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Ships and marine technology -- Vocabulary related to Autonomous Ship Systems

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Technical Specification

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Foreword

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Introduction

Highly automated ships, including fully uncrewed and/or autonomous ships, are part of complex systems that have properties that are very different from conventional ships. This area is still under development and will remain so for many years to come. This means that there is a need for a harmonized and as consistent as possible vocabulary and related definitions for the concepts and objects that are used in the research on, design of and the eventual use of highly automated ships. It is the intention of this technical specification to provide this. Recognizing that the area is developing, this document is published as a technical specification rather than an international standard. Some of the terminology and definitions are expected to need updates as well as new terminology and definitions is expected to be added in future editions.

The term autonomous is used in this technical specification also for systems that are not fully independent of human control and intervention. This is also reflected in the definition of autonomy.

This technical specification has clause 3 containing the definition of the terminology. Informative annexes are referenced in notes to the definitions and give more detailed and/or additional explanations where necessary. Clause 3 is divided into the following parts:

1. General concepts. The main concepts related to autonomous ship systems.
2. Autonomous ship system components: The main components of the autonomous ship system, including required off-ship support.
3. Operational concepts: Terminology related to division of responsibility between human operators and automation.
4. Operator control modes: Definition of specific modes for operator control modes.

This is a technical specification and addresses work still under technical development. A Technical Specification is published for immediate use, but it also provides a means to obtain feedback. The aim is that it will eventually be transformed and republished as an International Standard.

Ships and marine technology -- Terminology related to Autonomous Ship Systems

1 Scope

This technical specification defines terminology related to Autonomous Ship Systems. Autonomous Ship System is the general term used in this technical specification for ships that can be classified as a "Maritime Autonomous Surface Ship" (MASS) according to the preliminary definitions from the International Maritime Organization (IMO). The term Autonomous Ship System can also be applied to similar ship types for use on Inland Waterways. The specification is, as far as possible, based on commonly used terminology and the general understanding of what the terms mean. The context of the terminology defined here is technical, with a focus on what the terms mean in a physical and practical context.

2 Normative references

There are no normative references in this document.

Note 1 to entry: A non-normative list of references is available in the bibliography. References to items listed in the bibliography is by numbers in square brackets.

3 Terms and definitions

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 General concepts

This clause contains terminology of a general nature.

For the purposes of this document, the following terms and definitions apply.

3.1.1
automatic
process or equipment that, under specified conditions, can function without human control.

[SOURCE: IEC 60050-351 [6], modified – "can function" instead of "functions", see *autonomy*]

3.1.2
automation
implementation of processes by automatic means

[SOURCE: ISO/TR 11065 [8]]

Note 1 to entry: As a noun, automation refers to the automatic control functions in the autonomous ship systems.

3.1.3
autonomy
one or more of a ship system's processes or equipment, under certain conditions, is designed and verified to be controlled by automation, without human assistance

Note 1 to entry: Autonomy is implemented by automation but emerges when automation is designed and verified to allow operation without human assistance.

Note 2 to entry: This definition qualifies autonomy by giving it a temporal (period when conditions are satisfied) and a process dimension. The term "autonomy" on its own should be avoided unless sufficiently qualified with respect to what processes, period, or conditions it refers to.

3.1.4
autonomous
possessing the property of autonomy

Note 1 to entry: Except when used in a general sense, e.g. as in Autonomous Ship System, the term "autonomous" on its own should be avoided unless sufficiently qualified with respect to what processes, period or conditions it refers to (refer also to Note 2 to autonomy).

3.1.5
autonomous ship system
all elements that interact to ensure effective functioning of the autonomous and non-autonomous processes and equipment that are necessary to perform the ship's operation or voyage

Note 1 to entry: The autonomous ship can depend on systems not located on the ship, e.g. communication systems, shore and port infrastructure, remote control centres etc.

Note 2 to entry: The autonomous ship system refers to a full system, including the ship. If the reference is made to the ship itself, the term "autonomous ship" or just "ship" can be used.

3.1.6
control
purposeful action on or in a process to meet specified objectives

[SOURCE: IEC 60050-351 [6]]

Note 1 to entry: The term *control* does not preclude that the action is only to monitor the process, e.g. to raise an alarm or to request intervention. Control can be exercised by a human or by automation.

3.1.7
process
set of interrelated or interacting activities that transforms inputs into outputs

[SOURCE: ISO 9000 [7]]

Note 1 to entry: Processes onboard a ship can correspond to function as defined in STCW [3]: Function means a group of tasks, duties and responsibilities, as specified in the STCW Code, necessary for ship operation, safety of life at sea or protection of the marine environment.

3.1.8
remote control centre
site remote from the ship that can control some or all of the autonomous ship system processes

Note 1 to entry: A remote control centre may consist of more than one control room or stations that may be located at different physical locations. See ISO 11064-3 [4] for a more extensive set of terminology for control rooms and centres.

Note 2 to entry: The terms shore control centre and remote operations centre are sometimes used to refer to remote control centres.

Note 3 to entry: When the abbreviated form of the term Remote Control Centre is used, i.e. RCC, one should be careful to avoid confusion with a Rescue Coordination Centre.

3.1.9
uncrewed
ship with no crew onboard

Note 1 to entry: Crew does not include passengers, special personnel etc.

3.1.10
unmanned
ship with no humans onboard

3.2 Autonomous ship system components

This clause contains proposed terms and terminology related to the autonomous ship and some of its support systems. These support systems are parts of the autonomous ship system. The remote control centre is also part of the autonomous ship system and is defined in clause 3.1.

Note 1 to entry: Informative Annex A gives a more extensive informative overview of these components as well as other entities that the autonomous ship system may have to interact with.

For the purposes of this document, the following terms and terminology are proposed.

3.2.1
automatic facilities services
collection of automatic offshore services and automatic port services

3.2.2
automatic offshore services
fully or partly automatic services provided from an offshore facility or in the autonomous ship's operational area outside the port, that are defined as part of the autonomous ship system, but that are not located on the ship

Note 1 to entry: Automatic offshore services do not include local sensor systems or planned response services.

3.2.3
automatic port services
fully or partly automatic services provided in a port area, that are defined as part of the autonomous ship system, but that are not located on the ship

Note 1 to entry: Automatic port services do not include local sensor systems or planned response services.

3.2.4
autonomous onboard controller
automation onboard the ship that is used to control one or more of a ship system's processes or equipment, under certain conditions, without human assistance

3.2.5
autonomous remote controller
automation in the remote control centre that is used to control one or more of a ship system's processes or equipment, under certain conditions, without human assistance

3.2.6
connectivity
network facilities to maintain communication between the ship and other parts of the autonomous ship system

3.2.7
local sensor systems
environment sensors and data processing systems located in the ship's local operating area, but off the ship, that provide additional data and/or information to the autonomous ship system's environment assessment functions

Note 1 to entry: This can be used, e.g. to remove radar shadows, improve positioning accuracy and otherwise assist in complex operations, e.g. in high density traffic or during berthing.

3.2.8
planned response services
services provided by organizations with facilities not located onboard the ship, to assist in situations where the onboard systems are unable to handle the situation alone

Note 1 to entry: This may include, e.g. towage in case of critical sub-system failure on board or evacuation services for passengers on an uncrewed ship.

3.3 Operational concepts

This clause contains terminology that can be used to describe aspects of the ship's operational strategies, division of responsibilities between humans and automation, and corresponding system designs requirements.

Note 1 to entry: Informative Annex B gives a more extensive and informative overview of these concepts.

3.3.1
tolerable event
technical or operational event for which there is a designed response that keeps the system within its operational envelope

Note 1 to entry: A tolerable event includes events that are part of routine operations as well as events that are not considered part of normal operation but occur in practice as a result of different operational contexts (e.g. heavy weather, damage, failures, reduced communications capabilities, operator errors, etc.).

3.3.2
operator control mode
working mode, sometimes supported by technology or procedures, that represents the expected class of actions performed by the crew or remote control centre operators

Note 1 to entry: Modes can be changed during a voyage or operation and/or for specific functions.

Note 2 to entry: Clause 3.4 defines four operator control modes.

3.3.3
fallback state
designed state that can be entered through a fallback function when it is not possible for the autonomous ship system to stay within the operational envelope

Note 1 to entry: Being in a fallback state should not result in an intolerable risk (frequency and severity of any consequence).

3.3.4
fallback function
means to reach a fallback state

3.3.5
fallback space
set of all fallback *states*

3.3.6
operational envelope
conditions and related operator control modes under which an autonomous ship system is designed to operate, including all tolerable events

Note 1 to entry: The operational envelope should cover at least all relevant voyage or operation phases as well as all relevant autonomous ship system processes. The conditions should include geographic or fairway conditions, environmental conditions, own ship conditions, traffic conditions, division of responsibility between human and *automatic control*, as well as any other factors that have a significant impact on the operation of the autonomous ship system.

Note 2 to entry: The operational envelope (OE) is inspired by the Operational Design Domain (ODD) as defined in [1]. However, as the OE also includes operations under human control, and as the relationship between OE and fallbacks are somewhat different than for the ODD, it has been decided to not use the name ODD and rather call this Operational Envelope. See also informative Annex B.3.

3.3.7
system control tasks
all *process* control tasks, implemented by automation and/or humans, that are required to sustainably operate the autonomous ship system within its operational envelope

Note 1 to entry: A process control task is the control task or function related to a specific process. The task or function can be automatic or performed by a human.

3.4 Operator control modes

This clause contains proposed definitions for the different operator control modes. The definitions are written as the expected class of actions that are or can be performed by the crew or the remote control centre operators, to influence on those of the autonomous ship system's processes or equipment that are necessary to perform the ship's operation or voyage.

3.4.1
monitoring
monitor operations but do not take any action to influence any necessary process

Note 1 to entry: In monitoring mode, operators may adjust non-necessary processes or equipment to facilitate gathering of information. Monitoring could, for example, be to adjust a system for exclusively human use, such as external lights or cameras, or to inspect equipment or trends in performance parameters.

3.4.2
strategic control
implement fleet-wide instructions and, if appropriate, define specific functions to be used by the automatic decision-making units

Note 1 to entry: Strategic control corresponds to a Master's standing orders on a conventional ship.

3.4.3
tactical control
influence the conclusion made by the automatic decision-making units of the autonomous ship for a particular purpose

Note 1 to entry: Tactical control would, for example, be changing the required minimum closest point of approach (CPA) to other ships or the port of destination and let the autonomous ship system afterwards construct the avoidance manoeuvre or route itself. It could also be adjustment of a technical alert level, based on prevailing conditions, for example, the time delay in actuation of the bilge alarm.

3.4.4
direct control
directly control a specific function or parameter

Note 1 to entry: Direct control would mean, for example, that the operator changes a waypoint that would otherwise be decided by the autonomous ship systems directly, or that the operator selects and overrides the machinery standby configuration, for example, change of generator or pump standby status.

Annex A
(informative)

The components and context of the autonomous ship system

A.1 An overview of the autonomous ship system components

The autonomous ship system is illustrated in Figure A.1 which shows some of the main components that can be included in the autonomous ship system. In addition, there will be other services that are used by the ship system but that are under control of other parties. These are schematically illustrated in Figure A.2 and briefly described in A.2. The arrows represent the connectivity between the different components of the system.

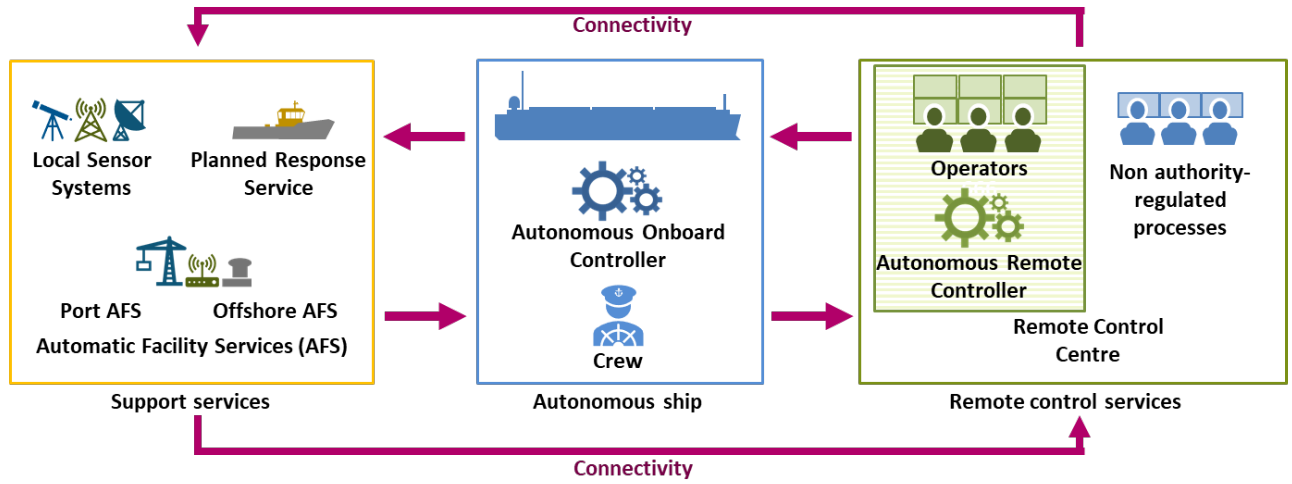

Figure A.1 – Autonomous ship system

Here, the autonomous ship system is illustrated as four main groups of components:

1. The autonomous ship itself (middle);
2. The remote control services(s) where some of the ship system's control functions may reside (right);
3. Support services located in the ship's operational area (left); and
4. The connectivity (arrows) which provides communication between the components.

This figure describes some common system components. All may not be used in all scenarios and in all situations, and any given autonomous ship system may also need additional components.

A.1.1 The autonomous ship

The autonomous ship is the ship with all on-board equipment, sensors, automation and communication systems, as well as any crew. The automation system onboard the ship will be referred to as the Autonomous Onboard Controller. As some automation functions may also be implemented in the remote control centre, it is useful to define terminology for both types of autonomous control.

A.1.2 The remote control services

The remote control functions are collectively referred to as the Remote Control Centre. Some of these may be related to mandatory services that have been taken over from the onboard crew on the ship. In the remote control centre, there may also be automatic control functions that can control some of the ships processes. These control functions will be referred to as Autonomous Remote Controller.

The remote control centre can also be referred to as a remote operations centre or a shore control centre.

A.1.3 The support services

The autonomous ship may also be designed to use other specialized services that are located off-ship. To be included in the autonomous ship system, these should be services that are designed especially for use by autonomous ships and will not include normal nautical services like, e.g. VTS, aids to navigation, etc. The latter are considered to be in the ship's context as described in A.2.

The Local Sensor Systems are environment sensors and data processing systems located off the ship that can provide additional data and information to the ship's sensor and sensor processing systems. This can be used, e.g. to remove radar shadows, improve positioning accuracy and otherwise assist in complex operations, e.g. high density traffic or berthing.

The Automatic Facility Services are services implemented, e.g. in the port, at an offshore facility or in the operational area, to serve the autonomous ship. Examples are automatic mooring systems, automatic cargo handling etc. The service may also include digital services, e.g. precision positioning systems for berthing and similar, but it will not include environment sensing services (see local sensor systems above). The components of automatic facility services that reside in the port or port approach can be termed Automatic Port Services and the services located in other locations can be called Automatic Offshore Facilities.

The Planned Response Services are services that are required onboard conventional ships, but that are not part of the onboard autonomous ship functionality. These services are provided physically on board or close to the ship, to assist in the planned tasks for the autonomous ship. A common example is evacuation services for passengers. Planned response services can be a manual or partly automatic service.

A.2 The context of the autonomous ship system

The autonomous ship system as described in A.1, will meet a context similar to the one shown in Figure A.2. Dependent on the intended system operation, the actual entities may change.

This diagram only shows the most important and normally used entities. In addition, there may be a need to contact, e.g. maritime rescue coordination centres, suppliers of nautical publications and so on. Some of the entities may also in the future have extended functionality to better cater to autonomous and smart ships, e.g. smart aids to navigations, extended VTS etc. The Autonomous Ship System is the physical ship with all onboard ship systems, the remote control centre, and all relevant support services as discussed in A.1. This is the "centre" of the context diagram in Figure A.2. The entities shown are briefly described in the following paragraphs from the top right and clockwise. An operator icon is added to those entities that often will require human to human communication.

Fairway information consists of various information that is made available to the autonomous ship system. Maritime Safety Information – MSI is transmitted from coastal authorities to ships sailing in their area of responsibility, typically related to changes in navigable waters or infrastructure that may have impact on safe passage. Aids to Navigation – AtoN are various physical or virtual devices that are installed to directly assist in the ship's navigation. It can be lighthouses, markers and buoys, or virtual AIS-based AtoN.

Traffic services: Vessel Traffic Services – VTS; Mandatory ship Reporting System – MRS; River Information Services – RIS: Ships interact with these shore-based entities. Interaction includes sending reports and sometimes receiving advice. Today, reporting is normally via voice VHF, but digital messaging standards are being developed. Note that RIS is defined as a general information service in EU

Directive 2005/44/EC [5]. Here it is mainly looked at as a service similar to VTS that interacts directly with the ship.

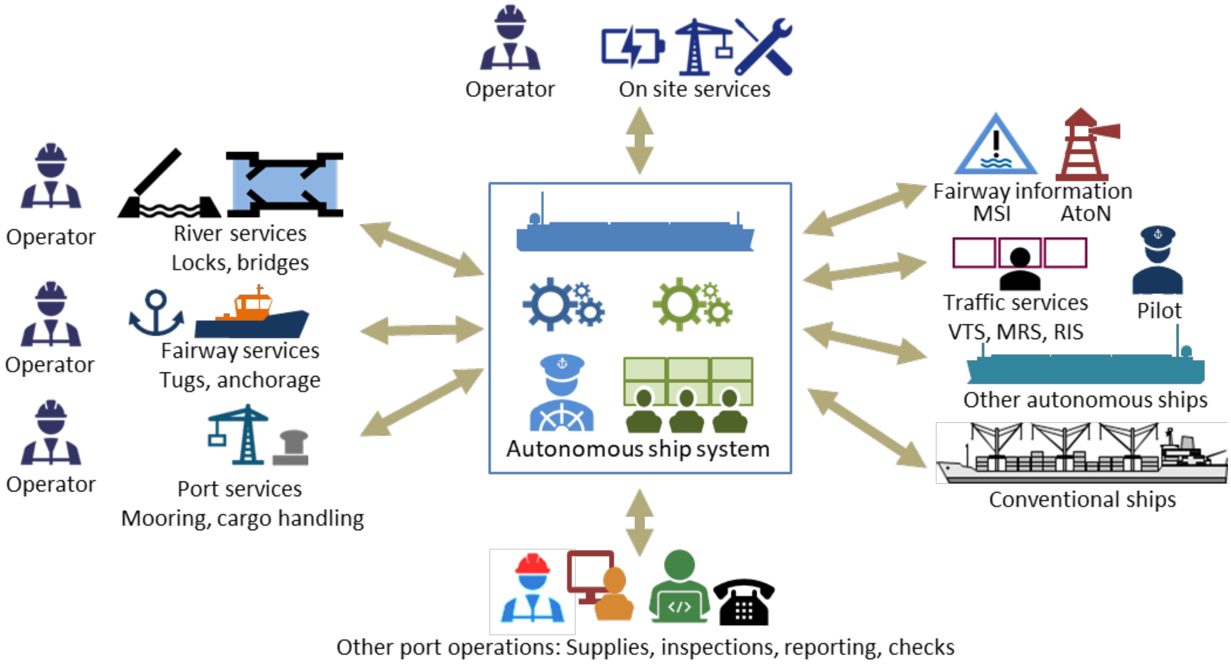

Figure A.2 – Autonomous ship system wider context

Pilot: This may also be a mandatory service for the autonomous ship. For an uncrewed ship one may need some form of remote pilotage, although there are various concerns and considerations for future formulation of policies and technical solutions pertaining to pilotage for autonomous and remote controlled vessels.

Other autonomous ships: In the future one may expect to need special interactions with other autonomous ships. This should in general be based on standardized digital messages and mainly for ensuring safe and coordinated behaviour.

Conventional ships: Interaction with conventional ships is a major challenge for the realization of autonomous ships. Autonomous ships should behave in a way that makes their intentions clear and they should also be able to communicate with other ships via AIS and VHF communication.

Other port operations: These are various services provided to the ship when in port. It may be related to supplying the ship with maintenance or supplies or various authority functions related to inspections and certification.

Port services: These are services rendered by systems or operators in the port that are not automatic. Coordination with these services will often use VHF communication. These services may be related to mooring, cargo handling, shore power supply or other.

Fairway services – tugs, anchorage: During transit through the port area, it may be necessary to get assistance from tugs or to wait and drop anchor in a waiting area before proceeding to berth. Support is expected to be coordinated through the use of VHF communication to operators of these services.

River services – Locks and bridges: These are physical objects that need to be controlled to allow ships to pass. Operators will often be involved in the shore control of these objects.

On Site Services: These are services that may be provided to autonomous ships outside normal cargo and port services. This could be related to survey missions or special transport contracts that are not delivered at conventional ports.

Note that this diagram only includes entities with which the autonomous ship exchanges information. Geographic objects or unknown objects in the water are not included in this diagram. This is not a complete diagram of all possible entities that the ship may interact with and not all entities will be used in a given autonomous ship operation.

Annex B
(informative)

Operational envelope and system control tasks

B.1 Introduction

This informative annex will give some background to how autonomous ship systems can be described and how the operational envelope can be used in the description.

IMO is the main organization for international regulation of ships and suggested the following preliminary definition of ship autonomy [2]: "Maritime Autonomous Surface Ship (MASS) is defined as a ship which, to a varying degree, can operate independent of human interaction". Autonomy versus automation has caused some disagreement in the autonomous system community. SAE [1], as an example, suggest depreciating the word "autonomy" and rather use automation as a more consistent term. However, the word *autonomous* is already used in the shipping community, and autonomy as currently defined by IMO does point to structural changes in how regulation and approval of autonomous ship systems will be done. For the time being, it is therefore useful to retain the concept of autonomous for the new developments that will challenge the current regulatory and operational framework.

In this document the differentiation between automation and autonomy has been proposed as automation being a prerequisite for autonomy, but that autonomy emerges when automation is designed and verified to be used to operate certain processes, under certain conditions, without human control.

As the above discussion shows, ship autonomy is likely to be implemented only partially, and the autonomous ship system will rely on humans to share some of the control functions. This means that the relationship between human and automation (human-automation interface – HAI) will be an important issue. This also means that the description of the autonomous ship system's capabilities should have mechanisms to differentiate between the human's and the automation's responsibilities. For this reason, the operational envelope is introduced to define the capabilities of the system and how the responsibility is shared.

B.2 The descriptive components

Very simplified, one can represent the relationships between main descriptive components of an autonomous ship systems as shown in Figure B.1. The starting point is a description of the autonomous ship systems and its processes, the context the autonomous ship system operates in and the intended voyage or operations. This can be used to describe an operational envelope and the corresponding system control tasks.

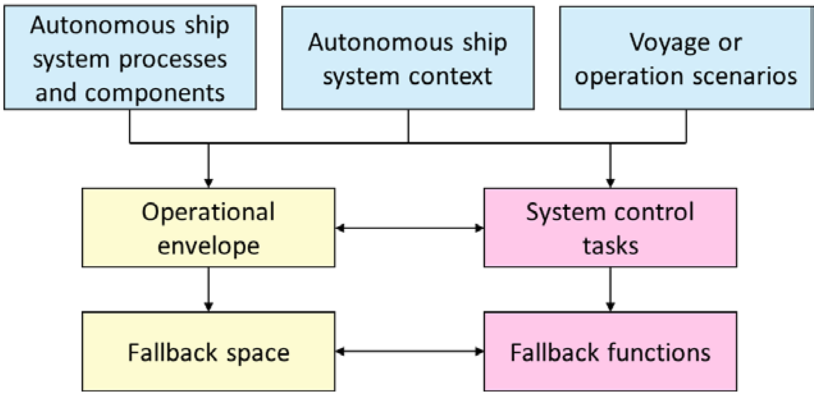

Figure B.1 – Some descriptive elements for autonomous ship system control

In conjunction with the definition of the operational envelope and the system control tasks, one will also need to define the fallback space and fallback functions.

B.3 The operational envelope

The Operational Design Domain (ODD) has been defined by the Society of Automotive Engineers (SAE) as "The specific conditions under which a given driving automation system or feature thereof is designed to function, including, but not limited to, driving modes" [1]. This definition only covers the automation systems, which is in part predicated on an assumption that cars eventually will be fully automatic and completely independent of human intervention. This is not necessarily the case for ships, where the common assumption is that many ships will have a human in the control loop, although with gradually decreasing responsibility, as automation and the reliability of automation increases. Another difference between ships and cars is that ships are arguably more complex than most cars, with many critical processes that needs attention in addition to just the "driving mode". For these reasons, this document defines an *operational envelope* (OE) as an alternative to the ODD. This document does not prescribe any specific format for the OE, but some characteristics may be:

1. The OE may have to be sub-divided into a number of OE "sub-domains" for different phases of operations or voyages as well as for some of the different processes. Examples are that navigation process requirements in port areas are very different from those in open sea, and that an energy production process is generally less dependent on geography than the navigation process. This also means that the different sub-domains may need different strategies for using automation or human control.
2. The OE needs to define requirements to all system control tasks, also those performed by humans. Of particular importance are the OE sub-domains that need to use a combination of automation and human capabilities. These sub-domains will require special attention to ensure that the automation provide provides an ergonomically designed interface to the human operator to enable him or her to safely take over control when needed.
3. Similarly, the transitions *between* sub-domains with different levels of human control needs attention with respect to how the human-automation interface is designed.
4. The identification of tolerable and intolerable events is a critical part of the overall risk assessment and should be complemented by definitions of fallback functions and states.

Ships are very different in trade and design, and it is likely that the OE should be defined based on one or a set of specific operational cases. This makes the OE similar to a "Concept of Operations" document, that is a common requirement from several class societies and authorities. Thus, the OE can be seen as a central part of the Concept of Operation.

B.4 Human-automation classification of operational envelope sub-domains

Very generally, the level of human control on a process may be classified as having three different "degrees": C0 is where automation handles the system control task and where a human is not needed at all. C1 is where the human has responsibilities for some parts of the system control task and the automation others. C2 is where the human has the full responsibility for the system control task, and where automation is only assisting or offering advice to the human. An example of C1 is sailing on open sea where automation may be able to handle simple encounters with other ships, while human assistance is required for more complex situations, e.g. when collision regulations becomes less applicable.

Correspondingly, automation can also be generally classified in three degrees: A0 is where automation is not able to control the process alone and always requires human attention. A1 is the degree where automation can handle some parts of the process, but not all. A2 is where automation can control all aspects of the process and does not need human assistance. An example of A1 is the same as in the previous paragraph.

By plotting degree of automation and degree of control into a matrix, we can define some basic degrees of autonomy. This matrix is shown in Figure B.2.

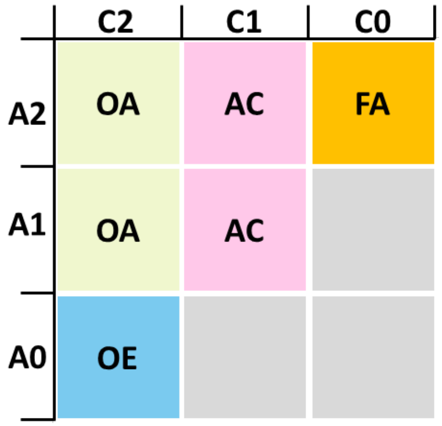

Figure B.2 – Relationship between automation and control degrees

In this document, autonomy is defined as when automation is designed and verified to be used in situations without human supervision. Clearly, the automation capabilities should be at a high enough degree to corresponds to the human control degree. If not, the system is not safe to use (grey areas). The other possibilities are:

- Fully autonomous (FA): The upper right box represents a fully autonomous system that is approved for operation completely without operators. Operators may still monitor the system, but they will not need to intervene.
- Autonomous control (AC): The boxes at the top middle represents combinations where automation can control the systems under certain conditions and where humans should be available to intervene when required. The time horizon for intervention is obviously important for how the crew can spend their time when not in control.
- Operator and automation (OA): Automation can do certain control tasks and will give assistance, but a human is required to be near a control position so that he or she can supervise the process and intervene when necessary.
- Operator exclusive (OE): Automation can only give limited assistance, and the operator needs to be continuously in control of the processes.

Note that the degree of autonomy as illustrated in the figure is using the actual human control degree as defining factor. If the autonomous ship system operation uses human control level C1 or C2, even an A2 degree of automation will still be considered to qualify for only AC or OA degrees of autonomy.

There are other ways to define degrees of autonomy, but this approach can be argued to represent a minimum set, where the relationship between the operator and the automation is easily defined and is specific with respect to the responsibilities of human and automation.

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