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THE UK NAVAL AUTHORITY GLIDEPATH TO CERTIFIED IMO DEGREE 4 AUTONOMY

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SUMMARY

The pathways and standards to certification are well travelled for crewed vessels, and are now modified for uncrewed. This paper touches on technology and design challenges faced in achieving IMO degree 4 autonomy. Readers should not fear regulatory barriers, as the UK Naval Authority welcomes further dialogue with any in the UK Defence Enterprise, and broader NATO allies. Working with the UK MCA, and the DSA-DMR, the regulatory spheres of authority are agreed and aligned to legal principles. The goal-based thinking enables staged certification of IMO degree 3 systems and onto degree 4. Reflections on early experiences and challenges to the paths lain, the choices of standards, risks and technology will be discussed. The Naval Authority's approach is adaptive to changing contexts of use, seeking to be responsive as technologies and new architectures emerge, each with the potential to alter what is materially 'safe to operate' and can be 'operated safely'. Despite the challenge, it is possible to certify machines that are remotely operated and even those that are expected to think for themselves.

NOMENCLATURE

AMofC	Accepted Means of Compliance
ANEP	Allied Naval Engineering Publication
COLREGs	Convention on International Regs for Preventing Collisions at Sea, 1972
CPA	Closest Point of Approach (CPA)
DMR	Defence Maritime Regulator within the Defence Safety Authority
IMO	International Maritime Organization
IOpC	Interoperability Operating Concept
KMHA	Key Material Hazard Area
MAP	Maritime Acquisition Publication
MASS	Maritime Autonomous Surface Ship
MoD	Ministry of Defence
NATG	Naval Authority and Technology Group
NSC	Naval Ship Code
NSubC	Naval Submarine Code
ROC	Remote Operations Centre
SDR25	Strategic Defence Review 2025
SIP	Software Integrity Policy
UUV	Unmanned Underwater Vessel

1. INTRODUCTION & CHALLENGES FACED

We engineers are naturally drawn to specific technologies or design challenges, informed by our backgrounds and disciplines. The challenge in achieving IMO Degree 4 autonomy[1] is often said to require new skills and new ways of thinking. This is the 4th RINA Autonomy Conference and RINA's technical committees for technology and for safety are already engaged in the topics herein. These committees keep close links to the Nautical Institute, to IMarEST's Special Interest Group (SIG) for autonomy and to regulators. Forums such as the UK Maritime Autonomous Systems Regulatory Working Group (MASRWG) have usefully contributed for some years [1]. Acknowledging the Defence sector has certain unique legal considerations, some insights and lessons are offered to the broader community.

The RN's Interoperability Operating Concept (IOpC) [2] talks of an inflection point between the Industrial Age and a new Information Age, where the Defence sector needs to retain a competitive edge. Keeping this edge requires competence to choose appropriate standards that enable procurement of the needed technologies. In understanding what is appropriate, it is important to reflect that autonomous shipping is not entirely new or

[1] **IMO Autonomy Degree four**: Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

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novel. Experiences from hydrography, oceanography and seabed engineering provide helpful lessons and many vessels that already meet IMO autonomy degree 2[2] and 3[3] criteria [3], especially in use of Remote Operated Vessels (ROV). The broader transition from manned to unmanned machinery and use of autopilots provides lessons about IMO degree 1[4] & 2, if not degree 3. The Defence sector's own experience compliments and informs these other sectors. The policies leading up to UK's Strategic Defence Review (SDR25) challenge us to change our thinking, requiring a blend of the best old and new ideas, and the right mindset.

Autonomous systems need not remove the human completely. One vision envisages a blend of a manned system, supported by a swarm of loyal 'wingmen', (or perhaps ducklings or a school of fish?) to increase the mass of the naval task-force. Most nations find complex warships expensive and face pressures on crew numbers, with the range of design options and complexity expanding fast. As the economics of warfare change, the balance between large, manned ship concepts and small craft, as well as the balance of offensive and defensive countermeasures may change designs further. Such changes could make possible the sought crew reductions, or even fully un-crewed autonomous vessels a realistic prospect.

To date, technical challenges on conventional marinization topics have been as numerous as those on autonomy technologies. This lesson highlights how complex a warship capability is [27], and that they remain much more than a simple transport system or a simple missile barge, irrespective of whether they are reimagined as Maritime Autonomous Surface Ships (MASS) or Unmanned Underwater Vessels (UUV) in the future.

2. USING RISK-BASED DESIGN (RBD) STANDARDS

Standards[5] regularize good practices [4], by adopting proven or effective solutions and help reduce inconsistency. Adopting technologies from other sectors can reduce development costs allowing rapid introduction into service, but can also draw regulatory requirements for revalidation. Revalidation, testing or reassessment adds cost up-front, but can also help reduce overengineering (driving-in cost), or under-engineering (missing use-cases and lessons) that will cost a user (or a life) later. An important lesson from naval, cruise and offshore energy sectors is that different "use-cases"[6], infer different choices of standard and manifest in differing design or product solutions. By taking design concepts from other industries, it is highly likely they will have prioritized what is important to that sector. Modes of failure may differ, risks that are tolerated by the last customer, may not be for the new one. The significance of risk needs to be understood to focus on what is to be achieved.

For the Defence maritime operating environment, it has proven important to reflect on choices made, to set goals [5] and strategize what uses the MASS or UUV is to be applied to. This is called a Concept of Operations (CONOPS) in INSA Codes [6]. It is clear an autonomous vessel is likely to be used for the long-expressed "dull, dangerous and dirty", while other authors have extended this to also include "Deep, Dear and Duration", [7] but all such operations need to be outlined in the CONOPS.

[2] **IMO Autonomy Degree two:** Remotely controlled ship with seafarers on board. The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
[3] **IMO Autonomy Degree three:** Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
[4] **IMO Autonomy Degree one**: Ship with automated processes and decision support. Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
[5] Standards are "A document providing for common and repeated use, rules, guidelines or characteristics for activities or production of results", ISO [25]
[6] A methodology used in system analysis to identify, clarify and organize system requirements. Use of a specific situation in which a product or service could potentially be used, ISO [25].

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3. ON REGULATION

3.1 DON'T FEAR THE REGULATOR

3.1 (a) Sandboxes and Play

For those that fear regulation prevents innovation, it must be remembered why regulations exist. Regulation[7] exists [8] to protect the public from unfettered risk, to regulate is thus to assure (or compel) control, so risk is managed. UK law focusses on risk being controlled by those who create it, rather than by the Regulator [25]. When the responsible (and the naïve but curious) manufacturers or their users proactively seek engagement, it is possible to discuss ideas, without ramifications. Such "sandboxing" enables innovation and experimentation through open discussion [9], complimented by some regulatory relaxation when exploring these ideas via controlled management of risk.

3.1 (b) Alignment

The UK's Maritime & Coastguard Agency (MCA) and the Defence Safety Authority's Defence Maritime Regulator (DSA-DMR) have an agreed demarcation, through the MOD-MCA Memoranda of Understanding [11]. Once DMR registers a MOD vessel [12] its mandate enables Naval Authority certification. The Naval Authority is chartered to certify compliance with standards and processes that reduce risk to life. Certification is defined through Naval Authority Rules [13] and by providing engineering advice and services to the maritime community in areas such as warship survivability and standards.

The demarcation between the MCA and DMR is informed by Defence and security interests, asset ownership and control of activity. Assessment is made of the intent behind established legal Dis-applications, Exemptions and Derogations (DED) [8], with attention to where the public is at risk of exposure to harm. In general, companies developing autonomous systems for their own use (incl. export), will have fewer if any DED, than assets under direct crown-control or activity for a crown customer. Demarcation typically assumes:

(i) there is a crown servant in control, called an "Accountable Person",
(ii) that the vessel is crown owned and/or operated, or
(iii) a service is provided for the benefit of UK Defence.

3.1 (c) The Difference in Maritime Regulation

Small companies working with a MOD customer, or directly with a regulator, can find the volume and complexity of paperwork challenging and may need Naval Authority support or to draw on skills from elsewhere in their supply network. Small companies have proven they can be more agile than the larger ones, with the best able to learn quickly. Sometimes the sandbox reveals a healthy safety culture other times the absence of one. The DSA-DMR continues to facilitate discussions and has published high-level guides on the more significant topics to be addressed for maritime systems [10].

Discussions have ranged from consideration of safety-critical software, how rugged or attrit-able autonomous maritime systems need to be, as well as the conduct of trials and basic occupational health & safety, especially for those new to a maritime environment. Thus the sandbox approach give opportunity for those experienced in the maritime enterprise to mentor those without experience in dealing with an unforgiving sea, while those offering new technologies teach traditionalists new approaches. Through systems thinking, it is possible to collectively succeed and support each other on the integration of these Capabilities.

3.1 (d) Application

Risk can be managed in a controlled sea-range area, or through developing evidence of the autonomous behaviour. Activity will be treated differently when it impacts the general public in open seas, or activities create risk to other UK seafarers or international shipping. If geographic ranges and MOD risk management controls are not used, it is best to engage with MCA. Any vessel in a navigable seaway (even while under test for UK or for Defence export), may not automatically have MOD legal protections. Where the conditions are

[7] A prescribed Rule or authoritative direction required of a statutorily empowered body. Civil Regulatory policies are highlighted in Defence Safety Regulations by the executive word 'must', to indicate a legal duty. [DSA01 Defence Regulation[8]]

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met, DMR Registration and a Naval Authority Certificate may be achievable. The MOD-MCA MOU [11] and regular joint working helps coordinate regulatory oversight of all autonomous systems in UK waters, as well as offering a forum for sharing good-practice. Activities impacting other people or property, typically attract the major focus.

There is potential for standards and factors of safety to alter, where no risk to life exists [14] especially for an autonomous degree 4 vessel with no human onboard. Most certified vessels to date have applied small-craft vessel standards and have had associated risks managed in the standard fashion [15]. If any requirement is viewed as unnecessary, it can be tailored [21], [24] using the Standards Management process, but for now the Naval Authority approach is to assume:

- When a vessel presents a hazard to other mariners, it must meet COLREG, with a competent coxswain to provide overwatch, being sensible.

- Whenever a human is exposed to the risk of harm; such as when a maintainer, loader, replenisher comes aboard otherwise unmanned vessels the standards that protect life should be followed.

3.2 GOAL-BASED RULES AND WARSHIPS AT INSA

Rules and regulations are raised to protect the public, but occasionally the solutions may not work effectively for naval systems. For several decades, the Defence sector has developed goal-based regulations [5]. The evolution of the INSA Naval Ship Code [6], Submarine Code [16], [17] and Boat Code [18] facilitate international consensus on ways to achieve compliance with goals, functions and principles. Solutions are not mandated, rather they are selected according to the use-cases and standards plans. The UK recognizes the INSA Codes as Accepted Means of Compliance (AMofC) with the NA Rules [13], so each Code's goals, functions and assessment of risks become a UK Certification requirement. Requirements can be set, or tailored (removed with explanation). INSA develops Part 2 & 3 [19] to offer common solutions for compliance for each chapter, it records best-practices and shares lessons. Most nations develop their own solutions, or set levels for acceptance or adopt linked solutions, such as an endorsed set of classification society rules.

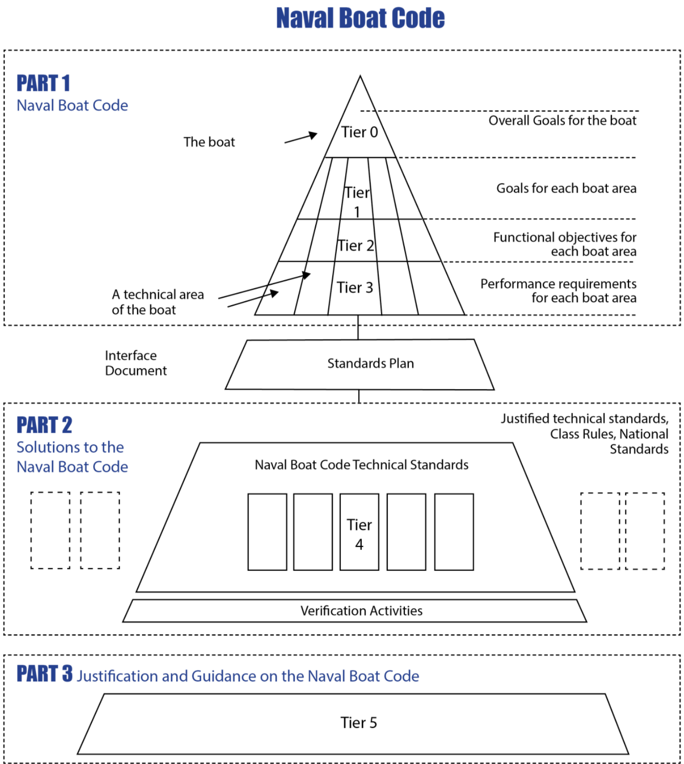

Figure 1: INSA Boat Code (Parts 1-3 Arrangements)

This approach offers a way to discuss equivalence and to use international procurement chains. The Naval Boat Code (NBC)[18] introduces the concept of the foundation safety standard, and the special function. Both foundation and the special functions can complement established technology standards, with the summative compliance helping build evidence and so achieve safety certification. The choice (fig.2) of solution, ability

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to alternate between standards or adapt requirements by "tailoring" requirements, so directly support innovation and consideration of more novel features. Decisions on standards selected and the extent of tailoring can be justified by the Safety Argument within a Safety Case. The NA Rules [13], Chapter 20 set out the process, supported by Maritime Acquisition Publication for Autonomous Systems [20].

It is for each Defence accountable person to strategize how they will fulfil their broad duty to demonstrate risk assessment, apply risk control and define thresholds of risk. To do this they need to be knowledgeable about new principles, system functions and solutions, and how risks are being controlled. Effort can be targeted by using known foundation standards (e.g. a known boat code), so that the 'special feature' of autonomy is the focus. Such tailoring and adaptation is already routine for manned vessels. The most widely used solutions are the classification societies rules, but international or national libraries of standards are also used.

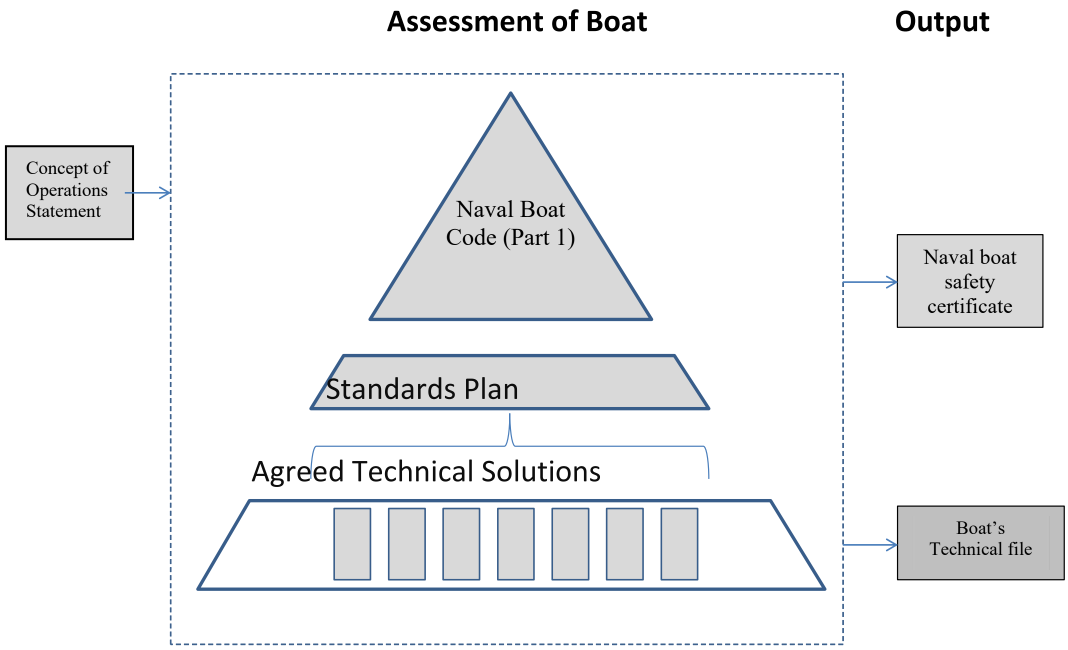

Figure 2: NBC Figure P1-0-1 main regulatory elements in the certification process of boats

Efficient certification requires dialogue, benchmarking and joint working. A broad range of solutions can be found when a vessel owner specifies special functions, on-top of a foundation safety standard or seek to replace elements of it (tailored to fit).

Figure 3: Relationship of Foundation Safety and Special Features Standards

The most widely chosen AMofC to date has been the Naval Boat Code (NBC) [18]. The approach has also allowed modified use of MCA workboat 3 [22] as a foundation. The ideas within the NBC have influenced the next version of the INSA NSC [19] which will use the same ideas of special features or functions (added or removed) for ships. Whilst we collectively improve our understanding of autonomy the importance of good relationships cannot be underestimated. The diversity of approaches and variety of autonomous machines has required the boundary of what is materially safe to operate and can be operated safely, to be kept in mind [5],[16].

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4. FOLLOW THE STEPS TO CERTIFICATION

4.1 THE WORK OF THE NAVAL AUTHORITY

The Naval Authority requires a certification strategy to outline the operating concept, mission and roles (INSA CONOPS). This certification strategy should select the preferred foundation safety code or standard. Certified systems have successfully used MCA's Workboat 3 [22] and INSA Naval Boat Code [18], with larger ships able to use Special Purpose Ship (SPS) [23], SOLAS or Naval Ship Code (NSC) [19] as their foundation standard. The special features for specific safety or mission needs can be added, as required.

Early experiences show many common risks associated with bringing any new technology into service. Although flexible selection of standards has allowed new functions to be tested, it has occasionally resulted in unusual combinations. The more unusual the mix, or the greater the tailoring of the original baseline, the more essential risk assessment is to help assess the consistency of features back to the safety principles and goals. As lessons are identified, Naval Authority Notices (NAN) [21] are being published and with time NA guides will be formally updated and published in Maritime Acquisition Publications (MAP) or Defence standards to be make the lesson available across the UK Defence Enterprise.

The flexibility to add special functions has enabled progressive certification of over 50 IMO degree 3 boats so far. Novel ship-types require a longer conversation than compliance with established hull-forms and roles with familiar Accepted Means of Compliance (AMofC), but most concepts can be accommodated. Tailoring of requirements has also allowed a previously certified baseline vessels to be modified with autonomous features, or to be used in a new fashion. Through revision of the risk assessment, changes to any specific context of usage can be addressed agilely, while permitting new use-cases to be added and novel technologies or architectures to be trailed.

4.2 OPTIONS

The Naval Authority has tried to simplify the different choices of baseline safety standard as Ship Regimes

Table 1. The Ship Regime

Regime 0			**Regime 1**	**Regime 2**
Domestic	Non-IMO	IMO Convention	Auxiliary or Patrol	Warship
Type 0 Recreational Boats Type 1 Boats (Commercial baseline) Inland & Coastal Domestic Shipping River, pleasure boats and Workboats	Special Purpose Shipping (MCA Type VII / VIII) High-speed Craft (HSC) Coast-hopping International (MCA Coastal II to VI) Workboats, Superyachts	Short-Haul international trade (MCA Type II, VIII(T), IX Ocean Tugs etc) Long-Haul international Trade (MCA Type I, VII, XI, XII)	MCA-baseline + Military Deltas to deliver NSC-baseline + special features Requirement (*to blended Civil & Military International & National standards*)	MOD Requirement (*to blended Civil & Military International & National standards*)
Baseline Safety Standards, Tools & Analysis		>>>>>>> <<<<<<<	**Baseline Survivability Standards, Tools & Analysis**	

Having written the Certification Strategy and standards plan, the steps to achieve certification are as follows. First to follow the Regime [24] and registration path [12], having understood the broad mission or role of the vessel:

- A regime 0 or 1a boat, must comply with MCA workboat code 3, as the foundation standard.
  Ability to tailor is limited. A baseline compliant with this foundation standard allows up to IMO Degree 3 autonomy, (no more).
- A regime 0 or 1 ship must similarly comply with statute and alignment to a foundation baseline of a

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UK domestic, Special Purpose [23], Short-hall SOLAS or long-haul SOLAS baseline Government Auxiliary. These red-ensign (chartered) or blue-ensign (auxiliary) vessels are likely to need a crew (no more than IMO degree 2 autonomy) [26].

- A regime 1b or 2 boat, would be expected to be compliant with NBC safety baseline, with one or more special functions or features (up to IMO Degree 4 autonomy, according to evidence). They can have a coxswain or be uncrewed.

A regime 2 or 3 ship would expect to have an NSC baseline, but could still use elements of SOLAS or other standards and multiple special functions. This would allow up to IMO Degree 4 autonomy, (according to evidence).

4.3 THE THREE CERTIFIED PATHS (SO-FAR) TO IMO DEGREE 4

Experience thus far, reveals three routes able to achieve certification. Each allows a safe environment, a safe system of supervision and a tested system:

4.3 (a) Route One: Certification based on use within a Cleared Range

The MASS or UUV may operate autonomously provided that no third-party is either within a range of 3 nautical miles (NM); or is shown to perform to a time & predicted range to Closest Point of Approach (CPA) with other traffic. If either caveat is breached, the MASS/ UUV must be capable of being taken back into direct operator control from a Remote Operations Centre (ROC) or by an embarked crew member.

4.3 (b) Route Two: Certification based of proven System Performance – Allowing Supervised Autonomy (D3)

MASS or UUV may operate autonomously (IMO Degree 4) or under operator supervision (IMO Degree 3) in an environment where third parties are also operating, as long as the system achieves, and can demonstrate either: it detects a non-charted object at adequate range and/or determines the CPA of the object.

Distinction is made between Open Waters and Constrained Waters. COLREG Rule 18 privileges determine the form of certification submission (e.g. COLREGs Rule 9 (Narrow channels), Rule 10 (Traffic Separation Schemes) or any local rules that apply). The autonomous system is then tested to show how the Commanding Officer and their Coxswain/ operator is informed. This type of MASS will detect objects at a range that is at least as good as a human operator in the primary conning position of the vessel (were it crewed) or equivalent. The vessel is typically equipped with sensors for situational awareness at least as good as equivalent crewed vessels. An acceptable CPA will be determined by factors incl.: Environmental conditions; Traffic density; Vessel characteristics; Vessel speeds; Aspect of vessels relative to one another; Proximity to navigational hazards.

4.4 (c) Route Three: Tailored Certification based on a Synthetic Environment Assurance Report

The COLREG application of the MASS or UUV is assessed by an independent third party (a Recognized Organization (RO) of the Naval Authority) using a synthetic environment and a report provided to the operator, and the NATG as the evidence toward Certification. This Synthetic Environment Assurance Service may have geographic or situational caveats, and allows the fullest possible range of autonomous operation. This method provides the operator with the maximum permissible freedom of operation. It may be applied for at any stage in a MASS's development. Contact the NATG for further details.

5. TECHNICAL DISCOMBOBULATION

5.1 REQUIREMENTS

Requirement sponsors seek to achieve IMO degree 4 autonomy quickly. However it may prove better to pick the degree of autonomy where it offers most value, rather than seek functions exclusively at the expense of other capabilities, that work satisfactorily. Even for degree 3 autonomy there are challenges, as remote control dislocates bridge crew from 1st party seamanship decisions aboard the vessel, and mission crew from the command centre. Engineers must engage and help with systems thinking, at component, system, warship and force design levels.

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A crewed warship retains situational awareness using a command structure. The deconstruction of a warship to a system of systems discombobulates command-control across a task group or the world. The implications for each Defence line of Development (DLOD)[8] and component parts is still being considered by navies. The split between safe-to-operate and operate-safely split also becomes different.

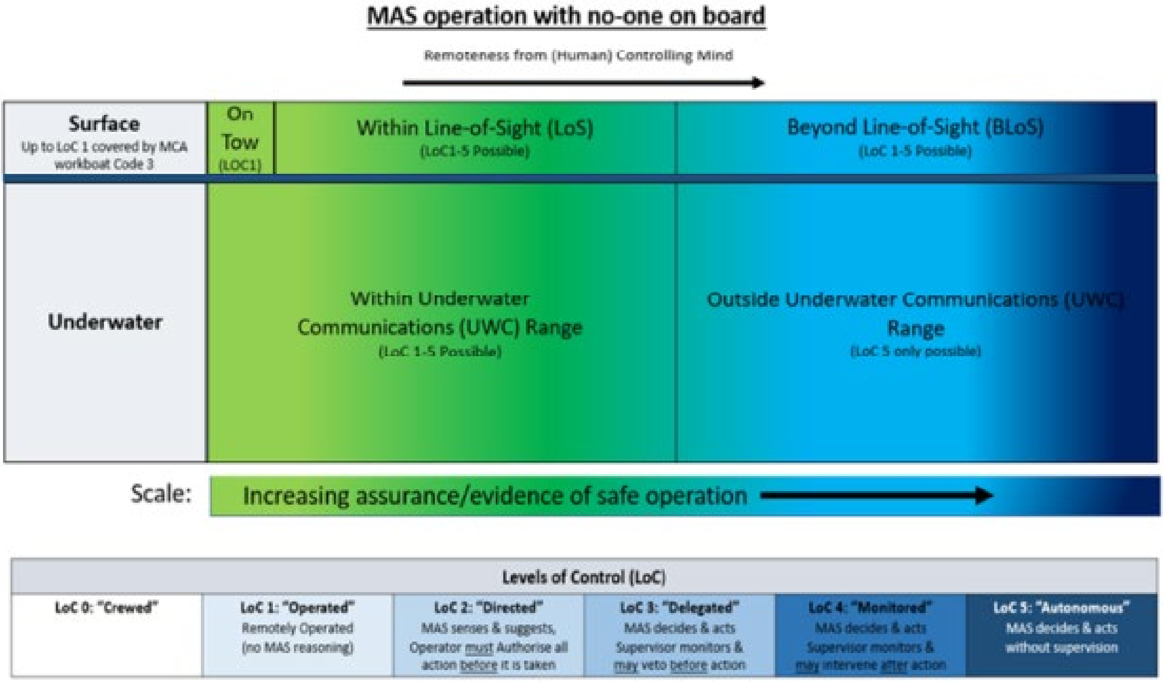

Figure 4: Levels of communication (DMR [10])

5.2 CONTROL AND ACOUNTABILITY

The DMR has recognised differing levels of control (DMR, Definitions [25]), and the need for more specificity (Fig-3), in the functions and technologies needed to step from IMO degree 3 to degree 4. As shown above (Fig-4), different autonomous functions could sit at different degrees. Compliance with:

- COLREG informs navigation and control of ship position & heading;
- the laws of armed combat informs control of the firing-chain, limiting levels of autonomy possible
- principles of machinery availability, internal damage control and supply of energy could become highly automated
- IMDG or military doctrine on use of a payload to deliver a mission function might define different degrees of autonomy.

Maritime-relevant solutions, such as in DNV's Rules for Autonomy & Remote Operation systems (AROS) can help illuminate how different levels of autonomy could work on the same vessel [28]. This standard has four defined function categories: navigation (NAV), engineering (ENG), operational (OPS), and vessel safety (SAFE). Other foundation safety standards for autonomy are emerging from Lloyds [29] and national centres [33], which can be applied directly to other special features.

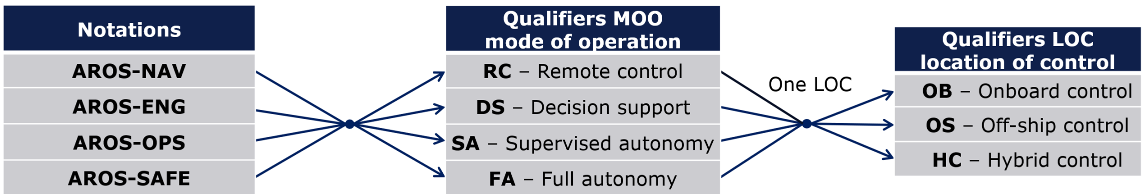

Figure 5: DNV Rules for Autonomy

[8] The DLODS are TEPIDOIL: Training, Equipment, Personnel, Information, Doctrine & Concepts, Organisation Infrastructure and Logistics

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Current generations of Remote Control Offices (RCO) are based upon those used for aviation drones (first-generation), typically with up to 3 seats (a coxswain, cargo/mission and master or Commanding Officer (CO oversight). This is likely to evolve with experience.

6. THINKING ABOUT FUNCTION

6.1 NAVIGATIONAL FUNCTION

A Coxswain needs situational awareness to avoid navigation hazards, adapt to weather, steer a course past seafarers, set commands to engines, propeller and rudder, compliant with COLREG. Numerous additional sensors have needed to be added to gain the same situational awareness inside the RCO as can be achieved by a chair on a bridge. Demands on navigation aids make them safety-critical decision systems, priced to reflect this kind of type approval.

6.2 MISSION FUNCTION

For mission package personnel/ teams have needed to share mission tasking, to draw their own situational awareness data, to communicate with each other and task-group mission staff. The receipt and execution of mission orders has (until now) been delivered by housing multiple personnel in a large operations room. The demand on sensors reliance on safety or mission critical components has added cost and made systems more complex.

6.3 COMMAND FUNCTION

For the mission CO requires the ability to delegate command-control, seek instruction from the task-group and a means to apply orders.

Finally, depending on the mission's length, each vessel needs to sustain its course(s), engine speed, reliably consume fuel/energy and be available to receive instruction such as the actuation of fire-fighting or other self-repair instructions.

6.4 OPERATIONAL ANALYSIS & NEEDS: DETERMINING THE FUNCTION

Either autonomous systems will all be disposable with a level of attrition accepted, or designs will need to be rethought. It might prove easier to vary the form of automation or autonomy needed, since each function will need a level of safety (if people interact with it) or survivability (if mission-critical). These levels will be defined for each vessel and at the fleet level, noting at a system of systems, the force-designer will need to consider what form secure communications will take and consider how military threats like grey-warfare, cyber etc erode functions or alter war-fighting needs.

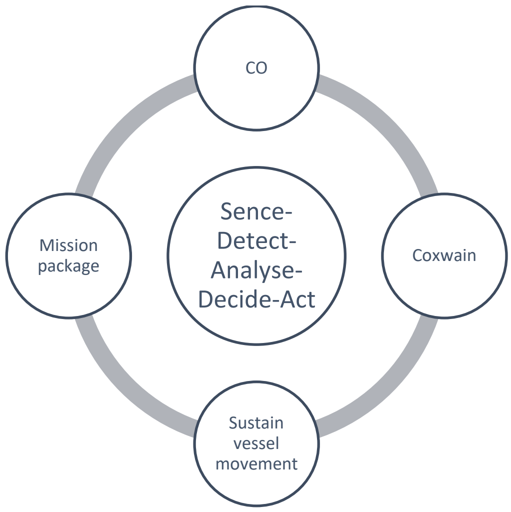

Figure 6: The Dislocated & Discombobulated Warship

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Systems requirements engineers and industry partners will need to work with traditional maritime engineers to agree demarcation of effort and leads for each function type. For now, the maritime safety certified elements are limited to:

- the safe equipment and conduct of navigation compliant with COLREG,
- where a mission package is a risk to life
  - Temporary on-board (of resupply, maintainer, stevedore functions),
  - Cargo/ mission package incl. IMDG or
  - Weapon safety/clearance and firing-chain

Acknowledging this future complexity and the genuine fear of regulatory barriers, the NATG retains its passion for helping other's innovation and enable rapid insertion of new but safe technology. We seek to help assess and declare risk and are supported by LR, DNV, INSA, and Defence colleagues. There is much that is commendable in civil approaches, as well as cautionary lessons on over specification and complexity in the requirement.

The NA's Rules [17] list Acceptable Means of Compliance (AMofC), and these standards can be modified on application to us. Requirements of an autonomous design should align with the standards selected, and the solutions should conform to those standards. Assessment evidence and assumptions that work for manned vessels might need re-assessed when there is no longer a crew to deliver required functions. The application of any standard for a MAS/UUV should link back to the functional requirements, until such times as specific standards are developed by appropriate 'agencies' e.g. Class, IMO, NATO or MOD.

Tailoring should consider the overall function to be delivered and the goals of the rule or objective, including where a direct human input is removed, where that impacts protection systems or command functions, that may need to be developed to provide an equivalent capability. Standards that are to be tailored are to be recorded in:

- The project standard database or management plan;
- Any associated Class society Tailoring document (as appropriate);
- The Naval Authority Certification Strategy. Significant deviations may be noted in certification.

For new vessels, the place to begin is to follow the certification steps for autonomy as set-out in Naval Authority (NA) Rules, Chapter 20, the supporting MAP151 [20] with NA Notes (NAN) for testing unmanned system's [30],[31]. For the more sophisticated systems, we can test how the autonomous navigator behaves within a Synthetic Environment Assurance Service (SEAS). We have also published NAN that define the requirements for the intrinsic safety integrity of the system software [32], and we signpost good-practices on assessment of AI and sensors [33], with more to be published this year. The main baseline safety standards include current thinking on system recoverability [34] and special features, is central.

Where novel special features are added (or substituted in), or where there is no risk-to-life, hazards may be revisited. In this case, standards or solutions might be radically different e.g. lightweight structure, machinery availability, or choice of safety features e.g. a hypoxic atmosphere to reduce fire risk when no-one is aboard. The Naval Authority publishes many standards to address such novel risks as well as known risks and technologies.

Ideas on autonomous recoverability are also being worked up as follows:

- Features whose failure will not lead to danger
- Features whose failure could eventually lead to danger
- Immediate lead to danger no mission impact
- Features for Degraded mission to Lost mission
- Ideas on Essential safety function

6.5 DISENTANGLEMENT AND FUTURE CUSTOMER INFLUENCE

Selecting technology and designing a system to work, needs a designer (the naval architect & their multi-disciplinary team) to know what the vessel is for (Andrews, [27]) and to disentangle the requirement into workable technology solutions. The design challenges increase when the need changes, the functions are distributed or do not settle. Change impacts budget, partnering and the physical functions needed. It may be

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that the other navies and forces the RN works closest with may change, if so, then the budgets, the technologies used, and training will need to adapt. It is clear procurement is already changing in most countries, requiring navies and materiel support communities to innovate.

How any system, particularly a ship-platform is designed and bought impacts how they are certified. The three-part process (plan-approval; material survey and trial) is well established [6],[23] but by introducing new technologies, we cannot assume established processes will still work. The assurance community is uncovering new risks being introduced when procurement sequencing or emphasis changes. How autonomous systems will be used could be different than anticipated. This means more work on Remote Operating Centres (ROC) and task-group level requirements. The integration and trials of these systems are important to build evidence and trust. They need time to be conducted efficiently, integrated physically and in the virtual software world, and to be assured (software and AI itself needing its own kinds of checks). These can be addressed by professionalism and clear-eyed application of engineering principles.

7. CONCLUSIONS

We know that expensive, crewed platforms cannot easily (or quickly) be replaced in the short-term and expensive manned systems cannot be lost needlessly. Therefore, the importance of independent certification of critical and expensive manned or unmanned vessels will remain a necessary role for bodies like the Naval Authority. The UK Naval Authority has been working to facilitate transition from manned to unmanned systems and has laid a pathway to allow certification. It is adaptable and can be modified.

Clearly the ability to remotely control a vessel, or future sensor nets of multiple vessels will need to extra considerations, including network robustness, cyber and electronic warfare. It is possible when sufficient mass of vessels are bought that levels of attrition or survivability to conventional countermeasures may shift. While our fleets transition, we are seeking to gain mutual confidence in how these new technologies perform from the high-seas, to the geographic narrows and in busy sea-lanes.

We believe while designers face undeniable challenges that the path for certification can enable this significant shift in national (and international) ship design, in a scaled and proportionate manner, while still offering safety assurance and certification when requested.

It is therefore timely that you join us in our sandbox, engage in discussions between regulators, the regulated, the designers, builders and users. it is only by such engagement that we can build understanding, empathy and the competencies necessary to face the challenges we face.

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