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Beware of the Low-Hanging Fruit – Autonomous Vehicles in the Maritime Dimension

T. Lim
S. Rajaratnam School of International Studies, Nanyang Technological University, Singapore

ABSTRACT: Autonomous vehicles have seen a meteoric rise in popularity amongst governments and corporations looking to utilize technology for both economic and strategic gains, both on land and out at sea. This paper focuses on the entrance of autonomous vehicles into the maritime dimension, examining the reasons driving the burgeoning reputation of autonomous vehicles out at sea, before dissecting some of the myths behind these reasons. The article will first assess three core reasons behind the rise in demand for autonomous vehicles out at sea, before contending that the benefits of introducing autonomous vehicles out at sea have been overblown, and that there are structural concerns and limitations that will hamstring the practicality of using autonomous vehicles in the maritime domain. These concerns intersect with the domains of technological maturity, maritime security, as well as international law, and that a presumptuous push for the widespread implementation of autonomous vehicles in the maritime domain will increase the dangers faced by seafarers out at sea, going against the natural progression of maritime operations.

1 INTRODUCTION

This article will analyze the implications regarding the application of automation into activities conducted out at sea, with a specific focus on autonomous vehicles and their operations inside the maritime dimension. Firstly, the paper will delve into the history of automation and assess the current state of affairs with regards to the infiltration of autonomous vehicles into the maritime industry itself. Secondly, the paper will examine the drivers of this trend of infiltration by looking at its material benefits and structural considerations presented to the relevant stakeholders in accordance with changing times. Thirdly, the paper will dissect some of the above-mentioned drivers, before thereafter contending that some of the benefits of autonomous vehicles in the maritime dimension has been over-stated, and that current technological developments are not yet conducive for the introduction of full-fledged automation out at sea. Fourthly, the paper will discuss other nexuses that have the potential to threaten the applicative practicality of autonomous vehicles into the maritime dimension itself, such as the role of the human element, as well as legal and political complications. Fifthly, the paper will offer a visual label by likening the implementation of autonomous vehicles into the maritime dimension to the concept of a low-hanging fruit, offering a cautionary take that delineates some of the concerns surrounding the infiltration of autonomous vehicles into the maritime dimension.

2 A HISTORY OF VEHICLES

The first traces of automobiles go back to 1886, when German Carl Benz patented and unveiled the Benz Patent-Motorwagen, largely viewed as the world's first functional automobile and car. Benz's creation laid the foundations for a land-based revolution that has transformed transportation methods around the world, providing convenience to individuals while increasing production efficiency, allowing governments and industries to utilize automotive technologies to drive economic growth on unprecedented levels. Since then, despite a decade characterized by meteoric technological developments across a multitude of sectors, cars have largely retained the overarching functional frameworks put forth by Benz's first patent – an engine mounted on wheels for travel on-land, with its travel speed and direction controlled by a human. However, recent centuries have been marked by a rapid development of autonomous technology, targeted to equip vehicles with certain levels of autonomy, defined by the United States' (US) Department of Defense (DOD) as a set of capabilities that enable a particular action done by a particular system to be automatic, or, within programmed boundaries, self-governing in nature [1]. These theoretical designs of autonomous technology have already transitioned to practical application on land, with Tesla's development of Autopilot 2.0 as the hallmark example of autonomous cars offering Full Self-Driving (FSD) capabilities for users. States have begun implementing domestic infrastructure developments to allow for the unfettered operation of autonomous land vehicles on their roads, and conglomerates such as Apple and Google have also re-directed resources towards the development of Artificial Intelligence (AI), particularly with the development of in-house mapping applications, in an ambitious attempt to capture the autonomous vehicle markets. With relevant stakeholders continuing the incorporation of autonomous land vehicles into their daily operations, market research experts have forecasted the global autonomous vehicle market to hit $2,796.33 billion in total value by 2032 [2].

3 AUTONOMY IN THE MARITIME DIMENSION

The most rudimentary definition of autonomy would refer to either self-regulation or self-government, essentially seeking to execute a particular task that was previously performed by a human [3]. Porter captures the essence of autonomous vehicles with a simple one-liner – vehicles powered by autonomous technologies, without needing human control [4]. While the "autonomous" terminology is often used across different industries to represent different things, a common classification that most invoke specifically for vehicles, both on land and out at sea, would be the Society of Automotive Engineers (SAE) taxonomy for levels of driving automation, an indicator which classifies automation levels from Level Zero to Level Five [5].

Looking into the maritime dimension itself, it is evident that automation has already infiltrated into both the commercial and military sectors, with these autonomous vehicles used for a variety of activities ranging from traditional product transportation to even marine science research. Furthermore, these autonomous vehicles have also been identified for an entire spectrum of uses such as oil spill removal, cargo shipment testing, fish abundance estimation surveying, and even for acts of terror [6] in recent years. Prior to the rise of the above-mentioned autonomous revolution in the past century, the maritime industry had already seen widespread usage of different variants of autonomous vehicles – in particular, unmanned underwater vehicles (UUVs) and remotely operated vehicles (ROVs). The commercial potential of these variants was only recognized after the discovery of offshore oil and gas resources nestled in the bottom of the North Sea – offshore corporations needed to develop automobiles with the capabilities to operate in extreme depths of the sea, while state militaries required these low-cost assets to execute covert surveillance missions and bottom-of-the-sea defense expeditions such as mine planting [7]. In an era where stakeholders, both public and private, prioritize the concept of value maximization heavily, such dual-purpose assets have become attractive propositions for governments and institutions looking to increase the efficacy of their monetary investments. This proliferation of autonomous vehicles has continued with the changing times, earmarked by the development of new variants that possess operational capabilities on the surface of the sea (unmanned surface vehicles – USVs / maritime autonomous surface ships – MASSs) and in the air (unmanned aerial vehicles – UAVs). Klein offers an umbrella-level terminology that aims to capture all the variants of autonomous vehicles in the maritime dimension under its entire auspice – Maritime Autonomous Vehicles (MAVs), defined as a variety of vehicles that operate both above, below, as well as on the surface of the ocean autonomously [8].

Delving deeper into MASSs and USVs, the meteoric growth of the MAV industry has exceeded all expectations, with industry bigwigs such as Rolls Royce, Mitsui Lines and Kongsberg shelving out significant resources into developing autonomous ships for container transportation [9]. Militaries have also identified the potential of MAVs in improving maritime defense operations such as anti-submarine warfare, with a specific focus on intelligence, surveillance and reconnaissance (ISR) capabilities. The United States of America (U.S.) Navy unveiled its Unmanned Campaign Framework on March 2021, a defense strategy aimed at fusing MAVs into its maritime operations to expand its naval warfighting capacity [10], while Japan announced plans to transform 50% of its domestic vessel fleet to MAVs by 2040 [11]. Other Indo-Pacific countries such as Korea and Australia have also unveiled plans to develop MAVs, with renowned Israeli USV manufacturer Elbit Systems announcing in 2021 its successful receiving of contracts worth approximately $56 million to provide USVs to an unnamed state navy in the Asia-Pacific region [12]. It is evident that international arms manufacturers have accurately identified the onset of the autonomous revolution in the maritime industry, thereafter attempting to jump onto this hype by constructing and employing MAVs for a wide variety of scientific, hydrographic, and military (both

ISR/offensive) applications in a bid to capture maximum economic gains [13].

4 MARITIME AUTONOMOUS REVOLUTION: THE DRIVERS

Any discussions about the proliferation of autonomous vehicles in the maritime industry has to start with a profound appreciation of the drivers behind the above-mentioned autonomous revolution – these drivers are more often than not, multi-directional in nature, and can be unpacked in terms of both material benefits and structural limitations. A survey conducted by the Institute of Marine Engineering, Science & Technology pointed to the primacy of corporations developing new technologies – more than two-thirds of the surveyed industry stakeholders pointed to technology providers as the primary drivers of the autonomous revolution in the maritime industry, while 44% of respondents expressed support for the introduction of MAVs into the shipping sector, compared to 33% who disagreed [14]. The same survey also asked its participants about the basis on which they would thereafter support the adoption of MAVs in the shipping industry, and the top three answer quoted were reduced operational costs, enhanced safety and increased operational efficiency [15]. Other less talked-about benefits would include increased ecological and social sustainability, as well as environmental advantages due to fuel savings.

4.1 *Driver #1: Cost Savings*

Delving deeper into the primary benefits of implementing MAVs into maritime operations, predictive studies have forecasted that the introduction of MAVs into commercial cargo schemes would generate an 5-10% improvement in the ship's life cycle costs per vessel due to fuel efficiency improvements and cost reductions from crew savings, with this percentage potentially rising up to 22% per transport unit [16]. Without the need for a living human element in these MAVs, there would be increased economic flexibility in terms of fuel expenditures, labour costs and ship design in particular, as MAV manufacturers can eliminate considerations of building a living space for the on-board crew. Resultantly, reducing the need for an on-board human element would allow for an industry-wide re-organization of manpower and the direct cutting of operational overhead costs, generating significant cost savings and longer vessel operation hours. Over 80% of the world's cargo transportation goes through the sea, and the successful infusing of MAVs as a reliable transportation system into current commercial maritime transportation operations would generate massive savings in cost for industry stakeholders [17]. Furthermore, space can be optimized and these MAVs can be designed to be more streamlined and wind-resistant [18], which would unlock significant amounts of untapped potential as manufacturers can now develop lighter and smaller vehicles, which would eliminate the need for states and corporations to invest into infrastructure building to aid the safe operations of larger vessels (port building / sea depth development), thereafter allowing manufacturers to develop lighter vehicles that would reduce cost and increase operational efficiency.

4.2 *Driver #2: Enhancing Safety*

The other primary benefits of MAVs commonly touted by industry stakeholders is the enhancement of safety – quantitative studies conducted by multiple scholars contend that more than 80% of casualties occurring inside the maritime industry can be attributed to some form of human error [19], and the view that human error is the main cause of vessel collision is one held by a majority of stakeholders inside the maritime industry itself [20]. The introduction of MAVs would reduce the need for a physical human element inside the vehicle, thereafter eliminating human factors such as negligence, fatigue, and non-compliance from safety calculations in its entirety. A quantitative study of past accidents by Wróbel et al concluded that the introduction of MAVs that fulfil Lloyd's Register Autonomy Level 5 (AL5) scale requirements would significantly lower the occurrence of maritime accidents [21]. More importantly, MAVs' most tangible safety benefit comes in the form of increased human security, as the removal of the on-board human element would ensure that the operator is not put in danger during the conduct of dangerous operations out at sea. The U.S. Navy has already been conducting tests for various USVs meant to conduct dangerous operations out at sea such as mine and anti-submarine warfare [22], with U.S. manufacturer Bollinger Shipyards being awarded a US$122 million contract in 2022 to produce MCM USVs for the U.S. Navy. The continued development of MAVs would allow these vehicles to extend their reach, enabling militaries to conduct increasingly complex military operations deep in their adversary's anti-access zones without putting their own forces in the path of harm, resultantly pushing the boundaries of military missions in the maritime sector [23]. Put simply, the removal of people from the purported 'line-of-fire' would undoubtedly increase human security and enhance the overall safety of operations inside the maritime industry itself.

4.3 *Driver #3: Structural Limitations*

Another driver that is less-mentioned would be structural limitations facing states and corporations amidst an ever-changing global climate. With the 21st century being characterized by COVID-19 and de-globalization, many countries have been dealing with internal domestic issues ranging from falling birth rates to the slow digitalization of operations, and stakeholders will be forced to constantly adjust its social and economic infrastructures to meet the requirements of the near future and beyond. Looking at Singapore, many have discussed the onset of its Silver Tsunami, with Singapore projected to be classified as a super-aged society by 2030 according to the United Nations' (UN) classification, with more than 20% of its population aged 65 and above [24]. Alongside the small island-state's low fertility rates, the pool of national servicemen available has been shrinking, and the Republic of Singapore Navy (RSN) has attempted to optimize its operations to function with leaner manpower through the development of its own Maritime Security (MarSec) USV, which was deployed out to Singapore waters for sea trials in end-2021 [25]. This move can be characterized as Singapore's recognition of its domestic structural constraints – these urban mobility challenges have become the direct drivers pushing the RSN to adjust its maritime operational structures to deal with the city-state's changing demographics. Furthermore, the issue of changing social demographics is more acutely felt inside the maritime industry due to the nature of the work involved – labour in the maritime sector is characterized by long periods at sea or off-shore, monotonous and dangerous working conditions (especially for the defence sector), and resultant disruption to family life – the traditional requirement to be out at sea for prolonged periods of time is becoming an increasingly unpopular prospect for younger generations of the workforce [26]. With generational change-over also holding relevance for the maritime sector, the push for MAVs is essentially technological advancements seeking to replace seafarers with an autonomous system that would allow for work to be completed from the comforts of the shore.

5 UNPACKING THE MYTHS: OVERBLOWN CALCULATIONS

The appeal of MAVs is apparent to most – the successful integration of autonomous vehicles into military set-ups would directly eliminate the potential risk of loss to human life in the conduct of dangerous operations out at sea, and the possibility of completing defence-related maritime operations such as mine removal, as well as the ability to conduct deep-water expeditions for marine scientific research without putting the human element in harm's way is a tantalizing prospect for all relevant stakeholders in the maritime industry. It is evident that the core tenets of the above-discussed drivers of the autonomous revolution in the maritime industry remain largely valid, founded on assessments of logic. However, this paper seeks to offer an alternative perspective – that the calculation elements of cost savings and enhanced safety/security has been overblown to a certain extent, and an unpacking of myths is required for a proper evaluation of the applicative practicality of autonomous vehicles inside the maritime dimension itself.

5.1 *The Cost Fallacy*

Firstly, the narrative of reduced cost certainly holds validity – cost savings in the form of reduced manpower costs and increased operational hours due to flexibility in vehicle design cannot be ignored, and while this spending was initially seen as sunk cost industry-wide, the potential of MAVs to unlock this element cannot be ignored, as industry stakeholders seek to exploit these benefits. However, it is important to note that there will definitely be an asymmetry of benefit measurement inside the maritime industry itself, as stakeholders in different sub-sectors will undoubtedly have different cutting interests. While labour shortages remain as one of the structural constraints causing an accelerated push towards MAVs, sub-sectors that have lesser labour cost outputs would not find MAVs as attractive when compared to sub-sectors with higher crew costs. The application of MAVs into the maritime industry needs to be put into perspective – sub-sectors that conduct operations with shorter sea routes and smaller ships (such as navies, intra-water border security etc) would certainly see more potential in MAVs as compared to sub-sectors that conduct daily operations with larger ships, alongside longer routes cutting through the open seas (container shipping, warship manufacturing etc). Relevant players would need to take a step back from the massive hype surrounding automation, and to properly assess whether the introduction of MAVs into their maritime operations would be as value-worthy a choice as it seems at first. The infusion of MAVs into maritime activities is not a simplistic vessel-for-vessel replacement issue – governments and industries would have to strengthen port capabilities to provide the necessary infrastructure for the docking of these MAVs, while also ensuring that there are sufficient technological coverages to prevent the MAVs from becoming victims of cybersecurity attacks.

This raises the question of whether the development of autonomous technology is truly mature enough to support operations in the maritime sector – countries have re-diverted significant portions of its budget towards investing into autonomous vehicles both on land and out at sea, yet yielding notably mixed results. For example, the U.S. Navy had invested nearly 17 years and $706 million of taxpayer money into the development of the U.S. Remote Multi-Mission Vehicle (RMMV), a UUV that was designed by Lockheed Martin to find, classify and remove mines from under water. However, the RMMV's reliability had failed to meet expectations and it led to the U.S. Navy terminating purchases at just ten units, down from its originally-planned 64, in March 2016 [27], eventually scrapping the RMMV project entirely inside the same year due to reliability issues and communicative difficulties. Former U.S. Senator John McCain criticized the RMMV project as an indefensible failure, while noting that the cost per system had risen throughout its development, yet delivering little results [28]. While the U.S. Navy's failure here is just one heavily-publicized example of a MAV developmental project that failed to live up to its initial billings, this leads to further suspicion regarding the cost savings of MAVs – while its benefits are recognized, the path trodden by stakeholders inside the maritime industry to achieve automation via developing MAVs could possibly be, similar to the RMMV, an extended and costly project that would end as an wastage of significant resources that could have been re-invested elsewhere for better results.

Furthermore, the purported potential cost benefits resulting from the removal of the human element from maritime operations should also be relooked at – multiple scholars have contended that the benefits of removing the human element from the equation has been, to a large extent, overblown. There is quantitative validity in benefits arising from the exclusion of the living human element from vessel operations – for example, it would remove the need for sewage treatment plants on-board, thereafter leading to reduction in infrastructure costs and stronger profit margins due to increased operational efficiency [29]. However, the removal of the human element represents a basic task-transfer operation, as the tasks previously performed by the on-board human element would now fall into the hands of the MAV operator back at shore. Of course, this argument is founded on the level of autonomy that MAVs eventually attain, but the crux of the issue remains: it is functionally difficult to imagine a scenario where MAV operations are able to achieve complete autonomy without the requirement of any human involvement, whether remote or physical. Human supervision would likely still be required in the case of an emergency, as the MAV's controller would be required to be on standby to take over control of the MAV in a case of an emergency. The attempted removal of the on-board human element via the development of MAVs could lead to increased human labour at shore or increased resource usage via developing port infrastructures, and cost savings would be resultantly minimal [30].

Another unintended consequence of the removal of the human element is related to marine insurance, and the development of MAVs will certainly lead to seismic changes for the insurance industry for ships and vessels. The official classification of MAVs remains largely ambiguous at this point, and existing frameworks in the marine insurance industry has not listed clear guidelines for coverages related to ships and vessels with autonomous technologies [31]. The issue of liability assignment would be a tricky one for the industry to solve, as the presence of the human element allows for easier apportioning of fault – if a collision out at sea occurs due to a technological malfunction, it is difficult to identify where the liability falls on, and the lack of the on-board human element as a failsafe option could lead to a spike in insurance costs for the maritime industry.

Another point to debunk the cost myth is related to the manufacturing of MAVs itself – there are technical infrastructural concerns that come with the designing of a MAV that can reliably reproduce the functions of a typical maritime vehicle out at sea. Building on the previously-articulated arguments, industry experts have contended that the potential saving in manpower costs by reducing the crew members on-board would simply be a transfer of these costs onto the shore, and that this cost reduction would be relatively inconsequential compared to the total expenses required for the safe operation of the vehicle [32]. Looking into the power sources of ships and vessels, there is a widespread usage of lithium-ion batteries to power their operations due to its higher energy density than other battery options. However, lithium-ion batteries have faced long-standing criticism about safety issues due to the potential for fire hazards, a risk that is ironically enough, amplified out at sea, as these vehicles often operate directly under the sun for extended periods of time. MAV manufacturers have attempted to circumvent this via designing vehicles powered by diesel or renewable energy sources, and platforms using these sources would be designed to exhaust their engines while charging onboard batteries using solar power. However, using diesel or renewable energy-powered engines would require additional machinery-control autonomy features to change operational speeds on the fly, which adds a layer of complexity to MAV manufacturing processes [33] – this resultant complication could end up eating into any of the 'saved costs' while even threatening to potentially create more infrastructure-related costs for the entire maritime industry during the shipbuilding phase, as well as the integration phase of MAVs into daily operations.

5.2 *The Safety Fallacy*

Secondly, the narrative of enhanced safety and human security also has obvious merits – the potential of MAVs to remove the on-board human element from harm's way largely reduces the occurrence of maritime accidents caused by human error and takes the operator out of harm's way when conducting operations of a more intrusive and dangerous nature, while unlocking the potential of MAVs to conduct marine expeditions that were previously impossible with a human on-board. However, the strength of this narrative can be whittled down when connected to the underlining argument of Section 5.1 – the removal of the human element would be a simple transfer of safety and security-related issues from the on-board operator to the human element on-shore. The development of MAVs largely hinges on their automation levels and whether these vehicles are able to reliably abide by laws governing the maritime dimension (maritime traffic rules), as well as whether they are able to perform the functions of a normal vessel, as delineated by the International Maritime Organization (IMO) and the UN Convention on the Law of the Sea (UNCLOS). Removing the human factor from ships and vessels without the full assurance that autonomous technologies are able to reproduce human functions could be a recipe for disaster, with the example of internal fires and explosions out at sea being relevant here – removing the human element could equate to the removal of a failsafe reactionary option in the case of serious emergency, which could complicate matters out at sea or even lead to more maritime accidents occurring with the introduction of MAVs. Taking reference from the IMO's International Convention for the Safety of Life at Sea (SOLAS), SOLAS requires periodically unattended ships to have fixed local fire-fighting systems with both automatic and manual release capabilities [34], and putting the MAV's fire-fighting capabilities in the hands of an autonomous system still seems like a distant possibility. Furthermore, SOLAS Regulation 17-1 (that entered into force in July 2014) dictates that all ships are required to have plan and procedures for the recovery of persons of waters [35], and the removal of the human element could hamstring the ability of vehicles out at sea to conduct rescue operations on persons-in-need. While the removal of the on-board human element certainly enhances human security from one angle, attempting to construct and implement MAVs into maritime set-ups could be a costly process that could end up putting other seafarers at risk. This safety and security issue is further exacerbated by a simple thought: if countries and corporations start integrating MAVs into their operations, there is a possibility of human security being complicated due to the lack of the human element to make on-the-spot judgements to rescue persons out at sea – MAVs could end up endangering more seafarers out at sea and resultantly leading to more complicated safety and security risks than originally imagined, if the relevant stakeholders do not conduct proper planning, war-gaming, assessments and trials while hastening the process of introducing automation into the maritime industry.

5.3 *Jumping the Gun*

Furthermore, while the security of the operator is protected, gunning for the short-term benefits of MAVs without truly understanding the depths of autonomous technologies could lead to the opening of a can of worms for all stakeholders inside the maritime industry itself – cyber-security threats. There are risks and vulnerabilities associated with the operation of MAVs and this could expose the maritime industry to cyber threats, including attacks on the MAVs itself or other areas of the maritime industry that are reliant on technology for operations, such as automated gantries controlled by software, MAV docking systems and autonomous tugs. Attacks on these segments are major unknown factors as these cyber-hackers could potentially alter data-gathering computers and systems, which could cause significant damage to the overall functioning of the maritime industry [36]. Any flaw in the design of the software governing the control of MAVs' movements and operations could be disastrous as well, as this could give unauthorized access allowing criminal elements to take control of the electronics of a MAV – which could lead to disaster on an unimaginable scale. The above-mentioned problems are particularly relevant, especially when looking at the sea-based transport of natural gas and oil. Past notable cyber-security attacks include targeted strikes on shore-side corporation such as Saudi Aramco, the world's most valuable oil producer, as well as on the IMO itself in 2020, when its website and web-based services were breached by a cyber-attack according to its official press release [37]. Another hallmark example of cyber-attacks in the maritime sector is the LockBit ransomware attack on Petrologis Canarias, a supplier of maritime refuelling services, in 2021 – a simplistic display of the fragility of the maritime domain to cyber-security attacks [38]. With these natural resources notoriously known for its profit margins and flammability, if the implementation of MAVs is rushed without the necessary cyber-security precautions set in place, this could potentially lead to exacerbated safety and security concerns, setting the stage for seaborne disasters on an unimaginable and potentially irrecoverable scale.

The dynamic and ever-changing cyber environment necessitates a constant updating of the maritime industry's technological systems, security features and threats to defend MAV users against cyber-attacks, and the field of cyber-security has become one of increasing concern for the IMO and other international bodies [39]. While the IMO has provided additional documents to cover risks related to the cyber space such as the Guidelines of Maritime Cyber Risk Management in 2017, some scholars have contended that the legal acts, standards and draft in place do not pay enough attention to the cyber-security of MAVs, arguing that the IMO has not developed an up-to-date standard for assessing cyber-security risks, while postulating that the IMO lacks any functional mechanism to exert influence on owners and manufacturers of ships [40]. Klein essentially offers the same argument by stating that the number of states who have ratified the Convention for the Suppression of Unlawful Acts Against the Safety of Maritime Navigation (SUA) in its entirety remains low [41] – the IMO website states that while 94.88% of states had ratified the original SUA 1988, only 39.74% of states, which amounts to 52, have ratified the updated 2005 Protocol to SUA 1988. While there are other underlying issues that have contributed to the low signatory/ratification rates of the 2005 Protocol, the non-ratification would mean that a large majority of states are not covered under the legal umbrella of the IMO, as the SUA Convention is the primary safeguard in the case of a cyber-security attack meant to cause death, serious injury or damage to others. States' non-signature and/or non-ratification would undoubtedly complicate safety and security issues plaguing the development and implementation of MAVs in the maritime industry.

A proper unpacking of the myths surrounding the drivers behind the autonomous revolution in the maritime industry presents grounds justifying the gross over-calculation of benefits that industry stakeholders have imagined for MAVs to contribute to their operations. Firstly, while the complete removal of the human element from maritime operations seems logical in theory, it is still impractical and unrealistic in actual application. For full autonomy to be achieved, MAVs need to be in-built and retrofitted with a myriad of operating systems that will fulfil the requirements of a ship set forth by the IMO and allow it to travel in accordance with maritime traffic rules, while autonomously equipped to reproduce the functions that were previously fulfilled by the on-board human element. A survey conducted by the Institute of Marine Engineering, Science and Technology revealed significant levels of pessimism towards the replacement of the human element, with 85% agreeing that seafarers would continue to be an essential component of the long-term future of the maritime shipping industry [42]. There was also notable ambiguity towards the prospect of human operators being replaced by autonomous technology and machines – with more than 80% expressing concern towards the potential impacts of MAVs to the maritime industry itself, citing examples such as Tesla's car crash while operating on its Autopilot technology [43]. While recognizing the tantalizing prospects surrounding the future of autonomous vehicles, this paper contends that similar to how autonomous land vehicles have yet to reach full autonomy, the development of MAVs remains a far cry from reliably replacing the on-board human element in its entirety.

Secondly, while the increasing relevance of the above-discussed drivers have added societal pressures on governments and corporations to look towards autonomous technology as a solution, this paper contends that the relative immaturity of the autonomous vehicle dimension means that a rushed implementation of MAVs without understanding its operational framework and limits would open a bag of worms and lead to complications that could cripple the entire maritime industry's operations. The depths of autonomous technology have not matured to a stage where it is able to reliably perform all the functions imagined by the wider international community, and its rushed introduction could possibly lead to the reverse effect from intended, in the form of additional exorbitant costs and increased danger sprouting from categories such as emerging cyber-security threats and increased occurrences of maritime collisions.

6 OTHER NEXUSES OF MAVS: COMPLICATING THE EQUATION

After unpacking myths surrounding drivers of the autonomous revolution inside the maritime industry itself, this paper seeks to go one step further by looking into other implications surrounding the implementation and applicative practicality of MAVs into maritime operations in both the commercial and military sectors. A working label is attached to discussions in this segment – Other Nexuses of MAVs, which will be divided into two sub-discussions. The first will discuss the legal status of MAVs in international law and its ambiguous political status with respect to maritime travel, while the second will look at structural constraints and the overall operational environment itself.

6.1 *Legal Complications*

First off, an appreciation of MAVs and its label, legal position(s) and rights in international law is only possible after understanding the international organizations (IOs) and conventions set forth to delineate rules and streamline behaviour inside the maritime industry. The IMO is a specialized agency under the UN's Economic and Social Council, the global standard-setting agency primarily responsible for the security, safety and environmental performance of the shipping industry [44]. Some of the more prominent and known IMO conventions include the International Convention for the Prevention of Pollution from Ships (MARPOL), the Convention on the International Regulations for Preventing Collisions at Sea (COLREGS), and the previously-discussed SOLAS – the IMO designed these conventions as regulatory frameworks meant to dictate the rules in the maritime industry, and to guide ship and seafarer behaviour out at sea ever since the IMO's formation came into force in 1958. However, the kicker lies herein – the regulations and conventions designed by the IMO were clearly written for manned vessels, or essentially, human-controlled ones. This is understandable given the fact that autonomous technology was an undeveloped and far-away possibility at the time, but potential cracks in the glass start to emerge when thinking about how the rules are going to apply for MAVs that eventually do not require the on-board human element, especially those that are able to attain full autonomy.

Following the rise of autonomous technology to prominence in the maritime industry, the IMO's Maritime Safety Committee conducted a Regulatory Scoping Exercise (RSE) for the use of MASSs – it provided a working definition for MASSs and set four degrees of autonomy that will be used for the classification of autonomous vehicles in the maritime dimension. Degree One and Two still includes the presence of the on-board human element, while Degree Three is the classification for remotely-controlled ships, with Degree Four referring to fully autonomous ship [45]. MAVs that are classified under Degree Three and Four autonomy would face issues when attempting to apply the regulations of other IMO conventions that were written earlier in time. This in-built problem can be illustrated by first looking at MARPOL – MARPOL Regulation 37 indicates that in the event of an oil pollution incident, every ship has to carry a Shipboard Oil Pollution Emergency Plan (SOPEP) on-board that describes the immediate action taken by persons on-board to reduce and control the discharge of oil into the ocean [46]. It is evident that SOPEP was drafted under the assumption of the presence of an on-board human element, and without it, MAVs would be unable to meet the requirements of a SOPEP set by the IMO. Incidents of accidental discharge of pollution into the sea are extremely harmful to marine biodiversity, and adaptations/adjustments would have to be made to many other IMO conventions beside MARPOL, to ensure that MAVs can be properly and safely infused into the daily operations of the maritime industry. History is irrefutable evidence of the long-drawn process when it comes to re-drafting of international conventions, one that requires the continuous investment of time, resources and energy, and attempting to introduce autonomous technology into the maritime industry without accurately drafted IMO conventions in place could produce safety and cost complications on a potentially unimaginable scale.

While not dismissing or undervaluing the importance of environmental protection, the issue of adaptation is even more pervasive when looking at the Convention on the International Regulations for Preventing Collisions at Sea (COLREGS). COLREGS came into force in 1977 and as its name suggests, it is the primary IMO document that serves to prevent collisions out at sea – it delineates the rules of maritime traffic and applies to all vessels that can be used as a means of transportation on water. In this case, the position of MAVs is clear – regardless of the presence of the on-board human element, MAVs are expected to comply with COLREGS. Questions have been raised over whether MAVs are able to maintain total compliance – Li and Fung points to the primacy of the role of the master's role when on-board a ship, while raising their doubts over the ability of unmanned ships to replace the on-board role and to discharge the master's responsibilities in ensuring the safe operation of the vessel, in line with international maritime law [47]. A few concerns come to the surface when attempting to analyse MAVs and COLREGS, and many scholars have raised concerns over the ability of autonomous technology to replicate functions of the on-board master – Rule 14 of COLREGS states that when two power-driven vessels are on a collision course, both vessels are expected to alter their course to starboard in order to ensure that they will pass on the port side of the other. Turning starboard when on a collision course is delineated in COLREGS, but also forms part of an unwritten rulebook that mariners are expected to abide by when out at sea – these unwritten rules are often generated in hindsight after ship-ship interactions take place, and this rulebook allow for increased convenience and greater clarity. [48] Furthermore, Rule 5 of COLREGS states that every vessel shall maintain a proper look-out by sight and hearing and all other available means to make a full appraisal of the situation and of the risk of collision - Rule 5 is the hallmark example of an IMO convention that is written under the assumption of the presence of an on-board human element. While audio-visual sensors have been developed by the advancement of technology and a future where autonomous technology is able to fulfil Rule 5 can be visualized, there is notable ambiguity in the writing itself, with no further elaboration besides the one-liner summarized above. Carey contends that ship owners could find themselves subject to criminal liability for failing to obey COLREGS, if the terms of Rule 5 represent an implicit statement that delineates the compulsory requirement of an on-board human element [49]. While the RSE conducted by the IMO in 2021 has attempted to address the applicability of COLREGS to MASS and MAVs in general [50], clarity is still an issue, and the IMO will require more time to work with stakeholders inside the maritime industry to adjust the wordings of its international conventions to ensure that MAVs are able to operate safely out at sea.

The above-discussed ambiguity of MAVs and their legal and political position inside the maritime industry is further amplified by the classification of MAVs under the auspices of international law – UNCLOS does not provide an official definition for the terms, "ship" or "vessel", and a study of IMO's conventions does not provide further clarity – MARPOL Article 2(4) defines a ship as "a vessel of any type whatsoever operating in the marine environment …" – this appears to suggest that the two terms can be used interchangeably, and scholars have criticized the UN for failing to define either term [51]. Norris appears to use both terms interchangeably in his work [52] due to the same critical reasons, but other scholars like Vallejo have challenged this claim of interchangeability, contending that the term "ship" is built upon the term "vessel" [53]. The very fact that scholars are unable to identify a uniform position by both the UN and its IMO arm is a clear indicator that there is a serious problem of ambiguity in the writings of official IOs and international law as an extension – if ships and vessels are not allocated proper definitions by the relevant authorities, it would be even harder to identify the position to park MAVs under, and thereafter harder to assign liability to operators, seafarers and manufacturers of MAVs in the case of maritime accidents, which could prove to be both a logistical and political nightmare for stakeholders in the maritime industry.

6.2 *One is not the Other*

Secondly, it is also important that stakeholders consider the operational environment of the maritime industry itself when attempting to assess the applicative practicality of MAVs. This point is a simplistic, yet poignant one – key activities of the maritime industry are conducted out at sea, and the operational context has to be considered before attempting to introduce a new feature out into the high seas. Most autonomous vehicles operate via pre-computed geographical maps for self-navigation, along with a host of sensors and artificial intelligence to ensure vehicular safety and operational reliability. The success of autonomous technology on land should not come as a surprise – the management of road conditions, maps and navigational routes fall under the supervision of the state's ruling polity (and therefore have limited levels of variance), but this situation unfolds itself in drastically different manners out at sea. There are little demarcations of lanes and travel routes out at sea, and while the IMO and states have attempted to recommend and enforce specified sea travel routes for safer maritime operations, these enforcement mechanisms remain severely limited in nature due to other political and legal concerns surrounding issues such as conflicting territorial claims. Furthermore, the environmental effects of climate change also create a foreboding sense of unpredictability, as changing sea levels could produce new obstacles that could impede the navigation of MAVs out at sea, while essentially deeming the mapping of the maritime dimension as a near-impossibility.

7 BEWARE OF THE 'LOW-HANGING FRUIT'

The rapid advancement of technology in the past century has unlocked possibilities like never before – the prospects of mobile phones and unfettered internet access were viewed as dreams by past generations, yet these dreams have translated into actual reality, and the current generation is resultantly enjoying the ease of access and convenience that technology has afforded to them. This development has also encouraged many to dream about the limitless possibilities of convenience, from online shopping and cashless payment to ideas like self-driving vehicles. However, this paper seeks to attach a figurative expression to label the infiltration of autonomous technologies into the maritime dimension – the "Low-Hanging Fruit", which seeks to encompass all the concerns over MAVs and its applicative practicality into the maritime industry itself. As its name suggests, a low-hanging fruit is often used to describe an easily-achievable task or goal – and the purported success of Tesla's self-driving vehicles into countries' land transportation system is the paint on the surface here, a direct display of the potential of autonomous technology in vehicular operations. Along with the drivers of autonomy, the push for MAVs is understandable.

However, it is important that industry stakeholders have to consider the operational environment of the maritime dimension when attempting to introduce autonomous technology into ships and vessels. The potential benefits of cost, safety and security seem attainable at first glance, but a closer study would reveal that there are other concerns behind MAVs that could exacerbate these problems – attempting to pluck the fruit from the tree could end up collapsing the whole tree instead. Furthermore, the relative immaturity of autonomous technology, combined with the under-development of state and industry infrastructure, as well as the ambiguity surrounding the political and legal writings for MAVs, are further displays of the issues surrounding the applicative practicality of autonomous vehicles in the maritime industry itself. Without these technological, infrastructural and legal developments catching up, the rushed introduction of MAVs into maritime operations could prove disastrous. Putting these developments into context, the fruit might not be fully ripe yet – are we attempting to reap the rewards by 'plucking' the fruit too early?

7.1 *Conclusion – Pumping the Brakes*

As the wave of autonomous technology continue dominating discussions worldwide, both state policy-makers and engineering bigwigs should make it an imminent priority to re-assess the overall practicality and cost-benefit measurements surrounding the increased investment into the development of MAVs – these concerns present significant risk of implementation, and the rushed plucking of the 'Low-Hanging Fruit' could end up inflicting massive economic and political consequences on stakeholders inside the maritime industry. This paper contends that it is crucial to start pumping the brakes on the implementation of MAVs in the maritime dimension itself, and this paper intends to serve as a gloomy and cautionary tale for governments, automotive manufacturers and seafarers who rely on the continued operation of the maritime industry for survival – after all, unlike cars on land, ships and vessels simply do not stop instantly when the operator hits the brakes. Water simply behaves differently from land, ships and vessels have different operating systems from cars, and industry stakeholders have to start a level-headed reassessment of the supposed potential and applicative practicality of autonomous vehicles into the maritime dimension itself.

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