NAVIGATING THE FUTURE: ANALYSING MARITIME AUTONOMOUS SURFACE SHIP PROJECTS AND ANTICIPATING FUTURE NEEDS

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Keywords

MASS, Maritime Autonomous Surface Ships, projects, prototypes, analysis

Abstract

Maritime Autonomous Surface Ships (MASS) represent a transformative paradigm in the maritime industry, leveraging advanced technologies to revolutionize vessel operations. Despite the proliferation of MASS projects, there remains a critical gap in understanding their architecture, operational requirements, and socioeconomic impacts comprehensively. This review aims to address this gap by systematically analyzing existing MASS projects to identify key projects results and areas of focus. The results reveal discrepancies and some omissions in current projects, emphasizing the importance of a holistic approach in research and prototype projects to develop MASS effectively. By highlighting essential areas of focus for further research and prototype projects, this study contributes to advancing the understanding and implementation of MASS technologies. Ultimately, this research informs policymakers, researchers, and practitioners, facilitating the seamless integration of MASS into maritime operations and enhancing efficiency and safety in the maritime domain.

1 INTRODUCTION

Maritime Autonomous Surface Ships (MASS) represent a pivotal advancement in the shipping sector, embodying the convergence of cutting-edge technologies such as artificial intelligence, smart sensors, and wireless networks. With the dawn of the fourth industrial revolution, MASS promise to revolutionize various maritime operations, ranging from scientific research and military applications to commercial shipping and urban freight systems (Campbell et al., 2012) (Ahmad et al., 2011) (Ghaderi, 2020). As unmanned surface vehicles (USVs) become increasingly prevalent, their versatile applications encompass tasks such as hydrography, security surveillance, pollution monitoring, and resource exploration (Liu et al., 2016).

Moreover, the automation of cargo ships, driven by the imperative to address manpower shortages and enhance operational efficiency, underscores the transformative potential of autonomous technologies in the maritime domain (Manno, 2015). Automation in cargo ships started back in 1961, when Japan introduced the first automated ship (Kinkasan Maru) (Manno, 2015). The ship was equipped with an automated engine, which, at the time, demonstrated a breakthrough in remote operation and automatic control of the main engine. Scandinavian countries (e.g. Norway, Finland) follow suited and integrated innovative automation solutions to seagoing vessels (Manno, 2015).

The urban freight systems, on the other hand, considerably utilised emerging automated technologies, such as those in autonomous vehicles and driverless pods, unmanned aerial vehicles for urban delivery, 3D printing, and autonomous trains (Paddeu & Parkhurst, 2020) (Ghaderi, 2020). The advances in transport development by using automation and remote operation in vehicular, aviation, offshore, and aerospace are viewed as an opportunity for maritime transport to learn from and thus meet today's and tomorrow's challenges (Chen et al., 2016). It is worth to note that autonomous vessels are driven by many factors, such as safety improvement (Campbell et al., 2012), operational and supply chain efficiency (Ghaderi, 2020)(Alamoush et al., 2020, 2022; Alamoush, Ölçer, et al., 2021), improvement in decision making (Kim et al., 2019), environmental benefits (Li & Yuen, 2022)(Alamoush, Ballini, et al., 2021), and cost benefits (Tsvetkova & Hellström, 2022)(Alamoush et al., 2023). Furthermore, the International Maritime Organization (IMO) and other maritime authorities started devising guidelines and currently discussing future regulations for the operation of MASS to ensure safety and operability in international water, i.e., the coping exercise and its results (IMO, 2018) (IMO, 2021). To facilitate the integration of MASS with existing maritime infrastructure, standards for communication protocols, collision avoidance systems, and cybersecurity measures are being developed by different classification societies and manufacturers, e.g., DNV, Lloyds List and Register, Kongsbergs, etc.

As investigation of autonomous ships grows to span oceangoing vessels (Ölçer et al., 2023), it becomes increasingly important to study the development of automation technologies to eliminate new challenges and address ensuing impacts.

Research Problem

Despite the burgeoning interest and numerous projects focusing on MASS development, there exists a critical gap in the comprehensive understanding and integration of MASS architecture and operational requirements. Many existing projects may overlook crucial aspects or fail to provide a holistic view of MASS functionalities and technological needs. This discrepancy highlights the pressing need to identify gaps in current MASS projects and delineate areas for future research and prototype projects.

Significance of the Study

This study holds significant implications for both research and practice in the maritime industry. By systematically reviewing existing MASS projects and identifying gaps in their architecture and needs, this research aims to foster a deeper understanding of the challenges and opportunities associated with MASS implementation. Furthermore, by shedding light on areas requiring further exploration and development, such as advanced sensors, data analytics, and the role of the Ship Control Centre (SCC), this study will guide future research endeavors and prototype projects in the field of maritime autonomy. Ultimately, the insights gleaned from this study will inform policymakers, researchers, designers, shipbuilders, and maritime practitioners, facilitating the advancement of MASS technologies and their seamless integration into maritime operations (Ghaderi, 2020).

The outline of this study is as follows. While Section 1 introduced the topic, Section 2 provide the results of the global MASS projects, and Section 3 is the conclusion.

2 GLOBAL PROJECTS AND PROTOTYPES

Small size application of autonomous surface models were comprehensively reviewed (Schiaretti et al., 2017), which was mainly less than ten meters in length and mostly used for scientific purposes such as maritime monitoring, hydrography and survey, and military applications and oceanographic observation. However, the scope of the newly designed autonomous vessels is shifting from small size applications to bigger cargo ships. Considering the facts that MASS involve technical, operational and legal implications, several projects have been developing globally. Until now, several project have been successfully realised, in addition to a handful of others under development. In this study, the focus is on applications for commercial purposes, e.g. cargo, passenger, ferry ships in addition to large, automated tugboats, see Table 1. Many project prototypes have been developed recently all over the world. Some projects built the concept and requirement for MASS, others designed and operated automated cargo, ferry, and passenger ships and tugs (Table 1). The industry indeed is facing challenges that motivated them to move to MASS, sustainable shipping, environmental regulations, growing freight volumes, shortage in skilled seafarers (Ölçer et al., 2023).

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In the EU, the **MUNIN**[1] (Maritime Unmanned Navigation through Intelligence in Networks) was a platform to advance a feasible model of 200-meter autonomous **bulk carrier.** The project built the design and tasks including insights on MASS technical, economic, and legal viability. MUNIN indicated that MASS contributes to the EU sustainable maritime supply chains, via reduction of operational costs, and environmental impacts in addition to attracting skilled workforce (H. Rødseth & Mo, 2016) (MUNIN, 2016) (Burmeister et al., 2014) (Ø. J. Rødseth & Burmeister, 2015).

Rolls-Royce has boarded the autonomous ships journey within the Advanced Autonomous Waterborne Application (**AAWA**) project. AAWA's aim is to provide understanding of the current state of technical, safety, regulatory and financial aspects of MASS (Rolls-Royce, 2016), (AAWA, 2016). The project declared the technical characters and design description for the MASS concept model in 2017. AAWA laid out three phases timeline for MASS development, i.e., remote controlled vessel with reduced crew (by 2020), remote controlled unmanned coastal vessel (by 2025), remote controlled unmanned oceangoing vessel (by 2030), and autonomous unmanned oceangoing vessel (by 2035). By 2035, MASS would be able to autonomously conduct all operations which include decision making, action taking, and exceptions handling, in addition to being able to communicate with other moving vessels and extend cooperation to ports and other vessels in the fleet.

[1] http://www.unmanned-ship.org/munin/

Another collaboration is between Rolls-Royce and FinFerries through research project called "Safer Vessel with Autonomous Navigation" (**SVAN**). SVAN is an extension of the AAWA and funded by business Finland. In 2018, SVAN demonstrated the first fully autonomous ferry (Falco), which is 53.8 meter in length and capable of carrying 54 cars (Rolls-Royce and Finferries, 2018). The ferry sailed autonomously including berthing operations and object avoidance in one demonstration, and in another, sailed in remote control by a remote shore centre located 45km away from the ferry. Furthermore, Rolls Royce and Svitzer developed a remote 28 meter tugboat (**Svitzer Herold**). The captain of the tugboat remotely controlled safe navigation, manoeuvres, piloting, berthing and undocking from a remote control centre (Rolls-Royce, 2017). Similarly, Robert Allan Ltd developed autonomous fireboat and tugboat **RAmora** to assist in ships berthing (Hertog et al., 2016), and the **C-worker** designed off-shore unmanned vessel (oil & gas operations) (ASV, 2014). Such innovations are conceived as a way to address dangerous aspects of ship-handling that pose high risk on tugs' crews, like those of working under the deck and bow.

The DNV, a global classification society and registrar, advanced the unmanned shipping by building a design of an autonomous container vessel (**ReVolt**)[2] – with no crew onboard – for coastal and short sea shipping (SSS). ReVolt is a 60 meters and fully powered container ship. ReVolt sails at 6 knots speed, and is capable of carriage of 100 TEU (20-foot equivalent unit) for a range of 100 nm (natural miles) (DNV, 2015). ReVolt intends to operate in the territorial waters between Oslo and Trondheim (Norway).

The ship simulator manufacturer "Kongsberg"[3], has launched a project with Yara (a fertilizer producer) for the design and construction of the world's first unmanned electric (zero emission) 80-meter commercial ship (120 TEU) "**YARA Birkeland**". The ship electric propulsion depends on batteries that also provides a permanent ballast. After being remotely operated, the ship is set to go underway completely autonomous by 2022. Yara will ship fertilizer within Norwegian territorial waters (12 nautical miles from the shore) between Yara's production sites and three ports. Thus, Yara is anticipated to reduce 40,000 trips of diesel-run trucks per annum (Kongsberg, 2020). On the other hand, Kongsberg is developing a full-electric (zero emission) ferry concept, i.e. Autonomous Ferry (**PILOT-E**) (Kongsberg, 2017). Likewise, BOURBON marine offshore services company in collaboration with Automated Ships Ltd and Kongsberg developed a 37-meter vessel as the world's first autonomous – fully automated – prototype "**Hrönn**". Which is dedicated for offshore operations supporting energy, and hydrographic applications and fish farming industries. As it can be seen from the table, Kongsberg is deemed a catalyst in developing various projects, mainly small-scale projects, small container or cargo ships that operate within coastal water of Norway. These developments are viable, as it is feasible to request authorisation of small ships for working in national water, opposed to complex deep sea shipping international regulations.

In 2019, the Chinese unmanned cargo vessel (**Jindoyuyn O Hao**) set sail – developed by Yunhang Intelligent. The vessel is remote controlled and equipped with an electrified power plant. It uses the automatic navigation technology. The vessel is 12.86 meters in length, 3.8 meters in width, and has 1 meter draft. The vessel can sail at 8 knots speed. Under the same load capacity, builders can save more than 20 % on construction costs and 20 % on operation costs, while reducing fuel (emissions) consumption by 15% (navyrecognition, 2019).

The recent *Autonomous Shipping Initiative for European Waters (***AUTOSHIP**) project aims at accelerating the transition towards the next generation of autonomous ships in the EU. The project intends, by 2024, to build

[2] 1:20 scale model was built for testing.

[3] In April 2019, Kongsberg purchased (acquisition) Rolls-Royce Commercial Marine.

and operate two different autonomous vessels, and demonstrate their operative capabilities in Short Sea Shipping and Inland Water Ways scenarios, with a focus on goods mobility. AUTOSHIP is a partnership with research institutions, Kongsberg and Rolls-Royce, among others (AUTOSHIP, 2020).

A more specialised studies were also undertaken, e.g. SINTEF's Hull-to-Hull (**H2H**) for the safety of navigation of MASS in proximity of other ships or objects, and **Samsung and Amazon Web Services** for developing container ship self-piloting system taking into account diverse designs and operational aspects of MASS (Ghaderi, 2020).

Katana - designed by Israel Aerospace Industries and represents an advanced, multi-purpose, unmanned surface vessel (USV) (Bratić et al., 2019). It is produced for military services, uses dual-mode operation, meaning that it can be used as unmanned or as a crew vessel. Additionally, the joint research of Shenzhen **HiSiBi Boats** Company and Harbin Engineering University in China resulted with Tianxing-1, an unmanned surface vehicle (USV) primarily made for military operations (Bratić et al., 2019).

Classification societies work

Many classification societies also addressed MASS from different perspective (operation, and risk-based design approaches) and in various projects that resulted in various technical reports, eg., Lloyd's Register " Application of the lloyd's register unmanned marine system code to a small remotely controlled survey vessel" and "Cyber-enabled ships" (Lloyd's Register, 2016) (Chaplow et al., 2017), DNV "class guideline" and "risks and regulatory issues of specific cases of MASS" (DNV, 2018), (DNV/EMSA, 2020b), (DNV/EMSA, 2020a), China Classification Society "Guidelines for Autonomous Cargo Ships" (CCS, 2018), Bureau Veritas "Guidelines for Autonomous Shipping" (Bureau Veritas, 2019).

Autonomous ships companies, manufacturers and technologists

Autonomous ships manufacturing companies also emerged. For example, Massterly is a joint venture between **Kongsberg** Maritime and Wilhelmsen, which offers entire value chain services for the autonomous ships customers, e.g., vessel design, approval from relevant authorities, control systems, logistics services, vessel operations, insurance and possible assistance on financing, in addition to provision of skills, resources and experiences needed to enable a full-service of ships (Massterly, 2015). **Massterly** has signed a contract with the leading Norwegian grocery distributor ASKO to operate two new 66-meter vessels, which are equipped with autonomous technologies from Kongsberg Maritime. The two battery-powered vessels will replace 2 million kilometres of truck transport and save 5,000 tonnes of CO_2 every year. The vessels will initially operate in 2022 with a reduced crew before moving toward unmanned voyages (Wilhelmsen, 2020).

Of consideration, industrial collaborations surfaced as well; an example is the One Sea Ecosystem project for Autonomous Maritime Ecosystem (One Sea, 2017). In this collaboration, global maritime forerunner industries and research (e.g. ABB, Cargotec, MacGregor and Kalmar, Ericsson, Meyer Turku, Rolls-Royce, Tieto and Wärtsilä) jointly collaborate to lead the way (by 2025) towards operation of an autonomous maritime ecosystem. The association of Finnish Marine Industries supports the project work while the Finnish funding agency (TEKES) provides investments.

As it seems, in addition to the cargo owners investments and projects such as Brikland, the shipping lines and companies started involving in the development of MASS, e.g., MOL, CMA CGM, Wilhelmsen, which again reveals shipping operators commercial desirability of such concepts.

Project	Type	Country	Year	Organisation /institution
MUNIN	Unmanned Ship Research Platform (concepts verification and development)	Multiple European	2012-2015	European Union and multiple partners (consortium)
AAWA	Remote and Autonomous Ships design	Finland	2015-2018	Finnish funding agency, and led by Rolls-Royce and research community
SVAN	Autonomous ferry Falco- 2018	Finland	2018	Finferries and Rolls-Royce
Svitzer Herold	Remote controlled tugboat	Denmark	2016	Rolls-Royce and Svitzer
RAmora	Autonomous Fireboat & tugboat	Norway and Canada	2015	Robert Allan Ltd. And Kongsberg
C-worker	Off-shore unmanned vessel (oil & gas operations)	UK/USA	2014	Autonomous Surface Vehicles Ltd
ReVolt	Autonomous container vessel (100 TEU)	Norway	2014-2018	DNV GL supported by Transnova
YARA Birkeland	Fully Autonomous 120 TEU container ship	Norway	2017-2020	Norway Yara and Kongsberg
PILOT-E	Zero emission and fully electric Autonomous ferry	Norway	2017	Kongsberg and PILOT-E
Hrönn	Offshore utility vessel	Norway	2016	Automated Ships Ltd., Kongsberg and BOURBON
Jindoyuyn O Hao (UCSDA)	Unmanned cargo vessel (remote only)	China	2019	Yunhang Intelligent, CCS, Yunzhou Tech, ABS
AUTOSHIP	Building 2 Short Sea Shipping and Inland Water Ways autonomous vessels	Multiple European European	2019-2023	European Union and multiple partners
Massterly	Autonomous Shipping Company	Norway	2020	Wilhelmsen and Kongsberg
ASKO	Zero emission autonomous ships	Norway	2022	Massterly (Wilhelmsen and Kongsberg)
One Sea	Provision of intelligent devices and solutions for autonomous ships	Finland	2016	Finnish Marine Industries and funding agency

Table 1 MASS prototype projects description

Shipping companies' engagement

Shipping liners, on the other hand, have started investing in automation technologies. Led by MOL (Mitsui O.S.K. Lines) in association with research institutions, a project set out to develop cutting-edge navigational support systems, and other automated technologies. The project worked as well on the development of required infrastructure and investigated societal repercussions of MASS (MOL, 2017).

Equally important, projects for retrofitting of existing conventional ships, to provide automated navigation and decision support (making) systems, have begun. CMA CGM (shipping line) collaborated with Shone Automation to instal artificial intelligent (AI) systems onboard container vessels (CMA CGM, 2018). The AI system innovation will facilitate the work of crews on board, whether in decision support, and maritime safety, or piloting assistance. Similarly, Sea Machines (a start-up based in Boston) provides commercial autonomous systems, which can be retrofitted and installed onboard operating vessels, or newbuilds, thus enabling remote and autonomous operations (Ghaderi, 2020).

Incubation Countries

Many countries have declared that they plan to build MASS projects include the Netherlands, Belgium and Denmark in EU. In North America, Canada and the USA have founded the Smart Ships Coalition of the Great-Lakes-St. Lawrence (Heffner & Rødseth, 2019).

In this sense, current testing areas for autonomous and remotely controlled ships are now open in various countries (Table 2). According to International Network for Autonomous ships, testing areas are becoming a necessity for MASS (Bratić et al., 2019).

Country	Location	Remarks
Norway	Storfjorden, Horten, and Trondheim	Remote and autonomous
Finland	Jaakonmeri	MASS and ships under ice conditions
Belgium	De Vlaamse Waterweg nv	MASS
China	Wanshan Marine Test Field	Offshore test field for unmanned surface vehicles (USVs)
USA	The Keweenaw Peninsula Waterway (by Smart Ships Coalition)	Autonomous surface and sub-surface vehicles
UK	Various testing areas	MASS

Table 2 MASS testing areas

3 CONCLUSION

In conclusion, the analysis of Maritime Autonomous Surface Ship (MASS) projects has unveiled both the remarkable advancements achieved and the critical gaps that persist in current endeavors. By delving into the contributions of various stakeholders and the evolution of MASS technologies, this study has provided valuable insights into the trajectory of autonomous shipping.

As part of reviewing the developments in the design and construction of autonomous shipping technologies, a number of trends are evident. Kongsberg is observed as a key catalyzer in many of the projects. This indicates that the technologies used for ship simulation and training are being adopted for the navigation and operations of autonomous vessels. Furthermore, it seems that the current slate of projects focus on small-scale cargo vessels (100–200 TEU) suitable for coastal domestic shipping, mainly because it's more convenient to seek permission locally for a single flag vessel. It is thus expected that electrically powered vessels are those that begin operations first, primarily because of ease of operations and maneuverability in comparison to traditional engines (Ghaderi, 2020).

In addition to the cargo **owners investments** in projects such as Brikland, the shipping lines and companies started involving in the development of automated technologies, e.g., MOL, CMA CGM, Wilhelmsen. This again reveals the shipping industry commercial desirability of such concepts. Technologies, e.g., Artificial Intelligence (AI) and Deep Learning (DL) systems, among others, are attractive and can be retrofitted on existing conventional ships, which eventually reduce crew number and human errors, and improve safety of navigation. On the other hand, it seems that most of the projects are small scale projects, i.e., small container or cargo ships operate within coastal water. These projects will definitely influence the design and implementation of future MASS. While Kongsberg stimulates development and operation of ships in Norway in many projects, the developments of small ships and operation in territorial water is viable and feasible due to simplicity in requesting authorisation in national water as opposed to the complexities in deep sea, which is governed by international regulations.

Of consideration, the MASSs that have been tested so far in real world scenarios barely exceed the Level of autonomy two (remotely guided ships) of the IMO classification considering that decision support systems and automated navigation are already installed onboard. Although some projects envisaged times in the future for the readiness of unmanned ships (LoA three) and fully autonomous (LoA four) oceangoing ships, such advance is of course highly interrelated with technological readiness, verification, and international regulations, and more importantly the interest of the industry to uptake such high levels. It should be noted that MUNIN, Rolls-Royce, ReVolt and YARA Birkeland utilised the SCC to supervise and run MASS, still it is not widely adopted and widely explained in many projects.

Most of ongoing research projects are focused on key technological trends. First is the sensor fusion technology, which will enable the virtual captain onboard the ship to collect all the data from thousand of sensors and make decisions accordingly. This includes data from the navigation, external data sharing, maintenance and repair reports, and safety considerations. The second, yet so important, is the artificial intelligence (machine and deep learning techniques), that will be the brain (virtual captain) onboard the MASS. These softwares will mimic human behaviour, i.e., captain, watch officer, lookout, engineers, and thus intelligently take over various ships' functions. The third is the cyber security issues. Hence, researchers, and classification societies (DNV) concentrated on designing secure communication standards, intrusion detection systems, and methods to protect MASS from cyber threats (hijacking or malware injections).

It is worth noting that not all projects highly engaged key stakeholders. Engagement, collaboration, and cooperation among stakeholders in development of MASS is fundamental to openly debate the nature of the envisaged opportunities, examples of stakeholders are ship owners, charterers, managers, and seafarers, seafarers' unions, ports managers, technologists, academics, manufactures, classification societies and insurance firms, and regulators (e.g. maritime administrations). Moving forward, collaborative efforts between researchers, policymakers, and industry stakeholders will be instrumental in addressing these challenges and steering MASS projects towards a future marked by efficiency, safety, and sustainability.

Research is advancing rapidly, but still the scale of adoption of MASS is limited, that is because MASS is only working on national waters and cannot be a seagoing vessel until a legal framework is on place. Based on the analysis provided in this study, various gaps are identified, thus, It is worth to note that research or prototype projects should focus on the following:

- Human elements involved in the MASS operation and Shore Control Center (SCC)
- Skills and competencies required for MASS
- New jobs and career paths
- New training materials and requirements that include information communication technologies
- Investigation of the economic implication of MASS based on real world scenarios
- Engagement of shipowners in MASS construction and operation including cost of **crews that** shift to SCC, communication technologies
- New business models for integration of MASS in commercial shipping
- Study of environmental implication (energy intensity, consumption and other life cycle impacts)

- Cargo management issues (e.g. stowage, leakage, loading and unloading, and security of cargo from theft)
- Addressing the issue of fire, flood, and pollution prevention, apart from search and rescue missions that are not applicable in MASS
- Biggest challenges facing the growth of the MASS industry
- Who will have control over MASS and the SCC
- The required political role to enable regulations, policies and standards, and facilitates operation of MASS and shows its clear benefits

This study has various contributions and implications, by shedding light on areas requiring further exploration and development in future MASS projects, this study will guide future research endeavors and prototype projects in the field of maritime autonomy. The identification of areas requiring further attention underscores the need for continued research and innovation to realize the full potential of MASS in maritime operations.

Ultimately, the insights gleaned from this study will inform policymakers, researchers, designers, shipbuilders, and maritime practitioners, facilitating the advancement of MASS technologies and their seamless integration into maritime operations

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