BPG 2022
PUBLIC VERSION

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Annex A: Code of conduct
Annex B: Sense and avoid policy

This Best Practice Guide for Unmanned Maritime Systems Handling, Operations, Design and Regulations (SARUMS BPG) edition 2022 is the first official release in its public version.

SARUMS BPG is the outcome of the European Defence Agency (EDA) Research Technical Proposal (RTP) "Safety and Regulations for European Unmanned Maritime Systems" of 18 March 2011, with the following establishing Member States: Belgium, Germany, Finland, France, Italy the Netherlands and Sweden, in close coordination with DCNS (FR) and SAAB (SE). The 2022 edition was established under the framework of the EDA ad-hoc working group "Safety and Regulations for Unmanned Maritime Systems" (AHWG SARUMS) with the support of the following additional participants: Poland and Portugal.

The relevance of this material is neither more nor less than its usefulness for establishing and promoting concepts and practices leading to safe operations of unmanned maritime systems. AHWG SARUMS is engaged in the continuous development of this material, mostly focused on legal and liability aspects. Any comments and/or suggestions regarding the current content and/or future lines of development are most welcome, by email to cap@eda.europa.eu and info@eda.europa.eu, subject "SARUMS BPG".

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Contents

FOREWORD

Unmanned Maritime Systems (UMS), Maritime Autonomous Systems (MAS), Maritime Unmanned Systems (MUS), Maritime Autonomous Surface Ships (MASS) are nowadays well established in the maritime world of e.g., flag and coastal States, authorities, navies, shipowners, classification societies, shipbuilders, industries, and insurers.

The EDA ad-hoc working group "Safety and Regulations for Unmanned Maritime Systems" (AHWG SARUMS) attempted to provide the European navies with guidance for areas in design and operations for unmanned and/or autonomous maritime systems. It was their intention that this guidance should be considered as an advisory UMS safety framework rather than a set of binding rules.

The first edition of the Best Practice Guide for Unmanned Maritime Systems Handling, Operations, Design and Regulations (BPG) was produced on 5 May 2018. Since then, various terms, acronyms, definitions regarding UMS settled in. Although it was not the intention of the AHWG SARUMS to consider the BPG as a binding instrument, nonetheless they sought to provide the UMS community guidance in order to contribute to the safe operations of UMS. Unfortunately, the lack of precise and uniform terminology and definitions does not contribute to the required safety of operations and navigation, let alone improve the interoperability of UMS between allied navies. The AHWG SARUMS will therefore examine this lack of uniformity and standardisation and will make proposals to EU Member States, the European Commission and the relevant industries to resolve these inconsistencies where possible.

The BPG is a living document, and this new edition will be the basis for e.g., the reassessment and refinement of the existing terminology and definitions in the maritime landscape, the continuous validation and updating of the BPG whether or not by means of experimentations at sea, and the development of new chapters on the interaction between UMS and other Unmanned Systems (UxS) in the maritime domain.

It is a great honour and pleasure to chair this working group of experts and to join them in their permanent undertaking to commit to the safety of operations and navigation of UMS.

Chairman AHWG SARUMS

CREATION AND OBJECTIVES OF AHWG SARUMS

Due to high interest in UMS, several research projects came together in a large programme launched by EDA with the participation of many Member States and industrial stakeholders. As the national or international rules, regulations and legislation governing safe operations at sea and applicable to unmanned maritime vehicles were virtually non-existent, a common understanding of minimum safety procedures and a shared view on rules and regulations among European Navies were needed to enhance interoperability in future maritime operations.

A dedicated working group was created to provide the European navies with a best practice safety framework for UMS that recognises their operational use and legal status. The working group developed a wide network of national representatives, industrial stakeholders, and academics to identify best practices and build upon existing material, through consultations, workshops, specific studies and search in national, European, worldwide documentation and UMS policies.

The outcome is the elaboration of this Best Practice Guide (BPG) in 2018, to propose guidance for areas in design and operations that should be considered unique and specific for unmanned systems.

The BPG is elaborated as an advisory UMS safety framework rather than a set of binding rules. End users and owners are therefore free to decide whether to incorporate the guidance document into their own national regulations, which has been the rationale for keeping the text as generic as possible. A significant improvement in interoperability and standardization in design and operation of UMV is expected if nations decide to adopt this guidance document.

The EDA working group “AHWG SARUMS” was established to provide EDA participating Member States with an adequate working structure to discuss UMS from a regulatory and safety perspective, and to engage the maritime community at a broad scope and depth in the maritime policies. It brings together experts from the Member States to contribute to shape the UMS landscape towards more coherence from a safety and regulatory perspective, to strengthen the link with relevant institutions, organisations and industrial stakeholders, to identify collaborative opportunities and to promote them further through projects and programs. In this context, the AHWG SARUMS is in charge of the continuous monitoring and necessary updates of this BPG.

1. Introduction to Unmanned Maritime Systems (UMS)

1.1. Aim

The aim of this guidance is to provide European UMS users and designers with a best practice safety framework that recognises their operational usage and the needs of maritime actors.

The document is written as a best practice guide and could be adopted by organisations if they so choose.

1.2. Philosophy and principles

The philosophy behind this BPG is based on the management of risk as well as applicable rules and regulations. It provides advice for areas in design and operations that should be considered unique and specific for unmanned systems. Guidance, considerations, rules and areas for which unmanned systems features coincide with normal manned ship design and normal naval operational practice are not elaborated on.

The principle of this guidance is to provide advice on the management of risks and how to utilise UMS in a safe manner. This is addressed through:

1. guidelines to achieve safe UMS through defined safety precepts,
2. the definition of the Concept of Operations that describes the role, attributes, required survivability, the environment, and the operating and maintenance philosophies,
3. the selection of verification methods adapted to the Concept of Operations and the safety goal,
4. the assessment of the system against the verification methods by which achievement of the safety goal can be judged,
5. the issue of certification by a national Naval Administration (or its Recognised Organisation) to provide a visible demonstration of safety management and compliance with the safety goal,
6. periodic survey to ensure that the identified verification methods are being met and compliance with the safety goal is maintained.

While this document is intended to serve as a guide, usage of the terms “shall” and “should” reflects the level of concern of the statement.

Unmanned maritime vehicles (UMV) that are a fired weapon in itself or could be considered as a weapon with armed engagement as its main purpose, such as torpedoes, are considered outside the scope of this guidance.

This document is principally focused on, and is applicable to, UMS that fit into the Unmanned Surface Vehicles (USV) and Unmanned Underwater Vehicles (UUV) descriptions below.

It shall be noted that exemptions may exist to many guidance statements below whenever the type of, or size of the UMV makes it irrelevant or impractical to achieve.

Even though this guidance has been produced with smaller categories[1] of UMV size in mind, a major part of the guidance statements will be applicable for larger UMV as well.

1.3. Advice to the reader

Below is a brief description of the contents of this document.

Document main body

Section 2 Overview and basic characteristics. This chapter introduces some of the basic terminology related to UMS and its operational phases.

Section 3 Control. This chapter defines methods of control.

Section 4 Safety. This chapter provides guidance in the format of safety precepts in the areas programmatic, operations and design.

Section 5 Collision avoidance. This chapter defines fundamental terminology and considerations related to collision avoidance.

Section 6 Verification. This chapter addresses verification and Controller qualification and training.

Section 7 Regulations and legal status. This chapter provides an overview of international laws and how they may relate to UMS.

Appendices

Appendix 1 Acronyms and definitions: presents abbreviations and definitions of UMS related terminology.

Appendix 2 UMS Breakdown structures: establishes terminology and definition of UMS system and subsystem.

Appendix 3 Risk list: provides a list of risk and control measures for UMS operations.

Appendix 4 Legal status for Unmanned Maritime Systems: provides an overview of international regulations and laws applicable to UMS.

Appendix 5 [*governmental use only*].

Appendix 6 UMS categorisations: provides a collection of different descriptive UMS parameters.

Appendix 7 UMS Operational phases: suggests USV/UUV mission phases.

[1] Small to medium-large as described in Appendix 6.

Annexes

Annex A Code of Conduct: provides a code which is suggested that UMS using organisations or duty of care holders should adopt.

Annex B Sense and Avoid Policy: elaborates upon and clarifies issues surrounding UMS Sense and avoid systems. It also states positions on the influencing concepts and provides guidance to operational use of sense and avoid systems.

2. Overview and basic characteristics

Unmanned Maritime Systems (UMS) are typically divided into Unmanned Surface Vehicles (USV) and Unmanned Underwater Vehicles (UUV) and are significant in that they operate without any on-board bridge crew. Unmanned Air Vehicles (UAV) may also be included in UMS but are not covered in this document.

The concept of UMS in this document is understood to include all systems, associated components and subsystems needed to operate these systems and covers a full UMS system with control system, vehicle, logistics and interacting personnel as outlined in Table 1.

UMS may be categorised in accordance with several areas such as way of control, size, endurance, application and degree of autonomous functionality (see Appendix 6). One subset of UMS is Remotely Operated Vehicles (ROV) that during their mission are physically connected to a controlling site, such as a support ship, by an umbilical cable. Other variants of UMS are gliders, hybrid UxV and more static systems such as buoys.

NATO (Ref 1) defines Maritime Unmanned Systems (MUS) as “systems operating in the maritime environment (subsurface, surface, air) whose primary component is at least one unmanned vehicle. An unmanned vehicle is defined as a powered vehicle that does not carry a human operator and can:

a) be operated autonomously or remotely,

b) be expendable or recoverable,

c) carry lethal or non-lethal payloads.”

Also according to NATO, ballistic or semi-ballistic vehicles, cruise missiles, artillery projectiles, torpedoes, first generation ROV, mines, satellites, and unattended sensors without propulsion are not considered as unmanned vehicles. A detailed UMS system breakdown structure with defined terminology is provided in Appendix 2.

UMS Components	Description
Unmanned Vehicle	Waterborne part (or parts) typically consisting of Vehicle and Mission equipment.
Control station	Equipment needed for assuming command of one or more vehicles.
Support system	Maintenance equipment, spare parts, training facilities, documentation, and other logistics.
Personnel	Personnel as needed, typically interacting with Control station and Support system.

Table 1 – Unmanned Maritime Systems (UMS) main components

2.1. Regulation and legal status

There are currently no specific international regulations that recognise the existence of UMS, let alone any that cover the design, certification or operation of such systems. This situation is referred to in chapter 7. An overview of several maritime regulations and their applicability to UMS is also provided in Appendix 4.

2.2. Unmanned Maritime Vehicles

UMS may in principle contain any surface vehicle, underwater vehicle, amphibious vehicle or combinations of these or hybrid in combination with UAV or other.

Unmanned Maritime Vehicles (UMV) are defined as remotely controlled or autonomous craft, vessel or ship with the ability to function without a bridge crew on board. It can be designed to operate on the surface, semi-submerged and/or underwater.

An Unmanned Surface Vehicle (USV) is a vehicle which operates autonomously or is controlled and commanded remotely. It operates with continuous or near continuous contact with the water surface and, when at rest, displaces water and is buoyant.

An Unmanned Underwater Vehicle (UUV) is a submersible unmanned maritime vehicle which is operating autonomously or being controlled and commanded remotely. It is able to move with both horizontal and vertical components relative to the surrounding water mass.

UMV can be categorised by the following functions:

A. Functions related to navigation and manoeuvring,
B. Functions related to purpose, operation, task or mission,
C. Other functions.

UMV is thus a vessel, craft or ship that is operating with category (A) functions without any human onboard control. (B) and (C) functions may be manned.

A UMV could be considered as being inherently unmanned when the physical design and arrangement prohibits any human presence onboard.

2.3. Organisation

The operational UMS will have an organisation attached that may vary in complexity and size. In terms of size, at least one individual at the Control station will assume the role of Controller. There is no exception for an autonomous UMV, as it may have a Controller or Control station being standby. It might also be necessary for one individual to assume the role of Master (or Commanding officer) for the UMV, whenever this would be required as of law.

In terms of complexity, there might exist a hierarchical structure with a chain of command where a Controller may be supervised. There will always be an Owner. An Operator could be either the same as Owner or otherwise belong to another organization. Responsibilities exist for each entity and is further explained in Chapter 3.6.

3. Control

One mechanism for achieving safe operations in unmanned systems is to maintain control. One challenge of unmanned systems operations is that they may be controlled remotely. Control stations and unmanned vehicles may be distributed to different locations. In both cases the communication needed to interact between those distant units introduces temporal delays. Whether these delays are significant or not depends on the change rate in the operational context of the unmanned unit, at that location, in relation to the ability of the control system to react in time. In order to be relevant, controlling functions need to be executed before events have escalated above the capability of the system.

These controlling functions can be allocated either to human Controllers at a Control station or to on-board software-based functions. Furthermore, for a function to be executed, it is understood that an appropriate authorisation is asserted.

How a Controller interacts with a UMV is described in the Method of Control definition, which consists of five methods illustrated in Figure 1 (based on Ref 2). Typical interaction can range from full control to only a monitoring role.

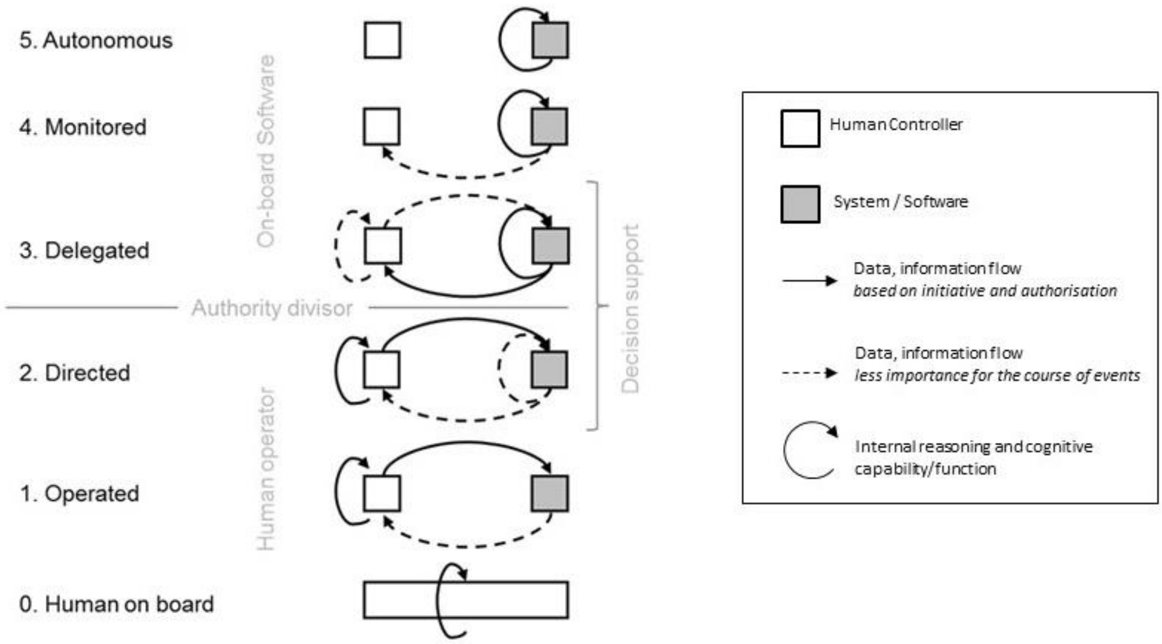


Figure 1 – Methods of control

The control methods range from traditional manned on-board control (method 0) to autonomous control (method 5).

Most UMS are designed to combine several of these control methods and for different functions, subsystem, or components. The method of control is also likely to change over time, operational circumstances, and phases during a voyage. Therefore, the choice of an appropriate control method should be based on the understanding and definition of UMS functions, the operational context, and the consequences of changing conditions to the communication capacity.

Manned on-board operation is defined as method 0. The following sections will describe the five control methods to some detail.

3.1. Operated (method 1)

Alternative description: Remote control, Tele-operation, or Manual Operation.

Under Operated control all cognitive functionality is undertaken by the human Controller. The Controller has direct contact with the UMV e.g., continuous radio (R/C) and/or cable (e.g., tethered UUVs and ROVs). The Controller makes all decisions, directs and controls the vehicle and mission functions. The UMV is afforded neither self-determination nor independence. For example, analysing, planning, and decision-making is done by the Controller who also directs all actions from his/her frame of reference. This represents maximum human influence over autonomous performance. The UMV has no reasoning capacity in itself but may provide sensor data. A Controller may receive feedback related to performance and observations of behaviour.

Table 2 shows an example of communication in the case of Operated control.

Controller	Turn to new course
UMV	<silent>
Result	UMV turns to new course

Table 2 – Information flow, operated control

3.2. Directed (method 2)

Alternative description: Permissive (UMV suggests/asks for permission) or Management by Consent.

The main difference to Operated control is that the UMV has on-board cognitive capability.

Under Directed control some degree of reasoning and ability to respond is implemented by the UMV. It may sense the environment, report its state, and suggest one or several actions to the Controller, such as e.g., prompting the Controller for information or decisions. However, the authority to make decisions is with the Controller. The UMV will act only if commanded and/or permitted to.

Table 3 shows an example of communication in the case of Directed control.

UMV	I would like to turn to new course		
Controller	Go	No go	<silent>
Result	Turn	As before	As before

Table 3 – Information flow, directed control

3.3. Delegated (method 3)

Alternative description: Declarational (UMV declares intention) or Management by Exception.

The main difference to Directed control is that the authority to invoke the function at hand now is transferred to the on-board system.

The UMV is now authorised to execute some functions. It may sense environment, report its state and define actions and report its intention. The Controller has the option to object to intentions declared by the UMV during a certain time, after which UMV will act. The initiative emanates from the UMV, and decision-making is shared between the Controller and the UMV.

Other characteristics are that:

- The Controller is alerted to function progress and exceptions,
- The Controller may veto, override, or alter parameters, and cancel or redirect actions within a defined time span,
- When the Controller by choice and/or lack of time does not react in time the function(s) will automatically be executed.

Table 4 shows an example of communication in the case of Delegated control.

UMV	I will turn to new course			
Controller	Go	No go (within time span)	No go (outside time span)	<silent>
Result	Turn	As before	Turn	Turn

Table 4 – Information flow, delegated control

3.4. Monitored (method 4)

Alternative description: Reporting (UMV reports action).

The main difference to Delegated control is that the on-board system invokes functions without waiting for (or expecting) a reaction from the Controller.

The UMV will sense the environment, report its state. UMV defines actions, decides, acts, and reports its action. The Controller may monitor the events.

Table 5 shows an example of communication in the case of monitored control.

UMV	I have now turned to new course
Controller	<silent>
Result	Turn

Table 5 – Information flow, monitored control

3.5. Autonomous (method 5)

The main difference to Monitored control is that the on-board system invokes functions without telling the Controller.

The UMV will sense the environment, define on action, decide and act. The UMV is afforded a maximum degree of independence and self-determination within the context of the system's capabilities and limitations. Autonomous functions are invoked by the on-board systems at occasions decided by the same, without notifying any external units or Controllers.

Table 6 shows an example of communication in the case of Autonomous control.

UMV	<silent> [vehicle decides to turn]
Controller	<silent>
Result	Turn

Table 6 – Information flow, autonomous control

Based on the intended quality of communication, autonomous control is subdivided into deliberate and emergent:

- Deliberate autonomy is when the absence of communication is intentional and according to plan. The UMV is equipped with the appropriate means for autonomous function and its behaviour is predictable.
- Emergent autonomy is when the absence of communication is a consequence of unforeseen events. The UMV may be neither intended nor equipped for autonomous control. The resulting functionality may be inappropriate and unpredictable.

Based on the degree of change in on-board plans, autonomous control is subdivided into deterministic and dynamic:

- Deterministic control, utilizing a static mission plan. The plan is prepared by the Controller prior to mission start and is not altered during the mission. The detailed behaviour of the system can be predicted by simultaneous simulation of the mission.
- Non-deterministic control, utilizing a dynamic mission plan. The initial plan is prepared by the Controller prior to mission start, but the plan may be altered during the mission without Controller interaction (e.g., by on board mission planning). The detailed behaviour of the system cannot be predicted.

3.6. Roles and responsibilities

The operation of UMS involves various actors of which the most important is the Owner, Operator and Controller. Depending on UMS size, type and operational circumstances, the UMS organization may also include roles like Commanding Officer (CO), Watch Officer (WO) and payload controller.

Each of them bears different responsibilities during the UMS Operation. Also, depending on operational concepts, they may be located on e.g., land, mother ships and/or at a scene.

3.6.1. Owner

The UMS Owner carries the responsibility for the proper certification, registry, maintenance, examination and manning of the UMS as well as for the certification and training of the UMS crew.

3.6.2. Operator

The Operator has various responsibilities like:

- to hold the UMS Operator certificate,
- to hold the certifications and registrations of UMS,
- to uphold the continuing seaworthiness of UMS,
- the safety management of UMS,
- the prevention of pollution by UMV,
- the UMS personnel management,
- the compliance with all document requirements,
- to keep UMS certification, survey, maintenance records valid and up to date and equally so for the certification and training of the UMS crew.

The ultimate responsibility lies with the UMS Operator for any UMS operation.

3.6.3. Commanding officer

The Commanding Officer (CO) of a UMS is considered Master of the same. The CO, if applicable, has the overall responsibility for the UMS (UMVs and crew) as well as for all UMS operations. The CO can be required to render assistance to any person(s) found at sea in danger, insofar as it can be done without serious danger to the ship (See Article 98 UNCLOS & Regulation 33, Chapter V SOLAS). The overall responsibility during the UMS operation lies with the CO.

3.6.4. Controller

The Controller is responsible for the proper execution of:

- the safety orders from the CO,
- the operation of UMV at the time allocated to the Control Station,
- the proper cooperation and communication with a payload controller or any other crew member handling the UMV during the operation,
- the mission planning, execution, and post mission evaluation of UMS.

The control methods (1) and (2) are in some sense “manned” since control is exercised by a Controller at some distance away from the unmanned system (e.g., from a remote position). If the control method is changed from anyone of these to control methods (3), (4) or (5) the authority divisor line is crossed, which means that control, or authority, is passed on from the Controller to the system.

A Controller (or his command) needs to be fully aware where responsibility and liability lies when crossing the authority divisor.

Alternatives are:

- Operator remains responsible,
- Supplier (manufacturer) of autonomous equipment is responsible.

The Controller has responsibility throughout the UMV operation notwithstanding any crossover of control from the controller to the system or vice versa.

The lack of, or non-fulfilment of responsibilities, can give rise to contractual, tort, criminal or State liabilities, depending on the applicable international and/or domestic legislations.

4. Safety

While most people and organisations recognise safety as an important property of systems and operations, things sometimes go wrong. A generally accepted definition of safety is “freedom from unacceptable risks”. The notion of system is understood as “a set of related components that provides a relevant functionality”. Admittedly vague, this allows a focus on any set of people and technology that may be of interest in some scenario.

The established views of safety as avoiding harm and injury to People, Environment and Materiel (the PEM safety view) is still valid. However, the safety framework of unmanned systems is extended beyond PEM in a few distinguishable ways. Some specifics of unmanned vehicle operations as parts of a larger system could be noted:

1. Unmanned system technologies provide an opportunity to separate a Controller from the vessel.
2. However, there are people in a system that operate unmanned vehicles.
3. The separation of people from the UMV is addressed with software and communication technologies, used to replace (at least some of) the functions normally provided by people in the vessels.

So firstly, people are not primarily at harm. This is usually recognised as one of the main benefits of applying unmanned vehicles to the dull, dirty, and dangerous situations in which one wishes to avoid accidentally hurting people. As one possible danger to people is harm caused by physical circumstances (e.g., long duration missions, acceleration, pressure, and temperature) it also follows from this that UMV can be designed to perform on levels that would be unacceptable if people were on board.

Secondly, while vehicles may be unmanned, the systems are socio-technical systems. People and vehicles (or technology, in a wider perspective) are interacting to pursue some defined objective. This means that the functionality provided by the more or less coupled parts of the system also differs in terms of performance, requirements and variability. People and technology perform better at different tasks. People are not (always) rational. Technology is not (always) working as expected. A system of interacting parts with variable performance is likely to show unexpected behaviours.

Thirdly, this leaves a design and control problem to be dealt with. The socio-technical systems including unmanned vehicles should be provided and operated so that the likelihood of unexpected behaviours is as small as possible.

4.1. Safety objective

UMS shall be designed, constructed, equipped, and maintained in a way that allows safe handling and operations taking into account all reasonably foreseeable safety risks.

This document considers the following three safety precepts for unmanned systems (ref 3).

- Programmatic Safety Precepts refers to program management principles and guidance that will help ensure that safety is adequately addressed throughout the lifecycle process.
- Operational Safety Precepts refers to safety precepts directed specifically at system operation. Operational rules that must be adhered to during system operation.
- Design Safety Precepts refers to general design guidance intended to facilitate safety of the system and minimize hazards. Safety design precepts are intended to influence, but not dictate, specific design solutions.

UMS Controllers are also recommended to adopt the Code of Conduct that is provided in Annex A.

4.2. Programmatic Safety precepts (PS)

4.2.1. Safety management

PS1 A well-established (by nation or organisation) program management procedure as well as a proven systems engineering process should be applied to the UMS program.

In addition, the programmatic safety management guidelines as defined below should be taken into account to achieve a safe UMS.

PS2 An overarching structure to develop claims that UMS are safe for a specified range of activities in a specified range of environmental conditions is suggested below (ref 4):

a) Safety Management Systems exist to ensure that policy and responsibilities for safety are clear, that actions necessary to achieve safety are carried out reliably, and that suitable monitoring and review mechanisms activities takes place,

b) A Guidance and Control Platform (GCP) (or other location) has been designed or modified (if needed) to accept and accommodate the UMS to suitable standards of safety,

c) A safe envelope of operation for the deployed platform has been determined, communicated to the user, and the platform is operated within this; Sub-claims to justify this:

- Operating envelope is defined,
- Operating envelope is communicated to Authority,
- Operating envelope is communicated to end user and enforced,
- Communications can be maintained[2] between platform and the Operating UMS command,

d) Suitable documentation to support safe operation and maintenance of the UMS to support the operations has been developed and validated,

e) A process is in place to ensure that the UMS is operated by an adequate number of suitably qualified and experienced personnel. Sub-claims to justify this:

- The design will be demonstrated to show safe platform operation,
- Hazards mitigated by training will be identified,
- UMS Operating Authority will validate training requirements for Operating personnel,

f) Suitable maintenance of the material state of the UMS is defined and conducted,

g) Suitable preparations are made for foreseeable emergencies,

h) Suitable mechanisms exist to identify and communicate potential safety weaknesses and to take suitable action to respond to these,

[2] Maintained as far as reasonably practical in particular taken into account limitations of underwater communications.

i) Suitable processes exist to manage changes to material, organization or procedure such that safety is not adversely affected.

System safety analysis

PS3 A system safety analysis shall be performed and maintained during design and production and over system lifetime to identify risks and their control measures.

PS4 Safety risks are to be categorized with a likelihood of occurrence and a consequence/severity. These parameters shall be assessed against an agreed safety risk classification scheme to allocate a Risk Classification. The control measures shall be developed to mitigate the risk to a level that is broadly acceptable or tolerable and As Low As Reasonably Practical (ALARP).

The system safety analysis shall include the following steps:

Identification of hazards

PS5 Identify hazards, through the system's lifecycle and operational cycle (see UMS operational phase description), through a systematic hazard analysis process encompassing detailed analysis of system hardware and software, the environment (in which the system will exist), and the intended use or application. Consider and use historical hazard and mishap data, including lessons learned from other systems.

PS6 Hazards or mishaps to be considered include (see ref 3):

a) Loss of control over the UMS

b) Loss of communications with the UMS

c) Unsafe UMS returns to base

d) Knowing when a UMS is in an unsafe state

e) Unexpected human interaction with the UMS

f) UMS system injuries to Controllers, own troops, etc.

g) Loss of, or inadequate, situation awareness

h) Emergency Controller stop

Assessment of mishap risk

PS7 Assess the severity and probability of the mishap risk associated with each identified hazard, i.e., determine the potential negative impact of the hazard on personnel, facilities, equipment, operations, training, maintenance, the public, and the environment. The assessment should at least consider the following consequence areas:

a) Injury or death of personnel,

b) Damage to property,

c) Non-completion of mission,

d) Damage to the environment.

Identification of Mishap Risk Mitigation Measures

PS8 Identify potential mishap risk mitigation alternatives and the expected effectiveness of each alternative or method. Mishap risk mitigation is an iterative process that culminates when the residual mishap risk has been reduced to a level acceptable to the appropriate authority. A more comprehensive list of UMS risk areas with suggested control measures available in Appendix 2.

Reduction of Mishap Risk to an Acceptable Level

PS9 Reduce the mishap risk through a mitigation approach, recommended to be mutually agreed to by both the developer and the Owner.

Verification

PS10 The UMS system shall be verified, taking into account verification and certifications by Naval Administration or authorized Recognised Organisation as appropriate. Certification may use the templates provided in Annex C (derived from the Naval Ship Code, ref 7).

4.2.2. Environmental management

PS11 UMS operation at sea will interact with and thus have an impact on the environment. This impact shall be assessed and managed by the application of a robust Environmental Management System (EMS).

PS12 The EMS should be defined in an Environmental Management Plan (EMP).

PS13 The application of an EMS shall be used to ensure that all surface and sub-surface platforms comply with the international, regional, national and/or local environmental legislation applicable to the operational areas.

PS14 Consideration of potential environmental impacts and risks associated with the integration with a GCP, operation, maintenance of the USV or UUV shall be assessed and managed.

PS15 Environmental management shall be implemented by developing an Environmental Case (EC) through the application of the EMS;

PS16 The EC shall provide the body of evidence showing a compelling and comprehensive demonstration that the environmental aspects, impacts and risks associated with the UMS operation have been identified and mitigated wherever possible, so that they are acceptable and minimised so far as reasonably practicable.

PS17 As with safety management it is necessary to define the UMS boundary with the operating environment. The boundary definition shall be recorded in the EMP.

PS18 Similarly, it is necessary to define the stakeholders responsible for environmental management. The stakeholders shall also be recorded in the EMP.

PS19 It is the responsibility of UMS designers and Controllers to ensure that the UMS do not contravene the applicable international, regional, national and/or local regulations by uncontrolled operations or releasing contaminants. For example, there may be restrictions on the use of sonar and deployment of in-water/seabed components in certain littoral/riverine areas.

PS20 Examples of Environmental Hazards to be considered includes but is not limited to:

a) Oil, greases and fuels,

b) Wire and lifting appliances hazards,

c) Battery leakage,

d) Heavy metals, PCBs and other toxins,

e) Asbestos,

f) Drugs and medicines,

g) Pyrotechnics and smokes,

h) Seabed debris (e.g., metals and plastics).

4.2.3. The Environmental Case (EC)

PS21 The EC shall cover the equipment and interfaces with their use and any associated maintenance activities, encompassing all phases of the project life cycle.

PS22 The EMP shall serve as a means of demonstrating that the required levels of environmental protection for the equipment are being or have been achieved.

PS23 Environmental studies and cases have no equivalent terminology for As Low As Reasonably Practicable (ALARP) or So Far As Reasonably Practicable (SFARP) used in safety cases.

4.2.4. Environmental Targets

PS24 Environmental aspects, impacts and environmental risks should be identified, characterised and the requirement for downstream assessments and controls established to minimise environmental impact as far as reasonably practicable. The environmental programme must include the means to comply with all relevant environmental legislation and government policy. Through this process a commitment to continuous improvement will be demonstrated.

PS25 The environmental case shall be deemed to be acceptable when all environmental aspects and impacts and environmental risks identified have been assessed, and the requirement for downstream assessments and controls for any significant environmental impacts and risks have been established.

4.2.5. Environmental Impact Screening and Scoping Study (EISS)

PS26 All of the activities associated with UMS integration, operation and maintenance shall be subject to an Environmental Impact Screening and Scoping (EISS) study (or by equivalent method)[3].

PS27 The EISS shall involve the systematic identification and recording of environmental impacts and risks relevant to the project.

PS28 The identified impacts, together with assigned significance values, should be recorded in the Significant Environmental Impact and Risk Registers within the EISS Reports.

PS29 These registers should be controlled documents, which will remain "live" throughout the life and disposal of the equipment.

4.2.6. Environmental Impacts and Risks

Criteria for both environmental impacts and environmental risks are defined using an approved process and managed by holding an EISS workshop together with environmental aspects applying the following definitions.

Environmental Aspects

An environmental aspect is any element of an organisation's activities, products or services that can interact with the environment.

Environmental Impacts

All actions will have some (predominantly adverse, but sometimes beneficial) impact on the environment. Thus, for the Project there will be a spectrum of direct consequences for the environment that are planned or inevitable. These consequences are termed environmental impacts.

Environmental Risks

Environmental harm can arise from unplanned events or equipment failure. Thus, environmental risks represent the combination of the likelihood of the unplanned occurrence (frequency) together with the probable consequence(s) on the environment. Environmental risks also include certain unplanned occurrences that may result in a breach of legislation, whether or not environmental harm is actually caused (e.g., the failure to conform to statutory documentation requirements).

[3] See e.g., EIA Directive 1985 (Directive 85/337/EEC)

4.3. Operational Safety precepts (OS)

The operational guidelines as defined below should be taken into account to achieve safe UMS operation.

4.3.1. Natural environment considerations

A safe and efficient deployment of UMS is likely to depend on suitable environmental conditions. Considerations of the effects of wind speed, rain, fog, snow, lightning, extremes of temperature and humidity, sea sate, swell and surf, currents, tides, water depth, pollution, and level of experience of operations within these conditions should be made with respect to safety, mission completion and against the operational phases.

Above water aspects

OS1 The design shall take into account implications, potential rules and regulations dependent on whether the foreseen operational area is ocean, coastal, harbour etc.

OS2 In coastal situations the effects of land mass and other issues of interference for accurate positioning and reliable communications should also be considered.

0S3 Consideration of UMS entanglement with flotsam including seaweed, nets and ropes should be made with procedures to respond to such an eventuality.

OS4 The sea conditions in which UMS shall be operated in (UUV in surface condition) are to be determined. UMS are typically designed for sea states with a significant wave height of at least 2 m, allowance being made for accelerations of 2 g downwards and 1 g upwards in the vertical and 1 g each in the longitudinal and transverse directions ($g = 9{,}81\ m/s^2$).

Further, environmental conditions at sea may be divided into meteorological conditions and the seaway conditions (ref 5) as shown in Figure 2. Both meteorological and seaway conditions are important to consider when developing specifications and concept of operations for new designs.

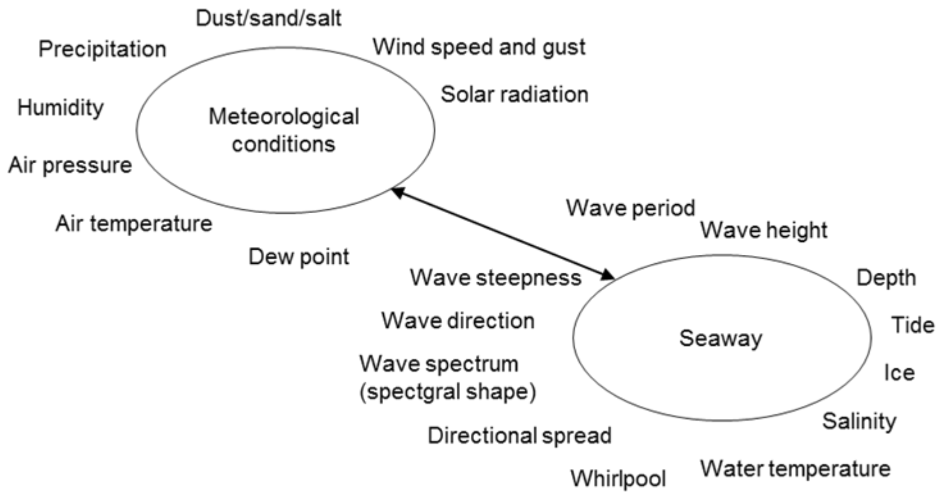


Figure 2 – Examples of significant parameters related to meteorological and seaway conditions

Occurrence of possibly extreme, low and high salt impregnated air temperature for transport, maintenance, inspection and trials out of water as well as for launch and recovery shall be considered. Summaries of above water considerations are listed in Table 7 and Table 8.

Meteorology and Climatology (above surface weather)	**Variables and effects**
Sea state	Steady or gusting wind. The combination of wind and wave height can be the most significant factor affecting UMS operation.
Humidity/precipitation	Fog, rain, sleet, and snow.
Air temperature	Tropical to polar.
Visibility	Night and day but also reduced visibility due to humidity effects. Visual observance of the deployed vehicle during launch and recovery is invariably essential.

Table 7 – Surface weather

Sea surface (interface)	**Variables and effects**

Wave characteristics	Sea state/wave spectra. Depends on the sea area, e.g., Pacific Ocean, North Atlantic Ocean. Baltic Sea, North Sea, Mediterranean etc. Wave height is a limiting factor for launch and recovery and operation at sea in general.
Sea surface quality	Floating debris, pollution, ice. Ice and its characteristics are a serious obstruction both for deployed vehicles and the launch and recovery system. Limits of operation for polar regions must be defined.
Vibration	Motion and Wave induced. Shock (e.g., slamming) and vibration should be considered for UMS platform design.

Table 8 – On surface interface aspects

Under water aspects

OS5 For the design of the propulsion and manoeuvring arrangement, the different influences of currents that may occur in the operational area and their possible combinations are to be considered. As a basis for the design, the maximum as well as the minimum tide at the relevant operation area shall be included. In addition, currents created by wind or geographic specialties (e.g., narrow channels) are to be considered.

OS6 Design and operational procedures shall take into account implications of water depth for the foreseen operational areas.

0S7 Water density will affect the buoyancy and trim which should be taken into account. It should be investigated if the operational area may have variations in water density caused by salinity changes. This issue could also degrade acoustic communication between Platform and Control station.

A summary of underwater considerations is listed in Table 9.

Oceanography (below surface)	Variables and effects
Pressure (water depth)	
Water quality	Estuarine, littoral, or open sea salinity. Buoyancy adjustments may be necessary, particularly for UUVs. Also, may cause camera and sonar problems in riverine/littoral areas.
Sea temperature	Dependant on UMS role and designated operating areas. Particularly extreme low temperatures, e.g., in polar regions will cause significant difficulties for deployed vehicle operations.
Tide	Operating duration may be affected by changing conditions. Particularly in estuarine/littoral waters, combined with wind and wave effects.
Current	
Bottom/Ground condition	Rocky, sandy, weed etc.

Table 9 – Below surface environment aspects

4.3.2. Operational environment considerations

General

OS8 The authorised control entities of UMS shall verify the state of UMS to ensure safe state prior to performing any operations or tasks.

OS9 UMS shall be considered unsafe until a safe state can be verified.

OS10 Only authorised, qualified and trained personnel with the commensurate skills and expertise using authorised procedures shall operate or maintain UMS.

Risk control measures

OS11 Should the operational risk analysis indicate that platform loss at unknown positions may be at risk, the control measures as described in appendix A3.4 should be taken into account

OS12 [*governmental use only*]

OS13 Should the operational risk analysis indicate that maritime pollution may occur, the control measures as described in appendix A3.7 should be taken into account.

0S14 Should the operational risk analysis indicate that damage or failure at sea may occur, the control measures as described in Appendix A3.8 and Appendix A3.9 should be taken into account.

OS15 [*governmental use only*]

OS16 Should the operational risk analysis indicate that there may be a risk that the platform could experience hazardous or unfavourable change in floating position (trim, heel, depth, stability), the control measures as described in Appendix A3.11 should be taken into account.

Operational envelope

OS17 A UMS operational envelop shall be determined and is to include (but not limited to) operational declarations such as:

a) Speed range(s)

b) Range (endurance)

c) Duration

d) Distance (from Control station)

e) Mission/task related issues

and environmental declarations such as e.g.:

f) Sea state

g) Visibility

h) Wind

i) Temperature

Specific mission-oriented considerations

OS18 Systems which are used in the vicinity of explosive endangered areas (e.g. close to oil and gas delivering platforms) are to be designed for the relevant explosion zones. This is also valid for Control station components.

OS19 In addition to affecting launch and recovery, care should be taken to ensure that a UUV does not subsequently surface in adverse sea conditions.

OS20 UMS shall be designed to safely operate within combined and joint operational environments.

Statement of work

A manual for operation shall be developed and include in detail the steps necessary for normal operation as well as for emergency operation in a clear and conceptual form and in the necessary sequence (e.g., as checklist). In addition, the measures for the loading of the operating systems (e.g. batteries) are to be defined. The planned lifetime as well as the permissible load and mission cycles of parts of the equipment (e.g., acrylic windows, batteries) is to be defined also.

Support system

OS24 UMS shall have an established maintenance and pre-mission checklist.

OS25 UMS maintenance status should be kept recorded.

OS26 UMS Owner´s should consider the need for UMS platform identification by means of marking the vehicle with contact details of the Owner as well as text and markings concerning hazards (including explosive charges) which may present themselves to a salvor or third party[4].

OS27 It is considered important to the safe and efficient operations that a comprehensive set of manuals, check lists and logbooks are provided covering system and equipment operating techniques and requirements, planned maintenance, health and safety issues, repairs, and continuous reporting logs.

OS28 For UMS transportation, it shall be ensured that the UMS manufacturer develops instructions of restrictions, limitations or concerns during vehicle transportation including inclined positions or environmental conditions such as in air transport (e.g., under-pressure/temperature).

Responsibilities

[4] See STANAG for colour coding: STANAG 2321.

OS29 Clear responsibility for controlling entities of the UMS operations should be identified and formally allocated. These can be separate functions and may be allocated to separate personnel/controls

OS30 There should be a clear demarcation of responsibilities for all stages of the operational cycle (see Appendix 7.4), with individual responsibilities identified.

OS31 Any handover of control or command of the UMS, whether internally or externally, should be formally planned and strict procedures developed and adhered to such that the full and itemised responsibility is always clearly allocated and promulgated both in terms of personnel and jurisdiction.

OS32 Responsibility for the overall management of the UMS system, over and above those of command-and-control responsibilities, should be addressed to ensure that the UMS system arrangements, maintenance, transportation, and storage for its use are fit for purpose.

Planning

OS33 Responsible planning is considered to be the most effective risk control measure and should be undertaken thoroughly by adequately trained and experienced (SQEP[5]) personnel

OS34 The balance shall be considered between water space segregation and the requirements for sense and avoid procedures. Full segregationu would require a low level of sense and avoid requirements. Partial segregation (such as area around a mothership) would require a heightened level of sense and avoid and operations in non-segregated areas would require a high level of sense and avoid. It may be relevant to seek partial segregation methods (such as separate sea lanes) in otherwise high-density traffic areas. The balance should also consider the size and speed of the UMS and how much of a danger it poses to other mariners and marine wildlife.

OS35 The need for permissions for UMS operations shall be investigated and if necessary, obtained.

OS36 Undertaking a pre-survey of the sea area and any necessary continued operational surveillance with respect to the sense and avoid abilities of the UMS shall be considered.

OS37 Responsible alerting procedures shall be considered including notices to mariners, NAVTEX and AIS.

OS38 Route, mission, and task planning should be undertaken for the entire deployment period.

OS39 Team briefings should be conducted to ensure all personnel are aware of the mission plan, deployment procedures and their associated responsibilities.

[5] Suitably qualified and experienced personnel

OS40 Specific Mission planning issues for UMS includes:

a) Safe path and navigation in terms of position, depth, and speed,

b) Location of known difficult passages, hazards, or risks to navigation, such as subsea structures or other object or vehicles in the area,

c) Other information on the operational area such as bathymetric data, infrastructure and overall environment,

d) Potential effects from currents or tides in the water volume.

Statement of work

Operational procedures should be developed to ensure that risks at each stage of the deployment are as low as reasonably practicable. These may include launch and recovery, pre and post mission checks, refuelling, handover of control and/or command, recovery from failure modes and “dead vessel” recovery.

Personnel

OS41 UMS operational team shall include a sufficient number of competent and qualified personnel to operate equipment, endure operating periods and to provide support functions rather than relying on personnel provided by others (e.g., clients, ship crew etc.).

OS42 Suitable levels of qualifications, competence, experience, and medical fitness as well as training for all required operational stages, including safety and technical issues shall be identified.

OS43 Size and balance shall be considered for knowledge and experience of the team covering UMS deployment, recovery, operations, and handling of foreseeable emergency situations.

OS44 Land and sea-based health and safety issues shall be considered including safe working periods and practices and the likely requirement for not working alone.

Basic Controller training highlights are provided in Section 6.5 – Training and qualification.

4.4. Design Safety precepts (DS)

The design guidelines as defined below should be considered to achieve a safe UMS.

4.4.1. General performance

DS1 Controller intervention shall as far as reasonably practical and possible, always be available when the system is in autonomous control (methods of control 3-5).

DS2 Autonomous intervention[6] shall as far as reasonably practical and possible, always be available when the system is in Controller control (methods of control 1-2).

DS3 UMS that are operated at high control level (e.g., autonomous) should be equipped with a "black box" in which time stamped data for post mission analysis is recorded.

The stored data could (as applicable) cover information from/about:

a) On-board system status monitoring (fault indications, operational status of subsystems etc.)

b) Data communication with external systems

c) Situation awareness sensors (radars, sonars, video cameras etc.)

d) Performed activities (activated systems, activated warning signals etc.)

e) Made decisions (evasive manoeuvres, speed changes etc.)

To save memory, the data recording can be arranged as a cyclic buffer, storing the most recent data to be used for evaluation of the sequence of events leading to an incident or accident. If a cyclic buffer is used, space should be provided for a sufficient time of data recording before overwriting of old data occurs.

No overwriting should occur if incident or accident occurs.

DS4 UMS shall be designed to provide contingencies in the event of safety critical failures or emergencies involving UMS. It should be a design aim to remove the effects of single point failures.

DS5 UMS shall be designed to ensure safe recovery of the platform.

DS6 UMS shall ensure compatibility with the test range environment to provide safety during test and evaluation.

DS7 UMS shall be designed to minimise exposure of personnel, ordnance, and equipment to hazards generated by UMS equipment.

DS8 The system shall have provisions to avoid environmentally induced degraded seaworthiness that may lead to capsizing, sinking and loss of vehicle.

DS9 The system shall be designed to only accept appropriate authorised human intervention.

DS10 The overall design and functionality of the UMS should be arranged to account for fitness for purpose, safety, and efficiency of operation. The health and safety of all interacting personnel or third parties should be considered (covering operations, maintenance, and storage).

[6] Meaning the ability of the platform to be self-contained in the event of command link interruption.

DS11 UMS security should be addressed with respect to UMS thefts, tampering and inappropriate salvage, considering the platform itself, the control system, and communications links.

DS12 UMS shall incorporate means that secure data/information/algorithms etc. against extraction/access by unauthorized parties (e.g. in case of loss or theft). It shall also prohibit tampering with data/information/algorithms by external parties. This can be achieved e.g., by applying encryption, data erasure.

DS13 Specific consideration should be given to the carriage of dangerous payloads or the undertaking of dangerous operations.

DS14 UMS shall have safety procedures and instructions that allow the operating organisation to use UMS under all likely circumstances as required by the missions and tasks.

DS15 The system safety analysis shall consider possible emergency situations and develop procedures for responding to them. These may include political incidents as well as physical incidents such as pollution, collisions with third parties, injury to personnel and failures resulting in dangerous navigational or mission situations.

4.4.2. Failures, mishaps, and hazardous situation management

DS16 Unexpected and abnormal situations may lead to faults, critical system failure, mishaps or events that the UMS needs to be able to handle. Pending control method, this means that either the Control station Controller or the platform needs to be able to handle situations.

UMS operated in Control methods 1-2

Control methods 1-2 are characterized by the situation where a Control station Controller has control or adequate influence.

DS17 Whenever an abnormal situation occurs, a common design and operational philosophy is for the Platform to inform the Control station. This could be an informative message, an alert, or an alarm. An alarm could be sent when a warning condition has been reached. The normal procedure is for a Controller at the Control station to assess the situation and, if needed, take mitigating or evasive actions to overcome the situation at hand

DS18 If no action is taken from the Control station, for whatever reason it might be (such as loss of command link), the Platform after a certain amount of time when warning conditions are exceeded and when a critical condition is reached, needs to have the capacity to decide and take actions to overcome the situation to reach a safe state. The platform then needs to adopt control methods 3-5.

UMS operated in Control methods 3-5

Control methods 3-5 is characterized by the situations where a Control station Controller has handed over control to the UMS platform.

DS19 A self-contained ability for the Platform to be able to identify faults or events, decide and act is the core of autonomy for UMS.

DS20 All reasonably foreseeable events that may lead to hazards and faults need to be identified.

DS21 Control measures need to be developed and implemented for each identified hazard and fault.

DS22 Actions, in the form of a sequence of actions, should be pre-programmed as default but also be possible to re-program to fit a specific mission type, operational area, sea state, visibility etc.

DS23 Actions could be categorized as primary or secondary. Primary actions could include:

a) Do nothing, continue as before

b) Change settings

c) Shut down specific subsystem(s) or component(s)

DS24 A certain action such as shut down of one subsystem may affect other subsystems or components. This must be taken into account in the algorithms.

DS25 Secondary actions could include various abort options, e.g.:

a) Controlled (graceful) degradation by selective shut down of subsystems or components

b) Full stop

c) Coasting stop

d) Complete shut down

e) Drop anchor

f) Manoeuvre

g) Go to emergency position…

DS26 The action or sequence of actions to achieve a Safe state condition shall be defined for all foreseeable mishaps or failures throughout operations, launch and recovery, maintenance and other off sea activities as needed.

4.4.3. Platform considerations

DS27 The platform shall provide adequate strength to support general operational loads including sea loads, lifting loads, launch and recovery loads, mission equipment loads and all platform subsystems or component loads.

DS28 The platform shall be robust enough to prevent loss under foreseeable operational damage scenarios.

DS29 The platform shall provide adequate buoyancy and stability for worst intended operational conditions and to prevent loss under foreseeable operational damage scenarios.

DS30 The platform shall provide adequate protection of all installed equipment under normal operations in the worst intended operational conditions.

DS31 Energy consumption estimation shall consider the required endurance as well as the foreseeable margin to compensate for manoeuvring, unforeseeable events for autonomous mode or changes to settings throughout the planned mission given the nature of the unmanned vehicle.

DS32 The platform shall provide appropriate arrangement for navigation equipment and sensors, including aerials and transponders.

DS33 The platform shall display all required lights, shapes, and other signs to meet the foreseeable operational navigational and identification requirements.

DS34 Should the operational risk analysis indicate that tampering or theft may occur, the control measures as described in Appendix A3.2 should be taken into account.

DS35 Should the operational risk analysis indicate that severe weather operations may occur, the control measures as described in Appendix A3.3 should be taken into account.

DS36 Design to consider provisions to remove any hazards to interacting personnel from residual electro magnetics from high energetic equipment.

DS37 If the platform is arranged for both manned and unmanned use, standards for manned crafts shall be considered as well as those for unmanned craft.

DS38 Any incompatibility between the manned and unmanned vessel operations requirements shall be addressed.

DS39 If the platform is large enough for personnel to embark or if the operational use will require personnel to embark such as for replenishment, maintenance or repair, the platform will become subject to working environment rules and safety is to be considered. It is recommended that the extent of arrangement of safety provisions is negotiated between Owner, producer, and applicable maritime safety Authority.

DS40 Should personnel be able to board the platform, the risk control measures as described in Appendix A3.15 should be considered.

DS41 All platform arrangements shall be fail-safe.

DS42 Critical systems shall be identified and the need for redundancies determined.

DS43 UMS shall have provisions to ensure that mission critical as well as safety critical systems are monitored and have alarm functions.

DS44 The platform shall provide adequate propulsion thrust and directional control for the required operations of the UMS with redundancy and back-up for single point failures or certain defined levels of reliability.

DS45 The platform shall be able to of manoeuvre adequately including turning and stopping.

DS46 The platform shall be able to acquire its position with the necessary accuracy.

DS47 For platforms intended for towing operations with towed or tethered equipment (e.g., sonars, arrays, and other equipment), the following issues should be considered:

a) Strength of towing/attachment points,

b) Safe setup, launch and recovery of UMS towed/tethered payload (for all control methods),

c) Safe operation of towed/tethered payload including sea-state related considerations,

d) Monitoring of towed/tethered payload position with respect to UMV (including loss of monitoring capability),

e) Communications with and control of towed/tethered payload (including loss of communications between payload and any controlling entity),

f) Safe recovery of towed/tethered payload,

g) Unintended loss (detachment) of towed/tethered payload,

h) Collision/snagging of towed/tethered payload with own UMV, other vessels, the environment (e.g. the seabed) and/or man-made structures,

i) Impact of towed/tethered payload on the environment (e.g. seabed, marine life),

j) Risks to swimmers/divers in water.

4.4.4. UUV specific platform aspects

DS48 [*governmental use only*].

DS49 All possible stability cases with minimum and maximum payload including all extension components are to be considered in surfaced and submerged condition.

4.4.5. Support system considerations

DS50 Launch and recovery are known to be high risk periods in UMS operations. Handling systems could be dedicated and designed specifically for the UMS platform. Handling systems could also be a device of opportunity such as a crane (such a system would have to be checked for suitability). Safe procedures, including those for aborting and for foreseeable failure modes should be developed. Suitable training and planning should be undertaken for normal launch and recovery and for emergency recovery.

DS51 As well as addressing interactions with a GCP, the scope of the launch and recovery system certification should be defined (ref 4). It is a requirement of most naval authorities that lifting appliances are approved, examined, tested, and certified by a competent person or organisation before being commissioned and thereafter are periodically surveyed to maintain the validity of the certification. Many navies require their ships to comply with Ship Classification Society Rules. These rules include plan approval of the structural arrangements i.e., the davit or crane etc. used to launch and recover vehicles, survey during construction and installation and witness of static and dynamic test loading under all conditions.

DS52 Certification requirements should be clarified to ensure that the Launch and Recovery System (LARS) and the deployment of manned and unmanned vehicles comply with international and national civil and defence Authority legislation, regulations, and codes of practice.

DS53 Recommended boundary conditions for launch and recovery with respect to speed and environmental conditions.

4.4.6. Control station

DS54 Control station equipment and systems shall be compatible with the communications link and the main control system.

DS55 Control station should provide the controlling entities with all relevant situation awareness information both for the safe navigation and efficient functioning of the UMS.

DS56 Control station should provide the ability for the Controller to re-programme the required activities and responses of the UMS platform and to take direct control at any time.

DS57 Control station should be arranged such that the transfer of control from one Control station to another or from one UMS to another may be undertaken safely.

DS58 In addition, UMS Control station equipment design shall address the following functionalities (ref 3):

a) The appropriate number of unmanned platforms a human Controller can safely control.

b) Define what “Positive Control” means for higher levels of autonomy.

c) Safely passing control of a UMV from one Controller or Control station to another.

d) Ensure control links to UMVs are maintained and appropriate notification provided in the event control links are broken or compromised, while maintaining safe operations. (e.g., EMI or jamming).

e) Loss (and recovery) of communications.

f) A data log function.

g) Bandwidth, data latency, and data aging.

h) Login and password authentication, maintenance actions, and mechanical or software upgrades.

DS59 Should the operational risk analysis indicate that there is risk for high Controller workload, the control measures as described in Appendix A3.14 should be considered.

4.4.7. Platform control system

DS60 Functions within the UMS control system are allocated to the Control station as well to the platform depending on applications, controllability alternatives or UMS type.

DS61 The control system shall provide adequate and safe control of the platform and the mission equipment under instruction from the Control station (or multiple Control stations) and/or from embedded software. This primarily covers situation awareness, situation promulgation, navigation, and vehicle control including all sensors and transponders required.

DS62 The control system should incorporate comprehensive fail-safe arrangements to account for all foreseeable failure and mission abort situations. It should allow reversion to manual control in hazardous situations.

DS63 The arrangement of the associated sensors should be such that adequate situation awareness is provided and that navigation can be undertaken safely in conjunction with the relevant operational functionality.

DS64 The control system shall monitor the performance and status of the UMS and provide an alarm and reporting system for all aspects of the system including all important sensors, lights, actuators, machinery, and mission equipment.

DS65 The system should provide sound transmission to and from the platform and Control station such that sound signals and hails can be monitored and responded to.

4.4.8. Communications link

DS66 The communications link should be compatible with the Platform Control System and the Control station and should provide a robust datalink between the two.

DS67 The communication links should be sufficient to provide adequate range, bandwidth, and reliability to allow for safe control and navigation of the vehicle and mission equipment. The communication links should also provide sufficient redundancy and diversity to reduce the likelihood of dropouts and total loss of communication. Preferably the communication links should use different physical implementations, e.g., WLAN, UHF, satellite communications and/or hydro acoustics, in order to further reduce the probability of simultaneous failure of all links.

DS68 The platform, mission package and control systems and any of their emissions should not interfere with the required performance of the communications link. The communications link emissions should not interfere with the platform, mission package or control systems.

DS69 In the event of unexpected critical loss or corruption of the command link, UMS shall transition to a pre-determined safe state and mode. Critical loss of command is understood to be when the continuous time of lost command status exceeds a pre-defined value adjustable to mission settings and circumstances accepting a certain time as irrelevant and harmless.

DS70 The Control station should be equipped with communication means enabling the Controller to receive, interpret and act on information transmitted from related UMVs, control stations and vessels.

4.4.9. Mission equipment-oriented considerations

The Mission equipment shall provide adequate functionality, reliability, and safety to undertake the mission in conjunction with the vehicle and control systems.

The following design considerations shall be taken into account:

DS71 UMS shall be designed to provide information, intelligence, and method of control to support safe operations.

DS72 UMS shall be designed to provide the controlling entities with adequate mission information to support safe operations.

DS73 UMS shall be designed to safely initialise in the intended state, safely and verifiably change modes and states and prevent hazardous system mode combinations and transitions.

DS74 UMS shall be designed with the aim to minimise the use of safety critical software.

DS75 All software and safety critical software shall only include required and intended functionality.

DS76 UMS shall be designed to minimise single-point, common mode or common cause failures that result in high and/or serious risks.

DS77 Should the operational risk analysis indicate that on board equipment may cause maritime wildlife disturbance or violate environmental legislation, the control measures as described in Appendix A3.5 should be considered.

5. Collision avoidance

5.1. Objectives

UMS shall be designed, handled and operated in such a way that safe and predictable navigation is maintained and collisions are avoided.

The controlling entities shall have provisions to avoid collisions, e.g., with other ships, vehicles and/or geostatic objects.

5.2. Situation awareness (SA)

Situation Awareness is a prerequisite for UMS sense and avoid capability. It is also a key safety concern in use of UMS. General considerations necessary to characterize adequate situation awareness for UMS are for example the following three terms:

1. Information

Data related to the operational context to the extent necessary for the safe operation of a UMS. Collecting, recognizing, and interpreting data in/from the environment builds information and allows storage, recall, and/or communication.

2. Intelligence

The capacity of a UMS to acquire, comprehend and apply information.

3. Method of Control

The means by which a UMV receives instructions governing its actions and feeds back information, as described in section 3 Control as control methods ranging from remote control to fully autonomous.

In the context of collision avoidance, situation awareness is focused on the local surroundings of the UMV.

5.3. Sense and avoid (S&A)

A sense and avoid (S&A) system shall provide the dual capability to a UMV of remaining clear of and avoiding collisions with other waterborne traffic and objects. S&A provides the intended functions of self-separation (SS) and collision avoidance (CA) as a means of compliance with regulatory requirements.

1. Separation Assurance

   This term is used to describe the routine procedures and actions that are applied to prevent vehicles getting into close proximity with other geostatic and/or dynamic objects. Any resolution manoeuvring conducted at this stage must be conducted by USV (and UUV at the surface) in accordance with the International Regulations for Preventing Collisions at Sea (COLREG).

2. Collision Avoidance

   This is the final layer of conflict management and is the term used to describe any emergency manoeuvre considered necessary to avoid a collision.

The UMS shall be operated so that the control method allows appropriate safety margins for both separation assurance and collision avoidance.

Safety related zones

The awareness zone (AZ) includes all relevant information provided by the UMS situation awareness capability.

The self-separation threshold (SST) is when the procedures and actions for assuring the safe passage in relation to other vehicles/vessels and in accordance with COLREG shall be activated.

The collision avoidance threshold (CAT) is when manoeuvring is required in order to avoid or limit the consequences of a possible collision.

Figure 3 illustrates the relations between a vehicle and safety related zones.

The thresholds are time dependent defined by e.g., vehicle/vessel relative positions, speed, and manoeuvrability. These thresholds are not constant values but depend on the actual circumstances and the type and capabilities of the other vessels in the vicinity of the UMV. The self-separation threshold is defined to indicate the necessary amount of time allowing the manoeuvring UMV to act so that the collision avoidance threshold is not violated. This is normally understood as keeping well clear from the stand-on vessel.

Neither self-separation nor collision avoidance sub-functions by themselves are sufficient to enable safe UMV operation. Therefore, the combination of the two should function as mutually exclusive elements. In this fashion two security layers work together to increase safety at sea.

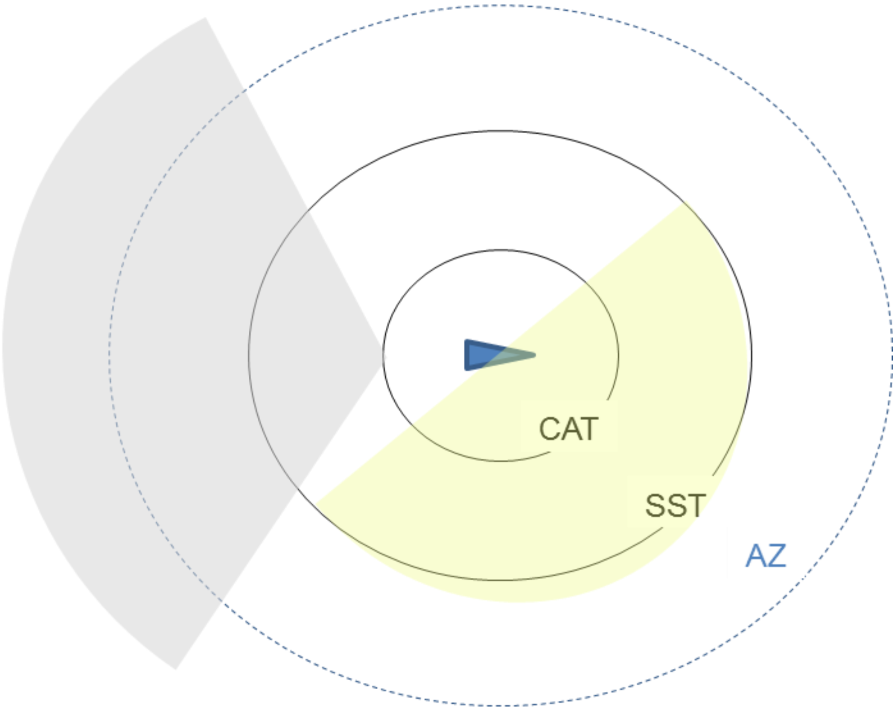


Figure 3 – Illustration of the vehicle and safety related zones

5.4. Situation awareness precepts (SA)

SA1 Without direct human control of a system onboard, an increase in awareness information must be gathered by the UMV platform to be used locally and/or by the controlling entity to fully understand the environment as well as any tactical situation.

SA2 An acceptable[7] method to sense and assess the situation in order to avoid collisions is required. General considerations necessary to characterize an adequate SA for UMS are stipulated by the Sense and Avoid policy as provided in Annex B.

SA3 UMS operations beyond the direct unaided visual line-of-sight of a Controller should only be performed with UMV equipped with a sense and avoid system of adequate performance. Otherwise, UMS operations should be permitted only in controlled and/or segregated sea areas.

SA4 UMS operating outside controlled and/or segregated areas are recommended to conform to COLREG (ref 6).

SA5 A surfaced UUV is to be regarded as a USV. However, as a UUV may not be expected to have sense and avoid systems and manoeuvre as a USV, it should therefore fulfil recommendations herein to a reasonable extent.

[7] "Acceptable" should be replaced with "Approved" as soon as an appropriate maritime safety administration have defined corresponding requirements. Reference also to SA Policy.

SA6 Attention should be paid to the surfacing phase of a UUV, considering the unusual risks attached to this phase.

6. Verification

6.1. General

In order for those responsible to discharge their duty of care, they must be able to verify that the UMS and equipment is safe and fit for purpose. Relevant certification is considered important in this regard.

UMS verification and certification may be divided into:

- Mission effectiveness,
- Safety.

Mission effectiveness is associated with validation and dependent on mission equipment and in turn, the UMS application. Validation is not addressed in this document.

UMS verification may include all normally used verification methods:

- Comparison - Similarity against best practice,
- Review/Inspection related to requirements,
- Simulation,
- Analysis,
- Test,
- Operation.

Significant for UMS verification and testing is the demonstration of safe and reliable performance of all functions, systems, equipment, and software that replaces the human.

6.2. Type Inspection and Type Certification

The Owner is responsible for ensuring that design, material and equipment selection, construction, in-service operation, and maintenance are carried out, and for demonstrating that this is undertaken correctly in accordance with standards agreed with the regulating organisation.

Normal operation shall be described in the Concept of Operations Statement (CONOPS). The CONOPS defines the UMS details, role and survivability and agrees the UMS type, foreseeable damage survivability, maintenance philosophy, principal standards, and environmental conditions.

The Naval Administration or authorised Recognised Organisation shall confirm verification of compliance and issue certification against the UMS role and operating envelope out in CONOPS (see form in Annex C[8]).

National or organizational procedures may require that the testing organization meets certain standards or is certified for UMS verification.

[8] This guidance document includes a form for CONOPS developed based on the format in the Naval Ship Code.

UMS shall be verified for safety and seaworthiness in accordance with the Naval Administration regulations. UMS Safety certification shall be issued, and the UMS should be registered and provided with identification (see form in Annex C[9]).

The following is performed within the scope of type certification:

- CONOPS compliance,
- UMS Safety certification demonstration.

CONOPS compliance includes verification to determine if the system is fit for purpose against its roles. This also includes mission equipment functions and performance which is not addressed in this document.

UMS Safety includes demonstration of safe performance for all significant or critical systems as well as seaworthiness.

The seaworthiness of a UMS platform type or class can be established if:

- the basic design and seaworthiness requirements are fulfilled,
- it is in accordance with type design documentation, and
- it has been demonstrated that it is safe and its operation trouble-free and sufficiently reliable in accordance with operating and environmental requirements.

The following is performed within the scope of seaworthiness certification[10]:

a) Seaworthiness inspection of the total system,

b) Seaworthiness inspection of the systems, equipment including software required for safe operations,

c) Seaworthiness inspection of emergency procedures,

d) Determination of UMS Compliance with Seaworthiness Requirements for

- mission equipment,
- non-essential equipment, and
- control station support and test equipment intended for the use on or with the platform which directly affects seaworthiness.

Separate type certification may be required for mission modules and their integration on UMS.

Methods for development and testing of software shall be in accordance with regulating Authority.

[9] This guidance document includes a form for CONOPS developed based on the format in the Naval Ship Code.
[10] Certification could be issued for modular, individual as well as for a class (type) of UMS as required and agreed with the Naval administration.

6.3. Type and scope of verification

Test programs corresponding to a relevant operational phase description shall be developed. They shall be based on operational challenges and will include (but not limited) to the following:

a) Demonstration of UMS integration in existing sea traffic control (if applicable),

b) Demonstration of safety for control measures against hazards and mishaps based on system safety and hazard analysis,

c) Demonstration of relevant performance parameters for the system and its mission equipment.

These types of verification comprise systems, subsystems and equipment including software installed within UMS which could affect safety, including both Control station equipment and platform.

In addition, system reliability and resilience shall be declared to clearly indicate redundancies or singularities and consequences in case of failure. The consequences of individual unit and subsystem failures shall be analysed in a failure evaluation.

UMS shall be verified in accordance with procedures that are no different from any other seagoing vehicle but there shall be a particular emphasis on all features and functions that replace the human in the system and those associated with autonomy, automation, remote control, and monitoring. Significant for UMS verification is to demonstrate:

a) the system ability to communicate, secure and reliably, and to detect the loss of communications and undertake communication loss procedures,

b) that the system/platform/Controller has adequate situation awareness,

c) the system ability to perform safely and avoid collisions,

d) control station platform control functions:

- ability for a Controller to safely perform critical tasks such as launching, recovery/docking, out of sight operation, navigating in close proximity to other vessels and objects, and reacting to unexpected obstacles.
- safety critical aspects of the control system, degree of Controller feedback, and degree of automation/mechanization.

e) performance in Operational limits in terms of environment:

- Meteorology and climatology (above surface),
- Sea surface,
- Geotechnical,
- Human Caused.

f) selected control measures to mitigate hazards as well as verification of developed guidelines for safe operations,

g) the system ability to achieve a safe state for each identified emergency situation,

h) the system ability of safe performance and conduct for all instances where there is a need for human interaction, such as maintenance, with the unmanned system,

i) the system ability of safe performance and conduct to replenishment at sea,

j) the system ability of safe performance and conduct of launch and recovery of the platform,

k) the system ability of safe performance and conduct to handle multiple platforms (if applicable),

l) the system ability of reliable performance as regards to all other, not above mentioned, autonomous and automatic functions and systems.

Demonstration of these capabilities may include showing measurable performance in a standard test track of some design including tasks such as waypoint/route precision navigation and turning rates at different speeds and load conditions. Different standard tests can be applied for different application areas.

6.4. Verification methods

6.4.1. Verification by simulation

The increasingly complex behaviour and high level of autonomy found in UMS calls for extensive verification and validation before the systems can be released for use. There are a huge number of possible situations and combinations of events that the systems will have to manage. Because of this, the correctness of autonomous systems cannot be fully verified by exhaustive testing, as this would be prohibitively expensive and time consuming. Instead, a process based on simulations must be used.

Hence, to ensure efficient verification and validation of an autonomous system, a comprehensive simulation environment should be set up. For design of the simulation environment the following guidelines apply:

- There shall be a separate simulation module for each physical system unit, to facilitate full simulation of the complete system. This encompasses modelling the UMS functionality and dynamics as well as the surrounding environment.
- By designing each simulation module in such a way that it exactly replicates the interface of the physical unit, an arbitrary simulated module can be replaced with a physical unit, thus tested in an environment appearing as identical to the real system. This facilitates simulation with a mix of hardware and software in the loop.
- All signal paths (transmission channels) for sensor- and control data within the complete system should be modelled.
- Stimuli generators creating signals from surveillance and navigation sensors should be made available.

As a basic principle the simulator shall be able to run in real time. It is, however, not always necessary to synthesize large volumes of e.g., sensor data in real time. In some cases, data is preferably generated off-line and entered into the simulation, e.g., by means of look-up tables, to generate data in real time. It is also sometimes possible to import recorded sensor data instead of using simulated data. This implies that real data can be used as stimuli for the whole, or parts, of the system. This gives good opportunities for verification of the system functionality. It is also possible to apply and compare different processing parameters and algorithms using the same input data.

Simulations should also be performed with variations of the input data and applicable system parameters by superimposing noise or other disturbances. This is an essential technique for assessing the robustness of the system. In this respect many simulation tools provide support for standardised statistical variation of parameters and data, such as Monte Carlo analysis. By applying this type of methodology statistically viable conclusions can be made regarding the stability and robustness of a design.

The requirements on the development process, for the simulation software, are as strict as for the target system software, justified by the fact that the simulator is used for system verification and validation. It is also of high importance that the simulator itself is thoroughly validated. Therefore, as a standard procedure, all real missions should, as a first step, be run as complete missions in the simulator. During the simulation, technical and tactical data should be recorded in the same way as during a real mission. During the real mission technical and tactical data should also be recorded. Once the real mission is completed, data from the simulation and real mission should be compared and analysed. The result from this analysis should then be used to iteratively tune and validate the simulator. In this way the simulator will be continuously improved and validated and will reach a high level of similarity with the real system from the lowest level (e.g., hydrodynamics) to the highest level (system functions and behaviour).

6.4.2. Verification of manoeuvring and navigation

Requirement

The platform shall have a specified manoeuvring ability performance in terms of course keeping, turning, stopping etc. Manoeuvring and navigation shall be achieved by means of all available methods of control.

Verification

Verification shall be documented with navigation performance as well as all relevant manoeuvring abilities with respect to sea keeping behaviour and background information (trial reports, methods, simulation, calculations etc) proving compliance to the requirements.

6.4.3. Navigation trials

Vehicle navigation trials shall be conducted for each available method of control:

0. On board vehicle control
1. Remote control from Control station/ “chase” boat/etc.
2. Directed control
3. Delegated control

4. Monitored control
5. Autonomous control

In addition, testing shall be conducted for all (as applicable) loading condition or mission equipment configurations.

Navigation performance shall be verified by having the vehicle moving around a predefined route. A number of waypoints shall define a track that shall include course change with turns exceeding 45 degrees starboard and port respectively, as well a one 180 degree turn. The last leg of the track shall lead back to the starting point.

The route shall at least contain the following waypoints (see figure 4):

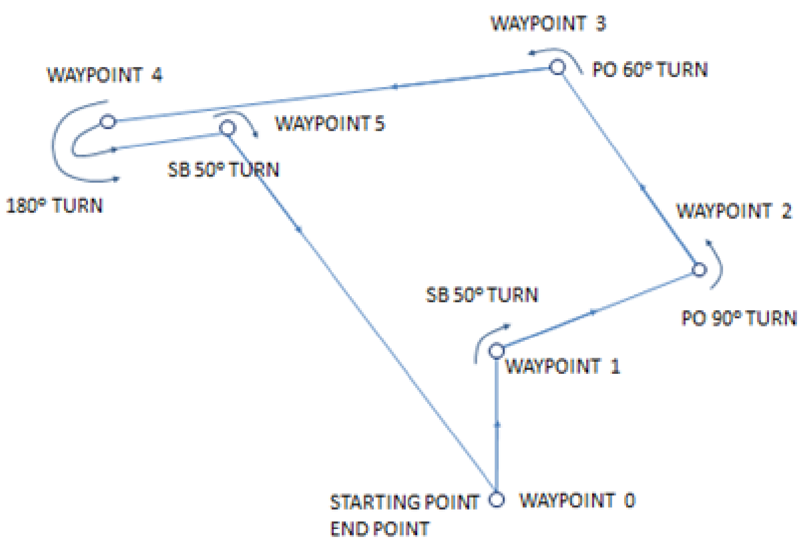
- Waypoint 0: Starting position.
- Waypoint 1: Turn (exceeding 45 degrees) to starboard to new course.
- Waypoint 2: Turn (exceeding 45 degrees) to port to new course.
- Waypoint 3: Turn 180 degrees.
- Waypoint 4: return to Starting position.

More waypoints may be added in between as needed. Each track leg should be long enough to take into account effects from current and sea state as applicable and if required.

Course keeping and track keeping should, if required, be measured along the route.

A UUV should be equipped with an underwater positioning system, such as a Doppler Velocity Log (DVL), able to register and measure the rate of travel over sea floor. For UUV, depth curves should be added as well between the waypoints.

Figure 4 – Example of route for manoeuvring verification



6.4.4. Manoeuvring trials

Manoeuvring ability performance such as turning, stopping should be verified using standard test methods (testing procedures same as used for manned vehicles).

Safe and reliable performance shall be verified for

a) vehicle cast-off and mooring

b) harbour manoeuvring

using (as applicable):

a) On board vehicle control manned by Controller

b) Remote control from Control station

For manoeuvring abilities:

- Cross track error
- Course keeping
- Turning
- Stopping.

6.4.5. Verification of situation awareness

Requirement

Control station/platform control/Controller needs information of the current situation on board the UMV and its surrounding area. A suite of suitable sensor systems shall ensure that the on-board decision-making systems (applicable for autonomous systems) and Controllers have sufficient situational information at any given time. In case the sensor systems fail to operate as expected, this shall be detected and communicated as applicable.

Verification

Verification of situation awareness shall demonstrate to the operator that the UMS sensors provide an adequate and correct situation picture. It shall address the following topics:

- Scope of information,
- Quality of information,
- Monitoring of system functionality.

Verification of the scope of information shall prove to the operator that the UMS is equipped with sensors, providing a sufficient amount and diversity of situation awareness information for the intended purpose (e.g., Visual, IR, RADAR, LIDAR, Echo Sounding, system health etc.). This is primarily performed by analysis of the sensor specifications and the UMS design, in combination with inspection of the UMS as built.

Verification of the quality of information shall prove to the operator that the sensor systems, and subsequent sensor data processing, provides information of the right quality for the intended purpose (e.g., range and resolution). This is primarily performed by analysis of the sensor specifications and the UMS design, in combination with tests of the actual systems.

Verification of monitoring shall prove to the operator that all sensors providing situation awareness information are monitored to a degree where all critical faults and performance degradations can be detected and reported. This is performed as a combination of analyses and tests where faults are deliberately introduced in the systems.

6.4.6. Verification of sense and avoid

Requirement

The UMV shall be able to undertake controlled manoeuvres in order to avoid collisions with other vessels or objects at sea. Situation awareness (the sense part of "sense and avoid") is assumed to be based on sensors verified separately as defined in section 6.4.5. Algorithms for the avoid part shall be implemented as applicable.

Verification

Verification of the collision avoidance system shall demonstrate that appropriate actions are taken to avoid collisions in response to scenarios applicable for the UMS.

Test cases shall be set up to verify:

- Correct behaviour under normal situation awareness conditions, i.e., when all sensor systems are working as expected.
- Correct behaviour under degraded situation awareness conditions, i.e., when information from one or more of the sensor systems is missing or degraded.

Verification of the Sense and Avoid functionality is primarily based on simulation of comparatively high number of collision avoidance scenarios, complemented with a suitable (lower) number of tests in order to validate the simulation models (see method in section 6.4.1).

6.4.7. Verification of operational limits

Requirement

UMV shall be able to operate up to a certain environmental condition including defined maximum sea state, visibility etc. A suite of suitable sensor systems shall ensure that the on-board decision-making systems (applicable for autonomous system) and Controllers have sufficient environmental conditions information at any given time. In case the sensor systems fail to operate as expected, this shall be detected and communicated as applicable.

Verification

Verification shall demonstrate that the system is aware of the environmental conditions and is able to take appropriate actions when limits are reached.

For the environmental condition sensing, verification shall address the following topics:

- Scope of information,
- Quality of information,
- Monitoring of system functionality.

Verification of the scope of information shall prove that the UMS is equipped with sensors, providing a sufficient amount and diversity of environmental conditions awareness for the intended purpose. This is primarily performed by analysis of the sensor systems specifications and the UMS design, in combination with inspection of the UMS as built.

Verification of the quality of information shall prove that the sensor systems, and subsequent sensor data processing, provides information of the right quality for the intended purpose (e.g., range and resolution). This is primarily performed by analysis of the sensor systems specifications and the UMS design, in combination with tests of the actual systems.

Verification of monitoring shall prove that all sensors providing awareness of environmental conditions are monitored to a degree where all critical faults and performance degradations can be detected and reported. This is performed as a combination of analyses and tests where faults are deliberately introduced in the systems.

Verification shall also demonstrate that appropriate actions based on the environmental conditions are taken.

Test cases shall be set up to verify:

- Correct behaviour under normal environmental conditions awareness, i.e., when all sensor systems are working as expected.
- Correct behaviour under degraded environmental conditions awareness, i.e., when information from one or more of the sensor systems is missing or degraded.

Verification of the Operational Limits operation is primarily based on simulation, complemented with a suitable number of tests in order to validate the simulation models (see method in section 6.4.1).

6.4.8. Verification of control measures to mitigate hazards

Requirement

UMV shall be able to identify faults and resulting hazards and to take appropriate actions to mitigate them. Built in system tests (BIT) and system monitoring functions shall ensure that the on-board decision-making systems (applicable for autonomous system) and Controllers have adequate and correct system health status information at any given time. In case faults are detected, and hazards are identified, mitigating actions shall be initiated.

Verification

Verification shall demonstrate that the BIT and system monitoring have an adequate coverage level, and that the system responds correctly in order to handle the faults and mitigate the resulting hazards.

For the fault detection and hazard identification functions it shall address the following topics:

- BIT and System Monitoring Coverage,
- Fault and Hazard Identification.

Verification of the BIT and Monitoring Coverage shall prove that the UMS is equipped with self-diagnostic functions able to detect all critical faults. This is performed by analysis of the UMS design, in combination with tests where faults are deliberately introduced, and the detection capability is observed.

Verification of Fault and Hazard Identification shall prove that the system diagnostic functions, based on BIT and System Monitoring, are able to accurately locate and determine the type of fault as well as to identify the resulting hazards.

The Fault Handling and Hazard Mitigation verification shall prove that the correct actions are taken to mitigate hazards with respect to each kind of detectable fault. Examples of appropriate actions can be reduced speed in case of sensor degradation, shut down of systems in case of overheating etc.

Verification shall also prove that additional information from situation awareness sensors and environmental conditions sensors (as covered by sections 6.4.5 and 6.4.7) is taken into consideration for the fault mitigation functionality where applicable.

6.4.9. Verification of human interaction

Requirement

It shall be safe for a person to interact with the UMV which may include embarking the UMV to perform testing or maintenance.

Verification

Verification shall demonstrate that the system is offline whenever a maintenance mode or person on-board mode is activated. This is done by analysis of the system design to make sure that:

- It permits any person embarking the UMV to disable the autonomous functionality manually and unconditionally. It shall also be verified that the disabling device (e.g., a switch), clearly indicates the status of the system.

or:

- An automated function for disabling the autonomous functionality is present. It shall also be verified that the disabling device (e.g., a presence detector), clearly indicates the status of the system.

Safe embarking and interaction with the UMV verification shall ensure that personnel safety measures such as railings and appropriate lifesaving equipment is available. This is done by a combination of Inspections, Demonstrations and Tests.

Verification should be based on the following steps:

- First, standardised procedures are defined for all basic activities requiring personnel to embark and move around on-board the UMV. (Examples of basic activities are refuelling, re-arming, cleaning, and a variety of other maintenance tasks).
- Next, a matrix describing under which conditions the standard procedures are to be performed is created, e.g., when at berth, when docked, when at sea etc.
- Finally, each standardised procedure is verified under the applicable conditions where it is demonstrated that human interaction can be performed in a safe way. This is done in accordance with the matrix to ensure that no combinations of procedures and conditions are missed.

Once the matrix is completed all aspects of human interactions are verified.

6.4.10. Verification of control station platform

Requirement

A Controller shall have functions available to be able to simultaneously control and monitor one or several UMV. The system control functions shall ensure that the Controller has full control of the specified number of UMVs under normal conditions and that adequate and safe control can be maintained under conditions with degraded system functionality.

Verification

Verification shall demonstrate that the system responds correctly to Controller commands and that the Controller has full access to system status information under normal conditions.

For these conditions, verification shall address the following topics:

- That the full number of UMVs can be controlled,
- That the full scope of control is available,
- The normal command latency is within specifications,
- That the full range of status information is available.

Verification shall also demonstrate that the system control functions are adequate and that the Controller has adequate access to system status information under degraded (mainly due to loss of communication channels) conditions.

For these conditions, verification shall address the following topics:

- That a minimum number of UMVs can be controlled,
- That a limited but adequate level of control is available,
- The degraded command latency is within specifications,
- That a reduced but adequate level of status information is available.

Verification of the Control station control functions is primarily based on simulation (where test scenarios are demonstrated directly by using the Controllers console or similar), complemented with a suitable number of tests in order to validate the simulation models (see method in section 6.4.1.).

For simulation and verification of “loss of communication procedures”, refer to section 6.4.11 Verification of communication and communication loss procedures.

6.4.11. Verification of communication and communication loss procedures

Requirement

The communication system shall, within a specified distance, have the ability to transmit and receive a required amount of data including monitoring and control of platform functions. Communication loss shall be detected, and procedures shall be in place to overcome situations in a safe way.

Verification

Typically, there are a number of redundant communication links between the UMV and the Control station. During verification of communication and communication loss procedures it shall be checked:

In case of partial communication loss or disturbed links:

- Link selection procedures and link fallback procedures work as expected,
- Link status is correctly displayed to the Controller.

In case of total communication loss:

- The vehicle manages communication failure as expected (this may imply actions such as transition to autonomous operation or mission termination),
- Link status is correctly displayed to the Controller.

In case of resumed communication:

- Link selection procedures and link re-establishment procedures work as expected,
- Link status is correctly displayed to the Controller.

Verification shall be performed in a controlled test environment, where the quality of service for each communication link can be accurately simulated and controlled.

Figure 5 shows an example of a test set-up, where a number of parallel data links are created between a Control Station and a UMV.

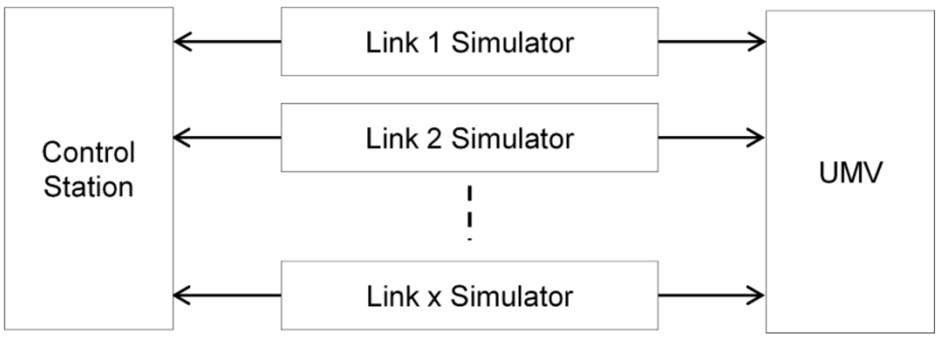


Figure 5 – Example of link simulator configurations

The test environment may be a combination of hardware and software. Individual data links may be realized in hardware (where actual physical equipment with link attenuators and noise injectors represents the link simulator) or in software (where the complete properties of the link are simulated).

A table including all applicable combinations of link loss/disturbances should be set up and used during verification.

6.5. Training and qualification

Operating UMS requires a skill set that approximates that of operating and manoeuvring a manned vehicle. However, there are additional skills that are unique to UMS such as relying on synthetic presentations to develop situation awareness. Also, the lack of such performance indicators as physical influences such as sea-state induced ship motions presents a unique challenge to UMS Controllers.

UMS control systems may vary; some systems use only manual controls while others may use a mix of manual and automated, or only automated control modes. Regardless of the type of controls, the Controller must be able to safely conduct UMS missions including precise and efficient response to emergency situations. These unique skills are especially critical when operating in conjunction with other manned and unmanned maritime systems.

UMS Controllers must have the ability to use and understand standard procedures and checklists throughout the mission and must understand how their system operates within a force structure and contributes to mission goals.

UMS Controllers must understand how to coordinate with Sea Traffic Services as it may be applicable and required. Controllers must have a thorough understanding of relevant maritime regulations of national and international controlling authorities, as well as to achieve integration with overall military operations.

6.5.1. General qualification precepts

UMS Controllers should preferably have a base qualification attained under an international maritime qualification system equivalent to that undertaken by crew or command of comparable conventional vehicle/ship operating in similar operating envelope.

The depth of knowledge required of Controllers will depend on the complexity of the UMS, mission, and the operating environment. The following list, which is not exhaustive, generally reflects a list of general knowledge requirements:

a) Operating area structure and operating requirements,

b) Maritime rules and regulations,

c) Vehicle hydrodynamics, including effects of controls,

d) UMS system knowhow,

e) Performance,

f) Navigation,

g) Meteorology,

h) Communications procedures,

i) Mission preparation.

In addition to base qualification, Controllers should undertake training and have demonstrated appropriate knowledge and skills to the satisfaction of the Administration, or a body authorized to act on behalf of the Administration.

Training shall be tailored to the needs of different UMS personnel (e.g., Controller, maintenance crew, etc.).

Controller is understood to be one (or more) person(s) positioned at the Control station equipment to monitor and control one (or more) UMS vehicle. Other UMS personnel such as engineers, maintenance crew etc. will also need suitable qualification which is not addressed in this document.

Certificates shall be issued by an authorized organisation for completed and approved training.

For UMS operating with control methods 3-5 (delegated and above) a Controller has limited or no involvement in UMS platform operation. For UMS working under manual control, Controller skill will become relevant.

The main focus in this document is from a safety perspective and safe UMS operations. Mission effectiveness accomplished through the UMS system Mission equipment will require special qualification and training but is left to the system Owner/Controller to define.

Training should be conducted within the UMS operational context and environmental boundaries such as up to a specified sea-state and for representative UMS platform conditions and operational scenarios.

This training should include both the general focus areas listed below as well as the system-specific knowledge required to operate the UMS in a safe manner.

6.5.2. Controller qualification

UMS Controllers shall complete a thorough practical at sea training program, which may also include accredited or certified simulation training devices. Practical training should enable Controllers to demonstrate control of a specific UMS throughout its performance parameters and potential operating conditions, including dealing correctly with emergencies and system malfunctions at any phase of the mission.

Major training focus areas are:

a) Type specific UMV knowledge. Sufficient basic system knowledge.

b) Navigation. To determine UMV position, course, speed and plan the route by means of all available Control station functions.

c) Manoeuvring. To perform manoeuvring in terms of change of speed and/or direction by means of all available Control station functions.

d) Emergency procedures. To take proper actions to overcome emergency situations.

e) Situation awareness. To make use of all available situation awareness functions including sense and avoid, obtaining knowledge of UMV in the maritime environment.

f) Control handover. To take proper actions in all type of control handover situations.

g) Launch and recovery procedure. To take proper actions as a Controller in launch and recovery situations.

h) Maintenance procedures. To take proper actions for UMV maintenance, in particular to ensure safety for on board personnel.

i) Mission set up and planning and other Control station user interface. Full knowledge of, and usage skill for Control station command, control and monitoring functions.

Specification of minimum standard of competence for Controllers in charge of an operational watch for UMS platform should be developed for each area. It is recommended that these are structured in the format described in the following paragraphs.

6.5.3. Knowledge, understanding, proficiency and currency

Proficiency refers to an achieved level of competence, while currency refers to maintaining that level, typically through study and practice. UMS Controllers shall maintain both proficiency and currency to conform to minimum national requirements.

Specification of required knowledge, related factors, functions, and significant components which could include the following:

- Ability to operate Control station and to interpret and analyse information obtained from this equipment,
- Knowledge of methods of UMS platform control and manoeuvring,
- Knowledge of precautions to be taken for the protection and safety when personnel are on board the UMS platform,
- Knowledge of action to be taken in emergency situations,
- Basic working knowledge of the relevant IMO Conventions including protection of the marine environment.

6.5.4. Methods for demonstrating competence

Specification of method such as examination and assessment of evidence obtained from one or more of the following:

- Approved in-service experience,
- Approved training UMS vehicle experience,
- Approved (accredited) simulator training, where appropriate,

- Approved laboratory and/or equipment training.

6.5.5. Criteria for evaluating competence

Specification of skill to competently apply the required knowledge in the operations, which could include the following:

- Selection of operational modes permissible according to the certification of both the Controller and the type categorization of the UMS vehicle,
- Selection of the most suitable control mode and settings for the prevailing weather, sea and traffic conditions and intended manoeuvres,
- Information is correctly obtained, interpreted, and applied,
- Safe operating limits of UMS platform are not exceeded for normal circumstances,
- Type and scale of emergency situation is promptly identified,
- Legislative requirements relating to safety of life at sea and protection of the marine environment are correctly defined.

7. Regulations and legal status

7.1. Introduction

The interaction between UMS and the maritime environment is currently undefined from a regulatory and legal perspective. One important reason for this is that UMS are not recognised or mentioned in any international conventions. There is an absence of defined responsibility at many levels, lack of agreed approaches to safety and operations and a lack of certification of system and components making discharge of duty of care impractical. There is also a long-standing debate on whether UMS could be regarded as a ship or vessel, which still remains to be resolved. Nonetheless a legal framework is crucial to enhance safety at sea and interoperability in future maritime UMS operations.

Most rules and regulations for safety at sea have a prime focus on the safety of people on board such as crew or passengers. For UMS obviously this is not applicable since their vehicles are unmanned. Instead, the safety of other water users versus the unmanned vehicle becomes a concern.

7.2. Liability

Uncertainty about liability for unmanned maritime systems is recognised as a factor that slows introduction of such systems, both in government/military and civilian applications.

In the case of Unmanned Maritime Systems and unmanned vehicles, it is not a priori clear where the responsibility for damages lies. For non-autonomous vehicles the Controller or supervisor is an obvious candidate, but arguments can also be made for the producer (as in product liability) e.g., when the Controller has bought an existing standard system, the designer or even the entity that decided that the task could (better) be executed unmanned.

7.3. Applicability of laws

This guidance document refers only to the laws and regulations generally applicable within the European Union, such as e.g., the international law, international customary law and/or European law likely of importance to UMS. However, there are currently no specific international regulations and/or European law that expressly recognize the existence of UMS, let alone any that cover the design, certification, or operation of such systems. Nevertheless, some of those legal instruments could be important to comply with where feasible in order to enhance the safety of navigation and operation.

Domestic laws of EU Member States have not been considered in this guidance. The reader should search for the proper national or domestic laws applicable to UMS if any. Such domestic laws will also differ from those of other countries. The applicability of national laws is predominantly determined by the geographical position and use of the UMS. The coastal state has limited jurisdiction and sovereignty over UMS, if being registered as ship, within its territorial sea (Articles 1 (1), 27 and 28 UNCLOS 1982) and has full national jurisdiction on whatever happens with UMS on waters on the landward side of the baseline of the territorial sea (article 8 UNCLOS 1982). The flag state has only exclusive jurisdiction over ships that sail under the flag of that state on the high seas (article 92 1 UNCLOS 1982). Which means that only UMS being registered as a ship will fall under the jurisdiction of the chosen flag state.

Furthermore, the reader should bear in mind that not all laws are equal and that a major distinction should be made between international law and international customary law, regional law such as European law and national or domestic law from a Member State of the United Nations.

There is also a hierarchy of written laws and international law ranks as the highest form followed by customary international law, regional law and national law, of which each will or might also have sublevels. The written laws differ from the judge-made laws. The country where the reader intends to use UMS shall determine the applicable laws and regulations.

7.4. Applicability to regulations

A general overview of several maritime regulations and their possible applicability to UMS is provided in Appendix 4.

REFERENCES AND RELATED TEXTS

[1] "GUIDANCE for developing Maritime Unmanned Systems (MUS) capability", NATO Combined Joint Operations from the Sea Centre of Excellence, 2012.

[2] T. B. Sheridan och W. L. Verplank, "Human and Computer Control of Undersea Teleoperators", MIT Man-Machine Systems Laboratory, Cambridge, MA, 1978.

[3] "Unmanned Systems Safety Guide for DoD Acquistion", US DoD, January 2007.

[4] "Launch and recovery of Surface and Sub-Surface Vehicles", NATO NIAG SG-171 study report, 2013.

[5] "Common Procedures for Sea Keeping in the Ship Design Process", NATO STANAG 4154, 1998.

[6] IMO, Convention on the International Regulations for Preventing Collisions at Sea (COLREG), 1972.

[7] "Naval Ship Code Edition F (NATO-ANEP77)", Int. Naval Safety Association (INSA), 2012.

[8] EDA document "Best Practice Guide for Unmanned Maritime Systems Handling, Operations, Design and Regulations", 2014.

[9] UN, "UN Treaty: Suppression of Unlawful Acts Against the Safety of Maritime Navigation Convention", 1988.

[10] IMO, "Draft Convention on the Legal Status of Ocean Data Acquisition Systems (ODAS), MSC/Circ.372", 1984.

[11] DNV, "MARINE SHIPPING QUANTITATIVE RISK ANALYSIS", 2010.

[12] MCA, "The Workboat Code" (Industry Working Group Technical Standard), 2014.

[13] IMO, SOLAS Chapter V (Safety of Navigation), 2002.

[14] IMO, "IMO Maritime Safety Comittee (MSC) COMSAR Sub-Comittee E-Navigation", E-navigation (imo.org).

[15] IMO Ship's Routeing, ISBN 978-92-801-1554-3, 2013.

[16] IMO, "International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention)", 1995.

[17] MCN, MGN 496 (M+F) Certificate of Competency for Master Workboat less than 500 GT unlimited, 2013.

[18] U. DoD, "MIL-HDBK-61A Configuration Management Guidance", 2001.

[19] IMO, "Resolution A.917(22) GUIDELINES FOR THE ONBOARD OPERATIONAL USE OF SHIPBORNE AUTOMATIC IDENTIFICATION SYSTEMS (AIS)", 2002.

[20] ISO, ISO/IEC 15288 Systems Engineering, 2002.

[21] UK Hydrographic Office, NP100 The Mariners Handbook, 2009.

[22] EU, Council Directive 96/98/EC Marine Equipment Directive, 1996.

[23] IEC 60945 Maritime navigation and radiocommunication equipment and systems – General requirements – Methods of testing and required test results, 2002 and IEC 62508 Functional safety of electrical/electronic/programmable safety related systems, 2009.

[24] IEC, ISO 61508 Functional safety of Programmable Electronic Safety Related Systems, 2010.

[25] ISO 17894:2005 General principles for the development and use of programmable electronic systems (PES), 2005.

[26] ISO 17894:2005 Ships and Marine Technology – Computer Applications, 2005.

[27] SAE, Joint Architecture for Unmanned Systems, 2010.

[28] NATO, STANAG 4586 Standard Interface of the Unmanned Control System (UCS), 2010.

[29] UK MoD, Defence Standard 59-411 Electromagnetic Compatibility (EMC), 2007.

[30] US DoD, "The Navy Unmanned Underwater Vehicle Master Plan," Nov 2004.

[31] US DoD, "The Navy Unmanned Surface Vehicle Master Plan," July 2007.

[32] Society for Underwater Technology, "The operation of autonomous underwater vehicles – recommended code of practice – Volume 1," 2007.

[33] "Rules for Classification and Construction, Unmanned Submersibles (ROV AUV) and Underwater Working Machines," Germanisher Lloyd.

[34] "Autonomy Levels for Unmanned Systems Framework (ALFUS, Spec. publ. 1011)," Nat. Inst. of Standards and Technology (NIST), 2003.

[35] US DoD, "The Role of Autonomy in US DoD Systems," July 2012.

[36] NATO, STANAG 4671 Unmanned Aerial Vehicle Systems Airworthiness Requirements (USAR).

[37] NATO, ATP-3.3.7 Guidance for the Training of Unmanned Aircraft Systems (UAS) Operators Ed.A Version 1," May 2013.

APPENDIX 1 – Acronyms and definitions

Acronym	Full text
AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
C2	Command and Control
COLREG	Collision Regulations
CPA	Closest Point of Approach
DSC	Digital Selective Calling
EDA	European Defence Agency
FOV H&V	Field of View - Horizontal and Vertical
GCP	Guidance and Control Platform
GMDSS	Global Maritime Distress and Safety System
GPS / GNSS	Global Positioning System / Global Navigation Satellite System
IMO	International Maritime Organisation
IMU	Inertial Measurement Unit
IR	Infra-Red
ISR	Intelligence, Surveillance, and Reconnaissance
JAUS	Joint Architecture for Unmanned Systems
JCA	Joint Capability Area
JOA	Joint Operations Area
L&R	Launch and Recovery
LARS	Launch and Recovery System
LOS	Line Of Sight
MCM	Mine Countermeasure
MDA	Maritime Domain Awareness
MIO	Maritime Interdiction Operations
MW	Mine Warfare
MS	Maritime Security
MSA	Maritime Situation Awareness
MSO	Maritime Security Operations
NATO	North Atlantic Treaty Organization
NAVTEX	Navigational text message
NDD	Nominal Diving Depth
NUC	Not Under Command
R&D	Research and Development
RAM	Restricted in her Ability to Manoeuvre
RAS	Replenishment At Sea
RHIB	Rigid Hull Inflatable Boat
ROE	Rules of Engagement
ROV	Remotely Operated Vehicle
S&A	Sense and Avoid

Acronym	Full text
SARUMS	Safety and Regulation for UMS
SATCOM	Satellite Communications
SMCM	Surface Mine Countermeasure
SME	Subject Matter Expert
SOF	Special Operations Forces
SOLAS	Safety Of Life At Sea
SQEP	Suitably qualified and experienced personnel
STC	Sea Traffic Control
STCW	Standards of Training, Certification and Watchkeeping
SWL	Safe Working Load
TCPA	Time to Closest Point of Approach
TEU	Treaty on European Union
TSS	Traffic Separation Schemes
UK MCA	United Kingdom Maritime & Coastguard Agency
UMS	Unmanned Maritime System
UMV	Unmanned Maritime Vehicle (synonymous with Platform)
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
VHF	Very High Frequency
WIG	Wing In Ground
VOO	Vessel of Opportunity
VTS	Vessel Traffic System

Table 10 – Acronyms

Definition	Full text
Abort	The premature termination of a function, procedure, or mission (ref 9).
Abort procedure	Pre-programmed sequence of actions to automatically undertake by the UMV to reach a safe state in the event of control disruption, malfunctions, or unexpected situations.
Acceptable risk	Acceptable risk is the part of identified risk that is allowed to persist without further engineering or management action. Making this decision is a difficult yet necessary responsibility of the managing activity (ref 9).
Accident	An unplanned event or series of events resulting in death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.
ALARP	As Low As Reasonably Practicable. A risk could typically be ALARP when the cost of any further risk reduction (in terms of money, time or trouble including the loss of defence capability), is grossly disproportionate to the benefit obtained from that risk reduction.
Anomaly	A state or condition which is not expected. It may or may not be hazardous, such as the result of a transient hardware or coding error (ref 9).
Authorised Control Entities	Organisation, command, person in charge of, or authorized to direct and control a UMS platform in operation (ref 9). The Control Entities may assume the role as Controller.
Authorised Entity	An individual Controller or control element (e.g., computer) authorized to direct or control system functions or mission (ref 9).
Autonomy	Autonomy is a capability (or a set of capabilities) that enables a particular action of a system to be automatic or, within programmed boundaries, "self-governing." Autonomy could be the UMV's own ability of sensing, perceiving, analysing, communicating, planning, decision-making, and acting, to achieve its goals as assigned by its human Controller(s). Autonomy may be characterized into levels by factors including mission complexity, environmental difficulty, and level of Controller interaction to accomplish the missions[11].
Authority	A body charged with the power and duty of exercising prescribed functions e.g., Regulatory Authority for UMS.
Awareness zone (AZ)	Total surveillance zone reach that could include information from external sensor sources (Awareness zone (AZ) will be the same as SST if no externals sources are present).
Backout (and Recovery)	The action(s) necessary in a contingency to restore normal safety conditions and to avoid a potential accident (ref 9).

[11] Historical perspective: The word "autonomous" is made of two Greek words : "αυτο" (myself,...) and "νομοσ" (law, rule,...). The word "αυτονομοσ" is used by the Greek historian Thucydides in its description of the Peloponnesian wars (VIth B.C.) to characterize a free city. Following this etymology, an autonomous system is a system that behaves with its own rules. On the contrary, a heteronomous system behaves with rules that have been created by other systems.

Certification	Recognition by a certification authority that a product, service, organization, or person complies with the applicable requirements. Such certification comprises the activity of checking the product, service, organization or person and the formal recognition of compliance with the applicable requirements by issue of certificate, license, approval, or other document as required by national law or procedures. Certification of a product involves: (a) the process of assuring the design of a product to ensure that it complies with a set of standards applicable to that type of product so as to demonstrate an acceptable level of safety, (acceptable risk), (b) the process of assessing an individual product to ensure that it conforms to the certified type design, (c) the issue of any certificate required by national laws to declare that compliance or conformity has been found with applicable standards in accordance with item (a) (ref 9).
Cognizance Levels	The levels of what a UMS can know or understand based on its sensory processing capability.
Collision Avoidance	Sense and avoid system function where the UMV takes appropriate action to prevent an intruder from penetrating the collision volume. Action is expected to be initiated within a relatively short time horizon before closest point of approach. The collision avoidance function engages when all other modes of separation fail.
Collision Avoidance Threshold (CAT)	The boundary around the UMV at which the collision avoidance function declares that action is necessary to avoid a collision and prevent the threat from penetrating the collision volume.
Commanding Officer (CO)	Is the person who commands a warship or military UMV, who is duly commissioned by the government of the State and whose name appears in the appropriate service list or its equivalent in accordance with article 29 UNCLOS regarding a warship. This person may be located anywhere provided that the required method of control and communication can be maintained to discharge the duties arising out of such commission. Any civil UMV is under command of a Master.
Concept of Operation	A verbal or graphic statement, in broad outline, of assumptions or intents regarding an operation or circumstances of how a system is used. The concept of operations frequently is embodied in campaign plans and operation plans; in the latter case, particularly when the plans cover a series of connected operations to be carried out simultaneously or in succession. The concept is designed to give an overall picture of the operation. It is included primarily for additional clarity of purpose (ref 9).
Contingency	An emergency situation requiring special plans, rapid response, and special procedures to ensure the safety of personnel, equipment and facilities (ref 9).
Contingency analysis	A type of analysis conducted to determine procedures, equipment, and materials required to prevent a contingency from deteriorating into an accident (ref 9).

Control Entity	See Authorized Control Entity.
Control Stand	Desk or console at Control station at which all essential indicators, controls, regulating devices, monitoring devices for remote control or operation of the UMS are arranged.
Control station	The set of equipment and control units that are needed at the site where remote control and/or monitoring of the platform is conducted. The Control station may be located on board a dedicated ship (GCP), vessel of opportunity or land based such as on a quay, other shore site, supply station on the coast or on a stationary offshore plant. It may be stationary, integrated to other systems or highly modular and portable.
Controller	Role assumed by the person performing remote control or tele-operation, semi-autonomous operations, or other man-in-the-loop types of operations. The controller's input is expected at certain stages during normal operations. During error conditions, the controller determines the problem that UMS is experiencing in interacting with the physical world, interacts with the UMS to solve this if possible. The Controller may report to either a Watch Officer or the Commanding Officer (Master) depending on the constitution of the control function and the required method of control.
Emergency Procedures	Procedures for automatic or manual failure handling.
Emergency System	System for the handling of emergency procedures.
Fail safe	A characteristic of a system whereby any malfunction affecting the system safety will cause the system to revert to a state that is known to be within acceptable risk parameters (ref 9).
Failure Cases	Failure types include: Catastrophic. All failures excluding a safe operation of the platform(s) and possibly causing deaths. Critical. All failures excluding safe operation. The platform is no longer able to reach a designated recovery point, the result being an abort procedure. This type of failure can cause injuries. Major. All failures resulting in a significant change of the operational status; the mission is aborted; a safe operation and emergency transit to a designated safe position are still possible. Minor. All failures resulting in minor changes of the operational status; the mission can be continued; a safe operation and recovery are still possible.

Fault	Any change in state of an item that is considered to be anomalous and may warrant some type of corrective action. Examples of faults included device errors reported by Built-In Test (BIT)/Built-In Test Equipment (BITE), out-of-limits conditions on sensor values, loss of communication with devices, loss of power to a device, communication error on bus transaction, software exceptions (e.g., divide by zero, file not found), rejected commands, measured performance values outside of commanded or expected values, an incorrect step, process, or data definition in a computer program, etc. Faults are preliminary indications that a failure may have occurred (ref 9).
Graceful Degradation	(1) A planned stepwise reduction of function(s) or performance because of failure, while maintaining essential function(s) and performance. (2) The capability of continuing to operate with lesser capabilities in the face of faults or failures or when the number or size of tasks to be done exceeds the capability to complete (ref 9).
Guidance and Control Platform	Guidance and Control Platform (GCP) is normally referred to as the ship on which the UMS is accommodated. The Control station equipment is placed on board the GCP. GCP may be a dedicated naval ship or a vessel of opportunity (VOO). Mother ship, Parent ship or Host ship, are often used synonymous.
Hazard	Any real or potential condition that can cause injury, illness, or death to personnel; damage to or loss of a system, equipment, or property; or damage to the environment (ref 9).
Interoperability (NATO definition)	Interoperability of systems and equipment largely determines the degree of flexibility inherent in the use of joint and multinational forces. Interoperability of systems and equipment employed by NATO essentially rests upon standardization, especially in order to comply with interchangeability, commonality or compatibility criteria all along their lifecycle (design and development, production, use and support). Interoperability of systems and equipment needs to meet Alliance Standardization Requirements while at the same time remaining cost effective.
Intruder	Ship/Vehicle within the surveillance volume
Launch and Recovery System	The plant and/or equipment necessary for launching and recovering a UMS platform (UMV).
Level of authority	The degree to which an entity is invested with the power to access the control and functions of a UMS. Level I - Reception and transmission of secondary information Level II - Reception of information directly from the UMV Level III - Control of the UMV payload Level IV - Full control of the UMV excluding deployment and recovery Level V - Full control of the UMV including deployment and recovery (ref 9).
MAS	Maritime Autonomous System. Used synonymous with UMS.

Master	Is the person being officially designated by the owning company or Owner as outlined in the applicable IMO instruments in order to discharge the responsibilities of the Master of a vessel. This person may be located anywhere provided that the required method of control and communication can be maintained to discharge these duties.
Mishap	An unplanned event or series of events resulting in death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment (ref 9).
Operational Environment	A composite of the conditions, circumstances, and influences that affect the employment of UMS and bear on the decisions of the unit commander (ref 9).
Operational Area	An overarching term encompassing more descriptive terms for geographic areas in which UMS operations are conducted. Operational areas include, but are not limited to, such descriptors as area of responsibility, theatre of war, theatre of operations, joint operations area, amphibious objective area, joint special operations area, and area of operations (ref 9).
Operational Envelope	Definition of boundaries with respect to natural environment as well as operational environment.
Operator	A(n) (Naval) Authority, organization, enterprise, entity, or person, engaged in or offering to engage in a UMS operation. The Operator discharges as an Owner all duties and responsibilities necessary to maintain the UMV in a seaworthy condition and to be compliant with all relevant international and IMO instruments and domestic legislation. Such compliance is equally required to ensure that the UMS crew shall hold the appropriate qualifications as required by international and IMO instruments and domestic legislation.
Owner	Either the Owner is the title holder of the UMV or when the Operator is not the Owner, then the Operator shall provide the Owner's details to the Authority.
Payload	Additional load for devices, equipment, people, materials, which are not necessary for the direct navigational transit operation of a UMS but are serving for the mission to be performed.
Positioning System	System to determine UMV position (latitude, longitude, depth)
Positive control	Positive control requires the completion of the following functions: (1) a valid command is issued, (2) the command is received, (3) the command is acknowledged, (4) the command is verified, (5) the command authority is authenticated, (6) the command is executed, and (7) notification of command execution is sent and received (ref 9).
Pressure vessel	A container able to withstand an internal or external overpressure.

Remote Control	A mode of operation of UMS wherein a human Controller, without benefit of video or other sensory feedback, directly controls the actuators of the UMS on a continuous basis, from off the vehicle and via a tethered or radio linked control device using visual line-of-sight cues. In this mode, the UMS takes no initiative and relies on continuous or nearly continuous input from the user.
Resolution Manoeuvre	An intentional change in vehicle path, velocity, or depth, or a combination thereof, to avoid a collision threat.
Safe State	A State identifies the conditions in which a system or subsystem can exist. A system or subsystem may be in only one state at a time. A safe state is when the system is behaving normally under normal operating condition and under full control by a Controller at the Control station or under pre-programmed control (Control level 4-5) or when the system has transited to an emergency condition. UMS platform is in general to be considered unsafe until it has transited to a safe state. When abnormal conditions occur, such as for mishaps or hazardous situations, the system shall strive to reach safe state. One or more actions would be undertaken commanded or pre-programmed in order to reach a safe state. A contingency analysis to determine actions to achieve safe state shall be conducted for as many situations as necessary pending type of platform, its tasks and mission. An action to achieve safe state could as example be a platform abort procedure that will shut down engines and anchor the vehicle.
Safe Working Load (SWL) of the Launch and Recovery System	The safe working load SWL is the load which may be loaded directly to the launching and recovery system.
Safety-Critical Software	Software that falls into one or more of the following categories: a) Software whose inadvertent response to stimuli, failure to respond when required, response out-of-sequence, or response in combination with other responses can result in an accident. b) Software that is intended to mitigate the result of an accident. c) Software that is intended to recover from the result of an accident (ref 9).
Self-separation	The capability of a vehicle (or aircraft) maintaining acceptably safe separation from other vehicles (aircraft) without following instructions or guidance from a referee agent for this purpose, such as sea (air) traffic control.
Self-Separation (SS)	Sense and Avoid system function where the UMV manoeuvres within a sufficient timeframe to prevent activation of a collision avoidance manoeuvre while conforming to accepted sea traffic separation standards. Any UMV manoeuvres will be in accordance with regulations and procedures.

Self-Separation Threshold (SST)	The boundary around the UMV at which the self-separation function declares that action is needed to preclude a threat vehicle from penetrating the collision avoidance threshold, thereby maintaining self-separation, and keeping the vehicle well clear of each other.
Sense and Avoid (S&A)	The capability of a UMV to remain well clear from and avoid collisions with other waterborne traffic. S&A provides the functions of self-separation and collision avoidance to fulfil any regulatory requirement.
Single Point Failure	The failure of an item that is not compensated for by redundancy or an alternative design measure (ref 9).
Sea Traffic Control (STC)	Sea traffic control. This is valid as applicable and if a traffic control exists within an area of operation.
Support ship	A surface vessel for control, support, and supply of UMS. Often referred as Mother ship or Guidance and Control ship (GCP) to which UMS may be an organic unit.
Supporting systems	Systems included in the Control station, which are supporting UMS with supplies necessary for the operation, like e.g., electrical energy, hydraulic liquid, as well as control and monitoring data.
System safety	The application of engineering and management principles, criteria, and techniques to achieve acceptable mishap risk, within the constraints of operational effectiveness and suitability, time, and cost, throughout all phases of the system life cycle (ref 9).
System Safety Management	All plans and actions taken to identify, assess, mitigate, and continuously track, control, and document environmental, safety, and health mishap risks encountered in the development, test, acquisition, use, and disposal of (UMS) systems, subsystems, equipment, and facilities (ref 9).
Teaming	The linking together of platforms, forces, or systems to complete a mission or task collectively that would be more difficult to do if the units acted separately. The process is characterized by distributed operations and high tempo manoeuvres, which demands rapid synchronization, swift adaptation of plans and control measures, flexible groupings of distributed staff elements, and direct exchanges between commanders across hierarchies. For example, manned and unmanned platforms can be teamed to emphasize their complementary strengths. The unmanned systems have the further requirements of being able to communicate their intentions, goals, present state easily and quickly in the accomplishment of these goals, intended next action, and current problem areas. Additionally, they have to be able to be re-tasked easily to participate in the current overall goal and to fit into their new position in the organizational structure. The above is critical if they are to perform effectively in team activities.

Teleoperation	A mode of operation of UMS wherein the human Controller, using video feedback and/or other sensory feedback, either directly controls the actuators or assigns incremental goals, waypoints in mobility situations, on a continuous basis, from off the vehicle and via a tethered or radio linked control device. In this mode, the UMS may take limited initiative in reaching the assigned incremental goals.
UMS	Unmanned Maritime System
UMV	Unmanned Maritime Vehicle
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
Valid command	A command that meets the following criteria: a) Originates from an authorized entity, b) The received command is identical to the sent command, c) The command is a valid executable (ref 9).
Valid message	A message that meets the following criteria: a) Originates from an authorized entity b) Valid format c) The received message is identical to the sent message (ref 9).
Velocity Obstacle (VO)	Moving object such as an intruder or ship or vehicle.

Table 11 – General definitions

Definition	Full text
Diving depth	UUV diving depth related to the design baseline.
Diving Pressure	The pressure, corresponding to the relevant diving depth, to which a UUV is exposed during underwater operations.
Exostructure	External fairing, supporting structures and fixtures outside of pressure vessels which are normally not designed to withstand the diving pressure for a UUV.
Nominal Diving Depth (NDD)	The nominal diving depth is the diving depth for the unrestricted operation of the UUV, in meters.
Collapse diving depth (CDD)	The collapse diving depth is the diving depth of a UUV, which is adequate to the calculated external overpressure, where the collapse of a pressure-proof component is to be expected, in meters.
Velocity v0↑	The velocity v0↑ is the maximum operational speed of a UUV in knots at a number of revolutions of the propeller according to the maximum continuous propulsion power surfaced (MCR 1).
Velocity v0↓	The velocity v0↓ is the maximum operational speed of a UUV in knots at a number of revolutions of the propeller according to the maximum continuous propulsion power dived (MCR 1).

Table 12 – UUV specific definitions

Appendix 2 – UMS breakdown structures

UMS constitutes a System of Systems that can be broken down to form a hierarchical structure. In this document a generic system structure is defined, from which a variety of UMS configurations can be created to match the needs in a certain situation.

- UMS contains a Platform System, which is the seagoing part (or parts) of the system. The Platform is broken down into the vehicle in itself and mission specific equipment.
- UMS also includes a Control station System, which is the equipment needed for remote control or monitoring of one or several Platforms. Control station equipment may be integrated with an on-board Combat Management System or a stand-alone system and may also be man portable.
- UMS also includes a Support System that may consist of a dedicated launch and recovery system, maintenance equipment, manuals and other logistics.
- UMS also includes Personnel that are mainly involved with activities within Control station System and Support System.

The following sections suggest a UMS breakdown structure.

A2.1 Platform System

A2.1.1 Vehicle

Structures System

- Hull and Deck
- Equipment Support and Bracket
- Launch and Recovery Interface
- Docking Interface
- Mooring Interface

Propulsion System

- Prime Mover System (Electric Motor / Combustion Engine)
- Drivetrain System (Shaft, Propeller / Water Jet / Pump jet)

Energy Supply System

- Electrical Energy System (Battery, Battery Management)
- Liquid Fuel Energy System (Fuel Tank, Fuel Metering, Fuel Management)
- Energy Management System

Auxiliary Machinery System

- Compressed Air Systems
- Hydraulic Systems
- Ventilation System
- Piping and Duct System

Electrical System

- Main Power Supply System
- Emergency Power Supply System
- Power Control and Distribution System

Vehicle Control System

- Vehicle Controller System (Central On-board Computer, System Control Software)
- Vehicle Dynamics Sensors (Pitch, Roll, Yaw)
- Position and Navigation Sensors (GPS, DVL, Depth Sensor, Compass)
- Situation Awareness Sensors (Radar, Sonar, Proximity Sensor)
- Autopilot System
- Navigation System
- Dynamic Control Actuator System (Rudder, Thruster)
- Displacement Control System (UUV Specific Ballast Tanks)

Fire and Explosion Protection System

- Fire Detection System (Smoke Sensor, Heat Sensor, Gas Sensor)
- Fire Fighting System (CO2 / Halon Extinguisher, Sprinkler)

Communication System

- Radio Communication System (VHF, UHF)
- Satellite Communication System (IRIDIUM)
- Hydro Acoustic Communication System
- Local Communication System (W-LAN)

A2.1.2 Mission equipment

Sensor System

- Surface and Air Sensors (Radar, ESM, IR Camera, LIDAR, Visual Camera)
- Sub-Surface Sensors (Sonar, Echo Sounder)
- Surface Environmental Sensors (Temp, Gas, Radioactivity)
- Sub-Surface Environmental Sensors (Temp, Salinity, Chemical Substances)

Communication System

- Auxiliary Communication System

Launch and recovery of payload

A2.2 Control station System

A2.2.1 Mission planning System

Mission Planning Computer

- Computer Hardware and Operating System
- Mission Planning Software

A2.2.2 Mission control System

Mission Control Computer

- Computer Hardware and Operating System
- Mission Control Software

Controllers Console

- Integrated Console (Part of Control Computer)
- Portable Console

Communication System

- Radio Communication System (VHF, UHF)
- Satellite Communication System (IRIDIUM)
- Hydro Acoustic Communication System
- Local Communication System (W-LAN)

Interface System

- C&C System Interface

A2.2.3 Mission evaluation System

Mission Evaluation Computer

- Computer Hardware and Operating System
- Mission Evaluation Software

Mission Simulation System

Mission Simulation Computer

- Computer Hardware and Operating System
- Mission Simulation Software

Controllers Console

- Integrated Console (Part of Simulation Computer)
- (Portable Console)

Interface System (Optional)

A2.3 Support System

A2.3.1 Preparation / Re-preparation System

Re-Charging / Re-Fuelling System

- Battery Charging System
- Liquid Fuel Refilling System

Re-Arming System

- Munitions Reloading System
- Countermeasures Reloading System

Consumables Replenishment System

- Gas Filling System
- Fluids Filling System

A2.3.2 Launch and Recovery System

Launcher System

Crane System

Cradle / Davit System

A2.3.3 On deck / shore handling System

Trolley System

Storage Rack System

Lifting System

A2.3.4 Maintenance System

Tool System

Spares System

A2.3.5 Documentation System

Operating Manual

Maintenance Manual

Training Manual

A2.4 Roles, personnel

Authorised Control Entities

System Owner

System Operator

Commanding Officer (CO, corresponding to Master)

System Controllers

System Engineers

Appendix 3 – Risk list

Risk areas and control measures identified below are intentionally described generic and in principle, applicable to all types of UMS. Control measures may include design considerations, procedures that are to be established, training and Personal Protective Equipment (PPE) or actions to take by a Controller for UMS in Control levels 0-2 (Controller authority) or by pre-defined algorithms for UMS in Control levels 3-5 (system authorised to invoke functions).

A generally accepted order of priority for control measures are:

1. re-design or re-specification
2. safety features
3. warning devices
4. operational and training procedures
5. PPE
6. warning notices
7. restrictions/limitations for operational use.

If the system safety analysis determines any of the risk areas listed below to be a significant risk, then the listed control measures shall be considered in the UMS design.

A3.1 Collision

Risk description

Collision risk is understood to be the situation when the platform comes to a position too close to another vehicle, other water users (installations, ships, small crafts, or swimmers) or any other in water or underwater objects or obstacles. This risk may also occur as result of a failure on UMS or caused by a third party.

Control measures

The system shall be equipped with a device able to build and maintain relevant maritime situation awareness. This maritime picture shall extend so far that a self-separation zone is covered, and the device shall be able to identify obstacles and track objects that are moving or geostatic. The device shall also be able to determine if any object could cause collision.

The device could be sensors of different types depending on the application and mission at hand. Sensing device could be placed on board the Platform but required information could also come from visual observations or any other sensing devices placed at the Control station or sensing devices placed elsewhere.

When a collision risk is established, the system (or Controller) shall be able to decide on appropriate actions through pre-defined algorithms. These actions could typically be:

- evasive manoeuvres such as turning, stopping and change of speed,

- no actions, such as in the of case of right of way[12].

In case of no solution can be determined to avoid collision, safe state or abort procedures shall always be available to invoke.

A3.2 Third party tampering or theft

Risk description

Third party is here understood to be any unattached, unauthorised, or unrelated actors that could possibly be hostile. 1st party is understood to be the organisation that operates UMS, 2nd party would be any friendly co-operative entities.

The risk at hand is third party tampering (possibly unknown) attachment of explosive devices or other hazardous objects, changing settings or feeding in faulty data or that third party may take possession of the Platform, data, or components.

The risk scenario could be described as a vessel, that should not be there, approaching and people trying to board with an aim of unwanted tampering or possibly theft of platform.

An obvious problem is to be able to determine if an approaching vehicle has malicious intent or just manoeuvring to avoid collision or another obstacle.

Control measures

The system shall be equipped with device able to build a relevant maritime situation awareness. This device shall be able to detect and track other vehicles and to determine if any vehicle would come close enough for people to board.

The risk situation could possibly be detected from the Control station by visual observation or by on-board camera feed.

When an unauthorised boarding risk is established, the system shall be able to decide on appropriate actions through pre-defined algorithms. These actions could include:

- Platform to report back to Control station,
- Manoeuvre to avoid,
- Send message to other party by voice or sound.

As precaution platform should have marking such as “This is the property of … “.

Procedures should also be established for making Platform safe after recovery, checking for third party tampering that could include viewing of camera recordings.

A3.3 Unexpected change in weather conditions

Risk description

[12] Assuming COLREG rules are adopted, and that other vehicle/ship also conforms to COLREG.

The risk area is unexpected change in weather conditions affecting platform outside operating limits, which could lead to unwanted situations and possibly cause damage. Weather conditions could be increasing wind and sea state, temperature change or decreasing visibility.

Control measures

The system shall be equipped with a device able to build a relevant maritime situation awareness. This device shall be able to monitor the maritime environment in terms of sea state, wind, temperature, visibility, and other parameters as necessary against operating limits.

When the maritime environment exceeds limits for safe operations, the system shall be able to decide on appropriate actions through pre-defined algorithms. These actions would normally lead to mission performance degradation and could include:

- Manoeuvre. Decrease speed or change to more favourable course.
- Mission re-planning and change of settings.

In case that no solution can be determined to avoid effects from severe weather conditions, safe state or abort procedures shall always be available to invoke.

A3.4 Loss of UMS

Risk description

UMS platform is lost at unknown position.

Control measures

Guidelines for safe operations to include development of emergency procedures including:

- Immediate promulgation of navigational hazard information.
- International rules for salvage to consider the case of UMS.

A3.5 Maritime wildlife disturbance

Risk description

UMS causes damage to wildlife, possibly physical contact, vibration, (sonar) noise, electromagnetic radiation (e.g., laser).

Control measures

Guidelines for design and safe operations of UMS shall consider effects of UMS emissions on the environment.

A3.6 [*governmental use only*]

A3.7 Maritime pollution

Risk description

UMS causes environmental pollution that could be chemicals or materials.

Control measures

Guidelines shall be developed for design and safe operations of UMS to ensure risk of pollution is minimised. Guidelines for safe operations to include development of emergency procedures including those for pollution control.

An Environmental Impact Screening and Scoping Analysis should be conducted that could lead to an Environmental Impact Assessment.

Pollution may also be a risk during replenishment at sea (RAS). This is however assumed not be unmanned but rather to be carried out by personnel. RAS to UMS is therefore to be controlled by following normal RAS safety procedures.

A3.8 Damage at sea

Risk description

Loss or damage of UMS through flooding/sinking, collision or contact, grounding, explosion, or fire.

Control measures

Guidelines for design to consider survivability requirements for foreseeable damage and emergency scenarios. Guidelines for safe operations to ensure risk of collision, contact, grounding, explosion and fire are as low as reasonably practicable. Guidelines for safe operations to include pre and post operational checks to minimise risk of flooding.

A3.9 Failure at sea

Risk description

Failed UMS dead in water causes navigational hazard. Collision or emergency avoidance of collision by third party may cause injuries.

Control measures

Design shall take into account the need to set day and night signals corresponding to vehicle without manoeuvring ability.

Guidelines for safe operations to include emergency procedures including the immediate notification of and rapid recovery of a dead-in-the water UMS. Guidelines for safe operations to include rescue arrangements within development of emergency procedure.

A3.10 UUV surface hazard

Risk description

UUV could potentially cause hazard when surfacing. Hazard could be damage to other water users or damage to the vehicle.

Control measures

Recommendations are:

- Surface at a predefined position and time at the end of the mission. UUV loitering underwater and waiting for a surface order from a recovery ship to be considered.
- Mission area to be controlled if the UUV is likely to surface for GPS fixes during its mission.

A3.11 Failure of equipment

Risk description

This risk area includes failure of equipment, hardware, or software. This may include:

- Failure of on-board computers,
- Failure of power supply,
- Overheating equipment, motors or inside machinery space.

Control measures

Guidelines for design and safe operations of UMS to consider nature and effects of failure modes and procedures to mitigate these effects. Design process shall identify critical systems and ensure that they are monitored during operations.

A3.12 Failure of navigation

Risk description

UMS failure of navigation or navigation process.

Control measures

Guidelines for safe operations to include detection of navigation failures and development of emergency procedures.

A3.13 Redundancy

Risk description

Inadequate reliability or redundancy.

Control measures

Guidelines for design and safe operations of UMS to consider the nature of specific missions and the data and information requirements, including specific training.

A3.14 Controller workload

Risk description

During UMS operations, Controller interaction may consist of monitoring in autonomous mode or manual control by a remote Controller. During manual operation, the Controller may be launching, navigating to a mission area, or recovering/docking the platform. Controller error during manual control may result in a collision with vessels or other obstacles. UMS must be designed to allow the remote Controller to safely operate the system under all conditions. Conditions of particular concern include operating near other vessels or docks, launching, and recovery. The risk is increased during adverse weather.

Primary causes for Controller error are expected to be e.g., task overload, inadequate feedback on the system, Controller inexperience, improper training, or a lack of Controller proficiency.

Control measures

UMS design shall take into account means of reducing Controller workload and providing realistic feedback to the Controller. The degree of mechanization/automation (even during manual control) must be defined to minimize required Controller actions. Once Controller functions are defined, a realistic method is required for providing the Controller with information necessary to make decisions and execute actions. If the Controller is to avoid unexpected obstacles during remote operations (out of immediate sight), the Controller must be provided with accurate information on obstacles.

Simulation of the planned control functions (with the planned degree of mechanization or automation and Controller feedback) should be performed during the design phase. This simulation should include the Controller and focus on:

- Demonstrating the ability for a Controller to safely perform critical tasks such as launching, recovery/docking, out of sight operation, navigating in close proximity to other vessels and docks, and reacting to unexpected obstacles.
- Evaluating safety critical aspects of the control system, degree of Controller feedback, and degree of automation/mechanization.
- Identifying high risk areas for further investigation.

Results from this simulation will enhance understanding of the potential for Controller error, and the degree to which the Controller can safely perform all required tasks.

During future phases of the program, attention should shift to developing a proper training course to ensure necessary Controller skills are provided and maintained.

A3.15 Personnel injury while boarding UMS platform

Risk description

Severe injury to personnel and damage to equipment could result whenever there may be a reason for personnel to embark the vehicle such as in retrieving an inoperative platform. Risk is compounded with adverse weather conditions such as rain, snow, wind, rough seas, etc.

Control measures

Design of the platform should incorporate a docking area for similar and dissimilar vessels to come alongside and transfer personnel. Minimally, boarding procedures should be developed that minimize the risk of injury to personnel and damage risk to the vessels.

A3.16 [*governmental use only*]

A3.17 Mission equipment hazards

Risk description

Hazards associated with mission equipment are typically assigned a severity classification of Critical.

The inability to retrieve mission equipment will restrict the area in which UMS can operate and will interfere with vehicle landing and docking.

Control measures

Restricting access to mission equipment mitigates this hazard with respect to personnel hazards. Hazards associated with mission equipment should be controlled through detailed risk analysis and design features.

A3.18 [*governmental use only*]

A3.19 Unintended usage

Risk description

UMS system or subsystem not fit for purpose through handling, inadequate specification, design, construction or maintenance.

Control measures

Guidelines for safe operations to be developed to ensure that UMS is fit for purpose.

Guidelines for design to ensure UMS design is fit for purpose. Development of adequate standards. Certification of design, build and operational arrangements required.

A3.20 Out-of-control operation

Risk description

Out-of-control operation results primarily from hardware failures of the onboard and Control station C3 systems but will also result from corrupted or faulty software and Controller errors. Any time the communication link is broken, or command and control signals cannot be transmitted or received may result in out-of-control operation.

Control measures

When this situation occurs, there is a need for the system to achieve a safe state. This could be a failsafe automatic shutdown sequence. This shutdown sequence should be triggered by BIT when a failure is detected which compromises control integrity. The shutdown sequence should then take actions such as to bring the vehicle to rest, deploy anchor and power down appropriate equipment.

To reduce the probability of a mission failure in the C3 system, redundancy should be included as suggested below:

On-Board Command System	Active Redundant
On-Board Communication System	Active Redundant
On-Board Platform Control System	Active Redundant
Control station Command System	Passive Redundant
Control station Communication System	Passive Redundant

Standby redundancy is not automatic and would require Controller intervention.

Not only hardware failures may result in out-of-control operation, but Controller error and vehicle control concepts may result in this hazard as well. With the vehicle under Control station control, either remotely piloted or autonomous operation, collision with other vessels, man-made obstacles, or natural obstructions is possible. Collisions of this type are highly probable when the vehicle is operating beyond line of sight or visual contact is obstructed in some way.

For remote control, a Controller can take control of the vehicle and avoid the obstacle if it is seen in time and evasive manoeuvres are initiated effectively. The design of a hand-held controller must be commensurate with the skill level of the personnel.

Finally, out-of-control operation can result from pilot error or inadequate software control and feedback monitoring. During remote and autonomous operation, a Controller is not in any onboard feedback loop. That is, the tactile, visual, and audible feedback is no longer available. This is especially important during adverse weather and high sea states. In these conditions, the vehicle may be driven beyond acceptable limits unknowingly due to the absence of human feedback.

Unless more severe sea states are expected to be encountered, the probability of this hazard occurring is remote. Controller training and appropriate operating procedures will further mitigate the occurrence of this hazard. Utilizing redundancy in the on board and Control station C3 systems will reduce the hazard probability even further.

Sophistication of the C3 system will be dictated by the ability of the Controller to remotely control one or many vehicles.

A3.21 Loss of platform

Risk description

Platform is lost at irretrievable position.

Control measures

International rules for salvage to consider the case of UMS.

A3.22 Data processing error

Risk description

UMS cannot process data/processes data incorrectly (program testing insufficient).

Control measures

Develop a multitude of system tests to ensure system can process data received by sensors correctly. Identify basic actions for UMS to take when data is conflicting.

A3.23 Control confusion

Risk description

Control confusion between Control station control and other control station (such as Controller with handheld control) located elsewhere.

Control measures

Ensure that proper handover procedures are in place and in principle that control can only be executed from one control station at a time.

A3.24 Unexpected Remotely Activated Operation

Risk description

The remotely controlled aspect of UMS operation may allow start-up with the Platform potentially out of sight of the Control station Controller. This remotely activated operation could result in severe personal injury if personnel are on board performing maintenance or other activities.

Control measures

On board personnel must have the capability to prevent system operation by locking out external control. The on-board lock out should be activated any time personnel are on board and performing maintenance. In addition, a warning of impending operation should be provided on board the vehicle. This warning would allow any personnel on board to take immediate action to prevent operation. A pre-mission procedure should require the vehicle to be safe for operation prior to system activation.

A3.25 Communication loss between Platform and Control station

Risk description

Communication is lost between a Platform and Control station.

<u>UMS control method 3-5</u>

For UMS function at Control method 3-5, this is in theory of low risk on the assumption that the autonomous Platform will continue its task until mission end. It is however not unlikely that a communication would be needed during an autonomous mission. Either from unexpected events that may occur on board the platform or from events or needs from the Control station point of view. Whenever communication is needed this case would transform into a Control method 1-2 case.

<u>UMS in Control method 1-2</u>

For UMS in Control method 1-2, communication loss is highly critical. A Controller at Control station is likely to detect communication loss almost immediately by absence of response to ordered actions. There are however almost no mitigating actions to take. The situation becomes totally dependent on the Platforms ability to detect that communication is lost and the Platforms ability to take actions to achieve safe state.

Control measures

The system shall be equipped with device able to detect that communication between Control station and a platform is lost. It is of particular importance that the Platform detects that the communication is lost. When established that communication is lost, the Platform shall be able to decide on appropriate actions through pre-defined algorithms.

A3.26 Communication error

Risk description

Communication error between Control station and Platform (or between platforms).

Control measures

Develop safe data management protocol.

Ensure data links properly encoded and encrypted to prohibit interference.

A3.27 Communication validity error

Risk description

Communication error between Control station and Platform caused by false message traffic possibly from third party tampering attempting to take control.

Control measures

Develop safe data management protocol. Ensure data links properly encoded and encrypted to prohibit interference.

A3.28 Control resonance error

Risk description

Latency in the control and communication mechanisms may cause new commands to be issued before the results of previous commands are apparent to the controlling entity. Under special circumstances this may lead to unintended reinforcement of unwanted phenomena, so-called control resonance.

Control resonance may occur between any units when new commands are issued before a full control feed-back loop cycle has been managed.

Control measures

Communication protocol design is to consider control resonance. Instructions to Controllers shall include information on the control loop feedback time and the shortest interval between commands that allows for appropriate system reactions.

A3.29 Communication information error

Risk description

Insufficient or untimely supply of information to or from UMS platform.

Control measures

Guidelines for design and safe operations of UMS to consider the nature of specific missions and the data and information requirements, including specific training.

A3.30 External communication failure

Risk description

Unaware that the UMS platform is unmanned, other water user (such as other vehicle or ship) tries to establish communication with it. There could be several reasons as to why another water user would want to communicate. Examples could be that other vehicle in distress and in need of help and assistance or other vehicle has observed something potentially dangerous to the UMV and wants to send warning or caution.

Control measures

Control station Controller to monitor appropriate radio channels and try to answer any calls directed to the UMS platform.

A3.31 Launch and recovery

Risk description

Physical impact and/or other trauma to personnel involved in crane lifts and slipway activities.

Control measures

Guidelines for safe launch and recovery operations to be developed. Consider scheme for safe final approach manoeuvring. Existing established standards for lifting to be used.

A3.32 Maintenance

Risk description

Including but not limited to e.g., unexpected machinery start, electric shock, chemical release, build-up of gasses, explosion and structural failure.

Control measures

Guidelines for design to cover requirements for general health and safety with respect operations, maintenance, repair, and storage.

Whenever personnel interact with the platform on land or at sea, a safety feature should be implemented to prohibit that any residual program instruction will execute or remote-control orders to be sent to the platform.

Ensure that a safe state maintenance mode exists to be set.

Appendix 4 – Legal status for Unmanned Maritime Systems

There are currently not many specific regulations that recognise the existence of UMS, let alone any that cover the design, certification or operation of such systems. In all but a few controlled situations, this makes the current legal position concerning the use of UMS particularly difficult and in some circumstances, untenable.

By the fact that UMS can navigate on, under or close to the sea surface, they are by default likely to fall under various existing maritime regulations. Whilst the definitions of a "vessel" or a "ship" are possibly not fully developed in law let alone defined under UNCLOS, it can been assumed here that the term "craft" covers UMS for smaller platforms and the terms "vessel" or "ship" for those (larger) UMS, which can be registered as such.

However, several countries start to regulate Maritime Autonomous Surface Ships (MASS) following the publication of the "Outcome of the regulatory Scoping Exercise for the use of Maritime Autonomous Surface Ships (MASS)", approved by the Maritime Safety Committee (MSE), at its 103rd session (5 to 14 May 2021)[13].

The first Regulatory Scoping Exercise (RSE) assessed various IMO conventions, which fall under the responsibility of the MSE.

The RSE determines four degrees of autonomy, contrary to the AHWG SARUMS, as described in section 3 Control:

- Degree one: crewed ship with automated processes and decision support,
- Degree two: remotely controlled ship with seafarers on board,
- Degree three: remotely controlled ship without seafarers on board,
- Degree four: fully autonomous ship.

The meaning of "remotely controlled" and "fully autonomous" is rather vague. To what level is a ship actually remotely controlled? Is there any difference between an autonomous and fully autonomous ship? If so, to what extent?

The AHWG SARUMS defines in its BPG five methods of control, as described in section 3 Control. The higher the precision of the delimitation of the control levels the more accurate and efficient e.g., the design, procurement, education, training, maintenance, repairs, C4SI, operations, interoperability, interchangeability, and safety of UMS. Precision is key for the reduction of errors and misinterpretations. It will indefinitely contribute to the reduction of (near) accidents and ultimate liability.

The RSE clarified the legal status of MASS by determining it as a "ship which, to a varying degree, can operate independent of human interaction". Although the IMO regulates predominantly commercial surface shipping and ships, such definition is equally applicable to UMS.

[13] See MSC.1/Circ.1638, 3 June 2021

Attention was also paid to the clarification of the meaning of the term “master”, “crew” or “responsible person”, especially for the Degrees three and four. The RSE addressed the functional and operational requirements of the remote-control station/centre and the possible designation of a “remote operator” as “seafarer”. The IMO and the ICAO apply different definitions for identical legal terms, which does not improve the safety of operations with UxV within the same maritime domain.

The IMO examines its conventions on MASS under purview of respectively the Maritime Safety, Legal and Facilitation Committees (MSC-LEG-FAL) and established an MSC-LEG-FAL Joint Working Group on MASS to examine and advise on common issues.

The European Commission transposes the IMO regulations, which fall under their area of competence.

The AHWG SARUMS draws the attention to the likely applicable domestic legislation of coastal and flag states on UMS, which might entail strict compliance with criminal or penal provisions.

The following sections introduce some regulations relevant to UMS operations.

A4.1 International Regulations for Preventing Collisions at Sea (COLREG)

1. These are probably the most relevant maritime regulations that likely apply to UMS. They are divided into a number of rules and, where appropriate, these are considered below:

   Rule 1 - Application

   These regulations apply to all vessels on the surface upon the high seas and in all waters connected therewith navigable by seagoing vessels. Thus, the COLREG apply to submarines and underwater vehicles when they are on the surface. The definition of “all” vessels specifically covers large as well as small and slow as well as fast vessels, and that of “all” waters covers international as well as territorial waters, harbours and rivers. Whilst there is an allowance for appropriate authorities to set special rules for local waters, these must conform as closely as possible to the COLREGs. Additionally there is a very limited allowance made for vessels of “special construction or purpose” which cannot meet the rules with respect to navigation lights, shapes and sound signals, but again these shall have the closest possible compliance with the COLREG. For ships of war there is a similar dispensation with respect to navigation lights, shapes, and sound signals. Rule 3 defines “vessel” by referring to “every description of watercraft” and which is “used or capable of being used as a means of transportation on water”. The reference to craft permits the COLREG to be applicable to all types and sizes of UMV. However, the latter requirement in the definition “as a means of transportation” will be in general likely never met by smaller UMV. However, by applying COLREG to UMV the Controller shall be compliant with its overriding duties of care and good seamanship in order to avoid any civil or criminal liability.

   Rule 2 – Responsibility

   This rule is considered to be of key importance with reference to the applicability of COLREG to UMS. The main aim of the rule is to emphasise the need for anyone who is, or may be, concerned with the safe outcome of a sea voyage (noted in the rules as including the vessel, the Owner, the Master and crew) to contribute to that safety by complying strictly with the rules and by taking any safety measures required by good seamanship or special circumstances that the vessel may encounter. Rule 2(b) permits to depart from the COLREG when there are special circumstances AND when there is an imminent danger.

2. With respect to any possible negligence in complying with the rules the following points are thought to be important:
   a) Every vessel shall at all times (in clear as well as restricted visibility) keep a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and risk of collision (Rule 5). This is fundamental to the safety of UMS in general and not only in non-segregated sea areas.

   b) Every vessel shall "at all times proceed at a safe speed so that she can take proper and effective action to avoid collision and can be stopped" within an appropriate distance (Rule 6). A range of factors are noted as being required to be taken into account which might influence the sensors and algorithms applicable to UMS.

   c) Using all available means appropriate to the prevailing circumstances and conditions to avoid any risk of collision (Rules 7 and 8). These rules outline a range of scenarios that would influence the navigational algorithms for UMS.

   d) Adhering to special rules concerning narrow channels and traffic separation schemes (Rules 9 and 10). Again, these rules outline a range of scenarios that would influence the navigational algorithms for UMS.

   e) Observing the steering and sailing rules prescribed for vessels in sight of one another as well as for vessels navigating in restricted visibility (Rules 11 to 19). These rules outline a range of scenarios that would influence the navigational algorithms for UMS.

   f) Carrying the correct lights and shapes at all times (Rules 20 to 31 and Additional Lights and Shapes). Whilst these rules outline the relevant lights and shapes to be carried, the applicability to UMS is considered to be associated with their ability to recognise such lights and shapes, in order to make informed navigational decisions, and to carry whatever prescribed lights are relevant. Under Rule 22, inconspicuous or partly submerged vessels should show an all-around white light visible for at least 3 miles.

   g) Sounding and deploying the correct sound and light signals (rules 32 to 37). These rules outline a range of requirements that would influence the design ad selection of sensors, actuators, and algorithms likely to be required for UMS.

3. As well as considering possible negligence issues relating to compliance with the specific COLREG rules, there is also the issue of the precautions that should be taken as required by good seamanship (see reference to Rule 2 above). This may include:

   a) Checking that the navigation lights and sound signals work and continue to work as required. This would influence sensors and algorithms likely to be required for UMS.

b) Maintaining an appropriate course and speed as may be expected by other vessels in the vicinity, applicable also in shallow water which may influence directional stability.

c) Regularly answering any fog signals. This would influence sensors and algorithms likely to be required for UMS.

d) Keeping out of the way of a vessel at an anchor. This is likely to be difficult to ascertain for a UMS.

e) Determining when to stop and keep clear when operating in significantly reduced visibility (particularly for vessels without operational radar). Again, this is likely to be difficult for UMS.

f) How to react in close quarters situations in order to avoid a collision when the strict application of the COLREGs would be inappropriate. It is possible that reversion to direct human control will be required to satisfy this issue for UMS.

4. There are a number of other relevant issues concerning the COLREG that should be considered:
   a) The existence of unmanned vehicles (other than barges and small vehicles that can be classed as ship’s equipment), particularly autonomous or semi-autonomous vehicles, are not envisaged or recognised by these rules. Thus, it might for example be argued that to operate a vessel without a person on-board would be poor seamanship. Thus, adherence to the underlying requirements of these rules might involve ensuring that UMS are recognised by them. There are precedents for the inclusion of new vehicle types within the regulations, such as WIG craft which have recently been added.
   b) The term “vessel not under command” is one used for a vessel which, through exceptional circumstances, is unable to manoeuvre as required by the rules. Loss of C2 could be such a cause for UMV. It is considered that, unless exceptional circumstances exist, a UMV is unlikely to be classed as a “vessel not under command” unless it is dead-in-the-water.
   c) The term “vessel restricted in her ability to manoeuvre” is one used to describe a vessel which, from the nature of her work, is restricted in her ability to manoeuvre as required by the rules.
   d) The size of a vessel has an influence on the requirements under these rules. In particular there are three relevant threshold values of length quoted: 7 metres, 12 metres and 20 metres. For example, the lights and shapes generally required to be displayed by vessels not under command or restricted in their ability to manoeuvre are not required to be displayed by vessels under 12 metres in length. Also powered vessels under 7 metres and operating at below 7 knots need only display an all-around white light when underway. It is considered that these thresholds lengths may possibly be of use in the definitions of UMS classes.

A4.2 International Convention for the Safety of Life at Sea (SOLAS)

This convention only applies in its entirety to ships larger than 500 GRT being engaged on international voyages, that is a voyage from a country to which SOLAS applies to a port outside that country, or conversely. It does not apply to ships of war. The application of SOLAS is administered by the government of the state whose flag the ship is entitled to fly (otherwise known as the Administration). The Administration may exempt any ship which embodies features of a novel kind from much of the regulation, although some Chapters would still apply. However, unmanned ships are clearly not envisaged or recognised and much of what is contained in these rules would be inappropriate.

All the same, Chapter V entitled The Safety of Navigation does appear to have applicability and relevance as described in the following paragraphs.

SOLAS Chapter V – Safety of Navigation – applies to all ships, irrespective their GRT, on all voyages except ships of war and ships navigating in some specific geographical areas. Whilst UMS are unlikely to be strictly defined as ships it is possible that some of the regulations making up this Chapter may need to be applied during the operations of UMS:

a) Regulation 19 – Carriage requirements for ship-borne navigational systems and equipment. This regulation outlines the navigational systems to be carried by all ships of any size and covers compasses, charts, GPS receivers, radar reflectors, and a sound reception device. For ships of 150 gross tonnage and above there are a wide range of additional requirements.
b) Regulation 24 – Use of heading and/or track control systems. This regulation covers the necessity to be able to revert from autopilot to manual control in hazardous navigational situations and to test the manual control after prolonged use of the autopilot.
c) Regulations 25 and 26 – Operation of steering gear, testing and drills. These regulations relate to the assurance of the availability of steering gear. There is an allowance for the Administration to waive this regulation in lieu of undertaking regular tests.
d) Regulation 28 – Records of navigational activities. For ships engaged on international voyages there is a requirement to keep a record of navigational activities and incidents relating to the safety of navigation.
e) Regulation 31 and 32 – Danger messages and the information required in them. This regulation requires the Master of any ship encountering a danger to navigation, to pass specific information onto other ships in the vicinity. This would require a suitable radio installation on the UMS.
f) Regulation 33 – requires the Master of a ship or the CO of a warship at sea, “which is in a position to provide assistance on receiving information from any source that persons are in distress at sea is bound to proceed with all speed to their assistance, if possible informing them or the search and rescue service that the ship is doing so”. The obligation to render assistance at those who are in distress at sea is as an international legal principle under SOLAS, UNCLOS, Salvage Convention and the SAR Convention and is equally applicable to UMV. If a UMV is in the vicinity of a vessel in distress, then it should render the assistance with all its available means where feasible.
g) Regulation 34 – Safe navigation and avoidance of dangerous situations. This regulation requires that the Master ensures that each proposed voyage has been pre-planned. The issue of the Master’s discretion is also covered, where he shall not be constrained from taking any decision which in his professional judgement is necessary for safe navigation and protection of the marine environment.

A4.3 United Nations Convention on Law of the Sea (UNCLOS)

This convention addresses the sovereignty of a coastal state extending beyond its land territory and internal waters and the rights and responsibilities associated with such waters. The convention is divided into 17 Parts, many of which are clearly applicable to the operation of UMS (in the sense that UMS operate on the sea and would thus be seen as ships for the purpose of the convention). Part 2 is entitled Territorial Sea and Contiguous Zone and addresses the rights and responsibilities of all ships (including warships, merchant ships and government ships operated for non-commercial purposes).

Article 20 on Submarines and other underwater vehicles would apply to UUV and states: In the territorial sea, submarines and other underwater vehicles are required to navigate on the surface and to show their flag.

Section 3 of Part 2 addresses the rights of innocent passage for all ships within such zones. In this context, it is currently uncertain whether a UMV will be regarded as a ship, the “passage” must be continuous and expeditious and to be “innocent” it must not be prejudicial to the peace, good order and security of the coastal state. Passage of a foreign ship shall not be considered to be innocent if it engages in certain listed activities. These include the launching, landing or taking on board of any military device, the carrying out of research or survey activities and any activity not having a direct bearing on passage. The coastal state may also impose local regulations, including the necessity to travel in specific traffic separation zones. This latter issue may require the UMS to listen out on specific radio frequencies and be able to respond to requests from local authorities. In terms of responsibility of warships and other government ships operated for non-commercial purposes, the flag state shall have international responsibility for any loss or damage to the coastal state resulting from the non-compliance by the ship with the laws and regulations of the coastal state concerning passage through the territorial sea or with the provisions of this Convention or other rules of international law.

Part 7 of UNCLOS addresses the rights and responsibilities associated with operations on the high seas (i.e., sea areas not included in exclusive economic zones or territorial waters). It provides for the freedom of navigation on the high seas to any state for peaceful purposes. However it requires that there must exist a genuine link between the State and the ship (i.e. all ships to be flagged by a state and thus to have a nationality) and goes on to define the duties of the state, which cover issues such as ship registration, the construction, equipment and seaworthiness of ships, the manning of ships, labour conditions and the training of crews, taking into account the applicable international regulations, the use of signals, the maintenance of communications and the prevention of collisions. Thus, it is evident that some clarification as to how the requirements of UNCLOS should be applied to UMS and their operation is likely to be required.

Part 13 on UNCLOS addresses marine scientific research on the high seas. All States, irrespective of their geographical location, and competent international organisations have the right to conduct marine scientific research subject to the rights and duties of other States as provided for within UNCLOS. For example, coastal states, in the exercise of their sovereignty, have the exclusive right to regulate, authorise and conduct marine scientific research in their territorial sea. Interestingly, safety zones of a reasonable breadth not exceeding a distance of 500 metres may be created around scientific research installations and all States shall ensure that such safety zones are respected by their vessels. Such installations or equipment shall bear identification markings indicating the State of registry or the international organization to which they belong and shall have adequate internationally agreed warning signals to ensure safety at sea.

A4.4 Salvage Convention

This convention addresses the salvage of vessels or any other property in any waters. A vessel in this context means a ship or craft or any structure capable of navigation and thus clearly would include UMS. However, the convention is not applicable to warships or other non-commercial vessels owned or operated by a state and which are entitled to sovereign immunity.

The conditions relevant to rewards for salvage and the duties of the salver and of the Owner and Master of the vessel are defined. It may be that UMS with limited communication facilities are more vulnerable to “un-requested” salvage (e.g., if the salver determines that salvage is appropriate and is not advised otherwise by the Master or Owner of the vessel). In this regard, the convention states that no payment is due under the convention if the salvage operation had no useful result. However, it is possible that payment may be likely to be required in this instance in order to retrieve the property. Thus, it is considered that the vulnerability of UMS to inappropriate acquisition by third parties should be addressed, possibly by clear markings on the UMS to this effect.

In summary it is considered that there is every reason to expect that this convention is fully applicable to UMS.

A4.5 Convention on Limitation of Liability for Maritime Claims (LLMC)

This convention is focused on limiting the liability of marine claims. It declares that “a person will not be able to limit liability only if it is proved that the loss resulted from his personal act or omission, committed with the intent to cause such a loss, or recklessly and with the knowledge that such a loss would probably result”. It is thought that if UMS are not recognised by law and they are operated at sea without a recognised code of practice, then it could be interpreted that a limit of liability might not apply.

If UMS are classed as ships and if the LLMC convention does apply, then the limit of liability for loss of life or personal injury is 2 million Special Drawing Rights (approximately USD 3 million) and for property claims is 1 million Special Drawing Rights (approximately USD 1.5 million).

Thus it is considered that ensuring UMS are recognised under this convention is critical to their general acceptance by the maritime industry for the future.

A4.6 Convention on Ocean Data Acquisition Systems

This convention has not, to date, entered into force but envisages the use of manned and unmanned floating and submersible devices for use at sea, specifically for ocean data acquisition. The convention focuses on identifications and markings, lights and signals to be exhibited by such devices.

A4.7 International Convention for the Prevention of Pollution from Ships (MARPOL)

This IMO Convention is the most important global treaty for the prevention of pollution from the operation of ships; it governs the design and equipment of ships, establishes system of certificates and inspections, and requires States to provide reception facilities for the disposal of oily waste and chemicals. It covers all the technical aspects of pollution from ships and applies to ships of all types (although it does not apply to pollution arising out of the exploration and exploitation of sea-bed mineral resources). Whilst it is applicable to all ships (defined as “vessel of any type whatsoever operating in the marine environment, including hydrofoil boats, air cushion vehicles, submersibles, floating craft and fixed or floating platforms” and includes recreational craft), it is unlikely to have a major impact on the design and operation of small UMS.

MARPOL also defines the roles of the various maritime administrations and thus, should UMS operate in international waters, these administrations will need to be made aware of the nature of these craft (the Flag State is required to implement the regulations applying to the ship; the Coastal State is required to implement regulations applying to shore facilities and the Port State is required to ensure that ships of other parties comply with the regulations).

A4.8 Standards for Training, Certification and Watch-Keeping (STCW)

It is clear that these particular regulations are totally incompatible with UMS since they were derived on the assumption that ships would be manned by a number of crew.

However, the issues of training, certification and watch-keeping are as important, if not more so, for UMS and thus such regulations should be considered in detail but considering the nature of the design and operation of UMS.

It is possibly relevant to note that since UMS may well be recognised as a type of ship or vessel, the fact that the STCW regulations cannot be met may add weight to the issue of the irresponsibility of operating UMS in situations that are not specifically controlled and approved by the relevant authorities.

A4.9 International Ship Management Code (ISM code)

The full title of this code is the International Ship Management Code for the Safe operation of Ships and for Pollution Prevention. It was adopted by the IMO in 1993 and came into force in 1998 as SOLAS Chapter IX. The origins of the code go back to the 1980s and revolve around the findings from incident investigations that not only are 80 to 90 % of maritime incidents attributable to human error but that this could be traced in many instances to shortcomings on the part of ship management both at sea and ashore.

Given the nature of shipping, and in particular the diverse range of organisations and cultures that are involved in international ship operations, the ISM Code is expressed in broad terms and is based on general principles and objectives, taking a holistic view of an organisation and the way in which it operates ships. It is primarily based on the requirement for the organisation to develop its own Safety Management System (SMS) whilst meeting the provisions of the ISM Code. The ISM Code is only compulsorily applicable to UMV registered as ship and larger than 500 GRT, but it "may be applied to all ships" by virtue of Article 1.3.

The introduction of an SMS requires a company to document its management procedures to ensure that conditions, activities, and tasks, both ashore and afloat, affecting safety and environmental protection, are planned, organised, executed and checked in accordance with legislative and company requirements. Auditing of the SMS is undertaken by suitably qualified and appointed (by the flag state) auditors covering two main documents as follows:

a) Document of Compliance (DOC) – this will be issued to a company when the shore-side aspects of the SMS are found to fully comply with the requirements of the ISM Code. The DOC is specific to the company and the ship types that it operates.
b) The Safety Management Certificate (SMC) – this certificate will be issued to each individual ship on completion of a successful SMS audit of the vessel itself, provided that the company holds a valid DOC.

It is clear that the operation of UMS could benefit from the ISM approach and that this system is probably applicable to UMS at present. Thus, again, the fact that UMS are unmanned may add weight to the issue of the irresponsibility of operating UMS in situations that are not specifically controlled and approved by the relevant authorities.

A4.10 Regional and national merchant shipping rules

There appear to be no Regional or National marine regulations that envisage the use of independent unmanned marine craft. However, there is a plethora of regulation that deal with the safety of ships and shipping whilst at sea and whilst in port. Many of these will be directly applicable whilst attending to UMS, such as lifting operations, manual handling, personal protective clothing, provision and use of work equipment, control of hazardous substances and the management of health and safety. It is considered inappropriate to research these rules and regulations but important to note that their application is likely to be statutory in most nations.

Many European maritime directives may be indirectly applicable and would probably need revision if UMS were to be formally recognised.

Appendix 5 – [*governmental use only*]

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Appendix 6 – UMS categorisations

UUVs may be categorised in accordance with size, speed etc. The tables provided in this section serve as examples for discussion on relevant classifications and quantifications. They are not to be regarded as recommendations or requirements.

A6.1 Cognizance levels

The levels of what a UMS can know or understand based on its sensory processing capability may be described by the three levels as described in table 13.

Level	Description
1	Raw data or observed data. In initially processed forms after measured by sensors.
2	Information. Further processed, refined and structured data that is human understandable.
3	Intelligence, knowledge, combat and actionable information. Further processed for mission needs. Directly linked to tactical behaviours.

Table 13 – UMS sensory processing capability levels

A6.2 Ability to communicate

UMS may also be categorised by its ability to communicate as described in table 14.

Type		Description
Tethered		Tether contains a high-bandwidth communications channel.
Untethered	a	Expected to maintain a permanent high-bandwidth communications channel.
	b	Expected to maintain a permanent low-bandwidth communications channel.
	c	Expected to have intermittent communications.
	d	Not expected to communicate during task/mission.

Table 14 – UMS categorisation by ability to communicate

A6.3 Length

Length based categorisation conforms to length relevant to IMO COLREG.

Category	Length (m)
Small	0 – 7
Medium-small	7 – 12
Medium-large	12 - 20
Large	>20

Table 15 – UMS categories based on length

A6.4 Endurance

Category	Distance (NM)
Low end	< 100
High end	> 100

Table 16 – UMS categories based on endurance

A6.5 Speed

Category	Speed (kt)
Low speed	0 – 12
Medium speed	12 – 35
High speed	> 35

Table 17– UMS categories based on endurance

High speed limit may exist that would require Controller high speed certificate.

A6.6 Weight

Category	Weight (Kg)
Man Portable	< 45
Light Weight	< 200
Medium weight	< 1500
Heavy Weight	< 3000
Large	< 10000

Table 18 – UMS categories based on weight

A6.7 Mid-frame diameter

Diameter	Comment
130 mm	
230 mm	Used for Man-Portable UUV
324 mm	Standard for NATO Light Weight Torpedoes
465 mm	
533 mm	Standard for NATO Heavy Weight Torpedoes
635 mm	
730 mm	
840 mm	
915 mm	
1000 mm	

Table 19 – UMS categories based on mid-frame diameter

A6.8 Operational depth

Category	UUV maximum depth (m)
Near Surface	< 30
Low Depth	30 – 100
Continental Shelf	100 – 300
Mean Depth	300 – 1000
High Depth	1000 – 3000
Abyssal UUV	> 3000

Table 20 – UMS categories based operational depth

A6.9 Kinetic energy

Category	Energy (J)
I	0 – 100
II	101 – 1000
III	1001 – 10000
IV	> 10001

Table 21 – UMS categories based kinetic energy

Appendix 7 – UMS operational phases

Descriptions of UMS operational phases per underwater and surface vehicles are suggested in table 22.

<table>
<tr><th colspan="2">Phase</th><th>Description for UUV</th><th>Description for USV</th></tr>
<tr><td>P1</td><td>Pre-mission procedures</td><td colspan="2">Mission planning phase, which could be conducted in advance of the actual mission. This may include definitions of operational area, information and notification to joint forces, related units, organisations, and Maritime authorities (including navigational warnings etc.) as required; need for infrastructure, environmental conditions and interaction with other ships or vehicles, route plan etc.</td></tr>
<tr><td>P2</td><td>Pre-deployment procedures</td><td colspan="2">Could include mission equipment or modules reconfiguration or preparations.</td></tr>
<tr><td>P3</td><td>Deployment</td><td colspan="2">Transporting system to operational area. Not applicable if organic system.</td></tr>
<tr><td>P4</td><td>Pre-launch procedures</td><td colspan="2">Detailed mission planning. May include updates and adjustments to previous planning as necessary.
Check lists including energy, communications, verification of functionality etc.</td></tr>
<tr><td>P5</td><td>Launch</td><td colspan="2">In water launch from ship (mother ship) or from shore side position (quay) using dedicated launching system, crane, or other equipment.
Launching could also be cast off if the platform is moored to a berth at a pier.</td></tr>
<tr><td>P6</td><td>Post launch procedures</td><td>In water check lists (where the platform may be in moored position). Including steering and manoeuvring device, communications, stability and displacement, emergency systems etc.</td><td>In water check lists (where the platform may be in moored position). Including steering and manoeuvring device, communications, emergency systems etc.</td></tr>
<tr><td>P7</td><td>Transit</td><td>Surface transit (normally short distance) to diving position.</td><td>Transit to point of mission start.</td></tr>
<tr><td>P8</td><td>Diving</td><td>Diving phase to operational depth.</td><td></td></tr>
<tr><td>P9</td><td>Underwater transit</td><td>Submerged transit to point of mission start.</td><td></td></tr>
<tr><td>P10</td><td>Mission conduct</td><td>Mission conduct phase. Normally includes one or more surface-dive phase for communication or GPS fix.</td><td>Mission conduct phase.
Phase lasts until Abort or Mission end.</td></tr>
</table>

Phase		Description for UUV	Description for USV
		Phase last until Abort or Mission end.	
P11	Mission conduct	A mission may consist of one or several tasks highly dependent on application. The platform(s) will move as commanded or through predefined way points. The mission may contain re-planning, that is modification of the pre-launch detailed mission plan either autonomously decided by the platform or commanded by the Control station.	
P12	Replenishment	Replenishment such as re-fuelling may occur within a mission or at its margins. This could also include changing or replacement of various types of mission equipment.	
P13	Underwater transit	Submerged transit to point of re-surface.	
P14	Surface	Surface phase.	
P15	Transit	Surface transit (normally short distance) to point of recovery.	Transit to point of recovery.
P16	Recovery	Recovery from water to ship or to position on land. Recovery could also be docking if the platform shall remain moored and in sea.	
P17	Shut down procedure	Procedures in accordance with check lists.	
P18	Re-configuration	Re-configuration to standard or special equipment fit pending nature of next assignment. May also include recharging of batteries etc.	Re-configuration to standard or special equipment fit pending nature of next assignment.
P19	Storage	Platform(s) and possibly other Control station equipment could be stored in dedicated storage compartment.	
P20	Maintenance	Maintenance and/or repair. This could also occur during storage or during mission conduct or at its margins.	
P21	Post mission procedures	Mission analysis.	

Table 22 – UMS operational phases

ANNEX A – CODE OF CONDUCT

1. Unmanned maritime systems operational code of conduct

The following code is proposed to organisations using UMS or duty of care holders. The code is built around three specific themes: *Safety, Professionalism, and Respect* (derived from AUVSI Unmanned Aircraft System Operations Industry "Code of Conduct"). Each theme and its associated recommendations are intended to represent a "common sense" approach to UMS operations. The code is meant to provide UMS users a convenient checklist for operations and a means to demonstrate their obligation to supporting a safe and responsible usage of the system. By adopting this Code, UMS owners/users commit to the following:

1.1. Safety

- We will strive to ensure that our UMS is at least as safe as a manned equivalent.
- We will not operate UMS in a manner that presents undue risk to persons, property, or environment on the surface or under water.
- We will ensure UMS will be operated by individuals who are properly trained[14] and competent to operate the vehicle and its systems.
- We will ensure UMS is equipped with sufficient sense and avoid system to meet navigational rules and regulations as well as to avoid collision with other water users.
- We will ensure UMS operations will be conducted only after a thorough assessment of risks associated with the activity. This risks assessment will include, but is not limited to:
  - Weather conditions relative to the performance capability of the system,
  - Identification of normally anticipated failure modes (lost link, power or equipment failures, loss of control, etc) and consequences of the failures,
  - Circumstances with respect to Operational area, compliance with regulations as appropriate to the operation, and off-nominal procedures,
  - Communication, command, control, and payload frequency spectrum requirements,
  - Reliability, performance, and seaworthiness in relation to established standards.

1.2. Professionalism

- We will comply with all international, national, and local laws, ordinances, covenants, and restrictions as they relate to UMS operations.
- We will operate our systems as responsible members of the maritime community.
- We will be responsive to the needs of the public and other water users.
- We will cooperate fully with national and local authorities in response to emergency deployments, mishap investigations, and media relations.
- We will establish contingency plans for all anticipated off-nominal events and share them openly with all appropriate authorities.

[14] Certified/authorised in accordance with national regulations.

1.3. Respect

- We will respect the rights of other water users.
- We will respect the privacy of individuals.
- We will respect the concerns of the public as they relate to unmanned vehicle operations.
- We will support improving public awareness and education on the operation of UMS.

2. UMS code of practice check list

In addition, a code of practice (derived from ref 32) is provided for UMS operations that could be utilized as a checklist:

a) Operating, safety, emergency and maintenance procedures should be put in writing and agreed upon by relevant parties (e.g., operator, manufacturer, insurer, and owners of seabed installations as well as potentially any hirers).
b) There should be clear demarcation of responsibilities for all stages of the operational cycle of a UMS, with individual responsibilities identified, with the individuals to be guided by the operating procedures as discussed above. Conditions and rules for delegating authority to autonomous platform control or platform functions control should be established.
c) A risk analysis should be undertaken for all stages of operations (or category of operations) before deployment of any equipment. There should also be third-party liability insurance in place, with operating procedures having been agreed with the insurers.
d) The UMS should only be operated by qualified personnel. Allied to this, there should be procedures to cover vehicle programming and system checks.
e) Procedures for vehicle repair/re-configuration/testing agreed between manufacturer and operator and agreed in writing should exist. Important examples include:
    - Maintenance procedures and intervals agreed between owner/operator and manufacturer,
    - Pre-sea checks/procedures,
    - Software function testing procedures agreed for software upgrade.

In summary, the development of a code of practice for UMSs requires, as a minimum:

- All procedures to be put in writing,
- Responsible individuals to be identified for all stages of vehicle deployment and given the appropriate authority to act on those responsibilities,
- Clear demarcation (and understanding) of responsibility between operators, deployment vessel, hirers, owners of seabed installations for each of the different stages of operation,
- Rigorous and independent system/programming checking procedures so that any human error on behalf of one individual is identified and rectified.

ANNEX B – SENSE AND AVOID POLICY

EXECUTIVE SUMMARY

The aim of this UMS Sense and Avoid (S&A) Policy is to elaborate upon and clarify the issues surrounding UMS S&A, to state position on the influencing concepts, and to provide guidance to operational use of UMS S&A. This policy guidance should be sufficient for stakeholders to ascertain if the UMS S&A capability being deployed will comply with applicable mandates to maintain safety of navigation and protection of life at sea.

It is recommended that this policy is adopted by nations, maritime safety agencies, industry or other organisations that develop or operate UMS.

The concepts within this Policy apply across the lifecycle of the UMS, therefore it is expected that this Policy will be consulted during specification of the UMS S&A capability, and throughout the subsequent phases of design, implementation, and UMS operation.

This framework is represented as an influence diagram, showing how the policy objective of ensuring safe and effective use of UMS S&A in an operational environment is influenced by many factors. The areas of influence are grouped into the following concepts, forming the structure for this policy document:

- UMS Sense and Avoid System Design & Configuration

  Understanding the drivers of UMS S&A capability and validation of the capability for the intended mission.

- UMS Sense and Avoid Mission Planning

  The planning and understanding of the operating environment, collision hazards and the effects of mission upon S&A requirements.

- UMS Sense and Avoid Capability in the Operational Environment

  Ensuring that the available UMS S&A capabilities are sufficient to enact collision avoidance against the required mission operating needs, including the effect of environmental influences.

Practical guidance is provided within the Policy document, suggesting what S&A considerations should be undertaken and recorded by the UMS designers and operators before UMS deployment, and the reasons why.

This policy has been built upon the foundations laid by EDA AHWG SARUMS members.

1. Background

Developments in technology will allow the transfer of maritime vehicle control from on-board human operator to artificial intelligence-based systems.

There is a general trend within the maritime community to maximise opportunities to exploit growing levels of UMS autonomy for both military and non-military operational use.

For coherence, the language and definitions used within this Policy align with that used in associated policies and documents such as the maritime Rules of the Road (Policy Section 3.2.1). The major definitions used within this policy are summarised below, with a full list provided in Appendix 1 – Acronyms and References.

1.1. UMS

UMS are defined as to include vessels that have no on-board human operator. The UMS may be subject to varying modes of human control, from remote pilot operation to no direct control e.g., autonomous. For the purposes of this policy, the subject UMS is presumed to be capable of some level of autonomous Sense and Avoid (S&A) behaviour. There are two categories of UMS vehicles: Unmanned Surface Vessel (USV) and Unmanned Underwater Vessel (UUV).

A major part of the guidance provided in this Policy is applicable to both USV and UUV. Some statements, in particular those related to existing regulations such as COLREG, are applicable to USV and may have limited relevance to USV.

1.2. UMS Sense and Avoid (S&A)

UMS S&A describes the capability of the UMS system to determine potential collision risks, to undertake planning for mitigation[15] of those collision risks, and to enact planned mitigation behaviours, in order to fulfil the key operational objectives. The key objectives of UMS S&A capabilities during an operational mission are to:

- Ensure the safety of other maritime users,
- Ensure the safety of the UMS,
- Conduct the planned mission.

Figure 6 defines the UMS S&A system boundary and shows the context explored within this policy document.

[15] Note that the collision risk mitigation may not necessarily comprise of taking an avoiding action such as UMS manoeuvre or a change in speed; it could be an alternative method such as UMS generation of a warning signal.

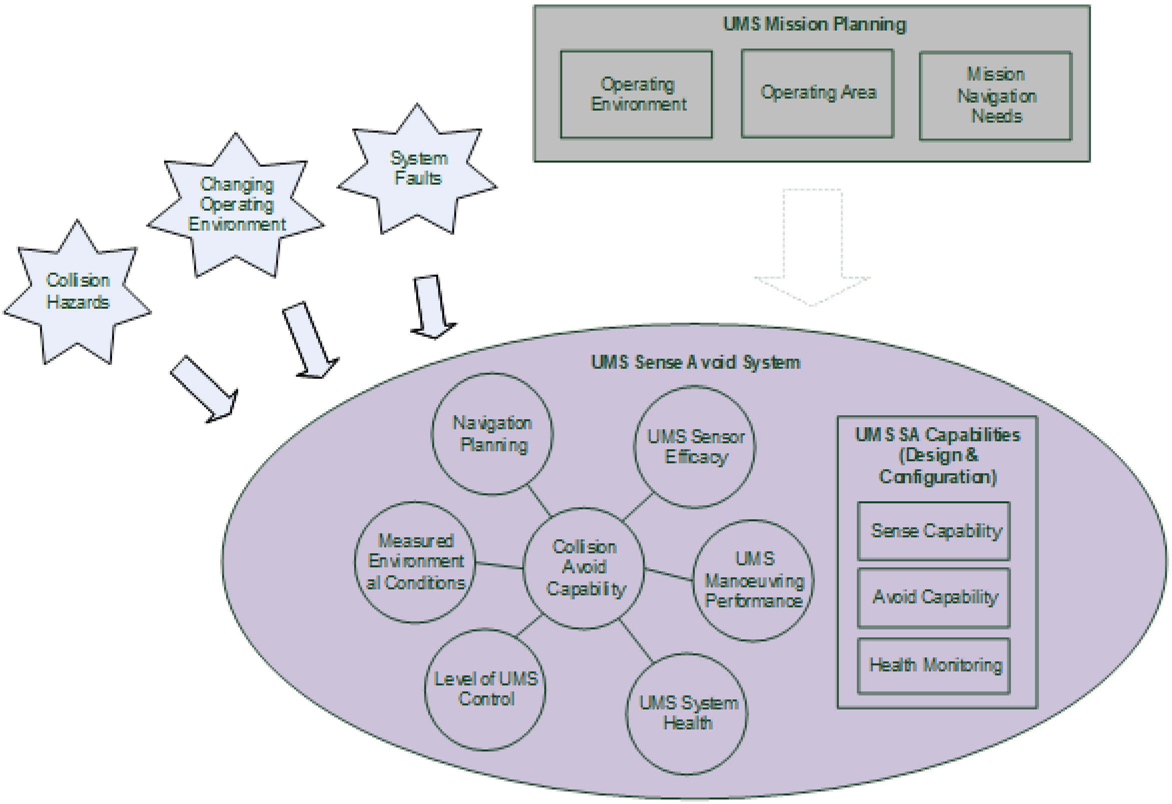


Figure 6 – UMS S&A system boundary

1.3. UMS operational mission

A UMS Operational Mission covers the application of a UMS system to a specific task, from mission planning and UMS selection to UMS preparation, deployment, execution, and recovery.

1.4. Policy language

This policy contains specific language when providing guidance. The term “should” denotes where user action is recommended, and “shall” indicates mandatory action by the user.

2. UMS Sense and Avoid (S&A)

2.2. Initial assessment

Safe operation of manned maritime vessels is achieved, in part, through the application and adherence to regulations that cover design, build, seaworthiness and system certification, and the training and certification of operators.

The same is not yet true for UMS, where regulations are still under development. Therefore, the issue for the operation of UMS is to demonstrate operations that are equivalent to that of manned vessels.

In the context of S&A capabilities that is, to behave in the way in which a manned vessel would in all situations and circumstances.

2.3. UMS S&A policy origins

This S&A Policy is driven by the evolution and application of technologies that enable the development of automation in UMS S&A, and will be updated by the AHWG SARUMS, reflecting subject-matter experts and governmental adoption and use of UMS S&A technology, and evolving maritime regulations.

2.4. Policy stakeholders

The stakeholders involved are armed forces operating UMS, other maritime environment users, any local applicable traffic control authorities, national regulatory authorities and international maritime regulators.

2.5. Policy applicability and scope

This policy is applicable to both military and non-military missions, covering the specification and operational use of UMS S&A. This policy applies to USV at all times, and UUV only when operating in the fully surfaced condition.

Policy concepts are considered from the point of view of the on-board sense and avoid capabilities of a single, unmanned vessel, although UMS S&A solutions that involve fusion of sensor data from other unmanned units or remote sites are not precluded.

It is outside the scope of this policy to inform how the UMS implements Sense and Avoid capabilities: the focus will be maintained on what autonomous or operator-controlled capabilities are required to ensure that the operation of the UMS complies with the overall objectives.

This UMS S&A policy only considers supporting UMS systems and capabilities where they have influence on UMS S&A policy concepts; examples are the UMS mission navigation planning, and the propulsive capabilities of the UMS, in accordance with BPG section 5.

2.6. Policy users and benefits

This policy is targeted for use by UMS operators, military capability planners, UMS Design Authorities, Maritime Regulators, and Industry. Application of the Policy Principles will enable the target audience to specify and select appropriate UMS S&A capabilities, such that the UMS can perform its operational mission safely and effectively.

In addition, this policy provides maritime regulators with early visibility of issues within current "rules of the road" regulations that arise from development of UMS S&A capabilities. S&A Policy will also inform other maritime environment users on UMS operational behaviours within the context of maritime collision avoid regulations.

The concepts within this Policy apply across the lifecycle of the UMS, therefore it is expected that this Policy will be consulted during specification of the UMS S&A capability, and throughout the subsequent phases of design, implementation and UMS operation.

2.7. S&A Policy document development, contents, and layout

To fully cover the subject domain of UMS S&A capability, this policy has been informed by the study and definition of a set of influencing factors, forming a conceptual framework. This framework is represented as an influence diagram, showing how the policy objective of ensuring safe and effective use of UMS S&A in an operational environment is influenced by many factors (see Figure 7).

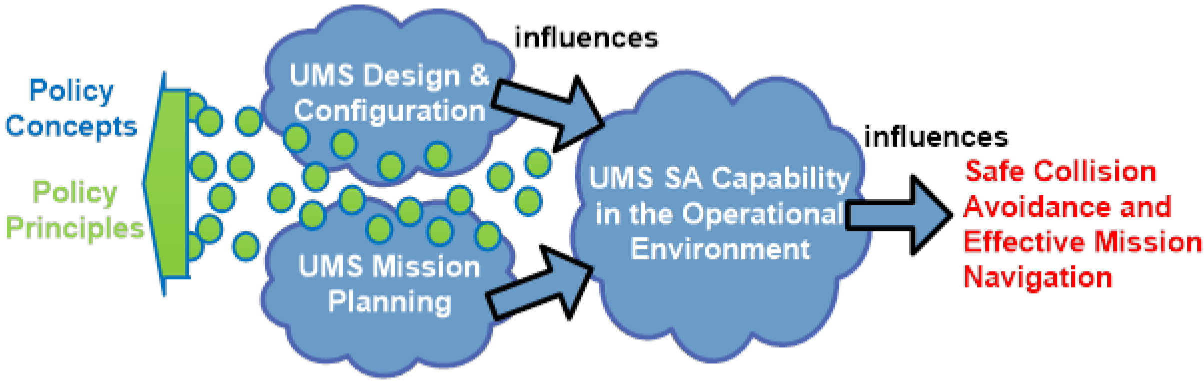


Figure 7 - UMS S&A Policy and Influencing Factors on UMS SA Operational Capabilities

The areas of influence are grouped into the following concepts, forming the structure for this policy document:

- UMS Sense and Avoid System Design & Configuration

  Understanding the drivers of UMS S&A capability and validation of the capability for the intended mission.

- UMS Sense and Avoid Mission Planning

  The planning and understanding of the operating environment, collision hazards and the effects of mission upon S&A requirements.

- UMS Sense and Avoid Capability in the Operational Environment

  Ensuring that the available UMS S&A capabilities are sufficient to enact collision avoidance against the required mission operating needs, including the effect of environmental influences.

The UMS S&A Capability in the Operational Environment concept is dealt with lastly, since it is influenced by factors from the other concepts.

This S&A policy is formed by exploring each concept in detail, provided as a set of Policy Principles, with statements declaring what influencing factor(s) are being addressed, followed by supporting arguments and research-based evidence to show why the principle is being declared.

Each policy principle contains:

- The specific objectives of the principle,
- Arguments and robust, research-based evidence to show why the principle is being declared, and the EDA position on the subject,
- A declaration of what factors and issues are being addressed,
- Elaboration on how the policy principle can be applied to UMS S&A, using a set of actionable guidelines where applicable.

An additional area of policy, linked to and supporting the policy principle concepts, provides users with practical guidance on the application of policy principles:

- UMS Sense and Avoid Mission Safety Assessment.

  What steps a UMS operation Duty of Care Holder should take before UMS operations commences, to assess collision hazards and to control risk to acceptable level.

Expert knowledge of UMS operation, mission planning, and the UMS system design/configuration is required when applying policy guidance for assessment of UMS S&A capability for a planned mission. Two specific roles are used in this policy document to describe those stakeholders charged with the assessment.

The UMS Operating Expert should be suitably qualified, equal to the certification needed for a manned vessel of the same size and purpose/mission as the UMS, including experience in applying maritime rules of the road.

The UMS Mission Planning Expert should understand the mission, the design of the UMS, and have experience in planning and executing UMS missions. Both experts should have knowledge of the legal and safety aspects.

3. UMS S&A Mission planning

UMS S&A mission planning identifies the factors that influence the S&A capabilities of the UMS during its operational use. The objective is to predict and quantify the influencing factors, so that it can be determined if:

- UMS S&A capabilities are adequate for the expected environment (see BPG section 5),
- UMS navigation capabilities are sufficient to execute the mission.

Figure 8 shows the framework used by this policy to identify the key variables. There may be additional factors within mission planning that influence the resulting objectives: in this case policy users are encouraged to supplement this guidance with consideration of those influences.

The key influences within this concept are described below, as policy principles.

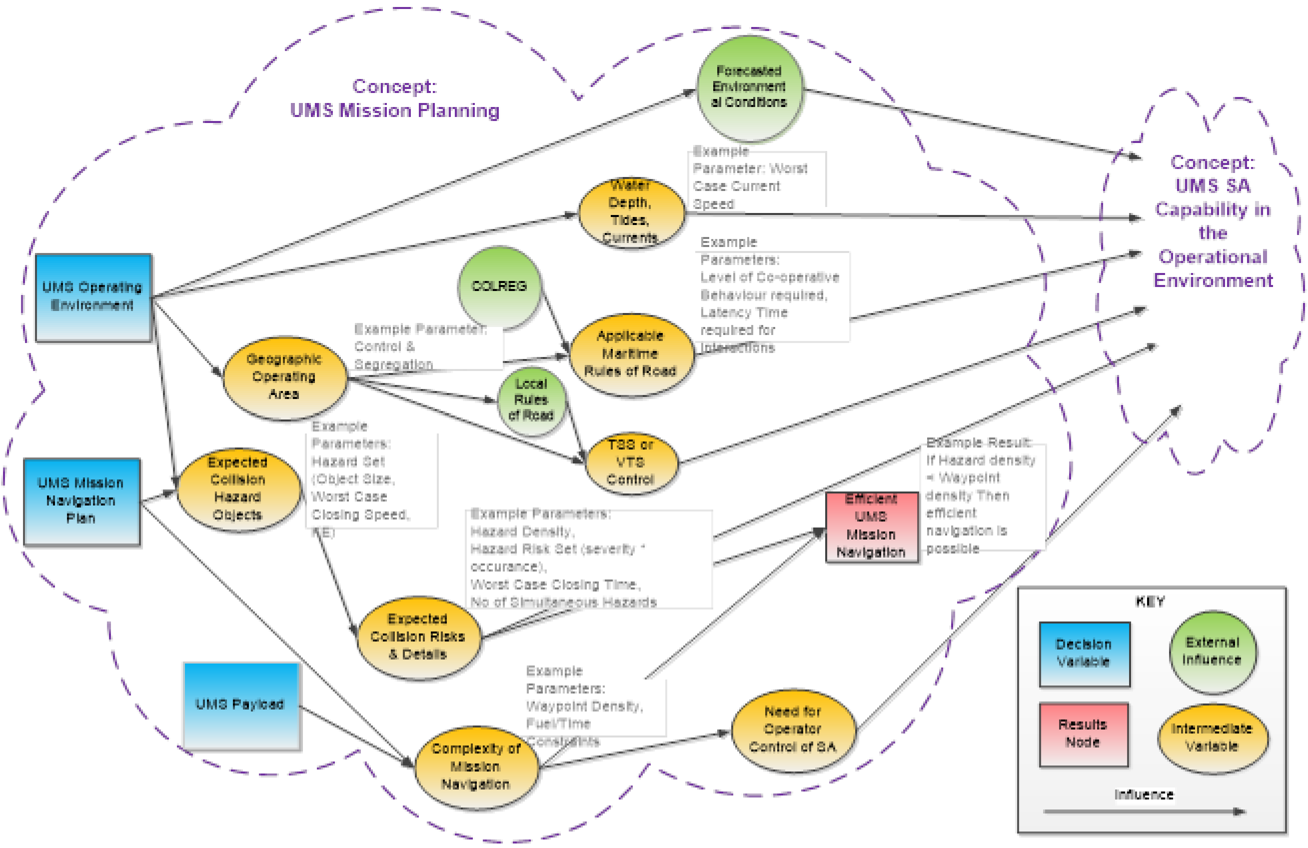


Figure 8 – Influences within the UMS S&A Mission planning concept

3.2. Policy principle: operating environment

The objective of this principle is to develop an understanding, by the UMS Operating Expert, of the environmental influences that impact the UMS S&A capabilities, based upon the proposed area of operation for the UMS mission.

For each UMS mission, the Mission Planning Expert should investigate, analyse, and document the following parameters. This record of influences forms the basis on which the UMS S&A capability can be assessed.

3.1.1 Forecasted environmental conditions

Environmental conditions affect the UMS S&A sensor capabilities in terms of range and accuracy, the UMS S&A avoid capabilities in terms of manoeuvrability response, the UMS S&A semi-autonomous modes in terms of command control link quality and availability, the UMS S&A control capabilities in terms of object detection, tracking and classification, and the health of the UMS S&A equipment in terms of environmental specifications.

The following group of parameters should be determined from the point of view of influences on the UMS S&A capabilities, across the area of operation:

- Weather Forecast including worst-case predictions for wind and local visibility (heavy rain, fog banks, mist, snow, sandstorms),
- Air and Sea temperatures,
- Sea State; including swell,
- Atmospheric and Underwater Background Noise Levels,
- Shore Lighting Levels and Density (at night),
- Electromagnetic Spectrum Usage,
- Pollutants in the atmosphere and in the water,
- Water Salinity (effects upon UUV buoyancy and speed of sound through water and hence communications systems).

3.1.2 Water depth, tides, and currents

The following group of parameters should be determined since they influence the UMS S&A avoid capability in terms of manoeuvrability, particularly for narrow channels or fairways, and worst-case closing speeds of collision hazard objects:

- Expected minimum and maximum water depth and seabed topology,
- Expected working depth (applying to UUV for SA equipment specification),
- Local tides, turbidity, and other forms of current.

3.2. Policy principle: geographic operating area

The objective of this principle is for the UMS Operating Expert to arrive at an understanding of the legal and legislative constraints within the proposed geographic location. Included in the analysis are any local rules of the road in force and Vessel Traffic System (VTS)/Traffic Separation Schemes (TSS) constraints. For this policy, the focus is on those factors that have specific influence on the collision avoid behaviours required from the UMS S&A capability.

For each UMS mission, the Mission Planning Expert shall investigate, analyse, and document the following parameters. This record of influences is then used as the basis on which to assess the UMS S&A capability.

In the absence of a defined, validated and assessed Sense and Avoid capability, UMS operations shall be only permitted within segregated and controlled sea areas.

3.2.1 Applicable maritime rules of the road and COLREG

Within the Convention on the International Regulations for Preventing Collisions at Sea (COLREG) (IMO, 1972), there is no specific definition or recognition of UMS. However, COLREG Rule 1(a) and 3(a) imply that UMS is considered as a “vessel”, and this S&A policy abides by this equivalence philosophy. Collision avoidance is an issue for all vessels, regardless of type.

UUVs shall be considered as surface vessels when operating in a fully surfaced condition. This policy therefore considers COLREG to be fully applicable to both USV and surfaced UUV. There are no underwater "rules of the road" regulations, the main purpose of UUV S&A is underwater obstacle avoidance.

The following list of current maritime Conventions to Autonomous Maritime Vessels may have applicability to this UMS S&A-specific policy. The references should be reviewed for applicability as part of the mission analysis:

- UN Treaty: Suppression of Unlawful Acts Against the Safety of Maritime Navigation Convention 1988 (UN, 1988),
- Draft Convention on the Legal Status of Ocean Data Acquisition Systems (ODAS), MSC/Circ.372 14 June 1984 (IMO, 1984).

Although Maritime Claims, Property, Liability, and Salvage Laws / Conventions are outside the scope of this UMS S&A policy, it is strongly recommended that these legal constraints should be also be investigated and considered by the UMS Operator Expert as part of mission planning.

3.2.2 COLREG UMS equivalency definition

Using the equivalence philosophy described above for application of COLREG to UMS as vessels, this policy uses the following equivalent definitions to COLREG rules:

- Rule 5 – The vessel "look-out by sight and hearing" should equate to "optical and acoustic sensing" for UMS S&A,
- Rule 3(k) – A vessel should be in sight of the UMS when it can be observed optically by the UMS,
- Rule 3(l) – The term "restricted visibility" should relate to "optical detectability by the UMS",
- Rule 19(e) – The term "hears" should equate to "acoustically detects" in UMS,
- Rule 7 – UMS use of radar is the same as that defined in COLREG,
- Rule 7(c) – The UMS should not make assumptions based upon the use of scanty information from non-optical sensors, radar, AIS, navigation aids, or other sources.

3.2.3 Local rules of the road, TSS and VTS control

To determine if COLREG Rule 9 (Narrow Channels) and Rule 10 (Traffic Separation Scheme) are applicable, it should be determined if the UMS will be navigating through those special areas. An analysis should also be made of any special rules of the road local to the UMS operating area as outlined in Rule 1(b) and 1(c), specifically those that influence the required UMS S&A Capabilities.

3.3. Policy principle: expected collision hazards and risks

The main purpose of this principle is the analysis and derivation of those influences on the required UMS S&A capability that originate from hazardous objects encountered within the operational area. The recorded information and data parameters will be analysed under the policy concept UMS S&A Capability in the Operational Environment to determine the required UMS sense and avoid capabilities.

It is assumed that danger of grounding, and collision with fixed static objects, has been mitigated through use of a planned navigation route or area, where known navigation hazards are charted, with avoidance of such objects planned into the UMS mission navigation system (see section 3.4.1 below). The remainder of the UMS collision risk originates from unknown objects (free-floating or fixed).

The recommended approach to gathering this data is to perform a risk assessment, where the area of operations should be reviewed to generate quantified risks for the UMS colliding with hazardous objects. Within this data gathering, additional parameters should be collected against each hazard object which will inform the analysis on the required UMS S&A capabilities.

3.3.1 Hazardous object set

The Mission Planning Expert should estimate all “unknown” collision objects that may be encountered during the UMS mission, forming a hazard set. The additional parameters recorded for each hazard should include the object size and aspect (and any other influences on its detectability), its expected density of occurrence in the areas of operation, speed-over-ground, kinetic energy, ability to sustain damage from UMS, threat to create damage UMS, and any other parameters or notes that will inform the analysis of collision risk and influence the S&A capabilities.

Note that the object’s speed should be worst case, factoring in local tides and currents. By using an estimate of the UMS highest speed for the mission, a worst case object -to-UMS closing speed should be calculated as an additional parameter for each hazard (assuming the worst case of a head-on approach).

3.3.2 Expected collision risks

The hazard set should then be used as the basis for a risk assessment, where the level of risk resulting from a collision should be assessed for each object in turn. The purpose of this step is to understand the mission collision risks sufficiently to inform and prioritise what S&A capabilities are required.

Specification of the risk model to apply is beyond the scope of this policy, but a typical risk model (DNV, 2010) should incorporate calculation of a risk severity figure based on the effect of a collision with the object (e.g., harm to persons, harm to environment, cost of damage to property, cost to mission) against the likelihood of encountering that object in the planned UMS operating area.

In addition to the risk analysis of the hazard set, there may be other generic mission collision risk parameters identified that inform the S&A capabilities required, an example is the collision hazard object densities expected along the UMS mission navigation plan (influencing UMS control system capability, i.e. the maximum number of simultaneously tracked contacts). These parameters should also be documented.

3.4. Policy Principle: UMS mission navigation plan & payload

The objective of this principle is to assess if the intended UMS Mission Navigation Plan can be executed efficiently within the operating environment, and to consider special navigation issues arising from activities involving the UMS mission payload, including any need for operator remote control of UMS navigation.

UMS navigation planning is outside the scope of this policy, attention is drawn to the following guidelines for further information:

- UK MCA Workboat Code (Industry Working Group Technical Standard) (MCA, 2014),
- For vessels over 300grt: SOLAS Chapter V (Safety of Navigation) (IMO, 2002),
- IMO Maritime Safety Committee (MSC) COMSAR Sub-Committee – E-Navigation (IMO, 2006),
- IMO Ship's Routing, latest Edition, ISBN 978-92-801-1554-3 (IMO, 2013).

For each UMS mission, the UMS Mission Planning Expert should investigate, analyse, and document the following parameters.

3.4.1 Mission activities and navigation plan

The Mission Planning Expert should review the UMS activities to identify collision avoid needs at each stage of mission execution. The phases are usually defined within the Mission Navigation Plan. An example mission may involve the following navigation phases:

- Deployment & Transit – safe initialization of S&A systems and autonomous navigation to a starting waypoint,
- Monitoring – autonomous monitoring a given area for a given subject (e.g., mines, divers, ships, pollution) by navigation between set waypoints,
- Tracking phase – semi-autonomous following and tracking of a dynamic subject,
- Termination phase – tracking break off and autonomous navigation to UMS pick-up waypoint.

Each phase should account for constraints such as navigable area, time available and UMS endurance (design power capacity). For collision avoidance purposes, the Mission Planning Expert shall also identify all factors that influence the UMS S&A capability, including factors that involve application of COLREG.

For each mission navigation phase, the influencing factors identified should include:

- Time of Day and Visibility (need for Navigation and Identification lights, and shapes carried),
- COLREG manoeuvrability status of the UMS vessel (need for Identification lights and shapes carried, depending upon the UMS activity),
- Specific collision risks from Hazard Object Set (see section 3.3),
- A navigation tolerance to account for deviations caused by obstacle avoidance behaviour, this should be used to allocate a power system contingency (see section 4.3.1),
- A navigational tolerance for adverse weather conditions,
- Need for COLREG Rule 6 Safe UMS Speed, dictated by forecasted environmental conditions.

Any such factors that could affect the UMS manoeuvrability, or related assumptions, should be recorded, so that the applicability of COLREG can be determined (see section 5.2). Example UMS activities are those that restrict the UMS ability to manoeuvre e.g., engagement in towing, pushing, surveying, underwater operation (Rule 3 contains more definitions), and exceptional events such as risk of the UMS running aground.

Protocols for partial or complete UMS system failure at any point during the mission should also be included in the Mission Navigation Plan: this issue is addressed within the UMS S&A Design and Configuration Concept of this policy.

An estimate of the overall density of mission waypoints should be assessed for use in ascertaining the efficiency of navigation in section 3.4.3 below.

3.4.2 UMS payload

The UMS Operating Expert should consider all payload (and UMS platform) effects on the UMS system elements delivering the UMS SA capabilities, including:

- Changes in UMS mass,
- Heat emission or changes,
- Chemical effects,
- Electrical loading,
- Radiant (Electromagnetic) emissions,
- Nuclear effects,
- Magnetic changes,
- Mechanical shock,
- Sound (In-water and in-air),
- Light emission,
- Power Usage.

It is assumed that payload control is separate from UMS S&A control (see section 4 below).

3.4.3 Complexity and efficiency of UMS mission navigation

Efficient UMS mission navigation is dependent upon the planned waypoint density, the collision hazard density, and the requirement of COLREG safe UMS speed.

The Mission Planning Expert shall understand the balance between the time spent by the UMS in collision avoidance, against that required for planned mission navigation.

For military UMS missions, there may be a need for covert or other special navigation measures. In such cases, the UMS Mission Planning Expert and Operating Expert may be tempted to make exceptions in applying COLREG rules, for instance, no UMS display of Navigation lighting at night because of a need for covert operation.

This policy strongly recommends that any such dispensation shall be recorded, justified with grounded arguments for the exceptions, particularly in terms of safety and legality, and shall be approved by the military operating authority.

3.4.4 Need for operator control of UMS S&A

The Mission Planning Expert should consider that if there are any requirements for semi- or non-autonomous UMS S&A control during the mission, then the Operator and S&A system behaviours and responsibilities for collision avoid during these periods should be identified, and the results fed into the policy principle that investigates the overall capability for collision avoid (see section 5 below).

Furthermore, operational and system protocols for handover of S&A responsibilities between operator and UMS S&A system should be established and verified. These protocols should include any dynamic changes in navigation planning commanded by the UMS operator.

In order to mitigate against introduction of emergent risks, formal operating procedures shall be defined to authorise any such changes in planned mission navigation. If in-mission navigation waypoint changes are made that extend the planned area of operations, then all the mission predicates should be re-visited.

Watchkeeping Certification of Competency standards for seafarers are covered by the IMO International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (ref 16). There are STCW competencies for deck officers in charge of, and deck ratings forming part of, ship's navigation watch. The UK MCA have guidance for certification of competency for Masters of workboats less than 500GT, covering navigation STCW functions, in notice MGN 496 (M+F) (ref 17). There are no current UMS Operator-specific certifications.

4. UMS S&A System design and configuration

Understanding the drivers of UMS S&A capability and validation of the capability for the intended mission.

This policy concept addresses policy principles associated with the design and configuration of the technical systems forming the Sense and Avoid capability within the UMS. Assessment of the UMS S&A configuration by the Mission Planning and Operating Experts should define what UMS S&A Capabilities are available for the mission.

The concept influence diagram is shown in Figure 9 below. Note that it is not intended to model the UMS S&A system, its purpose is to serve policy users as a guide on what influencing design features should be considered when assessing the concept of the UMS S&A capability in the operational environment.

The Policy Principles within this concept are listed below, with an indication of how the S&A system features influence the available UMS S&A capabilities available to successfully perform collision avoidance in the operational environment:

- Method for UMS S&A control, system health monitoring and autonomous collision avoid behaviours (available UMS S&A control modes and capabilities),
- UMS S&A remote command & control (C2) and data link system health monitoring (influencing the available level of operator control and ability to achieve collision avoid under system fault conditions); UMS SA System build & configuration, including overall UMS size, sensors, lighting and signalling effectors, control system, system design, interoperability and external system interfaces (available sense and avoid capabilities),

- UMS Propulsion Fit (effectors and other design aspects that affect the available avoid capabilities).

Detailed guidance on what elements in the UMS Design and configuration should be addressed by policy users are detailed as Policy Principles in the following sections.

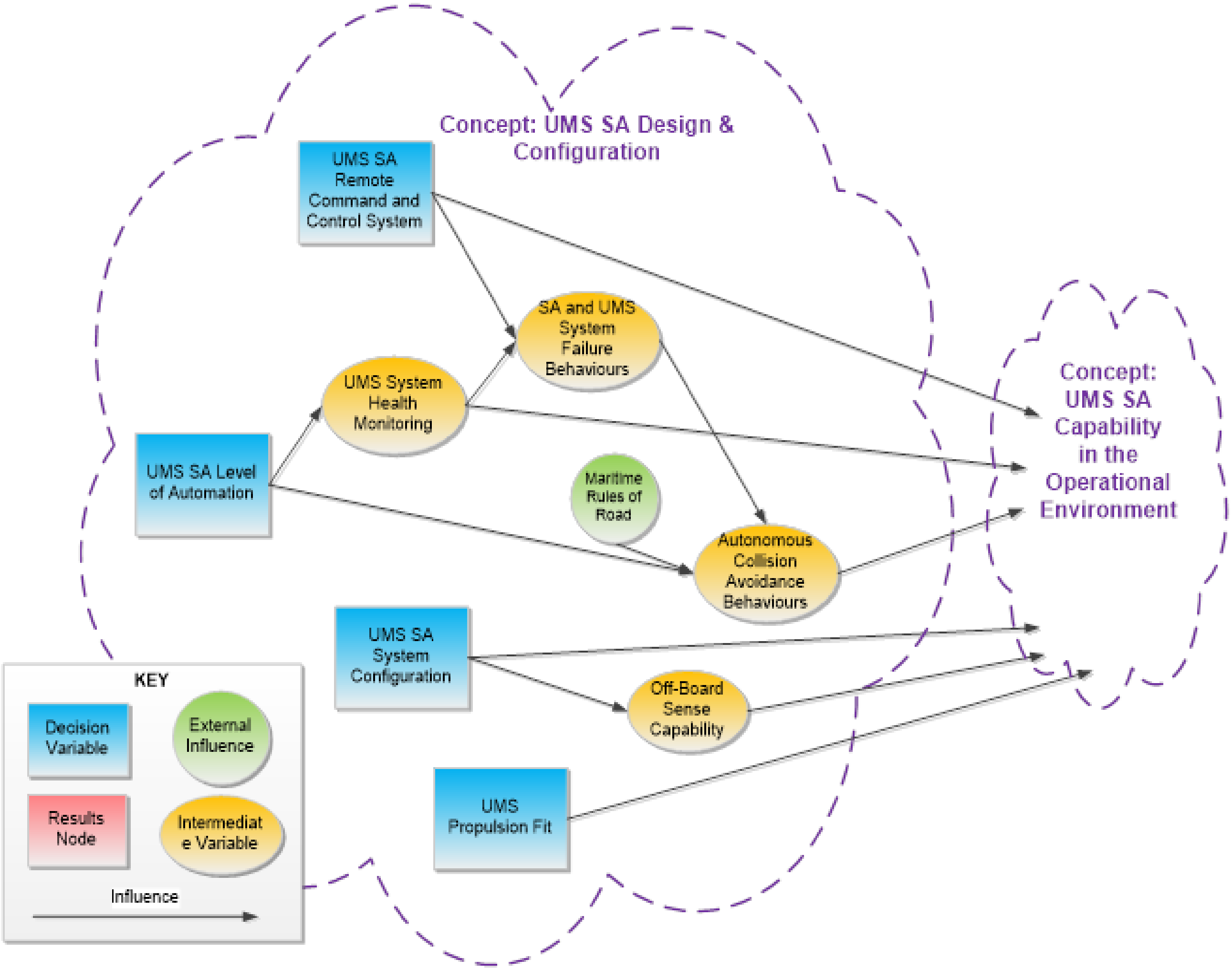


Figure 9 – Influences within the UMS S&A Design and Configuration concept

4.1. Policy principle: UMS S&A Control Methods

The control method for UMS SA shall be understood as described in the parent UMS Guidance document (ref 8) section 3 UMS Control:

- Control method 5 Autonomous,
- Control method 4 Monitored,
- Control method 3 Human delegated,

- Control method 2 Human directed,
- Control method 1 Human operated.

For the design configuration of the UMS S&A, there should be a specification of the control methods for all behaviours, including collision avoidance, so that there is an understanding of the UMS control responsibilities within the mission concept. Note that the UMS S&A may be capable of collision avoid behaviours with different control methods during the mission (section 3.4.4 provides more guidance).

Where UMS S&A remote control methods are used, the UMS S&A System boundary definition should be extended to include the operator and the means to connect the two entities. If an off-board sense capability is used by the UMS, then the system boundary should be carefully considered and a system interface defined. With any remote-control data link, there should be particular attention to S&A system timing dependencies and latency to ensure command and control integrity.

4.2. Policy principle: UMS S&A System Configuration

It is recognised that that there may be some UMS S&A system re-configuration possible, in order to match the UMS S&A system capabilities to the specific demands of the particular UMS mission. If this is the case, then the new UMS system configuration shall be subject to re-validation and verification against the mission requirements. The overall operating envelope of the UMS S&A configuration shall be defined and recorded, so that during exceptional operational conditions it can be ascertained if the UMS S&A system can continue to effectively carry out collision avoidance behaviour. This topic is detailed in section 4.3.

The principles of Configuration Management (DoD, 2001) should be applied to the UMS and S&A system designs, and that the "As-Built" configuration baselines should be specified and recorded. Any mission-driven system reconfiguration should be investigated, approved and the system re-tested against the recorded baseline: any re-configuration of the baseline system shall be assessed for impact-of-change to assure system safety.

4.2.1. UMS S&A Sensor configuration

Configured S&A sensors are those fitted to support UMS S&A system behaviours described in section 4.4.

COLREG Rule 7 (a) supports use of all sensors and use of data fusion to determine if risk of collision exists, especially in challenging environmental conditions where the situation awareness can be improved by non-optical sensors.

Facilities supporting the principles in COLREG rule 5 of maintaining a proper lookout and the subsequent design criteria from SOLAS V/22 shall be a part of the vessel design. These facilities shall serve the purpose of:

- Maintaining a continuous state of vigilance by sight and hearing, as well as detection of significant change in the operating environment,
- Fully appraising the situation and the risk of collision, grounding and other dangers to navigation,

- Detecting ships or aircraft in distress, shipwrecked persons, wrecks, debris and other hazards to safe navigation.

A Sensor Plan should be determined for the UMS, showing the minimum and maximum Fields of View (FOVs) and working ranges of the UMS S&A sensor fit, and the key parameters. This plan should be used to check that all possible areas of approach to the UMS have S&A sensor coverage.

<u>Horizontal field of vision:</u> Facilities supporting a horizontal field of vision (FOV) to the horizon of 360° around the vessel shall be provided.

<u>Vertical field of vision:</u> The view of the sea surface forward of the bow to 10° on either side shall not be obscured by more than two vessel lengths or 500 m, whichever is less, under all conditions of draught, trim and deck cargo.

The view of the sea surface from 10° on either side of the bow to 112,5° on either side shall not be obscured by more than 500 m.

The view of the sea surface from 112,5° to straight aft on either side shall not be obscured by more than 1 nautical mile.

<u>Blind sectors:</u> Blind sectors caused by obstructions appearing within the forward 225° sector shall be as few and as small as possible. No blind sector caused by cargo, cargo gear or other obstructions which obstructs the view of the sea surface as seen from the main navigation reference location shall exceed 10°. The total arc of blind sectors shall not exceed 20° in the forward 180° sector and shall not exceed 30° in the forward 225° sector. The clear sector between two blind sectors shall be at least 5°. Over an arc from right ahead to at least 10° on each side, each individual blind sector shall not exceed 5°.

<u>Pitching and rolling:</u> It shall be possible to detect all external objects of interest for safe navigation, such as ships, buoys and lighthouses in any direction when the vessel is pitching and rolling. In this context the horizontal and vertical field of view shall be sufficient to enable the equipment to fulfil the above performance requirements as well as being able to see the horizon.

It shall be possible to detect and recognise lights and shapes as described in COLREG Part C, and sound and light signals as described in COLREG Part D.

The performance of the sensor fit when subject to the mission environmental conditions (effects from atmospheric obscurants, sea clutter, and pitch & roll of platform and other factors), and requirements for resolution and detection rate for the expected hazards are explored in section 5. The key parameters for sense measurement quality are accuracy, reliability, update rate, and latency.

Sensor calibration and SA software system settings should be assured before the start of the mission. This should include angular alignment of sensors in accordance with the Sensor Plan, and software alignment for sensor object detection and tracking, in particular any settings required for adaptation of sensors to the expected environmental conditions. Sensors may require alignment against a positional Consistent Common Reference Point for data fusion.

4.2.1.1. *Position, platform motion and environmental condition sensors*

The UMS S&A System will require interfacing with the UMS Navigation System to obtain geospatial and temporal referencing, i.e. GPS/GNSS positioning data, as well as determination of UMS heading, speed and time. Inertial Measurement Unit (IMU) equipment will be used by the UMS Navigation System for dead reckoning if GPS is unavailable.

The vessel shall be equipped with navigational and position keeping equipment necessary to execute a safe voyage plan. In this process, there shall be a possibility to determine the vessel position by use of various and independent positioning methods or a combination of such. As a general rule, position determination shall be based on minimum two independent methods.

In addition, sensing of the prevalent operating conditions will be required in terms of meteorological conditions, optical visibility, and platform inertial motion (pitch, roll, yaw, and for USV, sway, heave and surge). The UMS Navigation System IMU may be able to provide the platform motion measurement where there is such a requirement for the information by other sensors or data fusion processors.

4.2.1.2. *Optical, thermal and infrared sensors*

This Policy Principle uses the COLREG UMS sensor equivalency definitions defined in section 3.2.2. Thermal and Infra-Red (IR) sensors are included within this section, although they extend the spectral range of optical sensors, the equivalent of the capability of a human look-out sight in COLREG Rule 5.

The UMS Designer should understand how the configuration of all optical, thermal and IR sensors contribute to the UMS SA system behaviours, and as a minimum, have a specification of:

- Sensor Resolution (FOV H&V, spatial resolution, max and min working distance, effects of zoom),
- Noise/Spectral Sensitivity (EMVA 1288 characterisation),
- Camera Shuttering (global is generally preferred for image processing, integration time);
- Lens and Lens Control (aperture, depth of field & focus, zoom),
- Digital Video Standard (including data rate, compression loss, latency),
- Video Frame Rates (detection and tracking time, and the processing requirements for the volume of data produced at required resolution),
- Physical Data interface (standard data interfaces for sensor interexchange),
- Environmental Specifications,
- Use of Gimballed Mounting,
- On-board-sensor Image Tracking Processing software configuration (FOV H&V, Detection Range, Tracking Range, Update Rate, Accuracy),
- For Laser-based sensors, the sensitivity to atmospheric conditions.

4.2.1.3. *Acoustic sensors*

COLREG Rule 5 includes use of look-out hearing, this S&A system sense modality is referenced in COLREG Rule 34 manoeuvring and warning signals, and Rule 35 sound signals in restricted visibility. Section 4.2.3 provides guidance on acoustic signal effectors.

The UMS design should incorporate acoustic sense capability as fully as possible, and provide a rationale for the implemented sound sensing capability against the level of UMS autonomy. For example, it may be deemed appropriate for the UMS S&A system to have a capability to provide a remote operator with the output of an acoustic sensor for collision risk object detection, but no capability for autonomous sensor signal processing.

4.2.1.4. Radar sensors

The UMS Designer should understand how the Radar sensor fit contributes to the UMS SA system behaviours, and as a minimum, have a specification of:

- Resolution (arcs covered, resolution, max and min working range),
- Visual presentation of the situation awareness, e.g. range and clutter control,
- S&A system use of ARPA facilities such as track CPA, TCPA and alarms,
- Track data interface (detect and tracking time, and the total no of track available),
- Physical Data interface (standard data interfaces for sensor interexchange),
- Environmental Specifications,
- Use of Gimballed Mounting.

Note that the equivalency argument described for COLREG Rule 7 (UMS use of radar is the same as that defined in COLREG), then the Radar features described in Rule 7(b) should be part of the specification.

The S&A system should follow specific COLREG guidance on use of Radar sensors (Rule 6(b) – Factors taken into account when determining Safe Speed, Rule 7 (b) – Risk of Collision, and Rule 19 – Conduct of Vessels in restricted Visibility). The UMS S&A system should not make any assumptions based on scanty Radar data - COLREG Rule 7(c).

4.2.1.5. Other radio navigation aids and AIS

Automatic Identification Systems (AIS) (IMO, 2002) and voice VHF radio communications shall not be considered as sole sources of reliable information for UMS SA system determination of collision avoid behaviour COLREG Rule 7(c).

The operating limits of AIS should be considered, including the following aspects:

- The unreliability of user-entered vessel data received through AIS, particularly the vessel COLREG status information,
- The potentially high number of AIS Type B targets received and presented to the S&A system in crowded inshore waters,
- The range and line-of sight constraints of AIS VHF radio wave propagation,
- The refresh rate of AIS vessel data.

Voice UHF communications are not considered reliable by the IMO, and therefore shall not be used for UMS S&A.

Any context-dependent AIS message fields transmitted by the UMS should reflect and correspond to the current vessel activity status as signalled by any UMS Identification lights and shapes.

4.2.1.6. Passive and active radar reflectors

Use of passive and active Radar reflectors should be considered to augment the Radar visibility of small UMS to other vessels, provided that their use does not interfere with UMS on-board systems.

4.2.2. Off-board sense capacity

UMS S&A sense can be augmented with off board information about vessels from local AIS and radar stations.

If off-board sense capability is used, then the S&A system design shall define the information interfaces, paying particular attention to timing latency within the communication links. Any exceptions to the integrity of the link shall be handled by the UMS S&A system.

4.2.3. UMS S&A lighting, shapes and sound signalling

This section describes the application of COLREG to UMS within the following categories:

- Navigation Lights – indicating vessel presence, aspect and size,
- Identification Lights and Shapes – indicating vessel manoeuvrability, providing an indication of the constraining activity,
- Manoeuvring Sound Signals for vessels in sight of each other, and Fog Sound Signals for restricted visibility.

As well as indicating vessel presence, aspect and size, the purpose of UMS lights, shapes and sound signals is to clearly signal any limitations to the vessel manoeuvrability. In the case of a collision risk, the manoeuvring responsibilities defined in COLREG Rule 18 apply, requiring the more manoeuvrable vessel to keep out of the way with those that are less manoeuvrable. Section 5 elaborates on UMS collision avoid behaviours.

In the case of UMS operating at night or in restricted visibility, COLREGs Navigation Lighting (sidelights, stern and mast lights) shall be carried, the exact configuration depending upon UMS size (COLREGs 20, 21, 22 and Annexes).

An encumbered UMS operating at night or in restricted visibility should carry COLREGs Identification Lighting, the exact configuration depending upon UMS size and the type of UMS activity (or its draught) that constrains its ability to manoeuvre (COLREGs Part C).

The UMS designer should consider application of the following specific Lights, Shapes and Sounds, depending upon UMS size, to indicate if the UMS has lost its ability to manoeuvre, i.e. through system failure or loss of operator control, or thorough restriction by its mission activity e.g. mine clearance:

- Not Under Command (NUC) COLREG Rules 3(f), 27 & 35;
- Restricted in her Ability to Manoeuvre (RAM) COLREG Rule 3(g), 27 & 35.

For UMS that may not be underway during its mission, additional use of COLREG Rule 30 Vessel at Anchor and Vessel Aground lights, shapes and sounds should be considered, depending upon UMS size.

Lights or sound used as part of the UMS mission payload (e.g. spotlights or revolving strobe lights) shall not be used where they can be mistaken as aids to navigation or signals to attract attention (COLREG Rules 1(c) & 36).

The use of navigational aids such as Radar and AIS is covered in section 4.2.1 above.

4.2.4. UMS S&A control system

The main purpose of the S&A Control System is to enact the behaviours defined in sections 4.3 and 4.4.

For collision risk object detection and tracking behaviours, the precautionary principle should be applied by the S&A Control System in accordance with COLREG Rule 7(a) – if any doubt of collision risk exists, then the risk should be deemed to exist, and Rule 7(c) – assumptions should not be made on the basis of scanty information.

Section 4.3.2 outlines S&A System parameters that can be monitored for UMS fault-detection. Before deployment, the S&A Control System should be pre-set with tolerances derived and agreed during mission planning, and should initiate exception behaviours based upon comparison with sensed parameters, for example, invoking UMS actions if sensed environmental conditions go out of tolerance.

The SA Control System architecture and configuration (e.g. sensor arrangement, S&A automation modes available, and operator remote control facilities) should be specified in the design, and should include all interfaces to other UMS Control Systems.

The operational states of the UMS Control System shall be defined and known, encompassing all implemented UMS S&A behaviours to prevent occurrence of unwanted behaviours during the mission.

Collision hazard object detection limits should be understood and documented based on the Sensor Plan and sensor specifications (see section 4.2.1).

If the implementation of the UMS S&A System involves interfacing with a UMS Navigation System (Radar ARPA, or other Navigation Planning components) then the architecture should be defined. The system behaviours, and information and hardware interfaces should be part of the design definition, and the navigation information should be compatible across systems (e.g. chart formats, positional Consistent Common Reference Point).

The S&A Control System processing performance should be demonstrated to be adequate for the volume of data produced by the sensors at the configured resolution, taking into account the maximum expected number of objects detected for the planned mission.

Operator remote-control communication data links should be demonstrated to be adequate for the maximum volume of data to be transferred, and specification of range, latency, error-checking, and loss-of-link detection known.

Facilities should be included in the S&A Control System design for control system detection of data link, sensor and sensor sub-system failures (see section 4.3 below).

Consideration should be made for UMS S&A behaviour logging (an on-board Voyage Data Recorder is a SOLAS requirement for ships of over 3000 gross tonnes) for recording of navigation data and autonomous behaviour decisions and actions. Parallel data logging by the remote-control station, if used, should also be considered, to provide navigation audit data in the case of loss of contact with the UMS.

4.2.5. UMS S&A system design

This section addresses key non-functional influences affecting the specification of any technical implementation. These influences arise from the environmental and other external dynamics affecting the UMS S&A system.

4.2.5.1. Security

The UMS S&A system design should show evidence that mitigation measures have been considered for the following S&A system-specific security issues:

- S&A control system software attacks (malware, tampering),
- S&A system data and communication link denial of service, hacking or other forms of attack,
- Compromise of mission navigation through C2 links or other emissions,
- Sensor spoofing or malicious interference,
- Physical security – on-board monitoring for out of tolerance UMS navigation or movement in case of theft or positional displacement.

4.2.5.2. Maintenance

Evidence of sensor calibration should be available, since the S&A capabilities will depend upon accurate sensor information, especially where data is fused from different sensors.

The UMS S&A system components should be covered by the overall UMS planned maintenance schedule.

UMS to record an electronic mission log of all S&A system fault and exception data applicable to S&A behaviour for post-mission maintenance.

4.2.5.3. Design standards

A system engineering (ref 20) approach should be applied to the development lifecycle of the UMS S&A system, where it shall be assured, through validation and verification, that the UMS S&A system capabilities are matched to those required by the mission need. Guidance on a suitable process can be found in the reference.

Safe and efficient navigation of manned maritime vessels and protection of life at sea is achieved through application of legal regulations covering shipbuilding design and seaworthiness certification. The COLREG rules applicable to UMS S&A systems are:

- COLREG Annex I for Positioning and Technical Details of Lights and Shapes,
- COLREG Annex II for Technical details of Sound Signal Appliances.

UK Hydrographic Office publication NP100, ref 21, provides details on beacon lighting for surfaced submarines which should be considered for USV.

Attention is drawn to COLREG Annex I.14 and Annex II.13 regarding approval of light, shapes and sound signals by state authority.

Other than the application of COLREG equipment standards above, there are no UMS-specific equipment standards applicable. The Marine Equipment Directive 96/98/EC (ref 22) certification and marine equipment Type Approval applies to navigation equipment fitted to registered and classified vessels. Where S&A type-approved sub-systems are commercially available, these should be used for the UMS System (AIS, Radar, etc.).

The equipment specifications of all S&A items shall be compliant with the required level of environmental robustness as determined during mission planning. IEC 60945 (ref 23) should be consulted for specification and testing.

As discussed in Section 6.1 Safety Assessment Guidance, it is recommended that the S&A equipment functional safety is assured using a framework such as ISO 61508 Functional safety of Programmable Electronic Safety Related Systems (ref 24). Other assurance standards that should be considered are ref 25 and ref 26 (output of the EU-funded ATOMOS 4 project).

4.2.5.4. UMS interoperability and external system interfaces

Applicable operability standards for UMS are ref 27 and ref 28, however these are immature and focussed on command and controls aspects.

The UMS Designer and Operator shall consider the electromagnetic and sonic compatibility of UMS S&A systems to that of the mission operating environment. A process should be followed that defines both the electromagnetic and sonic environment for the UMS mission, evaluates the effects of the environment on the UMS S&A sensors, and vice-versa, and mitigates any performance risks arising. Ref 29 details such a process for electromagnetic compatibility, ref 23 also refers.

As part of the compatibility analysis, a Spectrum Management Matrix can be used to document the environment. The example provided in Figure 5 shows how sub-systems use the available RF network bandwidth. This example could be expanded to show the use of the sonic and electromagnetic spectrum in the operational area by both local maritime and shore-based users, and the UMS sub-systems (communications, sensors, etc.).

Note that in addition to management of UMS S&A operating environment, the evidence collected should be used to determine the environmental impact of S&A emissions (see section 6.1 Safety Assessment).

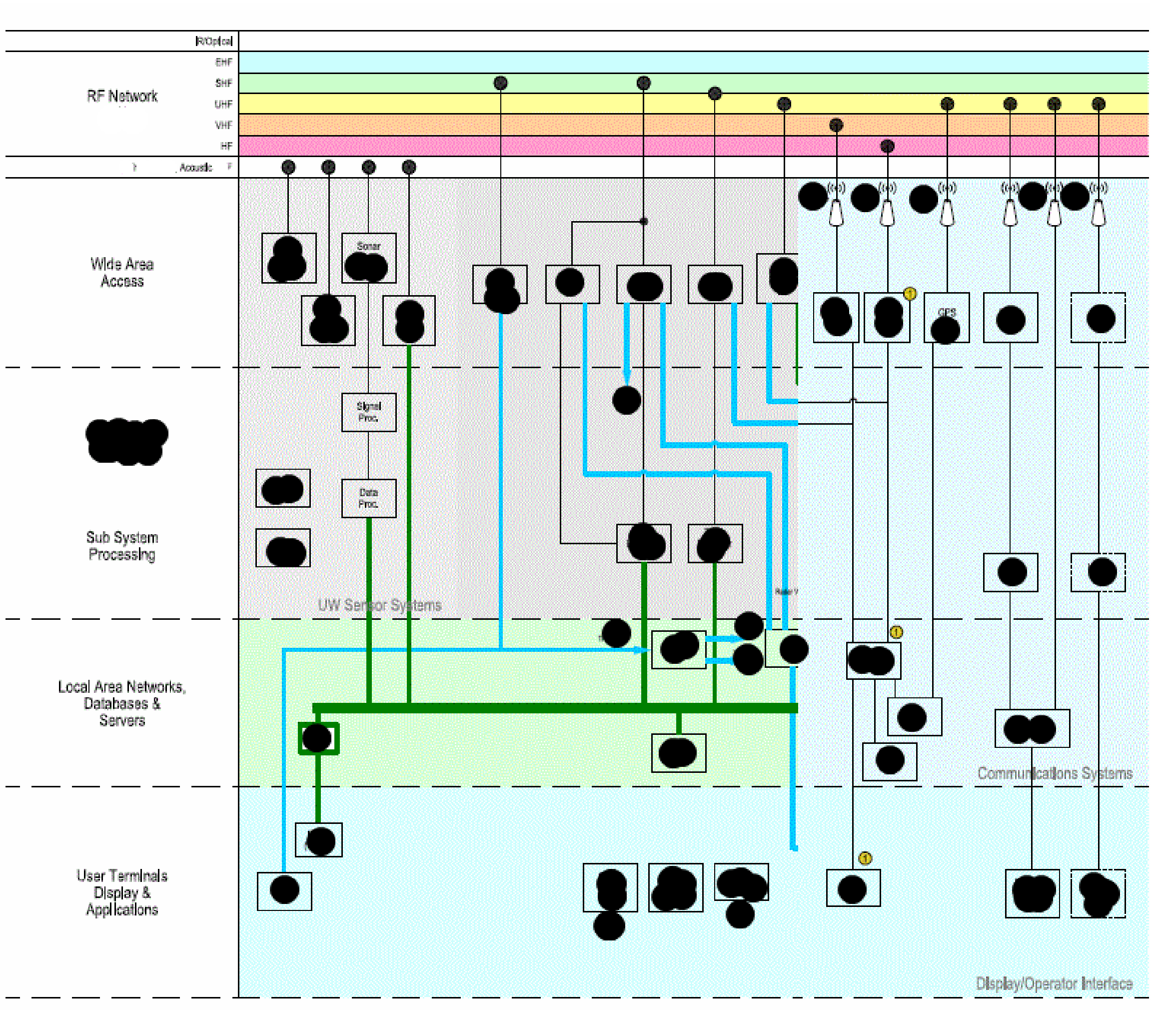


Figure 10 – Example, Spectrum management matrix for a UMS operating area

4.2.6. UMS S&A system testing and evaluation

The S&A behaviours and system functional and performance requirements should be determined and validated against the UMS mission, and a strategy should be adopted for verifying the UMS S&A solution before commencing the mission.

Testing of the S&A behaviours, sub-functions and exceptions should be performed using scenarios based upon mission use cases. The expected mission environmental conditions shall be factored into the testing as context for the use cases. Note that availability of a shore-based synthetic test environment for executing the test scenarios can save considerable time and effort in comparison with sea trials.

The UMS S&A system design and its embodiment should be maintained under the overall UMS configuration management system, so the system configuration of all hardware and software components is accurately recorded. Known configuration states are the basis on which change can be managed, and are used as the basis for making safety claims, as well as being baselines for testing.

Testing should be repeated, including regression testing, and configuration records updated, following any UMS system changes that arise from alterations to the mission.

4.3. Policy principle: S&A and UMS system failure behaviour

The purpose of this principle is to understand and define UMS behaviour under exceptional or technical fault conditions, ensuring that UMS S&A states are predictable and understood by the UMS Operating Expert. This understanding should also inform the safety assessment of the S&A system.

There are two areas of monitoring required for UMS S&A-related systems, detailed in sub-sections below:

- UMS System Health Monitoring – Detection of faults within UMS SA-related systems,
- UMS System Environment Monitoring – Monitoring that prevailing UMS operating conditions are within tolerance of the UMS SA system operating limits.

The UMS system architecture should have a watchdog capability to detect and track any exceptions arising from the monitoring. If there is a failure or degradation, then the UMS S&A system shall be placed into a known state. The system should enact defined behaviours that allow a predictable degradation. The order of degradation should be defined within the design specification, and there should be a scheme of priority defined, with sub-systems enacting the most critical S&A functions degrading last e.g. navigation lights and fog sound signalling.

A S&A function should be included to signal the UMS remote operator station and/or raise a Global Maritime Distress and Safety System (GMDSS) VHF Digital Selective Calling (DSC) distress alert if the UMS detects a collision with an object.

UMS System Failure Behaviour is triggered when the watchdog system detects a monitoring exception and ends when the UMS is in a known state. If the exception results in an inability to undertake COLREG collision avoid behaviours, including safe speed, then the UMS should be entered into a known COLREG-compliant state e.g. switching off propulsion and signalling RAM or NUC state (visual signalling requirement is UMS size-dependent), including transmit of state by AIS. The behaviour may include UMS generation of a request for operator control, UUV emergency surface actions etc., but complexity in this behaviour should be avoided with time-outs for surety of UMS entry into a COLREG-compliant state.

The UMS payload, mission navigation, and S&A control systems should have some form of behavioural separation, including a conflict arbitration mechanism within the overall control system architecture. This is to prevent unwanted effects on S&A behaviour from other non-S&A UMS control protocols.

4.3.1. UMS S&A system health monitoring

The UMS design should incorporate monitoring of internal health indicators and exception generation for faults in the following UMS systems:

- UMS Power Supply System,
- S&A System and its Components (sensors and control system, manoeuvrability sound and light signalling effectors),
- UMS Remote Control System (including data communication links),
- Propulsion System (effectors for collision avoid behaviour),
- Navigation and vessel status lighting and fog signalling components,
- Any other systems that can affect the operation of the collision avoid system (e.g. UMS Navigation System, UMS Payload Control System, Off-board Sensors).

4.3.2. UMS S&A system environment monitoring

The UMS design should incorporate monitoring of UMS prevailing environmental conditions, and related parameters, and should generate system failure exceptions when the measured parameters exceed pre-set design operating limits. Parameters that should be considered are:

- Atmospheric visibility, air and sea temperature, underwater background noise levels,
- Data Communication Link latencies and error levels,
- UMS platform stability,
- Uncertainty level in collision object detection & tracking,
- Number of simultaneous collision risk targets or uncertainty level in calculation of collision avoid action,
- Measured course or speed change from a directed collision avoid action,
- A collision-avoid system disable command is received from local control hardware or a remote operator.

4.4. Policy principle: Autonomous collision avoidance behaviour

Although it is outside of the scope of this UMS SA policy to specify system solutions, this principle explores what UMS S&A collision avoidance behaviours and sub-functions are required for COLREG-compliant operation.

These recommended behaviours should be considered for implementation into the UMS S&A system design. The objective is to provide UMS design stakeholders with an understanding of these behaviours, to ascertain what S&A system sub-functions may be required, and to provide input into the UMS S&A safety assessment.

Three key S&A behaviours should be available from the UMS system, and represented as capabilities within the UMS S&A system design and configuration:

- *Enact COLREG Collision Avoid Behaviour*: Ascertain COLREG risk of collision with each vessel (Rule 7) and take action in accordance with the rules, including detection and taking avoiding action of close quarter situations, engaging in suitable signalling where the action is co-operative. Triggered when a vessel is detected, and ending when the risk has passed,
- *Enact non-COLREG Collision Avoid Behaviour*: Sense hazardous objects and take reactive action for entities that have not been identified as vessels, or have not been identified as a collision risk, or have not been mitigated against as part of the mission navigation plan.

Triggered by detection of a close-range object, and ending when an avoiding manoeuvre is completed. It is important that a risk-based approach should be applied, so that the action of this behaviour does not result in a worse situation,

- *Maintain COLREG Safe Speed Behaviour* (Rule 6) by taking account of the factors listed in the rule, including environmental conditions. Triggered by measured conditions exceeding a pre-set mission tolerance, and ending with confirmation of alteration in UMS speed over ground.

None of the above behaviours include any automated capability for the UMS to take any pre-emptive avoiding action before risk of collision is detected. If this facility is required, then a further UMS behaviour should be considered to inform the UMS navigation planning system to avoid closing objects which are yet not considered a collision risk.

Note that the collision avoid behaviours may be automated, or involve UMS remote operator control, or a combination of both. Appendix 2 UMS Autonomous Behaviours provides a breakdown of recommended S&A System Behaviours, the sub-functions involved, the COLREG applicability, and the levels of UMS autonomy involved. This is not an exclusive list: other S&A behaviours should be considered for implementation if required.

The following mission-specific UMS behaviours are out of scope for this UMS S&A policy, but should be considered as part of the design concept:

- Enactment of pre-planned or ad-hoc mission navigation using waypoints or other UMS direction,
- Interactions with mission payload,
- Responding to special circumstances such as distress signals (SOLAS) – this could involve UMS detection of maritime distress signals including VHF DSC alerts for alert of the UMS remote operator, and facilities to relay alerts onto GMDSS VHF DSC or other means.

4.5. Policy principle: UMS propulsion fit

The purpose of this principle is to understand the design UMS manoeuvring capability, in terms of its speed, ability to change and maintain course, and stability as a platform for on-board sensors. The information should be specified for use in developing parametric information within the next policy concept to account for effects of mission-dependent variables.

For UMS collision avoidance behaviours, the defined COLREG actions are Rule 8(c) alteration of course and Rule 8(e) slacken speed or take all way off by stopping or reversing the means of propulsion. COLREG also states that alteration of course should be readily apparent and small alterations of course or speed avoided – Rule 8(b). These actions should be taken into consideration when reviewing the specification of the UMS propulsion system and implementing the S&A behaviours in the design.

5. Concept – UMS S&A capability in the operational environment

Assuring that the available UMS S&A capabilities are sufficient to enact collision avoid against the required mission operating needs, including the effect of environmental influences.

This concept illustrates how, before UMS deployment, the UMS Mission Planning and Operating Experts should answer the key question “Has my UMS got sufficient capability for collision avoid of hazards within the operating environment for the planned mission?”

This assessment explores how the available UMS S&A capabilities are influenced by both the proposed mission operating environment and the UMS design and configuration. The analysis will rely upon the policy user’s understanding of the influencing factors that have been derived from the UMS Mission Planning and UMS S&A Design & Configuration (see concepts in sections 3 and 4).

The concepts within this policy guidance should be used iteratively: if the result of the analysis shows that the UMS S&A capability is insufficient for the planned mission, then the UMS S&A Design & Configuration and/or the Mission Planning can be re-visited and the identified influence parameters modified (e.g. exchanging a sensor for a unit with a higher specification, changing the mission navigation plan to avoid an area containing a high density of collision hazards).

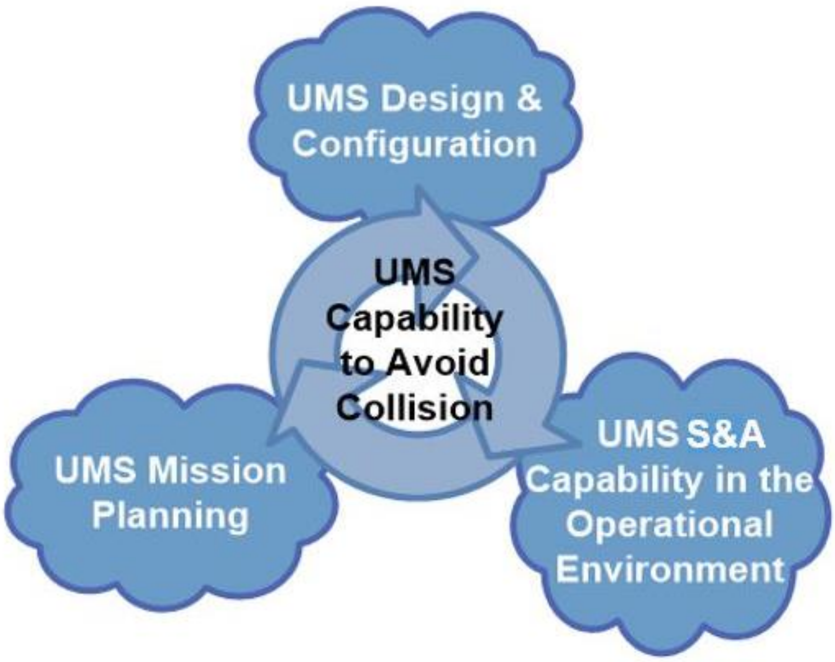


Figure 11 – Iterative analysis using the S&A policy

Note that the UMS Mission Planning analysis should identify worst-case conditions for the operational environment.

Launch & recovery procedures are outside the scope of this UMS S&A policy guidance.

5.1. Policy principle: Available UMS S&A capabilities

Depending upon the planned mission context, the UMS may be designed to apply combinations of the collision avoid behaviours defined above (COLREG, non-COLREG reactive, and various control modes).

Sufficient information should be available from the Design & Configuration and Mission Planning Concepts to understand the operating capability of the UMS S&A system for the planned mission.

Forecasted environmental operating conditions, predicted from the Mission Planning, should be used, together with an understanding of the configuration of the UMS propulsion and sensor systems, to determine and record the expected operating limits of the UMS sensors and its ability to action collision avoidance manoeuvres. Worst case environmental conditions should be used within parameters.

In terms of the UMS S&A Sense capabilities, operating parameters such as the limits of object detection (smallest Object Size, Range, and Detection Probabilities), and the worst-case detect times (based upon best UMS speed and worst-case environmental conditions) should be determined for the available UMS S&A collision avoid behaviours.

In terms of the UMS S&A avoid capabilities, the limits of UMS manoeuvrability, based on the propulsion system design as specified in section 4.5, and considering the worst-case environmental conditions forecasted in the mission planning concept should be determined. As part of this analysis the reviewer should consider dynamic changes in UMS manoeuvrability due to in-mission payload changes, and any restrictions on propulsion power available for mission power-saving. Note that although there is the notion of COLREG Safe Speed (Rule 6), actions are permitted under COLREG Rule 2(b) departure of COLREG, to avoid immediate danger.

These parameters should then be used to define the overall available operating envelope for the UMS mission. An example operating envelope parameter is the worst-case S&A system collision avoid reaction time (based on the worst-case operating conditions). An example timeline for UMS S&A behaviour is shown in Figure 12.

Note that the collision avoid behaviour for the specific threat terminates when the collision avert has been confirmed, or when an exception has occurred. The S&A system may have a prioritised list of multiple collision risk to act upon.

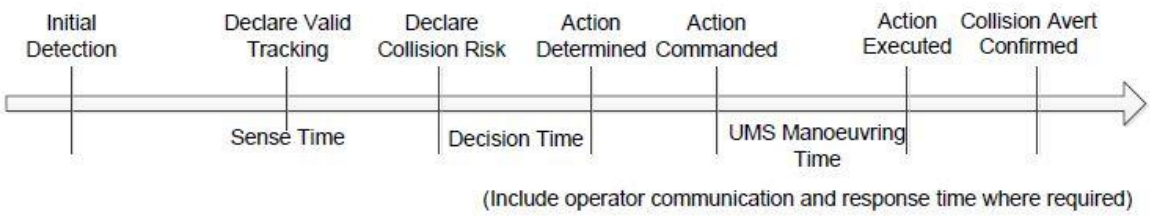


Figure 12 – UMS S&A system collision avoid timeline

5.2. Policy principle: Required UMS S&A capabilities

By using knowledge of the planned UMS Mission, an analysis should be made of which COLREG rules are applicable to the operational scenario. Any assumptions or reservations should be recorded. The applicable COLREG will dictate the UMS S&A capabilities required, specifically in terms of its collision risk behaviour and the UMS system configuration (for example, navigation lighting).

The influence of the rules on the required UMS S&A capabilities should be subject to analysis under the policy concept UMS S&A Capability in the Operational Environment.

Figure 13 illustrates how the mission planning concept should inform what COLREG are applicable.

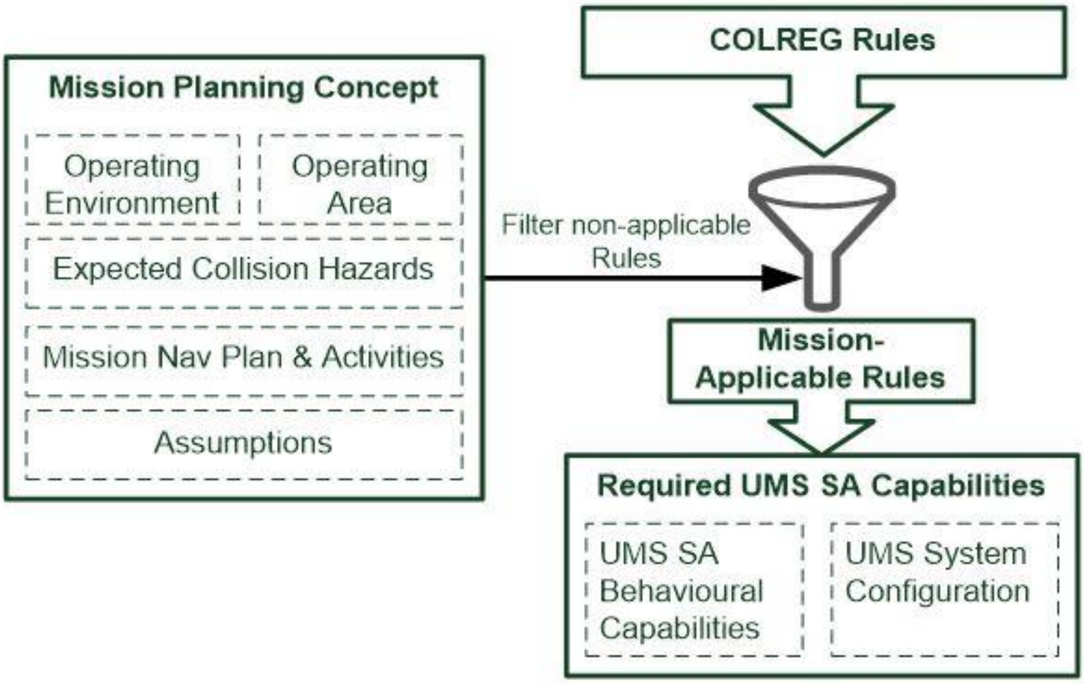


Figure 13 – Mission planning and applicable COLREG rules

The UMS Mission Planning Expert should review the COLREG general definitions in Rule 3 and record any assumptions made, and the resulting applicability, for example:

- Rule 3(b) - The UMS is a power-driven vessel,
- Rule 3(c) - The UMS is not a sailing vessel,
- Rule 3(d) - The UMS mission does not include fishing activity with nets, trawls, trolling lines or other fishing apparatus,
- Rules 3(e), 3(m), 23(b), 25(d) – The UMS is not a seaplane, or a WIG craft, or an air-cushion vehicle, or a vessel under oars.

Application of many COLREG rules within Part C – Lights and Shapes, and Part D – Sound and Light Signals, are dependent upon the size of the UMS and its mission tasks, therefore these influences should also be investigated.

If assumptions are made regarding non-applicability of COLREG rules to the UMS design or mission activities, then they should be recorded. For example:

- UMS Identification Lighting for the following types of activity may not be required: Sailing (Rule 25), Fishing (Rule 26), Pilot (Rule 29), Pushing, Towing etc. (Rule 24), Hovercraft (Rule 23(b)), WIG craft (Rule 23(c)), Propelled by Oars (Rule 25(d)),
- UMS Navigation and Identification lighting and shapes may not be required for UMS At Anchor or Aground (Rule 30) since there may be no possibility that the UMS can be in these conditions,
- UMS NUC and RAM Identification lighting and shapes are not required if the UMS is less than 12m in length and not engaged in diving operations (Rule 27(g)).

An example application of COLREG to UMS S&A capability is provided in Appendix B3. The purpose of this example is to show how the scope of COLREG should be considered against the available capabilities from the UMS S&A system.

5.3. Policy principle: UMS capability for collision avoidance

The precautionary principle shall be applied to UMS collision avoid: the UMS shall avoid all collision threat objects unless it can be validated and verified, in the configured UMS system design, that the UMS can enact collision avoidance behaviours in accordance with COLREG, in the context of the environmental conditions forecasted for the mission.

In the absence of a defined, validated and risk-assessed UMS S&A capability, UMS operations shall take place within a segregated sea area.

Parameters describing the available UMS operating envelope, described in section 5 above, should be compared against those parameters required for the mission (developed in 5.2), to show any deficits in the UMS S&A mission capabilities.

An example parameter is the UMS S&A collision avoidance behaviour worst-case reaction time:

- From the Hazard Set documented under the Mission Planning, the approach speed of the fastest object threat (allowing for worst-case forecasted environmental conditions such as tidal flow) can be determined, and from the detection range and CPA, a required reaction time for S&A collision avoid action.
- This parameter could be compared with the available UMS S&A collision avoid reaction time, taken from the analysis in 5.1. If a disparity existed, then the capability mismatch would be addressed. In this case, the logical alternatives are to change the UMS S&A design configuration to speed up the collision avoid behaviour, to alter the mission plan and avoid areas where the particular hazard exists, or to use an operator-involved control mode to enhance the S&A reaction times. In this example, each of the alternatives could be considered using UMS S&A parametric information, and the rationale and results recorded. Note that any change in UMS S&A design configuration should require system re-validation and verification (see section 4.2.6).

This example is provided to show how UMS S&A parameters are used by the UMS Operating and Mission Planning Experts to assure that the UMS S&A is capable of performing the required mission collision avoidance. All system parameters relevant to the mission should be explored and a record of the operating envelope of the UMS S&A capability kept. This record should be used for both the Safety Assessment (see section 6.1 below), and for reference during UMS operation.

6. Additional areas of policy

6.1. UMS S&A safety assessment guidance

What steps a UMS operation Duty of Care Holder should take to assess collision hazards and to control risk to acceptable levels based upon the UMS design and its operating configuration.

This area of policy is intended to provide recommendations to EDA UMS mission Duty of Care Holders on what safety assessment should be undertaken. Safety assessment should be implemented before UMS operations, to identify and control the risk associated with operational hazards, related to UMS S&A capability, to acceptable levels.

The related hazards encompass the potential for harm to be caused to other maritime environment users and self. Operational hazards include those directly associated with the S&A function (i.e. collision) and those that result from the technical implementation of S&A related systems (i.e. electromagnetic interference with other systems).

In order that risk is effectively managed, it is essential that the S&A safety assessment is integrated within the overall safety management system for the UMS. In this way, risks may be controlled and mitigated appropriately, recognising that the operational hazards associated with the S&A function have the potential to be caused by, or impact upon, other aspects of the UMS and its wider operating environment.

The duty of care for the management of risks associated with the UMS in operation resides with the person in charge of the UMS mission. They shall be assured that an appropriate safety assessment has been undertaken to demonstrate that the S&A function is safe, fit for purpose and that the residual level of risk associated with the UMS operation specifically, and the S&A function in particular, is at an acceptably low level. The duty of care extends to:

- The Design Organization: the organization responsible for the detailed design of the system to approved specifications and authorized to sign certificates of design in accordance with applicable procedures.
- S&A Technology Suppliers: responsible for supplying appropriately type-approved equipment that provides safe and reliable performance.

The S&A safety assessment should interface with the overall UMS (platform) Safety Management System as presented in figure 14.

As well as the Standard Operating Procedures, normally contained within an organisation's UMS Operations Manual, there should be documented mission-specific guidance covering:

- Mission task procedures, including definition of the roles and responsibilities of the UMS operator during the mission, agreed control hand-over procedures to/from autonomous UMS

S&A operation and UMS operator to UMS operator (during operation or as part of transit to the operational area),
- Procedures for degradation or loss of UMS control data link,
- Emergency procedures for the occurrence of a UMS collision event,
- Mission abort procedures covering UMS S&A system failure.

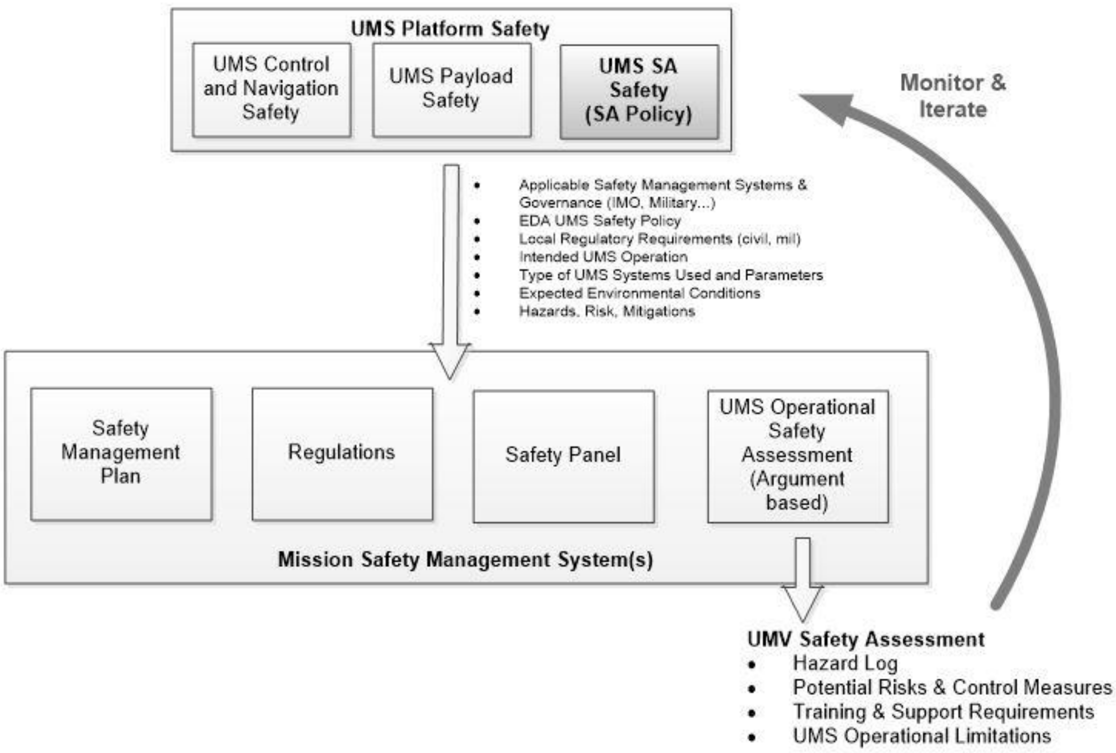


Figure 14 – S&A safety assessment interfacing with UMS safety management system

6.2. UMS S&A mission safety guidance

The influence diagram fragment in Figure 15 shows how UMS S&A Operational Safety Assessment fits in with the other policy concepts. The main influences on safe operation of the UMS S&A are an understanding of the S&A and UMS system behaviours under fault conditions, and the result of capable S&A system performance within the operating environment.

The process adopted for management of UMS S&A Safety will be dependent on the overarching UMS Safety Management System but it should consider, as a minimum the following safety lifecycle stages:

1. Scope of Assessment – Understanding of the context against which the safety assessment is undertaken to include the S&A system configuration, the UMS, the physical and legislative environment in which it operates and the mission it is to undertake.
2. Hazard and Risk Analysis – Identification of hazards and associated accident sequences to include all modes of operation and all reasonably foreseeable circumstances, including system failure behaviours. Identify associated magnitude of risk.

3. S&A Safety Requirements – Development of safety requirements in terms of the relevant S&A Policy Principles, identified necessary safety functions and mandated regulatory requirements.
4. Planning – Development of a plan to describe how the safety requirements will be achieved, considering all modes of operation.
5. S&A Function Realisation – Configuration of the S&A function to achieve safety and overall system requirements.
6. Safety Validation – Demonstration that the safety requirements have been met through the implementation of the S&A function.

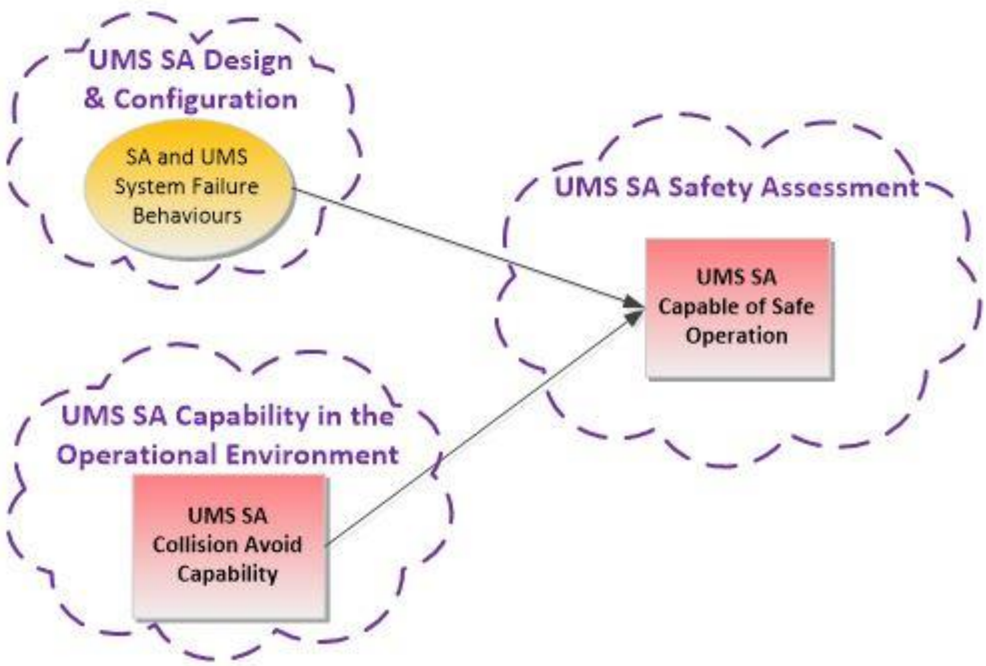


Figure 15 – S&A Policy Concepts influencing the UMS S&A Operational Safety Assessment

In the absence of any other formalised safety assessment process, tailored application of IEC 61508, Functional safety of electrical/electronic/programmable safety related systems (ref 24), will provide a mechanism to assure the safety of the S&A function.

As part of the overall UMS safety assessment, an approved method of assuring geographical clearance for UMS mission use is required.

APPENDIX B1 – UMS autonomous behaviours

The following table describes S&A policy, recommended S&A behaviours, sub-functions and applicable COLREG and UMS control modes.

Behaviours				Behaviour Sub-Functions	COLREG Rule	Applicable UMS S&A Control Mode (1 – 5)				
UMS System Failure Behaviour	Enact COLREG Collision Avoid Behaviour	Enact non-COLREG Collision Avoid Behaviour	Maintain COLREG Safe Speed Behaviour			Human Operated	Human Directed	Human Delegated	Human Monitored	Autonomous
x	x	x	x	Detect Objects (day, night, and restricted visibility)			x	x	x	x
	x	x		Track positions of detected Objects (including recognition of a tow vessel needed for Collision Risk assessment COLREG Rule 7(d)(ii))			x	x	x	x
	x		x	Determine Object Density in local navigating area	6		x	x	x	x
	x		x	Identify conditions of Restricted Visibility	3(l)		x	x	x	x
	x			Recognition of Warning Sound Signals in Restricted Visibility (should include sounds made by navigation marks and lighthouse fog horns)	35		x	x	x	x
x	x	x	x	Determine prevailing operating conditions (wind, sea state, water current, platform stability)	6		x	x	x	x

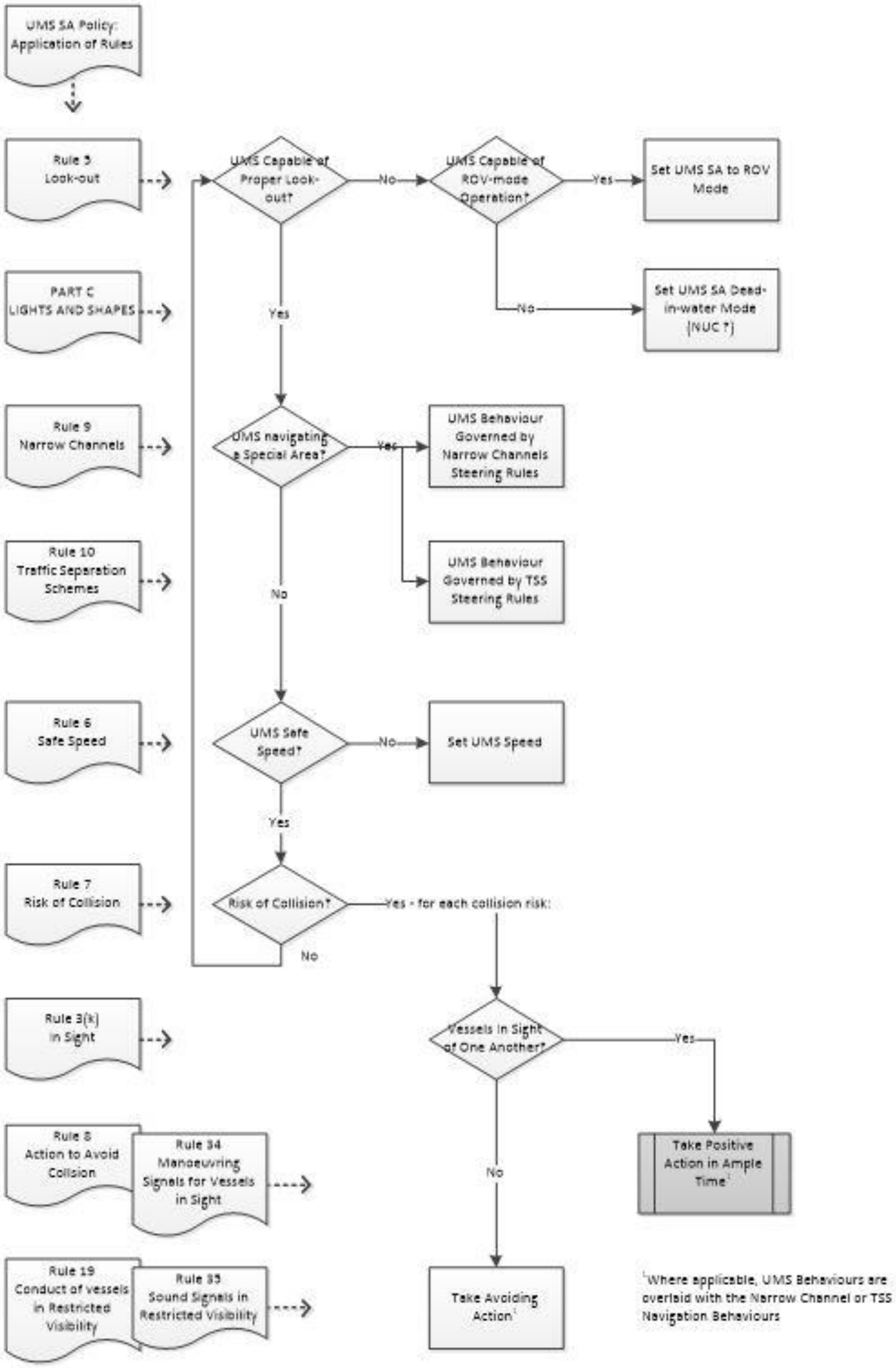
Behaviours				Behaviour Sub-Functions	COLREG Rule	Applicable UMS S&A Control Mode (1 – 5)				
UMS System Failure Behaviour	Enact COLREG Collision Avoid Behaviour	Enact non-COLREG Collision Avoid Behaviour	Maintain COLREG Safe Speed Behaviour			Human Operated	Human Directed	Human Delegated	Human Monitored	Autonomous
	x	x	x	Determine navigational constraints including depth of water under hull	6		x	x	x	x
	x	x	x	Determine UMS manoeuvrability, stopping distance and turning ability for prevailing conditions	6		x	x	x	x
			x	Determine and execute UMS Safe Speed	6, 19(b)		x	x	x	x
	x	x		Determine Risk of Collision for all Objects	7		x	x	x	x
	x			Determine which Objects are in sight	3(k)		x	x	x	x
	x	x		Take avoiding action for close-range threat objects (non-COLREG reactive action) and COLREG Close Quarters situations when overtaking, crossing, or in restricted visibility	2(b), 13(a), 17(a), 19(d)		x	x	x	x
	x			Visual recognition of other vessel aspect and size during daytime and by Navigation Lights at night	21		x	x	x	x
	x			Determine collision threat situation -Overtaking, Head-on, or Crossing	13, 14, 15		x	x	x	x

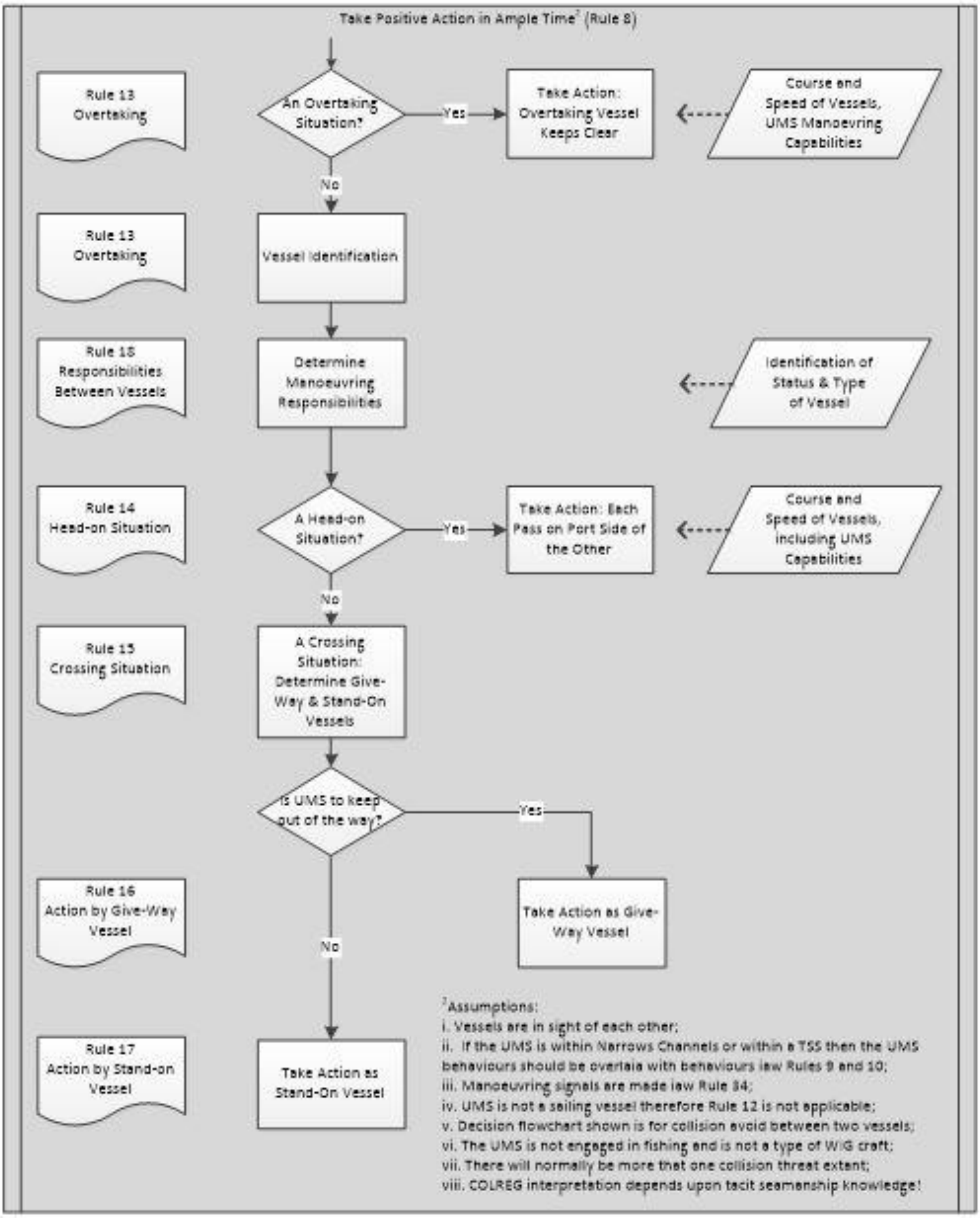
Behaviours				Behaviour Sub-Functions	COLREG Rule	Applicable UMS S&A Control Mode (1 – 5)				
UMS System Failure Behaviour	Enact COLREG Collision Avoid Behaviour	Enact non-COLREG Collision Avoid Behaviour	Maintain COLREG Safe Speed Behaviour			Human Operated	Human Directed	Human Delegated	Human Monitored	Autonomous
	x			Determine collision threat manoeuvrability by Identification of Shapes daytime	24, 25, 26, 27, 29, 30		x	x	x	x
	x			Determine collision threat manoeuvrability by Identification of Lights at night	23, 24, 25, 26, 27, 28, 29, 30		x	x	x	x
x	x	x		Predictably resolve contention arising between action of a mission navigation plan, action from COLREG collision avoid, and action when avoiding hazardous objects			x	x	x	x
	x			Take positive collision avoid action in ample time	8		x	x	x	x
	x			Recognition of Manoeuvring Sound Signals for vessel in sight	34		x	x	x	x
	x			Generate UMS Manoeuvring Sound Signals in sight	34		x	x	x	x
	x			Take collision avoiding action when navigating in Narrow Channels	9		x	x	x	x

Behaviours				Behaviour Sub-Functions	COLREG Rule	Applicable UMS S&A Control Mode (1 – 5)				
UMS System Failure Behaviour	Enact COLREG Collision Avoid Behaviour	Enact non-COLREG Collision Avoid Behaviour	Maintain COLREG Safe Speed Behaviour			Human Operated	Human Directed	Human Delegated	Human Monitored	Autonomous
	x			Take collision avoiding action when navigating in Traffic Separation Schemes (In order to meet the COLREG, a UMS avoid action is constrained by the need to flow in the correct lane or cross a TSS at right angles)	10		x	x	x	x
	x			Take collision avoiding action when vessels not in sight of one another or navigating in conditions of restricted visibility	19		x	x	x	x
x	x	x		Monitor result of avoiding action and raise exception on on-completion	8(d), 8(e), 13(d), 19(e)		x	x	x	x
	x			Generate UMS Sound Signals in Restricted Visibility	35		x	x	x	x
	x	x		Activation of appropriate UMS Navigation Lighting	20, 21		x	x	x	x
	x			Activation of appropriate UMS Identification Lighting	23, 24, 27, 28, 29, 30		x	x	x	x

Behaviours				Behaviour Sub-Functions	COLREG Rule	Applicable UMS S&A Control Mode (1 – 5)				
UMS System Failure Behaviour	Enact COLREG Collision Avoid Behaviour	Enact non-COLREG Collision Avoid Behaviour	Maintain COLREG Safe Speed Behaviour			Human Operated	Human Directed	Human Delegated	Human Monitored	Autonomous
	x			Display of appropriate UMS Identification Shapes	24, 27, 28, 29, 30		x	x	x	x
x				Monitor UMS system health and raise exceptions if faulty		x	x	x	x	x
x				Monitor UMS operating environment and raise exceptions if outside of UMS operating envelope		x	x	x	x	x
x				Detect exceptions to UMS system health or operating environment envelope and execute relevant system graceful degradation			x	x	x	x

APPENDIX B2 – Example application of COLREG rules to UMS S&A capability




Take Positive Action in Ample Time[7] (Rule 8)
Rule 13
Overtaking
An Overtaking Situation?
Yes
Take Action: Overtaking Vessel Keeps Clear
Course and Speed of Vessels, UMS Manoevring Capabilities
No
Rule 13
Overtaking
Vessel Identification
Rule 18
Responsibilities Between Vessels
Determine Manoeuvring Responsibilities
Identification of Status & Type of Vessel
Rule 14
Head-on Situation
A Head-on Situation?
Yes
Take Action: Each Pass on Port Side of the Other
Course and Speed of Vessels, including UMS Capabilities
No
Rule 15
Crossing Situation
A Crossing Situation: Determine Give-Way & Stand-On Vessels
Is UMS to keep out of the way?
Yes
Rule 16
Action by Give-Way Vessel
Take Action as Give-Way Vessel
No
Rule 17
Action by Stand-on Vessel
Take Action as Stand-On Vessel
[7]Assumptions:
i. Vessels are in sight of each other;
ii. If the UMS is within Narrows Channels or within a TSS then the UMS behaviours should be overlaid with behaviours iaw Rules 9 and 10;
iii. Manoeuvring signals are made iaw Rule 34;
iv. UMS is not a sailing vessel therefore Rule 12 is not applicable;
v. Decision flowchart shown is for collision avoid between two vessels;
vi. The UMS is not engaged in fishing and is not a type of WiG craft;
vii. There will normally be more that one collision threat extant;
viii. COLREG interpretation depends upon tacit seamanship knowledge!