WMU Journal of Maritime Affairs (2023) 22:317–344
https://doi.org/10.1007/s13437-022-00295-x

ARTICLE

Uncrewed autonomous marine vessels test the limits of maritime safety frameworks

Fran Humphries[1] · Rachel Horne[1,2] · Melanie Olsen[3] · Matthew Dunbabin[4] · Kieran Tranter[1,2]

Received: 4 July 2022 / Accepted: 24 November 2022 / Published online: 19 December 2022

Abstract
Uncrewed and autonomous marine vessels (UMVs) challenge the underlying paradigm of maritime laws and regulations. Yet UMVs are considered essential for safer, more efficient, and more effective maritime futures. There is a fundamental challenge facing industry and regulators about how to develop and support the nascent UMV industry while maintaining the safety and risk management principles and processes in legacy laws and regulations predicated on the conventional crewed vessel. This paper, drawing upon case studies of developer and operator experiences with Australia's maritime safety framework, argues for an "intent-based", flexible, and collaborative approach based on developers' and operators' experiences. The case studies show that ad hoc and bespoke regulatory pathways, utilising exemptions and discretions under Australian national laws, although problematic in terms of regulatory consistency and capacity to deal with scale, did allow for the trialling and deployment of two small UMVs. More importantly, the ad hoc approach facilitated information exchange between industry and regulators that is generating reforms and changes at the national level. Although focused on Australia, the findings are significant for maritime futures. It reveals a dialectical approach whereby maritime nations pragmatically work through the risks, standards, and processes that balance safety with facilitating local UMV industries, and in turn, this creates a body of knowledge to inform international reform processes. It also shows the importance of documenting and reflecting on the regulatory journeys of UMV pioneers as essential for safer, more efficient, and effective maritime industries that leverage the potential benefits of automation.

Keywords Maritime safety · Uncrewed autonomous · Marine vessels · Australia · Regulation

✉ Fran Humphries
fran.humphries@qut.edu.au

Extended author information available on the last page of the article

1 Introduction

From Nikola Tesla's 1898 patent that anticipated advanced autonomy in the maritime sector to today's explosion of research and development on autonomous vehicles (Pribyl and Weigel 2018), it seems certain that maritime futures will involve uncrewed and autonomous marine vessels (UMVs). International and national maritime (shipping) safety frameworks have evolved to regulate vessels in situations that assume onboard humans are in control of the vessel, including the master and crew. With the rapid evolution of artificial intelligence (AI), UMVs ranging from remotely controlled or fully autonomous surface and underwater vessels pose new challenges for developers and owners who wish to trial and operate their vessels in regulated waters. While there is a rapidly growing body of literature about UMVs (Ziajka-Poznańska and Montewka 2021), there is little publicly available information about the experiences of UMV developers and owners as they progress through national assurance, accreditation, and approval pathways to conduct trials and ongoing operations. Using the research and development pathway followed by two UMV developers under Australia's maritime safety framework as case studies, this article analyses the challenges for UMV developers in trialling and operating their vessels under existing civil[1] maritime frameworks. These challenges are grouped into two themes. First, the challenges that arise from the requirements that vessels are crewed by onboard humans and second, the challenges relating to the technical specifications for vessels, including risk management.

Automated vessels have attracted interest as a means of reducing accidents (of which up to 96% are related to human factors) (Liu 2019), addressing the global shortage of seafarers, and improving cost efficiency (Komianos 2018). They might also reduce environmental damage related to human factors, such as the generation and discharge of waste and effluent from onboard humans (Ahn et al. 2019), which is a key contributor to marine pollution and the reduction of biodiversity (Brondizio et al. 2019). On the other hand, AI and other advanced sensing and responding systems are not yet at a level where there is widespread trust to safely address human, property, and environmental risks (Lazarowska 2019). Risks include system failures causing collisions with manned vessels, loss of cargo, and ocean damage as well as an increased susceptibility to piracy and terrorist attacks (physical and cyber) (Liu 2019).

There are multiple ways that UMVs can be categorised, according to the operational domain (on, or below the surface) and the degree of autonomy (see Table 1). While there is no agreed international terminology for the range of UMVs (IMO 2018), terminology in the civilian sector relevant to this article includes the following:

- remotely operated vehicle (ROV) relates to underwater vessels with a tether that supplies power and communication and is controlled directly by a remote operator (Blidberg 2001);
- uncrewed (unmanned) underwater vehicle (UUV) or uncrewed (unmanned) surface vessel (USV), which contains its own onboard power and is controlled by a remote operator through a communications link (Blidberg 2001);

[1] Analysis of the use of UMVs for defence purposes is outside the scope of this article.

- autonomous underwater vehicle (AUV), which is a submersible system with its own onboard power and controls itself without the need for a communications link (Blidberg 2001); and
- maritime autonomous surface ship (MASS), which "is a ship which, to a varying degree, can operate independent of human interaction" (IMO 2021).

The International Maritime Organization (IMO) has acknowledged that "the number of regulatory barriers increases as the autonomy level is increased" (IMO 2018). Most research and development projects design UMVs with the capacity to change between levels of autonomy (IMO 2018), requiring flexibility in regulatory requirements to accommodate UMVs. Indeed, the literature on the regulation of UMV, especially in national waters, generally emphasises the emerging nature of the technology and highlights the challenges for the existing maritime regulatory regime when considering UMV (Qveim-Leikanger 2018; Yoo et al. 2020; Dean and Clack 2019; Judson and Horne 2019). Generally, the approach is to focus on the formal rules and processes in the regime and identify the gaps and difficulties that possible UMVs might have in being accommodated within the existing regime. The analysis is generally desk-based speculation, familiar in the law and technology discipline (Tranter 2011, 2021).

What is particularly rare is consideration of the practical experiences of pioneer developers of UMVs in gaining approvals for trialling their vessels under legacy maritime frameworks, which is what this paper aims to do. While Lutzhoft, Hynnekleiv, Earthy, and Petersen have begun to consider human interactions with maritime autonomy, they remain focused on the speculative potential within an automated future, rather than the present human experiences of innovating with automation and navigating existing regulatory frameworks (Lutzhoft et al. 2019). This paper, drawing upon two of the co-authors' experiences with Australia's maritime safety framework as developers and operators of UMVs, argues for an "intent-based", flexible, and collaborative approach to reform of maritime frameworks based on developers'/operators' experiences that balance safety objectives with UMV industry development.

This argument is in the following sections. Section 2 provides a brief overview of the international maritime framework, including relevant treaties, agreements, and guidance documents for addressing UMVs. It explains how international law impacts Australia's policy development for managing UMVs and provides a brief overview of Australia's maritime safety framework. Section 3 explores UMV developer and operator experience with Australia's maritime framework using case studies of the Australian Institute of Marine Science (AIMS) and Queensland University of Technology (QUT), which followed diverging approval pathways for the same class of small underwater autonomous vessels (CoralAUV and RangerBot). Two of this paper's authors led the development and approval processes for these organisations. Section 3 highlights the case study experiences and outlines the key *governance and process* challenges and opportunities for complying with Australia's legal and policy approval pathways. Section 4 focuses on the analysis of the case study experiences of *regulatory* challenges grouped into two themes: obligations relating

Table 1 Levels of autonomy (adapted from IMO 2021 para 3.4)

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
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
Remotely controlled ship without seafarers on board	The ship is controlled and operated from another location. There are no seafarers on board
Fully autonomous ship	The operating system of the ship is able to make decisions and determine actions by itself

to humans onboard and technical requirements. The challenges in each of these themes are framed in the international, national, and case study contexts. The case studies illustrate how the UMV developers addressed these challenges using risk-based approaches during their approval pathways. Section 5 draws upon the case study experiences of governance, process, and regulatory challenges and outlines recent developments in international and Australian forums to facilitate governance certainty for UMV actors. It highlights current developments for accommodating UMVs in maritime frameworks, including the recent Australian Code of Practice, with the COLREGs Operator Guidance Framework as an annex. The paper proposes an "intent-based", flexible, and collaborative approach to reforming maritime frameworks, based on developer/operator experience that balances safety objectives with facilitating the UMV industry.

2 Maritime law and UMVs

In Australian waters, there are a range of international conventions, Commonwealth laws, and state or territory laws that give rise to requirements for UMVs, depending on where the vessel operates and for what purpose. Australian waters comprise its coastal waters (to 3 nautical miles) and territorial waters (to 12 nautical miles) that are subject to Australia's sovereignty, and the exclusive economic zone (to 200 nautical miles) where Australia exercises sovereign rights for the purposes of exploiting, conserving, and managing natural resources in the waters and seabed below, among other rights.[2] This section outlines Australia's maritime framework after providing some context of the international framework that the domestic arrangements implement.

There are a range of International Maritime Organisation (IMO), International Labour Organisation (ILO), and United Nations Conference agreements that shape the international maritime framework and its obligations for state parties. While the

[2] See e.g. Seas and Submerged Lands Act 1973 (Cth).

framework covers a range of legal areas including safety, environment, liability, contracts, salvage, and insurance, for the purposes of the analysis below, the international agreements relevant to safety and conditions at sea include:

- *United Nations Convention on the Law of the Sea* (UNCLOS);
- *Convention on the International Regulations for Preventing Collisions at Sea* (COLREGs);
- *international convention for the safety of life at sea* (SOLAS);
- *International Convention for Standards of Training, Certification, and Watchkeeping for Seafarers* (STCW); and
- *Maritime Labour Convention* (MLC).[3]

UNCLOS is a legal framework for ocean governance in all marine spaces. While the framework is much broader than maritime law (see e.g. Freestone et al. 2006; Tanaka 2015), its provisions relevant to shipping include jurisdictional issues concerning the nationality of ships (flag state), sovereignty and sovereign rights concerning the subject matter and activities within maritime zones, shipping standards (including environmental), and piracy and rights of innocent passage for vessels (see e.g. Ringbom 2015; Marten 2011). COLREGs are a framework of navigational rules that vessels must follow to prevent collisions, including rules relating to responsibility, lookout, safe speed, and precautions to avoid collisions (Achnioti 2021). SOLAS sets out standards to achieve safety objectives on a range of issues, including construction, cargo handling, communications, life-saving equipment and procedures, maritime security, operations, and navigation (Chircop 2017). The STCW together with its associated code sets standards of training, certification, and watchkeeping for seafarers globally (IMO 2011). It uses a skills-based framework, where the seafarer needs to demonstrate knowledge, understanding, and proficiency of certain tasks to be deemed competent for each rank and is periodically updated to address competency requirements for new technologies (Sharma and Kim 2021). The MLC aims to ensure worldwide protection of the rights of seafarers and to establish a level playing field for decent working and living conditions for seafarers (ILO 2021). The MLC includes a two-part code containing mandatory standards and non-mandatory guidelines. The standards include minimum requirements for seafarers to work on a ship, conditions of employment, accommodation, food and catering, and medical care (Exarchopoulos et al. 2018). There are a range of codes that support the international maritime framework. For example, Sect. 4 below refers to the International Safety Management (ISM) Code, which is integrated into SOLAS as the international standard for the safe operation of ships and pollution provision and sets objectives and requirements for safety management systems.

[3] Other relevant international agreements include: International Convention for the Prevention of Pollution from Ships, Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, International Convention on the Control of Harmful Anti-fouling Systems on Ships, and International Convention on Load Lines.

Australia is a federation of states with three levels of government—Commonwealth (national), state/territory, and local governments, each with their own laws and policies. While maritime law is primarily the responsibility of the Commonwealth government so that it can comply with its international maritime obligations, state/territory, and to a lesser extent, local governments have overlapping laws and responsibilities that impact on marine safety and pollution issues, ports, and waterways management. The national marine safety regulator, the Australian Maritime Safety Authority (AMSA), is an entity of the Commonwealth Department of Infrastructure, Transport, Regional Development, and Communications and is responsible for registration, marine pollution, survey and certification of vessels, safety standards for foreign vessels, crew competence standards, navigation aids, and other responsibilities under a range of legislation. There are several other Commonwealth agencies with responsibilities in the marine space including environmental protection and marine parks, such as the Great Barrier Reef Marine Park Authority (GBRMPA) highlighted in the case studies in Sect. 3. The legislation administered by GBRMPA provides an additional layer of regulation for specific vessels operating in the Great Barrier Reef.

Vessels in Australian waters will generally be subject to one of four key maritime safety frameworks, none of which currently distinguish between conventional vessels and UMVs. These are outlined in Fig. 1. AMSA regulates two distinct frameworks for civil vessels; the third is the framework for defence vessels regulated by the Department of Defence, and the fourth is the framework for recreational vessels regulated by the relevant state or territory where the vessel is used. The first step for determining which maritime framework applies is whether the vessel falls under the definition of "vessel" for the purposes of the *Marine Safety (Domestic Commercial Vessel) National Law 2012* (Cth) (National Law).[4] If so, the next step is to determine whether it is a "domestic commercial vessel" (DCV) (Fig. 2). Generally, a DCV is a "vessel for use in connection with a commercial, governmental, or research activity" (National Law schedule 1, Sect. 7), which is not a "regulated Australian vessel" (RAV) or "foreign vessel" that are both regulated under the *Navigation Act 2012* (Cth) (Navigation Act); not a "defence vessel" (regulated under the Australian Defence Maritime Seaworthiness Framework[5]) or a recreational vessel or other vessel owned by a school, prescribed community group, or sports institute under certain circumstances (regulated under relevant state/territory laws).[6] Australian vessels used in connection with a commercial, governmental, or research purpose and which travel outside of the exclusive economic zone (EEZ) will generally be RAVs

[4] A vessel is a "a craft for use or that is capable of being used, in navigation by water, however propelled or moved, and includes an air-cushion vehicle, a barge, a lighter, a submersible, a ferry in chains and a wing-in-ground effect craft." National law schedule 1, part 1 Sect. 8(1). This is expanded upon and subject to various exclusions under *marine safety (domestic commercial vessel) national law regulation 2013* (Cth) Sect. 12.

[5] https://www.defence.gov.au/business-industry/seaworthiness#:~:text=Australia's%20Defence%20maritime%20capability%20consists,enough%20to%20be%20technically%20sound.

[6] An analysis of state and territory legislation relevant to maritime safety requirements is beyond the scope of this paper.

under the Navigation Act. An owner of a vessel that would otherwise fall within the National Law as a DCV may apply for an "opt-in declaration" that the vessel is a RAV to be regulated under the Navigation Act under certain circumstances (Navigation Act Sect. 25). Foreign vessels (a vessel that does not have Australian nationality and is not a recreational vessel) are regulated under the Navigation Act. Some small UMVs operated directly off a mothership, which is a RAV or foreign vessel, may be considered "ships equipment" and therefore not be subject to legislative requirements independent to the primary ship (which will include them in their safety management systems and survey) (Navigation Act Sect. 1; see McLaughlin 2011).

There is a standard set of requirements for DCVs under the National Law, which must be complied with unless a specific exemption or general exemption applies. Generally, a DCV must be crewed by persons holding the required certificate of competency and have a unique vessel identifier, certificate of survey, and be listed on a certificate of operation (National Law Schedule 1, Part 4, Divisions 1–4). AMSA will assign a DCV a vessel service category (the use and operational area categories), which determines the requirements that will apply under the marine orders and the *National Standard for Commercial Vessels* (NSCV), which includes the technical standards for compliance with international agreements, including vessel design, construction, equipment, survey, operation, and crew competencies (NSCV Part B, Sect. 2.4). As the National Law and associated standards are based on the assumption that vessels will be crewed, UMVs will not comply with all of the requirements for conventional vessels. However, the framework has built-in flexibilities for managing the risks of specific vessels under certain circumstances that might be relied upon in the short term to accommodate UMV trials and operations. Flexibility mechanisms include:

- general exemptions, which are instruments that set out relevant criteria and conditions for certain vessels, operations, and crew, including three that are particularly relevant to UMVs:
    - *Marine Safety (Certificates of Survey) Exemption 2020* (Cth), which exempts specified categories of vessels from the requirement to hold a certificate of survey subject to conditions (i.e. non-survey vessel permit);
    - *Marine Safety (Certificates of Operation) Exemption 2020* (Cth), which exempts specified categories of vessels from the requirement to hold a certificate of operation (e.g. vessels operating in sheltered waters under 7.5 m that do not carry passengers or dangerous cargo);
    - *Marine Safety (Temporary Operations) Exemption 2020* (Cth), which allows specific temporary operations including trials and operation without a certificate of survey or operation (i.e. temporary operations permit);
- specific exemptions, which AMSA may grant on a case-by-case basis if AMSA is "satisfied that the exemption concerned, taken together with the conditions to which it is subject, will not jeopardise the safety of a vessel or a human onboard a vessel" (National Law schedule 1, Sect. 143(5)). UMVs frequently require a

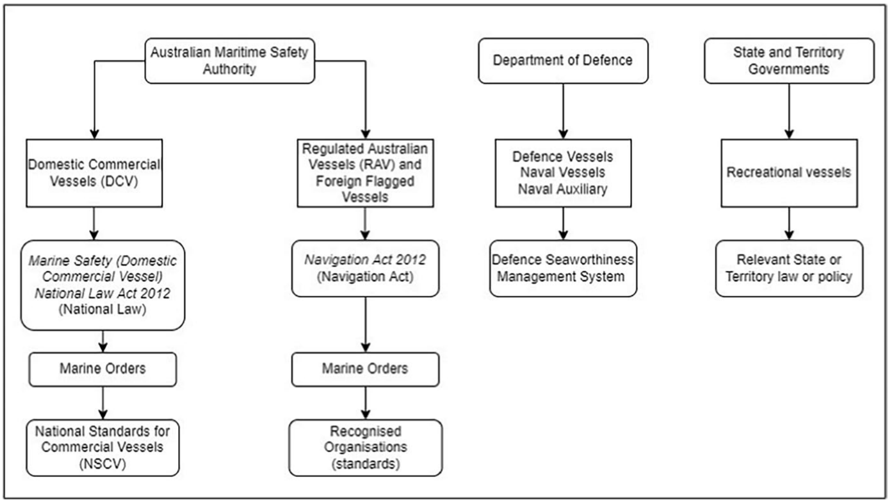

Fig. 1 Four key maritime safety frameworks in Australia

specific exemption from the survey and crewing requirements, but applying for these can be complex and time-consuming for each case and does not offer certainty for the UMV industry;

- equivalent means of compliance to meet a required outcome of the NSCV if AMSA is satisfied that it "is at least as effective as any part of the standards that it replaces" (*Marine Order 503 (Certificates of Survey—National Law) 2018* (Cth) Division 4, Sect. 17(2)).

Like the National Law, the Navigation Act framework, which regulates RAVs and "foreign vessels", assumes that humans will be onboard the vessel. The Navigation Act gives effect to Australia's obligations under international agreements. This means that a UMV would need to comply with relevant Navigation Act and marine order requirements, including the provisions that implement international convention requirements, depending in the vessel's size and class. For example, a RAV must have a safety certificate for the kind of vessel specified under the SOLAS or a non-SOLAS certificate,[7] which may be subject to conditions and if the survey requirements are satisfied, the vessel may be certified (Navigation Act Sect. 100). Foreign vessels are expected to be certified in compliance with relevant international conventions.[8] Foreign vessels entering Australian ports are subject to the port state control regime under the guidance of the IMO and two regional memoranda of

[7] *Marine Order 31 (SOLAS and non-SOLAS) Certification 2019* (Cth) s 7. Schedule 1. Passenger vessels or cargo vessels greater than 10 m in length must have a non-SOLAS certificate specified in schedule 2. See regulation 12 of chapter 1 or regulation 10 of chapter VIII of the *International Convention for the Safety of Life at Sea*.

[8] *Memorandum of Understanding on Port State Control for the Indian Ocean Region 1998* article 2.4; *Memorandum of Understanding on Port State Control in the Asia–Pacific Region 1994* article 2.5; see also relevant conventions e.g. *Maritime Labour Convention* art V.

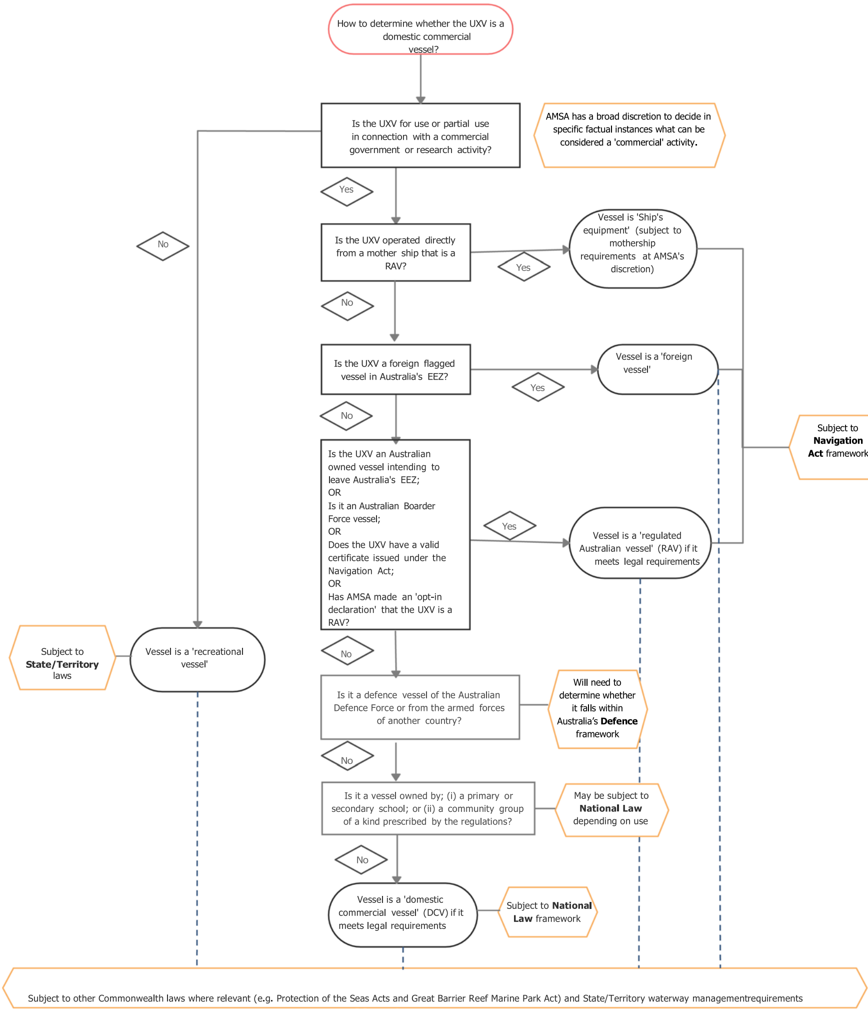

Fig. 2 Determining whether a vessel is a DCV, RAV, or foreign vessel. Examples are in order of decreasing size. *UW*, underwater

understanding, which provide guidance on how to meet the provisions of relevant international conventions.[9]

There is significant uncertainty regarding the exact requirements that UMVs need to comply with under the Navigation Act, due to the reference to international

[9] Australia is a member of two regional port state control regimes that cover the Asia–Pacific and Indian Oceans surrounding it, in cooperation with other countries: the Tokyo (Asia–Pacific) Memorandum of Understanding; *Memorandum of Understanding on Port State Control in the Asia–Pacific Region 1994* Memorandum rev18.pdf (tokyo-mou.org); *Memorandum of Understanding on Port State Control for the Indian Ocean Region 1998* https://iea.uoregon.edu/MarineMammals/engine/Documents/2-1036-1064.html

convention requirements, and there are also fewer flexibilities available than under the National Law. The flexibility mechanisms available include exemptions and alternative means of compliance in accordance with some international conventions, but they are limited by strict parameters and conditions in the international agreements themselves. These difficulties are likely part of the reason why there are currently no authorised RAVs which are autonomous and remotely operated vessels in Australian waters (only DCVs operating under the National Law). The following section outlines the experiences of UMV operators under the National Law regulatory pathway.

3 Australian experiences with regulatory pathways: challenges and opportunities

There is at least a dozen market-ready UMVs operating in a civilian capacity in Australian waters, but there may be many more that are not the subject of publicly available information. The Australian Defence Force also operates some of these vessels (or modified versions of these vessels) and several other vessels. While most UMVs operating in Australia are small, Table 2 demonstrates that sizes can range between 160 cm and 24 m. The variety of vessels (by way of size, purpose, depth and geographical areas) that are operating in Australian jurisdictions illustrates that regulatory frameworks already have the flexibility to handle diverse subject matter. This flexibility requires human resources to make informed discretionary decisions under the National Law. It could be anticipated that this resource-intensive regulatory approach risks being swamped with the expected influx of UMVs in Australian waters. This section highlights the vastly different experiences that AIMS and QUT had for the same class of vessels in the same geographical area to trial their vessels in Australian waters from 2020 to 2022. They are useful case studies for illustrating the complexity of Australia's regulatory pathway under the National Law.

The vessel structure and software for the submersible "RangerBot" were developed by QUT Centre for Robotics in Australia as a novel completely vision-based robotic tool to help monitor and manage various threats on the Great Barrier Reef. The RangerBot platform is a battery-powered small body (0.75 m × 0.44 m with a weight of 16 kg), with a range of 6 h at 1-knot speed and self-righting capabilities. It has rules-based fully autonomous software with machine learning capabilities. It has "real-time" onboard vision for navigation, obstacle detection, and management tasks.[10] Australia's tropical marine research agency, AIMS, purchased some RangerBots from QUT, which were used as a pre-testing platform for the development of the submersible CoralAUV. The CoralAUV was developed in a joint project that began in 2019 between AIMS and QUT. It has a small body (1.2 m × 0.51 m), weighs 35 kg, has a range of 4 h at 1knot using electric thrusters, and is self-righting. It has a rules-based fully autonomous software system with vision-based navigation systems, radio communications, and full transparency in decision-making.

[10] https://research.qut.edu.au/qcr/Projects/rangerbot/

Table 2 Examples of UMVs operating in Australia

UMV	Depth	Size	Operational area	Level of autonomy	Developer (D) and owner/operator (O)
SEA-KIT Omega class	Surface	24 m	Offshore	Remote and semi-autonomous	SEA-KIT International (D)
SEA-KIT X class	Surface	12 m	Offshore	Remote and semi-autonomous	SEA-KIT International (D) Fugro (O)
DriX	Surface and UW	8 m	All areas	Remote, semi- and fully autonomous	iXBlue (D and O)
Bluebottle Class	Surface	Up to 6.8 m	Ocean	Remote and semi-autonomous	Ocius (D)
C-Worker 5 ASV	Surface	5 m	Ocean	Remote and fully autonomous	L3Harris (D)
WAM-V	Surface	5 m	Inshore	Semi-autonomous	QUT (D & O)
Wave glider	Surface	3.5 m	Ocean	Remote and semi-autonomous	Liquid Robotics (a subsidiary of Boeing) (D)
Sirius	UW	2 m	Ocean	Remote and semi-autonomous	University of Sydney (D&O)
Slocum Gliders	UW	1.5 m	Ocean	Remote controlled	Teledyne Webb Research (D) range of partners with Australia's Integrated Marine Observing System (O)
CoralAUV	UW	1.2 m	Inshore	Fully autonomous	QUT and AIMS (D) AIMS (O)
RangerBot	UW	750 cm	Inshore	Fully autonomous	QUT and AIMS (D) AIMS (O), QUT (O)
Remus 100	UW	160 cm	Coastal	Remote and semi-autonomous	Hydroid (D)

AIMS has a research project with multiple partners to develop the next generation of artificial intelligence for the platform, so that it can make decisions based on its interpretation of the environment, rather than program input. There is limited literature available about how to safely handle this "true AI" autonomous decision-making function. The CoralAUV's computer has been built to handle the existing level of autonomy and the "true AI" system but is currently only authorised to use the lower level of autonomy.

AIMS' and QUT's RangerBots and CoralAUV operate within the Great Barrier Reef Marine Park (GBR) and are subject to a range of authorisation requirements. These include regulation as a DCV under the National Law and as a research vessel under the Great Barrier Reef Marine Park framework administered by the Great Barrier Reef Marine Park Authority (GBRMPA).[11] If there was no element of autonomy involved in the operation of the CoralAUV and Rangerbots, they would be treated in the same way under the National Law because they have a similar size and operate in the same operational area. However, because of the vessels' autonomous characteristics, regulators used a combination of temporary operations permits and specific exemption tools to make decisions about vessel safety and risk. In September 2020, QUT applied to AMSA and GBRMPA for approval to use the RangerBots in open water to carry out survey and imaging work in the GBR. GBRMPA issued QUT with a permit to use the RangerBots for multiple uses (including the crown of thorns elimination and reef imaging work on the GBR) until 2024. AMSA authorised the activities to be conducted between 16 September 2020 and 16 December 2020 under a temporary operations permit and issued a second temporary operations permit for the period 17 December 2020 to 17 March 2021. In 2021, AMSA advised QUT to apply for a 5-year specific exemption to continue to operate their vessels. In contrast, AIMS applied to GBRMPA for a special use permit, initially valid only for the duration of the trial itself, and to AMSA for a temporary operations permit (90 days) to trial the RangerBot and the CoralAUV in the GBR. AMSA granted the permit for trials between 3 July 2020 and 30 September 2020 for the RangerBot and between 24 February 2021 and 24 May 2021 for the CoralAUV. While it did not continue trials with the RangerBot, AMSA advised AIMS in April 2021 to apply for a 2-year specific exemption to continue to trial the CoralAUV. Similarly, AIMS sought and obtained a routine operations permit for the Coral AUV in November 2021 under AIMS' overarching GBRMPA general permit (2021–2027).

The first key observation about AIMS' and QUT's experiences of the National Law pathway is that the order of the steps in the application process is somewhat bespoke and ad hoc. AMSA advised both entities to apply for 90-day temporary operations permits as a first step for putting their vessels in the water for trials. After AIMS' first temporary operations permit for the CoralAUV expired, AMSA advised it to apply for a 2-year specific exemption to continue trialling the CoralAUV to build a safety case for another approval for ongoing operations. In contrast, after QUT's first temporary operations permit expired, it was advised to make a fresh

[11] There is a range of other legislation that applies to their operation in this geographical area, which is beyond the scope of this article.

application for another temporary operation permit to continue operational survey work by the RangerBot. When the second permit expired, AMSA advised QUT to apply for a 5-year specific exemption to continue operations apparently in lieu of a certificate of survey and certificate of operation. Since this advice was received, AIMS has maintained a holding pattern in lodging a specific exemption as it was clear that external support was going to be needed to work through the process, and there were other avenues to conduct approved test and evaluation (tethers or working with QUT). AIMS expects to submit a specific exemption for the CoralAUV in 2022, seeking a 5-year exemption with guidance from QUT.

There are practical reasons for this bespoke approach for the approval pathway. First, RangerBots and CoralAUV would not meet the threshold requirements under the existing maritime framework. Basic risk criteria for traditional vessels such as fuel type and engine power are not applicable, leading to confusion in how to categorise a novel platform class. Second, although the vessel size and operational area may be similar for the RangerBots and CoralAUV, they vary in their software, behaviour, and level of automation, requiring a case-by-case assessment of their safety case. For example, the CoralAUV is capable of self-navigating a reef contour, whereas the RangerBot is designed for simpler missions. Understanding the control logic assisted AIMS greatly in confidently assessing its safe operation in a complex reef environment. This level of trust is not available for black-box devices that have not gone through a rigorous test and evaluation regime (typically, these are associated with expensive military-grade systems). These commercial/low-rate-production level autonomous systems are challenging to assure in an operational sense due to the lack of insight into their control algorithms. A classic example of this was a bug in the software where the device would return to its home waypoint in China if a particular mission configuration was run at a particular time. The black box nature of this device meant AIMS could not predict this behaviour occurring. Unpredictability compromises the trust associated with an autonomous system.

A second key observation about AIMS' and QUT's experiences of the National Law process is the inadequate trial procedures and uncertainty about the end point of the approval pathway for ongoing operations. Both entities found that 90 days were too short to test and trial UMV platforms under a temporary operations permit. A more realistic development cycle is 2 years to implement an iterative build-develop-test approach with field trials. Sea trials typically have several months of lead time to secure ship, staff, and approvals, and understanding and implementing the learnings from the trials also take several months. A single test event can take 3 months from mobilisation to implemented lessons learnt. However, the developer requires certainty that their vessel will be approved throughout their test and evaluation phase, and so they would be targeting approval to conduct test and evaluation across multiple design iterations. Consistency and certainty for the trial phase are undermined by the current approach because each permit application is assessed individually by AMSA staff with varying degrees of understanding of AI and autonomy. Many of the permit conditions for the CoralAUV were not appropriate for longer-term trials, such as the requirement to beam over the radio "autonomous systems in progress" every few minutes to alert manned vessels in the area. There was also a lack of guidance on how to communicate awareness to the general public which predominantly uses mobile phones in inshore regions. Both AIMS and QUT required multiple temporary operations permits or a special exemption authorisation to build data for a safety case for ongoing operations. However, at the time of writing, there is no publicly available policy position from AMSA about the process for approving ongoing operations for UMVs. The cumulative cost of time and money for each application, together with the uncertainty about whether the trials can proceed beyond the expiry of the permit and what the process might be for approvals for ongoing operations, has the potential to significantly deter investment in UMV technologies in Australian waters.

A third key observation about AIMS' and QUT's experiences was the ad hoc nature of information requirements for building a safety case and requirements for a specific exemption, including safety management systems, for UMV applications. AIMS and QUT had different levels of operational use and operation experiences. For every hour of in-water operation, both AIMS and QUT invested many hours on background systems which are considered proxies for safety cases and approvals. There are no publicly available guidelines for the testing evidence needed to demonstrate a safety case for the temporary operations and the specific exemption pathways. This includes a lack of information about how AMSA would handle safety requirements that are not applicable in the case of UMVs, for example, minimum crewing requirements. The current framework also lacks protocols to manage circumstances that can go wrong with UMVs. For example, if the UMV drifts outside a certain area or is beyond its tolerances or running low on the battery charge, then it can be programmed to surface as a safety protocol. The current exemption permit application requires a fault analysis and effect evaluation; however, the mitigation is specified by the applicant. There are unique challenges for developing a safety management plan for UMVs including how to manage the "black box" features of artificial intelligence systems and conducting enough boundary testing to be assured that the platform's behaviour will be predictable in similar conditions. Control logic typically has some form of heuristics/rules-based overlay. It is impossible to be certain that the platform does not have any unanticipated actions without the visibility of the ruleset. For example, if an internal sensor fails and goes outside its tolerance, this could trigger a unique behaviour mode. Without the awareness that this linkage existed, it is unlikely that a real-world test case would trigger this behaviour mode. These "black boxes" range in their levels of visibility of machine decision-making. Opaque systems may result in unexpected behaviour when a vessel may attempt to automatically return to the country of manufacture as a default safety cut-off. Often, the regulator (and sometimes operators) would not have access to visibility for commercial and intellectual property reasons, which poses problems for developing a transparent safety case that may meet a regulator's standards for a safety management system. The lack of strategic guidance for a UMV test and evaluation framework and safety management plans may undermine the safety objectives of the legislation framework and increase approval timeframes and costs for the industry to build a safety case.

A fourth key observation about AIMS' and QUT's experiences was the blurring of government responsibilities for UMV safety approvals. Both obtained a permit from GBRMPA to operate their platforms in the GBR, which required information about risk management and safety management systems. The GBRMPA approval process—focused more on environmental risks to the GBR—is distinct from AMSA's process. In AIMS' and QUT's experience, there was no evidence that the two regulators worked together. GBRMPA took the lead in prescribing terms and conditions for trials and operations in the GBR, which AIMS and QUT shared with AMSA and were largely adopted for their approvals under the National Law. As the autonomous systems knowledge base grew, the terms and conditions became more consistent. There are broader regulatory factors at the federal, state, local, and community levels that impact on whether a UMV platform will gain approval to operate in Australian waters. These factors include the proposed use of platforms in First Nations people's sea country for which there seem to be ad hoc processes or guidance for consultation with traditional owners in the permitting process. While analysis of these other regulatory factors is beyond the current scope, they emphasise the importance of coordination between regulators in their approaches to new UMV technologies.

The experiences of AIMS and QUT offer valuable insights for Australia's approach to maritime governance and approval pathways. Overall, while Australia's National Law has built-in flexibilities for managing new technologies under bespoke approval pathways, this approach is not sustainable for regulators and the industry long-term. The human resources necessary for regulators and industry to understand the information requirements for building a safety case places significant cost in time and funding on regulators and developers to work through risk and compliance issues on a case-by-case basis. The ad hoc approach creates uncertainty for industry development and reduces the transparency necessary for trust between government, industry, and other stakeholders affected by UMVs in shared waters. As with the approach taken for conventional vessels, the end goal is to have sufficient trust that UMV systems will uphold the safety standards commensurate with the risk and move towards an assurance model where third parties certify compliance with these standards. Even if there is a consistent assurance process for UMVs, the flexibilities (case-by-case approvals) will continue to accommodate unique cases or high autonomy levels, until sufficient trust is established. An important lesson is that if there had been coordination and cooperation between different regulators as suggested in Sect. 5 below that drew more systematically from the past experiences of UMV developers, then the process might have been less ad hoc, focused, and streamlined in the case of the RangerBots and CoralAUV.

4 Compliance with maritime safety requirements at the international, national and industry levels

The literature on regulatory barriers for UMV trials and operations has grown exponentially over the past 10 years (Ziajka-Poznańska and Montewka 2021). Numerous industry and government-funded projects, bringing together many maritime stakeholders, are exploring the regulatory, technological, social, and economic factors relevant to accommodating UMVs.[12] There are a range of threshold questions to determine whether international agreements apply to UMVs. Generally, the relevant international maritime agreements disconnect the definition of a "ship" or "vessel" from the question of whether it is crewed (Ringbom and Veal 2017). There remain significant challenges, however, in the definitional, technical, and operational provisions of international and national frameworks for accommodating UMVs. There are a range of issues that regulators and stakeholders are grappling with. These range from worldwide jurisdictional, insurance, and cybersecurity issues that affect the maritime industry at a macro level (Ringbom et al. 2021), to issues at a micro-practical level such as the need for flag states to issue digital certificates and documents instead of requiring physical documents to be kept onboard (IMO 2018).

The analysis below focuses on some of the challenges that UMV developers face for trialling and developing a safety case for the use of their vessels in Australian waters under current maritime frameworks. These challenges are grouped into two themes, namely how the international and national frameworks manage: (1) obligations for humans onboard a vessel and (2) technical requirements. Drawing from the experiences of trialling the CoralAUV and RangerBot vessels in Australian waters, this section provides insights into the challenges that UMV developers and operators face for compliance of these requirements.

4.1 Obligations concerning humans onboard a vessel

Modern international maritime agreements were concluded during the twentieth century with the assumption that humans (master, crew, pilots, etc.) will be onboard and assume various rights and responsibilities for operating the vessel. The rise of UMVs raises questions about which international conventions apply to UMVs, which is the subject of ongoing debate[13] and not in the scope of this paper. It also raises the question of who assumes responsibility and liability in the case of UMVs (remote operator, computer programmer, vessel owner, etc.). Under UNCLOS, assuming it applies in a given case, all ships must be "in the charge of a master and officers who possess appropriate qualifications" (article 94(4)(b)). The obligation does not specify that the person in charge is present on board the vessel, so autonomy levels 1–3 might comply (see Table 1), but level 4 full autonomy possibly would not. However, various international agreements such as SOLAS, MARPOL, and STCW (and the Navigation Act that implements them in Australia) presuppose that there is a master onboard (IMO 2018). There are many other specific obligations relating to various seafarers being physically onboard such as the requirement

[12] E.g., Advanced Autonomous Waterborne Applications Initiative (AAWA) (2016), *remote and autonomous ships; the next steps*, AAWA position paper, https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf; advanced, efficient, and green intermodal systems (AEGIS) to design Europe's next generation waterborne logistics systems and autonomous vessels https://aegis.autonomous-ship.org/

[13] For example, note that whether UNCLOS applies to a UMV will depend on whether its legal status is "ship" or alternatively "devices" or "equipment", or something else, which is dependent on the policy of the flag state (Veal et al. 2019).

that the officer of the watch is "physically present on the navigating bridge or in a directly associated location such as the chartroom or bridge control room at all times".[14] While these obligations might be barriers to compliance by UMVs,[15] other obligations have scope for broader interpretations. For example, the obligation to render assistance to persons in distress at sea could arguably partially be carried out by a UMV if it is capable to render assistance through electronic lookout or towing.[16]

Under Australia's maritime framework, many regulatory requirements presuppose master and crew will be on board a vessel. The definitions of crew refer to the crew being on board the vessel,[17] whereas definitions of a "master" (the "person who has command or charge of a vessel"[18]) and "pilot" ("a person who does not belong to, but has the conduct of, a vessel"[19]) are not as narrowly defined. However, more detailed obligations may assume people are on board. For example, to have legal and internationally recognised nationality of a vessel and protection on the high seas and in foreign ports, a ship must be registered on the Australian International Shipping Register or the General Shipping Register or be exempt from registration. This poses challenges for UMVs because several conditions for registration on the International Register under the *Shipping Registration Act 1981* (Cth) require masters and seafarers to be on board the vessel. For example, requiring that:

- an Australian national or resident is a master and chief engineer onboard (Sect. 33A);
- a compulsory work agreement between the owner/operator and seafarers onboard a ship (Sect. 11A and 15F(3)(b)); and
- compulsory compensation insurance to protect human life onboard (Sect. 61AM(1)).

There do not appear to be similar limitations for the General Register, which may cause confusion and inconsistency in the case of UMVs.

International obligations concerning the standards of training, certification, and employment for seafarers often centre around the definition and location of "seafarers", which may be problematic for some automation levels of UMV. For example,

[14] STCW, chapter VIII, regulation 2(2)(1); see also SOLAS chapter V regulation 15.

[15] Under SOLAS, national maritime authorities have the ability to prescribe exemptions and equivalence standards concerning chapter 5 if their introduction is not unreasonable or unnecessary: SOLAS chapter V regulation 3(2).

[16] UNCLOS, article 98(1), SOLAS article 10(a); International Convention on Salvage, 28 April 1989, ATS 1998 No 2, article 10(1); see Chircop 2015).

[17] "***crew*** of a vessel means individuals employed or engaged in any capacity on board the vessel on the business of the vessel, other than the master of the vessel or a pilot"; *Navigation Act 2012* (Cth) s 3(1); *Marine Safety (Domestic Commercial Vessel) National Law Act 2012* (Cth) schedule 1, part 1, division 1, s 6. The *Shipping Registration Act 1981* (Cth) has a similar definition for "seafarer" s 3(1).

[18] *Navigation Act 2012* (Cth) s 3(1); *Marine Safety (Domestic Commercial Vessel) National Law Act 2012* (Cth) schedule 1, part 1, division 1, s 6; *Shipping Registration Act 1981* (Cth) s 3(1).

[19] *Navigation Act 2012* (Cth) s 3(1); *Marine Safety (Domestic Commercial Vessel) National Law Act 2012* (Cth) schedule 1, part 1, division 1, s 6; *Shipping Registration Act 1981* (Cth) s 3(1).

the STCW only applies to "seafarers serving onboard seagoing ships entitled to fly the flag of a Party" (article 3) and does not extend to remote operators (Nawrot and Pepłowska-Dąbrowska 2019). An extensive literature review has revealed an absence of a training framework for operators of autonomous vessels and uncertainty about the equipment that will be needed for training (Emad et al. 2021). The MLC, as a framework for seafarers' employment rights and conditions, applies to seafarers defined as "any person who is employed or engaged or works in any capacity on board a ship to which this Convention applies" (article 2(2)). However, the treaty provides that the competent authority of a member state has the authority to determine whether any categories of persons are to be regarded as seafarers for the purpose of the MLC if there is any doubt (article 2(2)), arguably providing flexibility to include remote operators of UMVs. These obligations may be interpreted and applied under National Law in a way that imposes conditions on UMVs that are difficult or impossible to comply with and which could create a discrepancy between different nations (Karlis 2018). For example, under Australia's Navigation Act, it is an offence to take a RAV to sea without a maritime labour certificate concerning the living and working conditions of seafarers with requirements for the minimum number of seafarers on vessels, food, water, and accommodation among others (part 5). A UMV operator could seek exemption from some accommodation and food requirements, but AMSA does not have the power to exempt the requirement for a maritime labour certificate.[20] Australia's National Law is more flexible when it comes to labour certificate requirements[21] so that the operator of domestic commercial UMV may apply for a specific exemption from relevant requirements.

4.2 Obligations related to technical requirements

Different levels of autonomy have implications for many of the existing rules and standards applying structural and technical requirements, including regarding software, to vessels. This section outlines two examples of the technical requirements that apply under international agreements and Australia's maritime laws with relevance for the case studies—technical requirements for navigation and firefighting purposes under COLREGs and SOLAS.

A fundamental principle of COLREGs is "that ships are controlled by human beings and that navigational decisions are based on a seamanlike assessment of the specific situation", (regulations 5, 6, and 8; IMO 2018)such as in situations of responsibility, lookout, safe speed, and precautions to avoid collisions. Many obligations imply human cognitive judgment that is not defined but rather is based on seafarer practice acquired through years of navigational experience, such as the principle of prudent seamanship in assessing a "proper" lookout, a "safe" speed according to the circumstances or other discretionary benchmarks in COLREGs (Achnioti 2021; Stevens 2020). As the obligations relate to vessels rather than the seafarers

[20] *Marine Order 11 (living and working conditions on vessels) 2015* (Cth) ss 7, 39, 41, 51, 54, 58, 60.

[21] See *Marine Order 11 (living and working conditions on vessels) 2015.*

per se, one interpretation is that they are capable of application to a remotely operated UMV (Nawrot and Pepłowska-Dąbrowska 2019) who controls the vessel but is perhaps difficult to apply to fully automated vessels (level 4) due to the obligations requiring human cognitive judgement.

Various obligations under SOLAS and associated codes for a fire emergency and evacuation preparedness are unsuitable for UMVs. For example, requiring the output signal for fire detection to the navigation bridge, continuously monitored central control station or onboard safety centre, and requirements that the main control station for the fixed deck foam system must be located adjacent to the accommodation spaces.[22] Other challenges under SOLAS include the many obligations for firefighting that require manual operations such as the capability to apply manual extinguishers and systems; the immediate replacement of discharged extinguishers; manual requirements for ventilation, detection of gas and other fumes, and cooling systems; requirements for supervision or patrols by personnel for early detection of hazards; drill procedures and means of escape; and the list goes on (Shiokari and Ota 2019). There is an exemption clause under SOLAS for ships "which embodies features of a novel kind" for various requirements if compliance with which might "seriously impede research into the development of such features and their incorporation in ships engaged on international voyages" (chapter 1 part A, regulation 4(b)). It is likely that this exemption clause will need to be used to more fully support the operation of regulated Australian vessels in compliance with SOLAS.

In the Australian domestic context, DCVs must comply with the *National Standard for Commercial Vessels*, being a technical standard covering vessel survey, construction, equipment, design, operation, and crew competencies. It was written with conventional vessels in mind and does not provide requirements tailored to UMVs. At the time of the case studies, UMV operators did not have access to tailored Australian technical requirements, which increased the difficulty and complexity of achieving compliance with technical requirements. However, in May 2022, Trusted Autonomous Systems released the Australian Code of Practice for the Design, Construction, Survey, and Operation of Autonomous and Remotely Operated Vessels ("Australian Code of Practice") which is intended to fill that gap.[23] As elaborated in Sect. 5, this Australian Code of Practice provides an Australian-centric voluntary technical standard for operators to use as a benchmark of good practice and to support applications to AMSA for approvals (Horne 2022a).

4.3 Case study observations and learnings

The National Law covers a suite of mandatory risk controls for crewed vessels but the risks informing these controls are not necessarily relevant to UMVs. For example, there is no need to have requirements such as minimum crewing, manual fire

[22] International code for fire safety systems chapter 9, paragraph 2.1.2.2, and chapter 14 paragraph 2.3.1; Shiokari and Ota 2019.

[23] The Australian Code of Practice is available to download here: https://tasdcrc.com.au/code-of-practice-autonomous-vessels/#download.

extinguishing, and other requirements like minimum drinking water onboard. Mandatory safety features for humans onboard such as life rafts and life jackets are nonsensical for uncrewed vessels. As was seen in the experiences of AIMS and QUT, the lack of a regulatory framework for UMVs means the developer/operator must demonstrate to AMSA that the UMV is safe (the equivalent of a survey), that the mission is sound (the equivalent of a certificate of operation), that the operator is competent and authorised to perform the mission (the equivalent of a licensing structure), and that the AI is trusted enough to perform the mission predictively (through a demonstrated body of evidence, or through controls to manage uncertainty). The industry is in a state of evolution and so each developer/operator has their own way of building arguments to address these criteria. For new autonomous system concepts and prototype vessel classes, this body of evidence does not exist. Therefore, the risk is managed through a combination of test-environment/test-range controls, mission constraints/controls, onboard safety features such as kill switches, and a layered safety management system for each component. This leads to a first principles assessment of autonomous systems conducting an operation in a target environment, which arguably is a safer approach than trying to certify an autonomous vessel against a legacy safety management framework not designed for it (such as the National Law).

After reviewing the National Law and having preliminary conversations with AMSA, AIMS and QUT identified that the temporary operations approach[24] was appropriate. AIMS took a high-level approach to justify that its small UMV trials were safe, and therefore, a temporary operations permit was appropriate. The National Law requirements were antithetical to the objectives, construction, and risk profile of small UMVs. AIMS conducted an assessment against the risks to the environment, to the vessel, to the deploying ship/personnel, and to other marine users. Controls were put in place to mitigate identified risks, and these controls formed the basis of the temporary operations permit application. By taking this approach, AIMS was able to focus on key risks associated with UMVs (such as lithium battery incidents). These do not necessarily track to the key risks associated with conventional crewed vessels, upon which the national law was formulated (such as the risk to humans from capsizing). The articulation of the specific risks and controls for the planned operation of the UMV coupled with demonstrated evidence of AIMS' experience in marine operations was sufficient for AMSA to authorise the temporary operations permit for the small UMVs in a controlled at-sea environment. This outcome was sufficient to meet AIMS' immediate needs but did not provide a pathway for the ongoing use of the vessels.

QUT took a similar high-level approach focused on addressing risks to the environment, the vessel, and other immediate marine users. Having similar controls to AIMS and specific fault behaviours mapped to mitigate environmental and operational risk for the temporary operations permit QUT also emphasised the operational

[24] "Temporary operations approach" refers to seeking a temporary operating permit under *Marine safety (Temporary operations) Exemption 2019*, which enables a domestic commercial vessel to operate for a specified period without certification (see Sect. 3 above).

context in terms of the small size low kinetic energy thresholds and the construction material of RangerBot as posing low environmental and operational risks.

One of the more concerning realisations that emerged from AIM'S and QUT's approval process under the national law was that risks unique to autonomous systems were not covered. These risks are some of the most dangerous (highest likelihood, highest probability) and if a gap analysis against the National Law approach is conducted, they are not considered in the approval process. As an example, autonomous systems typically have high-density power systems onboard. This has a suite of controls needed in order to safely manage to prevent injury to the deploying and maintenance crew. Recharging these battery systems must be done in a controlled, safe environment to minimise the risk of combustion, and cybersecurity considerations are essential for command and control and maintaining the integrity of the vessel's artificial intelligence-driven decision-making. Mechanisms for identifying and recovering from faults typically corrected by the crew in crewed vessels must also be established to maintain vessel reliability throughout its planned mission. Maintaining the integrity of telemetry recordings for post-mission analysis in the event of an incident in riskier missions is another area that may be critical in regulating autonomous platforms in higher-risk environments (such as near oil and gas platforms). The context and intent of autonomous systems differ significantly to that of crewed vessels and so an approach to regulation based on the risk profile of autonomous systems is essential if they are to be effectively and safely regulated.

4.4 An "intent-based" flexible and collaborative approach to maritime governance and regulation

In response to the rapid technological developments of UMVs, international organisations, regulators, and other relevant entities have begun to develop guidance documents for compliance with existing regulations and proposals for reform to maritime compliance regimes to ensure the use of UMVs are as safe as conventional vessels. In 2021, the IMO finalised a regulatory scoping exercise on MASS to assess how existing IMO instruments (including COLREG, SOLAS, and STCW) might apply to ships with various levels of automation. It identified a range of high-priority issues to address, including developing common MASS terminology and definitions (e.g. master, crew, responsible person) and gaps in functional and operational requirements concerning remote control stations and remote operators as seafarers (IMO 2021 paras 5.4–5.8). The IMO also recommended the development of a goal-based MASS instrument e.g. a code for completion in 2025 including functional requirements and corresponding regulations for different autonomy levels (IMO 2021 paras 6.2–6.3). In the meantime, the Maritime Safety Committee of the IMO approved Interim Guidelines for MASS trials in 2019 which provide guidance on how UMVs can comply with international obligation rather than creating flexibility for implementing them. Under the guidelines, "trials should be conducted in a manner that provides at least the same degree of safety, security and protection of the environment as provided by the relevant instruments" (IMO 2019 Sect. 2).

There are several Australian proposals which will support the use of domestic UMVs in the interim until convention-level and legislative-level amendments are made. The primary development is the publication of the Australian Code of Practice, with the COLREGs Operator Guidance Framework as an annex. The code provides an Australian-centric voluntary technical standard for operators to use as a benchmark of good practice and to support applications to AMSA for approvals (Horne 2022a), and the Framework helps unlock COLREG compliance. There is also an Independent Review of Domestic Commercial Vessel Safety Legislation and Costs and charging arrangements underway, which may lead to recommendations for legislative change to better accommodate emerging technology.[25] The GBRMPA is also in the process of developing an internal policy related to the management of autonomous systems. These are positive indicators of Australian support for the use of UMVs and should enable more efficient regulatory process to the extent possible until there are more substantive reforms.

4.5 Technological challenges and an "intent-based" approach

The case study experience demonstrated that (at least in 2021), AMSA appeared to lack applied expertise in AI or automation-specific technical know-how. Specific safety controls imposed without this technical knowledge may not be practically viable. The approach of issuing 90-day temporary operations permits fell short of the minimum 2-year development cycle for an iterative-develop-test-trials approach. The ad hoc specific exemptions did not provide a pathway for the ongoing use of the vessels. From a substantive compliance perspective, there were several examples where national and international frameworks were unable to accommodate UMVs, including the absence of humans onboard the vessel. The design and operational parameters of UMVs can differ significantly to conventional vessels requiring an approach to regulation based on the risk profile of autonomous systems.

Taking an "intent"-based approach to understanding and complying with legal requirements will likely be required to facilitate the use of UMVs until convention-level and then legislation-level change occurs. An example of this approach is the COLREGs Operator Guidance Framework developed in Australia in collaboration between Trusted Autonomous Systems and Frazer-Nash Consultancy.[26] This framework translates the COLREG rules into their "essence" in a way that makes sense for UMVs, sets out the capabilities required to comply with the rule, and helps operators identify in which circumstances specific rules arise (Horne 2022b). This enabling approach is likely to be attractive to operators and regulators alike and would arguably enable compliance for a broader range of operations.

[25] Further information is available here: https://www.infrastructure.gov.au/infrastructure-transport-vehicles/maritime/independent-review-domestic-commercial-vessel-safety-legislation-and-costs-and-charging-arrangements

[26] The COLREGs Operator Guidance Framework is available to download here: https://tasdcrc.com.au/code-of-practice-autonomous-vessels/#download

4.6 Informational challenges and a flexible approach

The case study experience demonstrated that the UMV operators/developers are also developing the safety management systems and risk and evaluation frameworks that the regulators use to regulate them. In effect, the "regulated'" is setting the rules for their regulation because decision-makers are unclear about what the endgame is and how to get there. At the same time, there was no evidence that information about the unique experiences of UMV progress through the regulation pathways was retained for current and future decisions.

While the experiences of AIMS and QUT highlighted some of the negatives associated with a bespoke and ad hoc approach to UMV regulation, the flexibility afforded by Australia's maritime frameworks can be an effective regulatory tool until more information about the needs of industry and regulators is known. The industry needs clear information about the opportunities and challenges for choosing different regulatory paths. For example, Australia's National Law is more flexible when it comes to general and specific exemptions and equivalent means of compliance. However, the "opt-in" provisions under the Navigation Act may be significant for developers/operators of UMVs which may not be suitable under the National Law. UMVs that fall under the scope of the Navigation Act need not spend any time outside Australia's EEZ as the requirements apply to vessels operating both within and outside Australia's jurisdiction. However, it offers developers/operators of UMV the flexibility of trialling or operating the vessels beyond Australia's national jurisdiction if desired. Furthermore, some small UMVs that operate directly off a mothership (which is a RAV or foreign vessel under the Navigation Act) may be considered "ships equipment" and therefore not be subject to legislative requirements independent to the primary ship (which will include them in their safety management systems and survey) (McLaughlin 2011).

4.7 Organisational challenges and a collaborative approach

The case study experience demonstrated that the regulatory challenges are much larger than determining a pathway through the National Law and instead require a whole-of-government approach to empower staff from AMSA, GBRMPA, and other relevant state agencies to understand how UMV works and what is required for building a consistent approval/accreditation system. There are other authorisations that need to be taken into account, including the proposed use of UMVs in Australia's First Nations peoples' Sea Country, for which there are no protocols or guidance for consultation as part of the permitting process. The expected influx of UMV applications will test the cohesiveness of Australia's national maritime safety regime. Although not within the scope of this paper, the interrelationship between air, sea, and land domains within their safety management frameworks and operational activities is a key driver for a whole-of-government approach built on cooperation and transparency of decision-making and information, which is currently lacking in Australia. Cooperation requires the genuine inclusion of all relevant stakeholders in the maritime framework including government, industry, First Nations peoples, surveyors, and so on in the development of the broader UMV maritime frameworks.

This cooperative approach extends to the international context. For some aspects of the navigational framework, for example, it might be possible to achieve international agreement on broader interpretations of existing requirements, such as an agreement that competence levels could be met if a human in real time is making decisions and remotely controlling the ship (IMO 2019). However, in many cases, international agreements will require an amendment to better accommodate various levels of autonomy. For example, the technical requirements for electronic lookout and communication, including redundancy requirements (e.g. COLREGs, SOLAS)[27]or procedures for changing navigational obligations when changing between levels of autonomy. Given that accommodation of the special characteristics of UMVs in the international framework will take time, there is likely to be a lag between the development of trusted automated technologies and appropriate international regulation (Liu 2019). National governments need to consider whether forging ahead with their own UMV frameworks will cause inconsistency with international obligations as the IMO suggests (IMO 2018), or whether national governments need to adopt their own positions on UMVs to inform and shape international law. In the meantime, UMV developers and operations need the scope to trial their vessels and build a safety case that can cooperatively feed into legislative and policy developments as the case studies demonstrated.

5 Conclusion

The regulatory experiences of AIMS and QUT in ensuring that CoralAUV and RangerBot were approved for trials and operation revealed the strengths and weaknesses of Australia's maritime framework. The strength of the National Law is that it did, eventually, allow for bespoke approvals. However, it highlighted how disruptive, at a fundamental level, UMVs are to maritime regulation and processes. The Australian maritime framework that is enacted and informed by international maritime treaties and agreements is predicated on the paradigm of a crewed conventional vessel, that is a vessel that has humans onboard, and that those humans are responsible for key roles in the operation, navigation, and safety. The bulk of the obligations under maritime frameworks concern humans onboard and the technical specifications for vessels to safely provide for onboard humans. UMVs, especially the small UMVs developed and deployed by AIMS and QUT, are antithetical to the foundational paradigm. While UMVs can have humans onboard and resemble conventional vessels that meet existing obligations, that is not the trajectory of development. UMV strategic advantage lies in size, build cost, and costs and energy consumption to operate compared with conventional vessels.

[27] For example, traditional requirements for a physical navigation bridge instead of an electronic bridge poses a significant barrier for UMVs, such as the SOLAS requirement for two independent means of communication between the navigation bridge and the engine room (SOLAS chapter II-1, regulation 37); IMO 2018 p. 20).

International and domestic maritime frameworks need to reckon with UMVs. The Australian case studies highlight, not only the limitations of legacy maritime frameworks, but also the need for an intent-based flexible and collaborative approach of regulators and developers/operators working together. The ad hoc reliance on bespoke exemptions, while not a long-term solution, is effective in building information flows between regulators and the UMV actors. This, as seen in the case studies, can be two ways. Firstly, regulators can increase their knowledge of the actualities of automation in the sector, and secondly, developers/operators, who are often located outside of the conventional shipbuilding industry, can engage with the safety concerns and priorities of regulators. This process can lead to a more adapted and informed approach to UMVs, as can be seen in some of the recent Australian developments such as the Australian Code of Practice. These ground-up reforms can be seen as parallel to formal UMV-related reform processes at the IMO. What could be seen is a dialectical approach whereby maritime nations pragmatically work through the risks, standards, and processes that balance safety with facilitating local UMV industries; in turn, this creates a body of knowledge to inform international reform processes. This means that the experiences of navigating regulatory pathways by actors such as AIMS and QUT for the trialling and deployment of small UMVs such as CoralAUV and RangerBot are not marginal. Rather, further studies and reflection on the regulatory journeys of UMV pioneers are essential for the facilitation of a safer, more efficient, and more effective maritime industries that leverage the potential benefits of automation.

Funding Part of this work was funded by the Queensland Government Australia and the Trusted Autonomous Systems Defence CRC (TASDCRC) under the Advance Queensland Initiative for the project “Enabling Agile Assurance of Drones in Queensland”.

Data Availability There is no raw data to share as the findings relate to the experiences of two of the authors.

Declarations

Conflict of interest The authors declare no competing interests.

References

Ahn J, Joung T-H, Kang S-G, Lee J (2019) Changes in container shipping industry: autonomous ship, environmental regulation, and reshoring. J Int Marit Saf Environ Aff Shipp 3(3–4):21–27

Achnioti E (2021) To what extent can unmanned ships comply with COLREGs 1972 and how will the liability of such vessels be assessed? Southampton Student L Rev 11:77–113
Blidberg DR (2001) The development of autonomous underwater vehicles (AUV): a brief summary. IEEE ICRA, Seoul
Brondizio ES, Settele J, Díaz JS, Ngo HT (eds) (2019) Global assessment report on biodiversity and ecosystem services of the intergovernmental science-policy platform on biodiversity and ecosystem services. Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) Secretariat, Bonn, Germany
Chircop A (2015) Assistance at sea and places of refuge for ships: reconciling competing norms. In: Ringbom H (ed) Jurisdiction over ships: post-UNCLOS developments in the law of the sea. Brill Nijhoff, pp 140–163
Chircop A (2017) Testing international legal regimes: the advent of automated commercial vessels. Ger Yearb Int Law 60:109–142
Dean P, Clack H (2019) Autonomous shipping and maritime law. In: Soyer B, Tettenborn A (eds) New TechnologieSs, Artificial Intelligence and Shipping Law in the 21st Century. Tailor and Francis, pp 67–89
Emad GR, Enshaei H, Ghosh S (2021) Identifying seafarer training needs for operating future autonomous ships: a systematic literature review. Aust J Marit Ocean Aff 14(2):1–22
Exarchopoulos G, Zhang P, Pryce-Roberts N, Zhao M (2018) Seafarers' welfare: a critical review of the related legal issues under the Maritime Labour Convention 2006. Mar Policy 93:62–70
Freestone D, Barnes R, Ong DM (2006) The law of the sea. Oxford University Press, Oxford
Horne R (2022a) Release of the Australian code of practice for the design, construction, survey and operation of autonomous and remotely operated vessels, Trusted Autonomous Systems Gamechanger Blog, 9 May 2022a. https://tasdcrc.com.au/release-of-the-australian-code-of-practice-for-the-design-construction-survey-and-operation-of-autonomous-remotely-operated-vessels/. Accessed 12 Dec 2022
Horne R (2022b) Release of COLREGs operator guidance framework. Trusted Autonomous Systems Gamechanger Blog, 4 May 2022b (https://tasdcrc.com.au/release-of-colregs-operator-guidance-framework/)
International Labour Organization ILO (2021) Compendium of maritime labour instruments: third (revised) ed, Geneva. https://www.ilo.org/wcmsp5/groups/public/---ed_norm/---normes/documents/publication/wcms_770091.pdf. Accessed 12 Dec 2022
International Maritime Organisation IMO (2021) Outcome of the regulatory scoping exercise for the use of maritime autonomous surface ships (MASS). MSC.1/Corc/1638, 3 June 2021. https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/MSC.1-Circ.1638%20-%20Outcome%20Of%20The%20Regulatory%20Scoping%20ExerciseFor%20The%20Use%20Of%20Maritime%20Autonomous%20Surface%20Ships...%20(Secretariat).pdf. Accessed 12 Dec 2022
International Maritime Organisation IMO (2019) Interim guidelines for MASS trials. MSC.1/Circ.1604, 14 June 2019. https://www.register-iri.com/wp-content/uploads/MSC.1-Circ.1604.pdf. Accessed 12 Dec 2022
International Maritime Organisation IMO (2018) Final report: analysis of regulatory barriers to the use of autonomous ships. MSC 99/INF.3, 18 January 2018. https://www.imokorea.org/fileup/MSC%2099-INF.3%20-%20Final%20Report%20Analysis%20of%20Regulatory%20Barriers%20to%20the%20use%20of%20Autonomous%20Ships%20(Denmark).pdf. Accessed 12 Dec 2022
International Maritime Organisation IMO (2011) International convention on standards of training, certification and watchkeeping for seafarers including the 2010 Manilla Amendments. IMO, London
Judson G, Horne R (2019) The regulatory approach for vessels capable of autonomous and remote-controlled operation. International Maritime Conference, Pacific
Karlis T (2018) Maritime law issues related to the operation of unmanned autonomous cargo ships. WMU J Marit Affairs 17:119–128
Komianos A (2018) The autonomous shipping era. operational, regulatory, and quality challenges. TransNav: Int J Marine Navig Saf Sea Transp 12(2):335–348
Liu D (2019) Autonomous vessel technology, safety, and ocean impacts. In: Werle D, Boudreau PR, Brooks MR, Butler MJA, Charles A, Coffen-Smout S et al (eds) The Future of Ocean Governance and Capacity Development. Brill Nijhoff, pp 490–497
Lazarowska A (2019) Research on algorithms for autonomous navigation of ships. WMU J Marit Affairs 18(2):341–358

Lutzhoft M, Hynnekleiv A, Earthy JV, Petersen ES (2019) Human-centred maritime autonomy - Anethnography of the future. Journal of Physics: Conference Series, Volume 1357, International Maritime and Port Technology and Development Conference and International Conference on Maritime Autonomous Surface Ships 13–14 November 2019, Trondheim, Norway

Marten B (2011) The enforcement of shipping standards under UNCLOS. WMU J Marit Affairs 1:45–61

McLaughlin R (2011) Unmanned naval vehicles at sea: USVs, UUVs, and the adequacy of the law. J Law, Inf Sci 21(2):100–115

Nawrot J, Pepłowska-Dąbrowska Z (2019) Revolution or evolution? Challenges posed by autonomous vessels for national and international legal framework. Comp Law Rev 25:239–255

NSCV National Standard for Commercial Vessels (Australian Government). https://www.amsa.gov.au/about/regulations-and-standards/national-standard-commercial-vessels-nscv. Accessed 12 Dec 2022

Pribyl ST, Weigel AM (2018) Autonomous vessels: how an emerging disruptive technology is poised to impact the maritime industry much sooner than anticipated. Artif Intell 1:17–25

Qveim-Leikanger S (2018) From manual to autonomous: one-hundred years of maritime ship-to-ship collision liability. On the material rules and evaluation of fault in collisions between vessels: Scandinavian maritime collision liability from 1918 to 2018. Masters Thesis

Ringbom H (ed) (2015) Jurisdiction over ships: post-UNCLOS developments in the law of the sea. Brill

Ringbom H, Røsæg E, Solvang T (2021) Autonomous ships and the law. Routledge

Ringbom HM, Veal R (2017) Unmanned ships and the international regulatory framework. Int Marit Law 23(2):100–118

Sharma A, Kim T (2021) Exploring technical and non-technical competencies of navigators for autonomous shipping. Marit Policy Manag 1-19.https://doi.org/10.1080/03088839.2021.1914874

Shiokari M, Ota S (2019) Considerations on the regulatory issues for realization of Maritime Autonomous Surface Ships. J Phys: Conference Series 1357(1):012005

Stevens F (2020) Seaworthiness and good seamanship in the age of autonomous vessels. In: Ringbom H, Røsæg E, Solvang T (eds) Autonomous ships and the law. Routledge, New York, NY, pp 243–260

Tanaka Y (2015) The international law of the sea. Cambridge University Press, UK

Tranter K (2021) Disrupting technology disrupting law. Law, Cult Humanit 17(2):158–171

Tranter K (2011) The Law and Technology Enterprise: Uncovering the Template to Legal Scholarship on Technology'. Law, Innov Technol 3(1):31–83

Veal R, Tsimplis M, Serdy A (2019) The legal status and operation of unmanned maritime vehicles. Ocean Dev Int Law 50(1):23–48. https://doi.org/10.1080/00908320.2018.1502500

Yoo J, Goerlandt F, Chircop A (2020) Unmanned remotely operated search and rescue ships in the Canadian Arctic: exploring the opportunities, risk dimensions and governance implications. In: Chircop A, Goerlandt F, Aporta C, Pelot R (eds) Governance of Arctic Shipping: Rethinking Risk, Human Impacts and Regulation. Springer, UK, pp 83–103

Ziajka-Poznańska E, Montewka J (2021) Costs and benefits of autonomous shipping—a literature review. Appl Sci 11(10):4553. https://doi.org/10.3390/app11104553

List of Treaties

Convention on the International Regulations for Preventing Collisions at Sea, opened for signature 20 October 1972, 1050 UNTS 16 (entry into force 15 July 1977), acceded by Australia 28 February 1980

Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, opened for signature 29 December 1972, 1046 UNTS 120 (entry into force 30 August 1975) (London Convention), ratified by Australia 21 August 1985

I*nternational Convention for Standards of Training, Certification and Watchkeeping for Seafarers*, opened for signature 7 July 1978, 1316 UNTS 190 (entry into force 28 April 1984), ratified by Australia 7 November 1983

International Convention for the Prevention of Pollution from Ships opened for signature 2 November 1973, 1340 UNTS 62 (entry into force 2 October 1983) (MARPOL), acceded by Australia 27 February 2004

International Convention for the Safety of Life at Sea, opened for signature 1 November 1974, 1184 UNTS 278 (entry into 25 May 1980), acceded by Australia 17 November 1983

International Convention on Load Lines, opened for signature 5 April 1966, 640 UNTS 133 (entry into force 21 July 1968) (Load Lines), entry into force for Australia, 29 October 1968
International Convention on the Control of Harmful Anti-fouling Systems on Ships, opened for signature 5 October 2001 (entry into force 17 September 2008) (AFS), ratified by Australia 9 January 2007
Maritime Labour Convention opened for signature 23 February 2006, 45 ILM 792, UNTS Reg No I-51299 (entry into force 20 August 2013), ratified by Australia 21 December 2011
United Nations Convention on the Law of the Sea opened for signature 10 December 1982, 1833 UNTS 397 (entry into force 16 November 1994), ratified by Australia 5 October 1994

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Fran Humphries[1] · Rachel Horne[1,2] · Melanie Olsen[3] · Matthew Dunbabin[4] · Kieran Tranter[1,2]

[1] School of Law, Queensland University of Technology, Brisbane, Australia

[2] Trusted Autonomous Systems (TAS), Brisbane, Australia

[3] ReefWorks, Australian Institute of Marine Science, Townsville, Australia

[4] School of Electrical Engineering and Robotics, Queensland University of Technology, Brisbane, Australia