A process for developing a regulatory framework for the certification of Marine Autonomous Systems (MAS)

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Synopsis

Development of Marine Autonomous Systems (MAS) has accelerated sharply in recent years. Government, academia and industry papers advising on the future of the maritime sector unanimously agree on the need for a regulatory framework to be established to enable the safe development, testing and operation of MAS. A regulatory framework must be developed which does not introduce constraints on the growth of MAS capabilities.

This paper analyses the existing maritime regulations and proposes necessary changes to guide a process to develop regulatory requirements. Regulation development guidelines include a range of considerations including technical, legal and insurance/liability, where adherence is complex the development of an alternative MAS specific regulation or an explanation of how the existing regulation may be complied with by MAS is required. The proposed process links MAS technical capabilities to appropriate testing regimes and associated supporting bodies of evidence and recommends testing regimes which combine simulation with demonstrations and real-world tests and leading to demonstrable levels of safety.

Establishing a regulatory framework for MAS is a challenging task, but a key enabler to the effective adoption of autonomous vessels in the maritime sector. Through proposing changes to the current process and a new approach for MAS, this paper aims to take tangible steps in developing a regulatory solution.

Keywords: Marine systems, Autonomous, Unmanned, Regulation, Roadmap.

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1. Introduction

1.1. Background

Technological development in the 21st century has been fast paced and vast, reaching every corner of the globe and every aspect of life today. In the maritime sector this growth has been exploited to increase efficiencies, improve operational safety, reduce costs, and expand capabilities. In recent years, the success of technology exploitations has led to the development of Marine Autonomous Systems (MAS). MAS are systems which operate away from a human, whether that is via partial 'remote control' or fully autonomously (no human intervention during operation).

1.2. MAS future projection

Development has accelerated sharply in recent years as industry seeks to leverage the potential of MAS, these include taking humans out of dangerous situations, reducing crew costs, increased efficiency and mission capacity.

MAS are being developed to fulfil a wide range of roles supported by rapidly evolving and capable autonomy functions. Some of these systems have been in use for years with a high technology readiness level (TRL) (NASA, 2017) and commensurate trust. More commonly MAS are undergoing trials and testing at a TRL of 3-6.

MAS are lagging behind the technological development in general autonomy as the industry struggles to establish clear societal and economic benefits, hampered by a lack of regulation and assurance. The lack of a regulatory framework means that proof of safety relies on rigorous real-world testing. Autonomous systems do not have regulator approved testing/assurance facilities using synthetic environments and require sea testing. Sea trials provide good evidence, but the generation of sufficiently complex interactions is resource intensive and subject to external interference.

To effectively harness the potential of rapid autonomous systems development, with new and novel technology constantly pushing the capabilities of MAS, the regulatory framework needs to evolve ahead of, or at least in parallel with that technology.

1.3. Identifying the requirement for framework development

A regulatory framework must be developed which does not unnecessarily constrain the evolution of MAS capability while providing the assurance of safe operation to regulators and the wider community. Extant frameworks cannot certify MAS as they do not provide the flexibility or technical assurance methodologies to handle autonomous technology development. Furthermore, a framework is required which will enable the safe integration of MAS into maritime operations.

Many MAS are in service in controlled or trial environments, where they are not using the full extent of capability or operating with the low levels of human interaction which could be possible were these systems assured and certified. Government, academia and industry papers have advised on the future of the maritime sector with unanimous agreement on the need for a regulatory framework to be established to enable the safe development, testing and operation of MAS.

Several similarities can be seen when comparing MAS with conventional in-service maritime and air platforms. Aspects of the regulation of those systems can be directly transferred to MAS. This paper will focus on the MAS specific areas of regulation, this covers the areas of technology that will become autonomous, remotely controlled, or interface with those crewless aspects.

This paper analyses examples of regulations which MAS do not or cannot comply with under the existing regulatory structures.

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This paper is cognisant of the existing regulatory development programmes already in place and recognises the need for collaboration to enable success. Building on past and current work, the paper will set out a process to develop regulatory requirements to address these areas of non-compliance and identify the need for common, repeatable methods for assurance.

1.4. A proposed process for framework development

Regulation development guidelines include a range of considerations including technical, legal and insurance/liability. Where direct adherence is not possible, as described in 3.3, the process will guide the development of an alternative MAS specific regulation which achieves the goal of the relevant regulation and demonstrates an equivalent or superior level of safety.

The technologies employed in MAS such as artificial intelligence algorithms and the absence of crew from vessels prevents the direct application of some existing regulation. The proposed process will link MAS technical capabilities to appropriate testing regimes and associated supporting bodies of evidence. The process will define guidance test cases combining simulation with demonstrations and real-world tests, leading to demonstrable levels of safety. The aim of this approach is to iteratively build trust in machine decision making in simulation and real-world scenarios where infinite possibilities exist, ultimately providing regulators with confidence in the systems they certify.

A useful comparison may be made with the approach developed within Combat Systems (CS). All CS new to operation are rigorously tested by Portsdown Technology Park (PTP) Naval Combat Systems Integration and Support Services (NCSISS), carried out within the Maritime Integration Support Centre (MISC) facility. This facility provides a representative testing and integration environment with simulation and stimulation to carry out assurance activities for safety, security, reliability and more.

After identifying this need for a regulatory framework, it is necessary to determine what the end vision should be and how the community could reach this goal. This paper explores the purpose and role of existing maritime regulations and proposes necessary changes. Enabling technologies and testing methodologies are discussed, recommendations are made about utilising these methods for MAS. This paper also discusses the timescales and blockers involved in reaching the vision.

2. Stakeholder agreement of future vision

2.1. Vision agreement

It will be important to define a future vision for the industry. Developing an understanding of the requirements for integrating MAS into the existing maritime ecosystem is the foundation of the regulatory framework. This understanding should be developed by and shared between all stakeholders so that the industry can move forward towards the goal, ideally enthusing the community of stakeholders to support the vision and invest in it. In this way Naval, Classification, and Port authorities can be presented with MAS they are able to assure and certify against a common understanding.

2.2. Stakeholder Engagement

Developing a regulation process will vitally require engagement with all stakeholders. The regulation needs to cover all aspects of operating MAS, which already comes in a variety of types and capabilities. Stakeholders such as those in Figure 1 - Stakeholder Map will need to be consulted early on as well as throughout the development of the regulatory process for their expertise and opinions.

To reach the end vision stakeholders will need to assist with trialling sections of the process and feeding back their information. It will also be crucial that all stakeholders completely adopt the final process.

If the stakeholders are not engaged to the level described, then the process will likely miss important sections and ultimately fail in its purpose. Engaging stakeholders throughout the development will cause them to feel ownership and empowered to input to the process, as well as making it more likely that they will fully adopt the final version.

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Looking at the key players in MAS will create a full picture of the MAS landscape. This will enable the correct stakeholders to be engaged in changes to regulation going forward and be a necessary part of the process in creating a regulatory framework. A map of expected core stakeholders can be found in Figure 1 - Stakeholder Map.

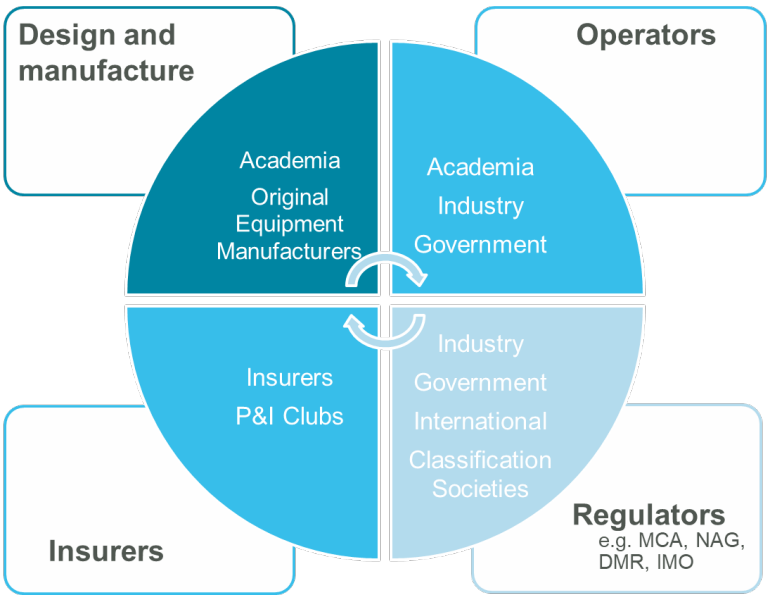

Figure 1 - Stakeholder Map

3. Proposing developments towards the regulation of MAS

3.1. Defining the boundaries of a MAS regulation roadmap

This paper cannot cover every type of MAS roadmap necessary, but by scoping out a particular area of MAS it can provide helpful guidance which will be adaptable to different areas.

MAS adoption has been pan-domain. The air domain is already well regulated while in the maritime MAS development of surface systems has progressed further than sub-sea. This paper will focus on surface MAS regulation development, but the translation into the sub-sea environment should be a logical extension.

A MAS may be bound by its concept and area of operation, but the principles of certification will be broadly similar throughout the sector. Due to the experience and expertise of authors inputting to this work, this paper focuses on UK owned MAS.

The use case examined is MAS operated by the Royal Navy (RN). This is one of the most difficult and stringent use cases meaning that it can be adapted easily for wider use, for example in the commercial sector.

3.2. Defining the scope and requirements development

One of the most important MAS regulatory framework aspects is a need to define guidance test cases as MAS testing requires unique guidance that cannot easily be adapted from elsewhere. Testing of autonomous software and interfaces will need to combine simulation with real-world to fully demonstrate system safety and reliability.

MAS are popular due partially to their abilities to work within a mix of assets, for example a manned ship launching an Unmanned Surface Vessel (USV) and an Unmanned Air Vehicle (UAV) with all three systems working together to complete a mission. A framework will need to consider concepts where the MAS will be utilised within several operating scenarios.

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3.3. Current regulation blockers

It is useful to examine one example in more detail and show how a regulatory framework can address MAS needs, the Collision Regulations provide a good case. MAS owners and operators have a legal duty to ensure the security of other vessels navigating in their vicinity. This is the duty to exercise good seamanship, by which is meant the customary good practices of competent seamen. The statutory requirement to obey the collision regulations sits under the broader duty of the exercise of good seamanship. The International Regulations for Preventing Collisions at Sea 1972 – as amended (MCA, 1996), (known as the COLREGs) have legal status under UK law.

The COLREGs are the rules applied by mariners to avoid collisions at sea and subsequently by maritime lawyers to apportion blame following an incident. They apply to United Kingdom ships[4] wherever they may be, and other ships while within the United Kingdom or the territorial waters thereof.

In a clarification with regard to smaller leisure craft the Maritime and Coastguard Agency (MCA) have issued the following: 'With respect to navigation and collision avoidance, any person in charge of any vessel that proceeds to sea, irrespective of size, is required to comply with the Merchant Shipping (Distress Signals & Prevention of Collisions) Regulations 1996 (SI 1996/75). These UK regulations implement the International Regulations for the Prevention of Collisions at Sea and it is of paramount importance that all persons in charge of vessels at sea comply with them. They are contained within the merchant shipping regulations which also set out the penalties for non-compliance. A breach of the regulations could result in a substantial fine or custodial sentence.' (MCA, 2013). It is clearly the intent that the COLREGs shall apply to all vessels.

The definition of a vessel presents a challenge in the MAS context, as systems are evolving across a wide range of sizes. The Naval Authority Group (NAG), as the certifying body for MoD Shipping, considers that if a MAS can transport one or more people, can be detected visually by another mariner, and appears as a ‘vessel’ then it will require COLREG certification. The implication of appearing to be a ‘vessel’ is that the observer in another vessel which is approaching the craft in question so as to involve the risk of collision would expect to apply COLREGs and would expect the other craft to do likewise.

The Collision Regulations are framed for traditional crewed vessels and in places some explanation of how they are to be interpreted in a MAS is required. The application of the COLREGs, along with some additional rules for autonomy, forms the basis for NAG Certification of any MAS and it may be expected that other bodies will form a similar view.

The implications for the MAS industry are that their systems will have to be able to meet the requirements of the COLREGs in order to achieve certification. The regulators perspective is that there is no overriding requirement for the use of autonomous vessels and that unless they can be used safely there is no need for them to be used at all.

The application of the COLREGs is deceptively complex and they may not be viewed in isolation, in interpreting them it is necessary to understand that they must be read subject to the ordinary requirements of good seamanship. The correct and consistent application of the rules by an autonomous system are a fundamental requirement and the regulator will require assurance that the MAS is always capable of operating in a compliant manner.

At first sight this would appear to create a significant obstacle to MAS deployment, as the rules are framed for a crewed vessel. However, with an adequate understanding of what constitutes the exercise of good seamanship, and of the rules themselves, it is possible for both the MAS operator and the regulator to satisfy themselves that a system is COLREG compliant. Fundamental to this appreciation is an acceptance of an argument of equivalence and an understanding of exactly what it is each element of the COLREGs is requiring of the vessel.

Rule 5 has often been referred to as an issue within the MAS community. Rule 5 itself is complex and far reaching, having direct implications for the application of many other elements of the COLREGs. If one looks past the words of the rule, the intent, the goal, is clear. The rule requires that: ‘Every vessel shall at all times

4 In this regulation ‘ships’ include hovercraft.

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maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.'

There are many aspects to a proper look-out however the two goals may be considered to be that:

a) That vessels and objects which represent a hazard to navigation are detected at sufficient range;

b) That vessels are assessed at the first available opportunity to determine the responsibilities between vessels.

The MAS Navigation Submission to the NAG will explain (along with other relevant aspects of the system) how the MAS will meet the goals of rule 5. By adopting an equipment agnostic goal-based approach to rules which do fit MAS architectures a robust argument of certification can be made.

It is possible that the development of a Goal Structured Notation will provide Classification Societies and Regulators with a framework within which to assess MAS COLREG compliance. The NAG are certifying autonomous systems and envisage that process (following the production of a Navigation Submission) culminating in an assurance test in an independent synthetic environment, during which the MAS will be tested in a range of lifelike encounters over a series of short voyages which test the systems application of the COLREGs. The MAS may include both autonomous and human elements, combined they must demonstrate that the system can operate in a compliant manner.

It is the view of the authors that a COLREG compliant MAS can be developed within the existing rules and certified based on equivalence in a goal-based framework, but this requires a proper understanding of the rules themselves and the intricacies of their practical application.

3.4. Critical operational aspects to be addressed by the enabling technologies

As mentioned in 1.4, it is appropriate to make comparisons between MAS and the CS approach to regulation given the similarities in complexity, CONOPS and interface requirements. This section looks at how CS regulates systems in comparison with our use case of surface MAS operated by the RN. CS areas which can transposed for our use case and areas which require further development are described.

An outline of the main areas of evidence required to certify complex systems for operational use in the RN are listed below. This certification approach requires evidence to be generated against the extant regulations relevant to each section and presented to satisfy the relevant MOD Authorities. This approach (framework) has been developed for systems in complex warships and focusses on the system's impact on the overall platform, e.g. the platform's safety propulsion system and the platform's manoeuvring system. The areas subject to certification are:

a) Safety Propulsion (Platform Authority / NAG);

b) Manoeuvring (Platform Authority / NAG);

c) Navigation Systems (Platform Authority / NAG);

d) System Security (CyDR (Cyber Defence and Resilience) / System Approving Authority);

e) System Safety (Platform Authority / System Approving Authority).

A MAS framework could encompass several 'groups' of evidence required to create a safe to operate argument:

Host Platform(s) Interface

a) Ship Air Safety (Platform Authority / Naval Authority Aviation).

b) Launch and Recovery (Platform Authority / NAG).

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c) MAS C2 & Monitoring (Platform Authority / MAS).

Surface MAS

d) MAS Safety Propulsion (MAS Authority / NAG). In addition to the usual requirements for a conventional ship the additional control and assurance of control between the vessel and any Remote-Control Centre (ROC) will need to be explained in detail.

e) MAS Manoeuvring (MAS Authority / NAG). As with propulsion the integrity of manoeuvre will need to be shown to be resilient.

f) MAS Navigation Systems (MAS Authority / NAG)

(i) Navigation Submission. This is the overarching explanation of how the system navigates and meets the COLREGs. The NAG has developed a rule set for autonomous vessels and the Submission also explains how these rules are met.

(ii) Naval Ship Code (NATO, 2019) Chapter IX. The NAG certifies against ANEP 77 and the Navigation Submission contains an explanation of how the requirements of these goal-based regulations are met.

(iii) The main issue for MAS in the sphere of safe navigation is the frailty of Global Navigation Satellite Systems, of which GPS is one. The Navigation Submission must also explain how safe navigation will be achieved in a GNSS denied environment (for instance a Coronal Mass Ejection).

g) MAS System Security (CyDR (Cyber Defence and Resilience)) / System Approving Authority).

h) MAS System Safety (MAS Authority / System Approving Authority). It is necessary to understand what system safety means in the context of the MAS itself. This could encompass the safety of embarked persons or simply be limited to manoeuvre to avoid collision and the avoidance of grounding in order to assure third party safety.

In terms of navigating safely and permission for waterways it is likely that, in the absence of an IMO structure, MAS operators will need to provide assurance to relevant administrations and authorities (such as flag states and harbour authorities) that their vessels are safe to operate. The UK Code of Practice and Guidance go some way towards this, but classification society certification is the next logical progression.

Safety, reliability, cost-effectiveness, IP and liability are important considerations. The reliability of systems in operation will need to be established over time. Demonstrating that operation is complaint and understanding how failures have occurred will be necessary. For this reason, MAS Voyage Data Recording standards will need to be developed, noting that the MAS/ROC architecture places very different needs on data recording and recovery.

3.5. Enabling technologies and tools

Tools on the market today have the capacity to test through simulation, in a synthetic environment and in real-world situations. The software used to operate MAS is often new and novel, therefore trust in it must be built. MAS lends itself to testing and assurance through simulation where the system can be taken through many tests quickly and safely. In the near future simulated tests are unlikely to have demonstrated complete assurance across all system aspects, therefore real-world testing will continue to feature as an element in certification strategies. Projecting forward it is anticipated that simulators will become reliable and trusted enough to use solely for assuring and certifying MAS.

An exploration of areas for speeding up the process will be beneficial. This will include research into where current usage of autonomous systems can be exploited, for example the automotive industry regulating self-driving cars.

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Tools that can be utilised for this purpose include:

Type of tool	Example
Operational analysis software	Agent based modelling, dynamic system modelling, discrete event modelling
Synthetic environments	Full platform simulation e.g. BMT REMBRANDT[5], AGILE[6]
Controlled testing facilities	Water tanks and at sea test areas e.g. BUTEC[7]

Table 1 - Tools that will enable assurance and certification of MAS

In comparison, testing of new CS is done at PTP in simulators and synthetic environments utilising a range of testing technologies. These tests have been accepted for replicating real-world operations fully enough to provide sufficient confidence in a system prior to at-sea testing. This process can be successfully replicated for MAS.

It is recommended that the process be iterative, initially assuring MAS within a synthetic environment before real-world demonstrations generate final certification. This robust process demonstrates compliance with rules and regulations whilst being succinct enough to enable systems to pass through certification and into operation quickly. It is important that a process enables efficient certification for in-service systems, as regular software updates need to be assured and certified.

The MAS industry has expended some effort in developing COLREG autonomy without, in some cases, an adequate understanding of the complexity of the regulations themselves. Attempts to apply the COLREGs in part has led to the development of systems containing fundamental flaws and which cannot achieve certification. System testing where tests have been conducted against an algorithm which may itself have a flawed understanding of the rules has resulted in vast testing which may be invalid. The synthetic environment must be appropriate, for example the effects of the environment must be adequately represented in testing. A framework for regulating MAS needs to guide designers and operators in their testing, ensuring the tests carried out are valid and can give confidence to regulators when they scrutinise the safety of the MAS.

The generation of suitable synthetic environment for the independent assurance as part of certification is critical. This requires not only the equipment and interface element but also a sufficiently robust assessment syllabus.

It will be necessary to identify new areas of technology to appropriately test the attributes required for assuring and certifying MAS. Many of these testing technologies are expected to be similar to those used in CS, however it may be necessary to develop new supporting technologies. Testing technologies available include synthetic environments, materials, modelling, integration, electronics, mechatronics, communications, cyber security, image recognition and haptics.

4. Timescale

4.1. Meeting the vision

The certification of systems for supervised autonomy is within the capability of regulators using their existing frameworks. The evolution of systems towards full autonomy requires the regulatory capability to expand at a commensurate pace. Essentially the regulatory process must expand to encompass the decision making of the autonomy controlling the MAS. To achieve this the independent virtual environment for assurance is key and should be developed ahead of the MAS it will need to test. This will require a common interface standard to enable candidate MAS to enter the synthetic environment for assessment.

5 BMT REMBRANDT is a versatile and readily configurable ship simulator which can be used to test operational capability within a high-resolution visual setting. https://www.bmtscd.com/products/

6 AGILE is a BAE Systems Tactical Data Link (TDL) test, simulation, emulation and training product. It allows testing and validation of a platform's capability. https://www.baesystems.com/en/product/agiletrade

7 BUTEC (British Underwater Test and Evaluation Centre) https://www.ltpa.co.uk/SitesAndRanges/Butec

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Understanding the requirements for and developing the MAS Voyage Data Recorder is essential for the in-service assessment of MAS performance, which may be a requirement for certification.

Rules and standards governing Remote Operations Centre provision and operation are also needed in order to assure and certify the human element of MAS operation. This should be led by Classification Societies.

4.2. Identify risks/barriers

Regulatory bodies need to develop the capability to understand and assure complex systems. A MAS presents a comparable certification challenge certification to a submarine, where compliance with statute (SOLAS etc) for a vessel of its class does not provide a sufficient level of safety in all modes of operation. The MAS certification process will require an in-depth understanding of how the system is constructed and is unlikely to be achieve by a simple carriage requirement and type approval structure.

Port Operations represent a significant challenge and MAS operators are only likely to succeed if cooperation with port authorities enables MAS operation within their confines.

The legal requirements for MAS operation should not form a significant barrier, as the liability for an incident will be determined under the COLREGs and where the actions of the MAS have causative potency blame will apportioned to the owners and operators accordingly.

Stakeholder agreement has the possibility to become a blocker. Flag Administrations, Classification Societies and other Recognised Organisations are already engaged with the MAS industry through the Marine Autonomous Systems Regulatory Working Group, and this may well represent the most appropriate vehicle for continued stakeholder engagement as the precise requirements for certification evolve.

Another potential blocker is the decision about who becomes the authority responsible for signing off these systems. The authority will be required to sign off evidence as well as necessary safety and security delegations with enough expertise of MAS to make considered judgements. This is expected to be the certifying authority, which will be the NAG for MoD Shipping.

5. Roadmap to develop the framework

The next steps to take on the roadmap to forming a framework are suggested as follows:

a) Market survey;

b) Recommended governance arrangements;

c) Facilitate collaborative development of regulation with the stakeholder community;

d) Regulation development guidelines;

e) Create alternative or MAS specific regulations.

6. Recommendations

This paper details the areas which need to be addressed in developing a regulatory framework for MAS, in doing so highlighting areas which require investment from the sector. It will be extremely important to engage with all stakeholders in the MAS sector to ensure the vision for future regulation can be agreed and eventually reached.

In looking into maritime regulations, some of the rules which are seen to be major blockers by the MAS community can be worked with and adapted to MAS in their current form. This will require clarification from the regulators in the form of discussion or additions to the regulation wording. It is expected that some new regulations will be required for MAS in the future.

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It is recommended that a framework could encompass several ‘groups’ of evidence required to create a safe to operate argument for giving authorities confidence in the MAS, similar to that used by CS. The development of appropriate testing software and facilities will enable MAS to produce this evidence.

The development of a virtual environment for assurance of software, which is recognised by approving authorities, is vital to the future of MAS certification.

7. Conclusions

Establishing a regulatory framework for MAS is a challenging task, but a key enabler to the effective adoption of autonomous vehicles in the maritime sector. Through developing a process and approach, this paper outlines tangible steps in developing a regulatory solution. Active participation from the wider maritime sector is vital to the success of this approach. It will also be crucial to utilise work done in other areas (such as CS) to ensure we develop a fully functioning framework in the timescales required. Further contribution to this work is required in order to detail the development process of regulating MAS and progress towards a full regulatory framework.

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