Autonomous Ships: A review, innovative applications and future maritime business models

Ziaul Haque Munim

Department of Maritime Operations

University of South-Eastern Norway

E-mail: ziaul.h.munim@usn.no

ORCID ID: 0000-0002-5942-708X

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Abstract

Over the last decade, a few autonomous ship prototypes have been developed. While Norway is pioneering the technological development of autonomous ships (AS), other countries such as China, Finland and USA have also made significant progress. However, future applications of AS and potential business models are not yet well explored. In the near future, AS are expected to be launched commercially, adding a new dimension in the merchant shipping industry. Thus, this study contributes to the maritime literature by (1) providing a review of the AS development projects and the benefits of AS from an economic, environmental and social perspective, (2) suggesting innovative uses of AS in short-sea-shipping (SSS), arctic shipping, and conventional shipping, and finally (3) discussing potential business models from the perspective of AS manufacturers.

Keywords: autonomous shipping; unmanned ship; intermodal transport; sustainable transport; vessel platooning; literature review

1. Introduction

The repeal of the shipping conference in Europe and the global financial crisis in 2008 have affected the container shipping industry adversely (Munim and Schramm, 2017). Since then, although the demand for container shipping grew in slow-pace, yet overall growth was limited due to slow growth in the world economy and surplus of shipping capacity (UNCTAD, 2017). As a result, freight rates hit all-time lowest in 2016 (SSE, n.d., UNCTAD, 2017), and shipping companies have been struggling to make a profit (Munim and Schramm, 2017). Meanwhile, South Korean shipping company Hanjin, at that time the seventh largest shipping line in the world, went bankrupt in 2017 (Song et al., 2018). While there was expectation of demand growth due to improvement in liner shipping connectivity and positive influence from the Chinese economy (UNCTAD, 2017), trade war between China and United States (Bryan, 2018) as well as Brexit in the United Kingdom may slow down shipping demand growth further (Munim and Schramm, 2018, Yang et al., 2019). Thus, major players in the shipping industry are looking for innovative solutions to overcome the shipping market turmoil (Yang et al., 2019). To increase demand for shipping, one idea could be to penetrate new markets through modal-shift of cargo from road to sea. Such an initiative will not only increase the demand for container shipping but also play a significant role in achieving environmental sustainability goals. Also, to maintain profit margin via reducing operating cost, carriers may explore new trade routes such as the Northern Sea route. New forms of alliance between carriers, for example, via vessel platooning, may also evolve in the future facilitating sustainable business growth of carriers. However, due to risks and costs involved with the mentioned initiatives, traditional ships may fall short in implementing them. On the contrary, with recent developments in the autonomous systems technology, autonomous ships (AS) can fill the drawbacks of conventional ships therein. Thus, this study (1) reviews developments in AS research and identify potential economic, environmental and social benefits of AS, (2) suggests innovative applications of AS, and finally (3) presents prospective business models for AS manufacturers.

1.1. Autonomous ships

Shipping in the context of maritime refers to ocean transit, that is, waterborne transport of goods through ships from one port to another, including port approach and departure. *Autonomous shipping* refers to the ability of a ship to independently control its own actions while transporting goods from one port to another (Rødseth, 2017). MUNIN (n,d) defined *autonomous ships* as the "next generation modular control systems and communications technology that will enable wireless monitoring and control functions both on and off the board. These will include advanced decision support systems to provide a capability to operate ships remotely under semi or fully autonomous control." According to Rødseth (2017) and IMO (2018), there are four key automation alternatives: (1) conventional ships with automated decision support system, for example, collision avoidance system, (2) periodically autonomous ships, that is, autonomous functions are activated during night, on high seas and fair weather, (3) fully autonomous ships with facilities for crew to take ships into or out of ports, and (4) fully autonomous ships with no crew facilities on board. For alternatives two and three, there will be a need for a manned shore control centre (SCC) on the land-side. Rødseth (2017) argued that to achieve the maximum benefit from AS in the *triple bottom line* (Slaper and Hall, 2011), that is an economic, social and environmental impact, the fourth alternative is the most viable. Thus, this study considers AS without any crew facilities as the standard. Initially, AS development projects considered conventional ship engines only, but later the focus shifted towards more environmentally friendly electric powered AS.

1.2. Autonomous ship development projects

The first autonomous ship technology development project, MUNIN, was initiated in Norway, to contribute to the competitiveness and sustainability of European shipping industry, in collaboration with partners from four other European countries. Currently, there are few more such projects worldwide, for example, Rolls-Royce project in Finland (Rolls-Royce, n,d), but still, the leading three — MUNIN, DNV GL ReVolt and YARA Birkeland, are based in Norway. These projects are briefly discussed in the next sub-sections and their concept AS are depicted in Figure 1.

(a) MUNIN (b) ReVolt (c) YARA Birkeland

Figure 1: Autonomous ship concepts

Sources: Norwegian Forum for Autonomous Ships

1.2.1. MUNIN

Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) is the first project dedicated to the development of autonomous ship technology (Rødseth, 2017). It was initiated in 2012 in collaboration with eight partners from Norway, Germany, Sweden, Iceland and Ireland (MUNIN, n,d). Currently, the European shipping industry is facing lack of seafarers, which was one of the main motivations to develop autonomous ship technology (ibid.). However, over time, the focus shifted more towards economic and environmental benefits of AS. The MUNIN project concluded that there are no major obstacles to the realisation of a fully autonomous ship, but a few constraints exist (Rødseth, 2017). Among the constraints, the major one was developing feasible business models in short and medium term (ibid.), which is one of the main contributions of this study.

1.2.2. DNV GL

DNV GL, a company headquartered in Høvik, Norway, developed an autonomous ship prototype dedicated for short-sea-shipping (SSS) within a range of 100 nautical miles, named the *ReVolt* (DNV GL, n,d). This project was initiated in 2013 in collaboration with Norwegian University of Science and Technology (NTNU). The motivations behind the project were reducing pressure on land-based logistics networks, reducing operating costs as well as improving safety in maritime operations by reducing fatalities (Adams, 2014).

1.2.3. YARA Birkeland

The autonomous ship YARA Birkeland is the world's first fully electric autonomous container ship, with zero emissions (Kongsberg, n,d). In 2015, the environmentally friendly autonomous ships development project became a part of the Norwegian government's *Maritime Opportunities – Blue Growth for a Green Future* strategy. Relying on the outcome of the MUNIN project, YARA — a Norwegian chemical export company, in collaboration with Kongsberg — a Norwegian maritime technology export company, developed the YARA Birkeland prototype. In 2018, VARD — a Norwegian shipbuilding company, also joined the project. Although the YARA Birkeland will be ready for operation in 2020, initially it will be operated semi-autonomously, but fully autonomously in 2022 (Kongsberg, n,d, Skredderberget, 2018).

The MUNIN project only focused on the feasibility of the visions of an autonomous ship. As they found it feasible, DNV GL ReVolt and YARA Birkeland took the vision one step further and implemented the learning from MUNIN project. The estimated key facts and figures of both autonomous ship prototypes are presented in Table 1.

Table 1: Facts and figure of autonomous ships

Particular	DNG VL ReVolt	YARA Birkeland
Capacity	100 TEUs	120 TEUs
Length	60 metres	80 meters
Width	—	15 meters
Service speed	6 knots	6 knots
Deadweight	—	3 200 tonnes
Battery capacity	—	6.8 MWh
Range	100 nautical miles	—

(—) represents missing information.

Source: DNV GL (n,d) and Kongsberg (n,d)

2. Methodology

A systematic literature review approach is adopted in this study to map the developments in the AS literature, summarize the potential benefits of AS from the triple bottom line perspective, reveal innovative applications of AS, and as a synthesis explore future business models for AS manufacturers. First, bibliography data (that is, published articles on AS) is collected from the Web of Science (WoS) database — world's most renowned scientific database. WoS has been used as a source of bibliography data for literature reviews by many scholarly articles in relevant scientific disciplines such as supply chain management (Maditati et al., 2018, Bensalem and Kin, 2019) and maritime transport (Munim and Saeed, 2019). For literature search in the WoS, a comprehensive four-step approach is followed as shown in Table 2. Initial search finds 101 articles, but after filtering for only English language publications and screening by relevance (based on keywords, title and abstract) 90 studies (including 58 journal articles and 32 conference proceedings) are found considerable. Finally, the 90 studies are screened manually. An iterative coding process of the 90 studies reveal five research clusters in AS literature: (1) technological development (68 studies), (2) collision avoidance (05 studies), (3) applications of AS (09 studies), (4) human elements (03 studies), and (5) regulatory and management issues (05 studies). A list of 26 studies representing the five clusters is presented in Appendix A. As the majority of the studies relate to technological development, only five most cited studies from the technological development cluster are listed in Appendix A. Also, the list of top 10 countries in terms of number of publications related to AS is presented in Appendix B. As the aim of this study in to review benefits and applications of AS and present future business models, the nine studies in Cluster 3 are focused in great detail. Out of the nine studies, five summarizes the potentials benefits of AS (see Section 4), and four studies are used as a reference point for the innovative applications of AS in the shipping industry (Section 5). The adapted research process is depicted in Figure 2.

Table 2: Keyword search in the Web of Science database

Steps	Keywords	Number of articles
1	**TOPIC:** ("autonomous shipping" or "unmanned ship" or "autonomous ship" or "autonomous vessel")	101 articles
2	Search **(1)** refined by English language only	100 articles
3	Search **(2)** manually filtered for relevance with the topic broadly (i.e. including technical development studies)	90 articles
4	Filtered **(3)** based on relevance with research questions.	26 articles (the list is presented in Appendix A)

The literature search was conducted on February 20, 2019. Please note that for all searches the following attributes apply:* ***Timespan:* *All years.* ***Indexes:*** *SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.*

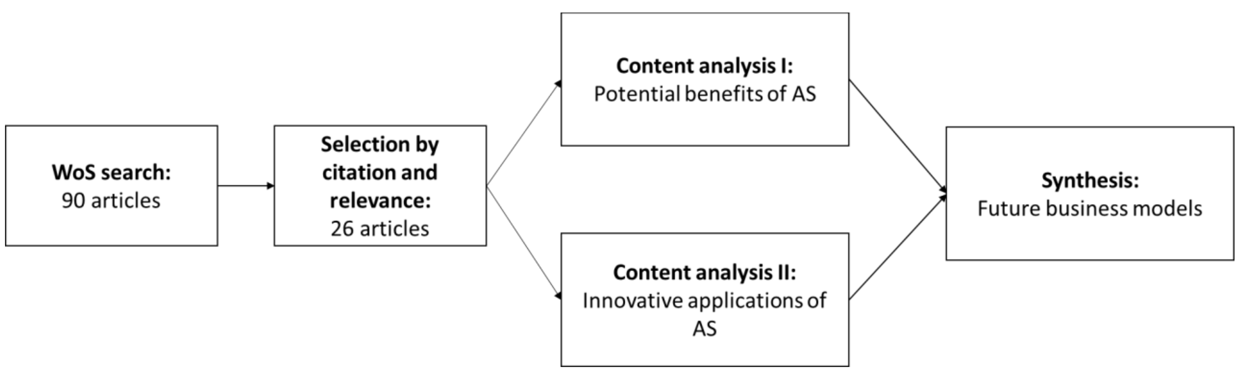


Figure 2: Work-flow for review of AS literature and knowledge synthesis

3. Potential role of AS in the supply chain

Supply chains are at the heart of the shipping industry. Majority of the seaborne shipping demand nowadays is derived from supply chain activities worldwide. "Supply chain is a set of … several independent firms involved in manufacturing a product and placing it in the hands of the end user. … Raw material and component producers, product assemblers, wholesalers, retailer merchants and transportation companies are all members of a supply chain" (Mentzer et al., 2001). Seaborne shipping supports supply chain through facilitating the flow of materials and products among supply chain members, particularly when members are located worldwide. Even after the World War II, production functions of goods were spread in close proximity within a region or a country. In the early 1970s, the standardization of container size and building of dedicated container ships reduced the expense of international trade greatly while increased the speed of trade. This development influenced the globalization of production functions adding a new dimension in the supply chains, that is, massive outsourcing. At that time, the main role of shipping in the supply chain was to provide access to the international market and in achieving economies of scale. However, since the 1990s, the demand of the shippers shifted towards a new standard. The role of container shipping freight rate (Munim and Schramm, 2017), timing-related shipping services (Lu, 2003, Notteboom, 2006) including agility and flexibility (Zhang and Lam, 2015), and environmental performance of carriers (Lai et al., 2011) became crucial. AS can have a positive influence on these factors. Monetary savings from operational activates such as no seafarer salary, zero or reduced fuel cost, energy savings and improved economies of scale will induce the ability of carriers to reduce freight rate as much as 3.4% (see Table 2). This estimation is valid after considering costs associated with the SCC and vessel maintenance crew at port (Kretschmann et al., 2017, Streng and Kuipers, 2018). Due to advanced technological requirements, newbuilding prices will be approximately three times higher than conventional ships of the same size (Paris, 2017). Overall, assuming 30 years of life expectancy of an autonomous ship, about USD 1 million could be saved in operational expense per year (DNV GL, n,d).

AS are data-driven and does not only process engine data but also data related to surrounding environment including weather condition. Thus, their scheduling reliability is likely to be better than conventional ships (ITU News, 2018). Unreliable schedule of container ships affects the inventory management of companies negatively, resulting in higher inventory costs (Vernimmen et al., 2007). AS will also contribute significantly in improving maritime safety by reducing the number of fatalities (Rødseth, 2017), likelihood of collision (Wróbel et al., 2017) and vulnerability to piracy (Arnsdorf, 2014). On the contrary, non-navigational accidents due to fire or ship loss due to structural failure may increase as well as the risk of cyber-piracy (Wróbel et al., 2017, Streng and Kuipers, 2018).

On top of the economic and service-related benefits, AS will contribute the most in reducing the environmental impacts of shipping both directly and indirectly. As for direct emissions from shipping, electric powered autonomous ships will emit zero CO_2 and NO_x (Kongsberg, n,d). Also, CO_2 and NO_x emissions from road transport can be reduced by shifting load from road to sea through utilising AS in SSS. Such modal shift will also improve road safety and reduce noise pollution in cities.

Table 3: Potential benefits from AS

Particular	Benefit from AS
Economic and Operational benefits	
Seafarer salary	Zero; currently 45% of total operating cost (Kretschmann et al., 2017)
Fuel cost	Zero for electric powered ships*; USD 357 saving per day for fuel dependent containership (Allal et al., 2018)
Energy savings	About 74% reduction compared to conventional ship (Allal et al., 2018)
Economies of scale	Improved ship capacity due to no crew facilities (e.g. gym, accommodation etc.) on board (DNV GL, n,d-a)
Overall savings	Approximately USD 1 million per year (DNV GL, n,d-b)
Freight rate	Likely to reduce or reman same; about 3.4% reduction for bulk carriers (Kretschmann et al., 2017)
Service and social benefits	
Reliability	Increased reliability of schedule (i.e. departure and arrival timing) (ITU News, 2018)
Safety	Less number of fatalities (Rødseth, 2017), reduced likelihood of collision (Wróbel et al., 2017), less vulnerable to maritime piracy (Arnsdorf, 2014)
Environmental benefits	
CO_2 emissions	For electric AS, zero from direct operation (Kongsberg, n,d)
Noise pollution	Modal-shift of cargo from road to sea (Kongsberg, n,d, DNV GL, n,d-b, Rødseth, 2017)

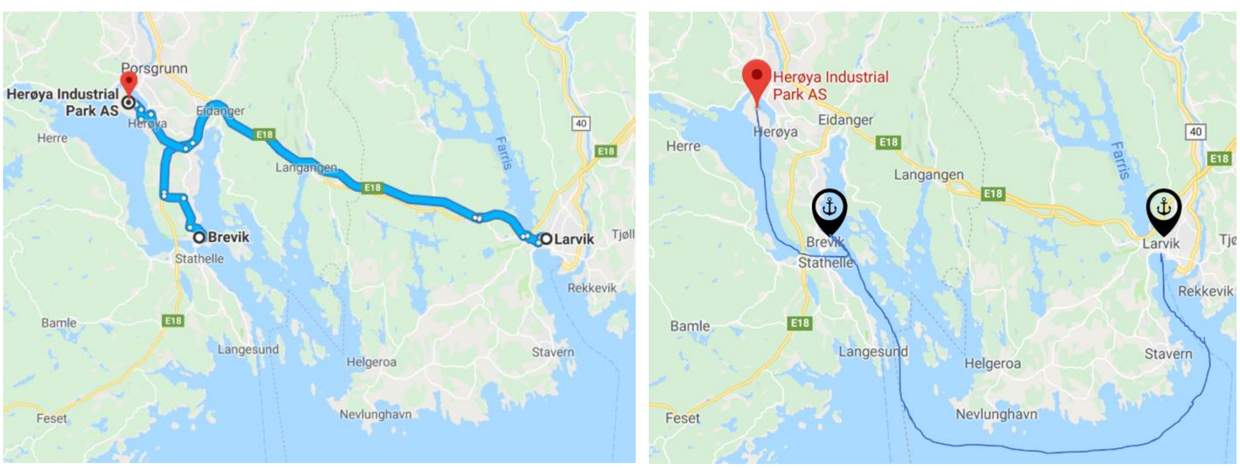
**Electricity also costs money and ship-owners must not overlook this fact. However, electricity cost is likely to be cheaper than conventional fuel cost.*

4. Innovative applications of AS

To form innovative applications of AS, studies on applications of AS (Appendix A) were examined in detail. Based on content analysis of those studies, a few innovative applications of AS in the context of SSS (Rødseth, 2017, Ghaderi, 2018), arctic shipping (Höyhtyä et al., 2017) and conventional shipping (Sanden and Hovland, 2017) are suggested.

4.1. Short-sea-shipping (SSS)

About 40% of Europe's population lives in the coastal areas (Rødseth, 2017). In the United States, the number is similar, about 37% of the total population when considering great lake counties (Crowell et al., 2007). Roughly, about three billion people worldwide live within 200 km from a coastline. Despite this, today's inter-city logistics network relies heavily on road transport. For greenhouse gas (GHG) emissions from the transport sector in Europe, road transport accounts for 72.8% (European Commission, n,d). Meanwhile, waterborne transport emits considerably lower GHG emissions than road transport, but still not utilised properly. Also, heavy load implied by city logistics on road, creates congestion, noise pollution and vulnerability in road safety. Thus, shifting loads from roads to sea through SSS can play a big role in greening the transport industry as well as improving road safety. Using autonomous ships, some of the challenges of SSS, for example, crew cost and their shortage can be eliminated (Ghaderi, 2018). Rødseth (2017) discussed how AS could lead a paradigm shift in freight transport through facilitating last-mile delivery using small-size autonomous ships. Notteboom (2006) used an example where ships are rerouted by carriers to avoid congested ports, and then cargo is transported to the final destination using inland waterway transport (IWT) to maintain schedule reliability. SSS utilising AS can be considered in such cases as well. Here, this study presents a real-life case to demonstrate the use of AS in SSS. The electric powered autonomous ship, YARA Birkeland, is about to sail in 2020, a 37 nautical miles journey in southern Norwegian water, from YARA's factory in Porsgrunn to Brevik (7 nautical miles) and Larvik (30 nautical miles) ports, as depicted in Figure 3 (Kongsberg, n,d). Every day, about 100 diesel trucks are used by YARA to transport fertiliser in this route. Thus, AS in this SSS route will replace approximately 40,000 trucks a year from the roads. This will contribute greatly to eliminate CO_2 and NO_x emissions, reduce congestion, cut noise pollution and improve road safety.



(a) Road transport route (b) Short-sea-shipping route

Figure 3: Transport modal shift (road to sea)

Source: author's own elaboration

4.2. Arctic shipping

Another potential use of autonomous ships could be in the Northern sea route (NSR), also referred to as arctic shipping route. While studies exist investigating the potential of NSR for bulk (Schøyen and Bråthen, 2011) and container shipping (Verny and Grigentin, 2009, Liu and Kronbak, 2010), researchers have already scrutinised the potential for AS in the NSR (Höyhtyä et al., 2017). Despite the appearance of studies on the commercial feasibility of NSR as early as in the 2000 (Ragner, 2000), only in 2018, world's largest carrier, Maersk, initiated the first experimental container ships voyage in this route (The Economist, 2018). The NSR (in Figure 4) is considered as a rival of the Suez Canal, as it could reduce the transit time from Asia to Europe by at least ten days (ibid.). While the NSR could benefit in cost and time savings for shipments on the Asia-Europe trade route, there are some bottlenecks. For instance, NSR is feasible only three to four months a year, ice condition is unpredictable, costly ice-classed specialised vessels are required, high insurance costs, navigational difficulties, lack of search-and-rescue teams and support infrastructure (The Economist, 2018, Liu and Kronbak, 2010). Meanwhile, AS can eliminate some of the risks associated with NSR to a great extent and facilitate arctic exploration with minimal risk to human life. Although there exist some challenges for AS in NSR too, it is possible to overcome them (Höyhtyä et al., 2017).

Figure 4: Potential route for arctic shipping

Source: The Economist (2018))

4.3. Vessel platooning in conventional shipping

Another form of autonomous shipping, *Vessel platooning* also referred as *vessel train* is a concept where multiple vessels follow a leader vessel (as demonstrated in Figure 5). Sanden and Hovland (2017) have already experimented vessel-to-vessel communication via establishing real-time wireless communication link. Further development of this technology can facilitate vessel platooning in fixed route liner shipping. The platooning concept is already well established in the road transport industry (see Larson, Liang and Johansson, 2014; Alam, Gattami, Johansson and Tomlin, 2014). After some further investigation on the platooning concept in relation to the maritime industry, the NOVIMAR project was revealed. The vessel platooning concept has already been initiated in 2017 by the NOVIMAR (Novel IWT and Maritime Transport Concepts) project funded by European Union's 2020 research and innovation programme, in collaboration with 22 partners from nine countries (NOVIMAR, n,d). In the earlier stage, it is expected that the leader vessel in a vessel train would be a conventional manned ship, and the follower vessels would be completely unmanned or reduced manned ships (NOVIMAR, n,d). Vessel platooning can reduce the operational cost of shipping in SSS, sea-river and IWT (Meersman et al., 2018, Netherlands Maritime Technology, n,d).

Figure 5: Vessel platooning

Source: Netherlands Maritime Technology (n,d)

Now, the question is, where in the conventional shipping can vessel platooning be adopted? As shown in Figure 6, today's conventional shipping relies on two liner service network designs, relay and hub-and-spoke (Kavirathna et al., 2018, Haralambides, 2019). This study proposes that the concept of vessel platooning can be adopted in providing feeder services between hub ports and feeder ports. Often, feeder ports are river-based, making it difficult for larger vessels to enter their navigational area. In many cases, multiple small to medium sized vessels are required for transporting cargo from a hub port to a feeder port. Vessel platooning can be a viable option in those situations, resulting in reduced operating costs as well as reduced environmental impact. Such initiatives may emerge a new form of alliances between shipping lines serving the same feeder ports from the same hub ports.

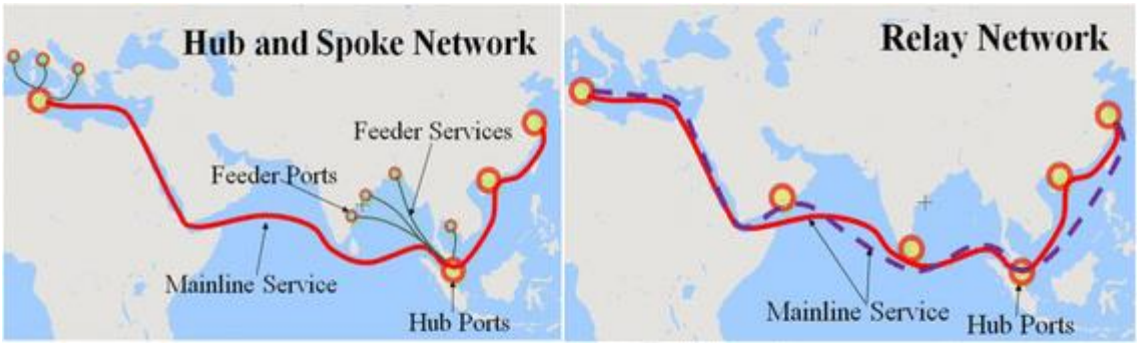


Figure 6: Relay and hub-and-spoke liner Networks

Source: Adopted from Kavirathna et al. (2018)

5. Business models for AS manufacturers

Like any other sustainable technology, despite the potential benefits of AS, it is likely to face challenges in penetrating the mainstream shipping market. One barrier to market penetration, often ignored, is that sustainable technologies challenge the existing business practices that heavily depend on the use of fossil fuels, particularly the oil and gas (Johnson and Suskewicz, 2009). The conventional shipping industry relies heavily on fossil fuels and incumbents have vested interests in making a profit from unsustainable business practices (Cohen and Winn, 2007). While new entrants are to drive the adaptation of sustainable technologies (Hockerts and Wüstenhagen, 2010), often unattractiveness of sustainable technologies to the market and competition with powerful incumbents are crucial barriers (Ansari and Krop, 2012, Johnson and Suskewicz, 2009). Also, the production process, required managerial expertise and customer preferences for sustainable technologies are often different than mainstream technologies (Johnson and Suskewicz, 2009), and only expected environmental benefits do not create largescale customer acceptance (Kley et al., 2011). However, as discussed earlier, AS will benefit in many ways economically and socially in addition to reducing emissions from shipping. Thus, the conceptualization of business models for AS can be based on three elements: value proposition, value chain configuration and revenue model (Osterwalder et al., 2005, Morris et al., 2005, Johnson et al., 2008, Kavin and Narasimhan, 2017). With innovation in the business model, shipbuilding companies (a list of world's top 10 shipbuilders is presented in Appendix C) can create new sources of value for their customers while driving sustainable technology adaptation. One crucial factor for AS market penetration is securing added customer benefits, that is, justifying the higher initial investment compared to buying a conventional ship. While business models are rather complex and many different conceptualizations exist (Zott et al., 2011), Figure 7 presents the elements of business models for AS based on the three major elements.

5.1. Value proposition

Value proposition refers to "the promised value of the product offered by the manufacturer to the client beforehand" (Kley et al., 2011, p. 3394). From the product content view, AS can be fully autonomous and semi-autonomous (see Section 1.1 for detail). While fully autonomous vessels will sail on its own, in the latter case vessels will be operated by SCC and varying degree of human crew involvement will be required. As can be seen in Figure 1, AS designs are futuristic, which allows for achieving higher level of economics of scale at handling of goods and energy efficiency. In contrast, conventional designs for AS will be cost and energy inefficient.

Also, future AS manufacturers must focus on service contents. Although, it is expected that AS will be initially used for SSS, for electric AS, fast charging of the battery and back-up battery technologies must be in place for long-range voyages. Moreover, the AS manufacturers need to guarantee required infrastructure systems, for example, battery charging stations for electric AS, SCC operation for semi-autonomous vessels. Furthermore, AS manufacturers can offer vessels sharing offers to their customers alongside ownership offers. In a vessel sharing contract, a customer can rent an AS on a pay per use basis. This would be the equivalent of chartering in the traditional shipping industry but offered by the AS manufacturer in this case.

From the business model viewpoint, it is important to define the target segment, that is, how will the firm (AS manufacturer) create value? As discussed in Section 4, AS will have novel applications for both the container and bulk shipping service providers. AS manufacturers can consider offering two categories of AS, high-class and economic. While both will be equally safe for navigation and operations, the high-class will provide longer range and better energy efficiency than their economic counterparts but comparatively more expensive as well. This will ensure adaptation of AS by both the market leaders in the shipping industry (that is, firms with high level of resources) and new entrants or smaller shipping lines or ship owners (that is, firms with limited resources).

5.2. Value chain configuration

Value chain configuration in this context refers to the possible development and production of the AS involving different stakeholders. The AS manufacturer needs to decide on production strategy, that is, whether to produce in-house or outsource. Due to the complexity involved in AS production, it is expected that at least some parts of the production process will be outsourced to external parties. Another production related strategy for AS manufacturer would be to decide whether to build new AS or to upgrade (or refit) conventional ships to AS or to adopt a mixed strategy and do both.

Sales procedure of AS will be a major concern for the manufacturers. They can sell directly to the shipping lines or shipowners based on orders, or they may involve shipbrokers in the sales procedure. For AS, after sales service can play a major role. Ships may require maintenance or repair when in the high sea or at ports. For maintenance in the high sea, skilled crews will be taken on-and-off the ship using helicopters. For maintenance at ports, it might be feasible to locate required skilled crews at large or dedicated ports. AS manufacturers can offer packages to their buyers for such services. Furthermore, considering fast technological advancement, periodic upgrading of technology (AS software and hardware) can be part of the after-sales service. AS are likely to be three times expensive than conventional ships due to advanced technology (Paris, 2017), and building on the concept of circular economy, it is likely that many of the AS technologies can be re-used in newbuilding of AS or for other purposes. Thus, AS manufacturers can offer end of life policy offering contracts for value at return or demolition.

5.3. Revenue model

Revenue model "fixes the type of payment the customer makes to the supplying shareholder as part of the offer" (Kley et al., 2011, p. 3394). Relying on the service content discussed in Section 5.1, AS manufacturers can sell an AS for fixed payment or can charter vessels for a prespecified voyage or time at a predetermined price per voyage or per day. Due to the economic, environmental and social benefits of AS, it is expected that government agencies will provide both financial and non-financial incentives to the AS manufacturers and other stakeholders in the AS production and development value chain. Such incentives should be integrated into the revenue model as it will reduce the overall cost of AS production. Furthermore, AS manufacturers can generate additional revenue from licensing the AS technology for the use of others.

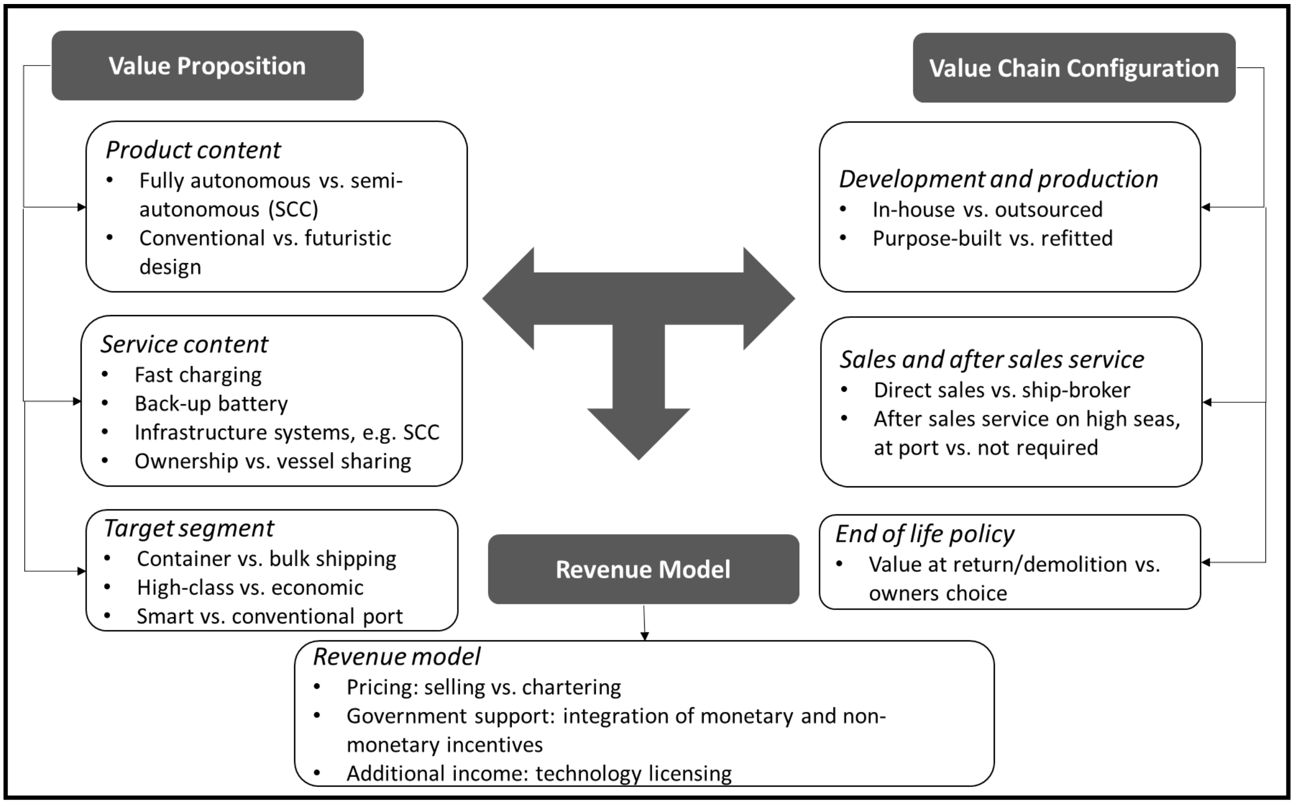


Figure 7: Elements of AS business model

Now, a business model can be developed for an AS manufacturing firm, combining different functions from the three elements of AS business model presented in Figure 7. A successful business model has the power to change the economics of an industry and can itself be a strong competitive advantage (Magretta, 2002). But how do we know what would be a successful business model for AS manufacturers? Usually, in emerging industries, firms keep searching for a standard business model initially (Morris et al., 2005), and when found, one model is usually shared by multiple competitors (Teece, 2010).

An illustration of future business models for AS manufacturers, considering one incumbent and one entrepreneurial firm, is illustrated in Table 3. According to Bohnsack et al. (2014), "incumbent firms are cognitively constrained by the existing business model and will make new technologies fit into existing business models", while "entrepreneurial firms are not cognitively constrained" and "will design new business models" (p. 287). In the same vein, Greve (2003) showed that high performing shipbuilding firms reduce research and development (R&D) intensity and innovation. Thus, the hypothetical incumbent firm (Firm A) in Table 3 is assumed to be conservative and constrained by existing business model, while the hypothetical entrepreneurial firm (Firm B) is assumed to be open and will design novel business model for

AS. It might be noted that, typically, "entrepreneurial firms will focus on a single business model at one point in time and leverage pre-entry knowledge from adjacent industries" but "incumbent firms experiment with different business models simultaneously and cross-subsidize with revenues from existing business models" (Bohnsack et al., 2014, p. 287).

Table 4: Illustration of potential business model for AS

Firm	Value proposition	Value chain configuration	Revenue model
Firm A (incumbent firm)	*Product/service content:* • Offers semi-autonomous vessels. • Fast charging and back-up battery. • Ownership of vessels. *Target segment:* • Container and bulk shipping. • High-class • Both smart and conventional ports.	*Development and production:* • Majority outsourced. • Mostly refitted. *Sales and after sales service:* • Direct sales and ship broker. • After sales service only at ports. *End of life policy:* • Does not offer demolition service.	*Pricing:* • Selling and chartering. *Government support:* • Low. *Additional income:* • Not applicable.
Firm B (entrepreneurial firm)	*Product/service content:* • Offers fully autonomous vessels. • Provides SCC. • Both ownership and sharing of vessels. *Target segment:* • Container or bulk shipping. • Economic. • Smart ports.	*Development and production:* • Majority in-house. • Mostly purpose-built. *Sales and after sales service:* • Direct sales. • After sales service at sea and ports. *End of life policy:* • Offers value at return or demolition.	*Pricing:* • Selling. *Government support:* • High. *Additional income:* • Technology licensing.

6. Conclusion

Autonomous ships are no more a fantasy, and their feasibility has already been established (Rødseth, 2017, Ghaderi, 2018, Kongsberg, n,d). This study presents a comprehensive review of extant AS literature by discussing AS development projects and benefits of AS from the triple bottom line perspective. Also, relying on the extant literature, it suggests innovative application of AS in three shipping contexts, namely, SSS, arctic shipping and conventional shipping. In all three contexts, the adaptation of AS can reduce operational costs largely at the same time reducing CO_2 and NO_x emission from shipping. Furthermore, this study presents potential business models for AS manufacturers building on the value proposition, value chain configuration and revenue model. This study argues that similar to any other emerging industry, AS manufacturers will keep trying different business models in the earlier years until the industry finds a standard.

Despite many potential benefits of AS, some challenges exist. For SSS, foreseen challenges include training of special crew for SCC, new port operational capabilities, operational risks in terms of cyber-piracy and inefficiency of the fleet due to the slower speed of ships (Ghaderi, 2018). From the arctic shipping perspective, AS can be the solution to many challenges for commercialisation of the NSR but insurance of AS sailing in the arctic route would be expensive. Arguably, the idea of commercialisation of NSR may not be appealing from the environmental sustainability perspective. We know that global temperature increase is causing the meltdown of ice in the high north making NSR a viable alternative to Suez Canal. But starting to use NSR for international shipping is likely to speed up the melting of ice in the high north and have an adverse effect on the climate. Finally, in the vessel platooning scenario, again, new port operational capabilities may be required as a few vessels will arrive at the port at the same time.

Being conceptual, this study leaves many opportunities for future research. The application of AS in SSS, arctic shipping and conventional shipping should be explored in detail. For example, optimization models (Munim and Haralambides, 2018) can facilitate designing potential SSS service networks, multi-criteria-decision-making models (Tseng and Cullinane, 2018) such as analytic network process may guide decision making in the NSR, and game theory models (Asgari et al., 2013, Park and Min, 2014) may be used in analysing cooperation situations among shipping lines in vessel platooning.

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Appendix A: List of 26 studies extracted from the systematic literature search

No.	Article	Title	Citations
Cluster 1: Technological development:			
1	Kim and Eustice (2009)	Pose-graph Visual SLAM with Geometric Model Selection for Autonomous Underwater Ship Hull Inspection	29
2	Tam and Bucknall (2013)	Cooperative path planning algorithm for marine surface vessels	29
3	Sanchez-Lopez et al. (2014)	An Approach Toward Visual Autonomous Ship Board Landing of a VTOL UAV	24
4	Larrazabal and Peñas (2016)	Intelligent rudder control of an unmanned surface vessel	19
5	Escario et al. (2012)	Optimisation of autonomous ship manoeuvres applying Ant Colony Optimisation metaheuristic	11
Cluster 2: Collision avoidance studies:			
5	Lee and Kim (2004)	A collision avoidance system for autonomous ship using fuzzy relational products and COLREGs	6
6	Statheros et al. (2008)	Autonomous ship collision avoidance navigation concepts, technologies and techniques	88
7	Perera et al. (2013)	Experimental Results on Collision Avoidance of Autonomous Ship Manoeuvres	0
8	Lee et al. (2015)	Fuzzy Relational Product for Collision Avoidance of Autonomous Ships	4
9	Johansen and Perez (2016)	Unmanned Aerial Surveillance System for Hazard Collision Avoidance in Autonomous Shipping	3
Cluster 3: Applications of autonomous ships:			
10	Rødseth (2017)	From concept to reality: Unmanned merchant ship research in Norway	0
11	Su et al. (2009)	An Autonomous Ship for Cleaning the Garbage Floating on a Lake	5
12	Ghaderi (2018)	Autonomous technologies in short sea shipping: trends, feasibility and implications	1
13	Höyhtyä et al. (2017)	Connectivity for autonomous ships: Architecture, use cases, and research challenges	2
14	Sanden and Hovland (2017)	Inverse kinematic control of an industrial robot used in Vessel-to-Vessel Motion Compensation	1
15	Allal et al. (2017b)	Toward a Study of Environmental and Social Impact of Autonomous Ship	0
16	Allal et al. (2018)	Toward energy saving and environmental protection by implementation of autonomous ship	0
17	Kretschmann et al. (2017)	Analyzing the economic benefit of unmanned autonomous ships: An exploratory cost-comparison between an autonomous and a conventional bulk carrier	2
18	Wróbel et al. (2017)	Towards the assessment of potential impact of unmanned vessels on maritime transportation safety	11
Cluster 4: Human elements in autonomous ships:			

19	Wahlström et al. (2015)	Human factors challenges in unmanned ship operations - insights from other domains	5
20	Ahvenjärvi (2016)	The Human Element and Autonomous Ships	5
21	Allal et al. (2017a)	Task Human Reliability Analysis for a Safe Operation of Autonomous Ship	0
Cluster 5: Regulatory and management issues			
22	Karlis (2018)	Maritime law issues related to the operation of unmanned autonomous cargo ships	1
23	Lafte et al. (2018)	International navigation rules governing the unmanned vessels	0
24	Rødseth and Mo (2016)	Integrated Planning in Autonomous Shipping-Application of Maintenance Management and KPIs	1
25	Cezon A (2016)	E-GNSS Use for Autonomous Vessels: Value proposition and market aspects	0
26	Komianos (2018)	The Autonomous Shipping Era. Operational, Regulatory, and Quality Challenges	0

Appendix B: Top 10 countries by number of articles published

Rank	Country	Recs	TLCS	TGCS
1	Peoples Republic of China	16	0	15
2	USA	15	0	105
3	Norway	11	1	9
4	Spain	9	0	69
5	Finland	6	5	23
6	South Korea	6	1	19
7	Morocco	5	0	0
8	Poland	5	1	19
9	UK	5	7	121
10	Australia	4	2	5

Recs. Number of published articles; TLCS. Total local citation, that is, times cited by 90 articles in the sample; TGCS. Total global citations, that is, times cited by all articles listed in Web of Science database.

Appendix C: Top 10 shipbuilding companies in the world in 2017

Rank	Company name	Headquarters
1	Hyundai Heavy Industries	South Korea Ulsan, South Korea
2	Mitsubishi Heavy Industries	Japan Tokyo, Japan
3	STX Group	South Korea Jinhae, South Korea
4	DSME	South Korea Seoul, South Korea
5	China Shipbuilding Industry Corporation	China Beijing, China
6	Samsung Heavy Industries	South Korea Geoje, South Korea
7	Sumitomo Heavy Industries	Japan Tokyo, Japan
8	United Shipbuilding Corporation	Russia Saint Petersburg, Russia
9	China State Shipbuilding Corporation	China Beijing, China
10	Hanjin Heavy Industries	South Korea Busan, South Korea

Source: Bloomberg.

Author’s Biographical Note

Dr. Ziaul Haque Munim is Associate Professor of Maritime Logistics at the Department of Maritime Operations at the University of South-Eastern Norway (Campus Vestfold). His research interests include maritime economics and logistics, supply chain management and international business. He holds a PhD degree in International Management from the University of Agder and an MSc degree in Supply Chain Management from the Vienna University of Economics and Business. His publications have appeared in leading journals such as the Resources, Conservation & Recycling, Research in Transportation Business & Management, Maritime Policy & Management, and others. He received the Best Paper Award at the IAME 2016 conference and the Young Researcher Best Paper Award at the IAME 2018 conference.