

Maritime autonomous surface ships (MASS): implementation and legal issues

330

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Abstract

Purpose – The purpose of this paper is to see whether the concept of autonomous ship is having an effect on pioneering the sea transportation as well as improvement of ship safety and the possibility of local development. Following the lead of the first autonomous surface ship by Norway that met to develop the Advanced Autonomous Waterborne Application (AAWA) and introduce of autonomous operation to the region, this study also aims to compare the initiation of action by surface ships to that of the air and land vehicle automation.

Design/methodology/approach – The ideas for writing this paper came from meeting and interview with maritime professionals such as ship captains, marine chief engineers and naval architects. Through the review of various international journals, the development of Autonomy and Technology are explored and analysed. Owing to the practical approach of this paper, a qualitative research method is used with collecting and analysing information.

Findings – The findings of this paper are as follows: it brings out the importance on the potentials of unmanned vessels and its competitive advantages over existing cargo ships. Besides its contribution to reduce fatigue and workload of navigating officers, the improvement of navigational safety by eliminating human errors and reduction of harmful exhaust emission can make shipping safer and more sustainable. However, as the technology is still under development, it is too early for a final evaluation. That said, as the international regulation body, International Maritime Organisation is required to gain acceptance to future unmanned shipping and to designate routes and impose regulations for their safe operation.

Originality/value – Recently, there are many conferences and meetings on autonomous surface vessel focussing on regulation, technology, human-factor, legal and regulatory framework for such ships around the world. This paper summarises the current development of the autonomous surface ships, in term of the design and technology, their interaction and co-existence with manned ships and suggest some operation issues on board an autonomous surface ship during voyage. Taking Hong Kong as an example, this paper attempts to examine the feasibility for introducing the autonomous surface ships in local waters.

Keywords Autonomy, Surface ship, Hong Kong

Paper type Technical paper

1. Introduction

In the past decade, there was a rapid development in the autonomous land vehicle and surface vessels. Autonomous land vehicles are being tested and running in different countries currently; while the world first autonomous surface ship is expected to conduct the testing in 2019 and deliver to commercial operation in Norway by 2020. Then it will



gradually move from manned operation to fully autonomous operation by 2022. Unlike the land vehicles, the autonomous surface ships are more complicated.

Similar to aviation industry, autopilot has a long history in marine industry. In 2016, the Autonomy Level guideline was launched in the UK and provided the route to classification for the autonomous ships. Meanwhile, funded by Finnish Funding Agency for Technology and Innovation, the Advanced Autonomous Waterborne Application (AAWA) had summarised their research on the technological, safety, legal liability and economic aspects of remote and autonomous operation. They proposed the specification and preliminary designs for a proof of concept demonstrator and a remote controlled ship for commercial use by the end of the decade. In 2017, a report by Global Maritime Technology Trends (GMTT2030) in the UK analysed the transformational technologies and offered their perspectives on the future of autonomy, its impact and the timescales. In 2018, there were concerns raised by trade unions of shipping industry around the world. From the result of their survey, they have expressed their view on human factor from the front line operator's side.

Autonomy vehicle has been used successfully long time ago in a "control" environment, such as a plant or a warehouse, or even within a container terminal recently. In an "open" environment, despite the autopilot has a long history being applied in aviation and marine industry, the level of autonomous in commercial transportation is still in a developing stage. It is observed that the marine industry is lagged behind when compared with the land vehicle.

In 2015, a Maritime Unmanned Navigation through Intelligence in Networks project (European Commission, 2015) has been co-funded by European Commission for an in-depth analysis of the autonomous vessel on safety and security impacts, economic impacts and applicable areas of law. It founded that an autonomous vessel is technically feasible in term of hazard identification and corresponding risk control options. It also found that it would be economic viable in certain circumstances. For the legal aspect, it concluded that the existing legal framework will require some formal amendments but no fundamental substantive obstacles.

A joint human-automation framework (Broek *et al.*, 2017) was studied in 2017 and proposed the migration from human supervision to partial supervision/autonomy stage and finally, the human intervener/fully autonomy stage. To move forward to a fully autonomy sea transportation, shore supports are also required. In 2017, the world's biggest automated container terminal started her operation in Shanghai. Automated service piers were also studied to a local operation.

2. The concept of autonomy

In the past few years, level of autonomy has been defined for road vehicles and the marine industry (Bureau Vertitas, 2017; Lloyd's Register, 2017). Despite different levels of autonomy, it could be observed that the operation decision is handed over to the system from human at the highest level.

Autonomy starts with a navigation, guidance and control system together with for a dynamic unmanned vessel and algorithm. It includes the guidance system providing navigation and obstacle detection and avoidance (ODA) system. In 2012, a control system adopting Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs), defined by the International Maritime Organisation (IMO) was studied (Campbell *et al.*, 2012; Naeem *et al.*, 2012). In 2016, the Advanced Autonomous Waterborne Applications (AAWA) [partners developing a set of electronic integrated system for a safety navigation and avoid collisions. The integrated system included three areas: the sensors technology using different types of radars, high definition visual cameras, LiDAR (Light Detection and Ranging), thermal imaging; a control algorithms based on the maritime rules

and regulations for navigation and collision avoidance; and a communication and connectivity for human input from land, to intervene when needed.

3. Implementation of unmanned vessel

Unmanned cars and aircraft have been commonly seen today and few are used in road transportation as well as military engagement. Last year in China, Shenzhen has deployed unmanned bus in a test trial for in town transportation, the service received much welcome by the community and proved to be successful. In Europe and the United States, there are also researches into small unmanned underwater and military vessels, some of them are already made available and in use.

In maritime industrial sector, there had been also researches into the unmanned surface and underwater vehicles. Initially these researches used the idea of remoted control functions on relative small crafts but as the demand grew larger, the size of these crafts are increasing. Developing a large unmanned cargo vessel involves similar idea but the implication would be far greater than land and aviation. Since over 80 per cent of worldwide cargo transportation is carried out by sea, it is considered to be one of the main driving forces of today's global economy. It would be a great step forward that a reliable and sustainable transportation system of unmanned vessels can be introduced in the sea transport.

In Norway, a ship similar to the actual size of a cargo vessel is being built as an unmanned cargo carrying vessel. "Yara Birkeland", is an autonomous container ship under construction and due to be launched in 2019. The "Yara Birkeland" project is planned to be the first fully autonomous logistics concept from industrial site operations, port operations and vessel operations in the world.

Comparing with the current cargo ships, the reliability and capability of the Artificial Intelligence Components (AIC) in terms of safety, ecological and cost effectiveness would be a main concern for the merit to develop unmanned shipping. Scepticism regarding unmanned vessels would exist and thus one must perceive those unmanned vessels are at least as safe as or even safer than the current cargo ships. It is also expected that the future unmanned vessel should be able to resolve some of the problematic issues that are facing with the current shipping.

Operationally, an unmanned vessel will chiefly be guided by AIC with automated navigational system on-board which make decision based on the detected surrounding situations. In case of an un-predetermined situation occurring to the unmanned vessel, it will automatically alert the Shore Command Centre (SCC). The SCC is a backup facility in which the unmanned vessel would be operated at ashore. Using communication satellites as bridges the unmanned ship and SCC will be constantly linked up.

The possibility to navigate below the sea surface during the ocean passage will also be explored in the latter part of this paper. Using battery as its means of propulsion the unmanned vessel might sail beneath the sea surface in the designated ocean route at a pre-assigned depth. Because of being submerged, the resistance between the surface water and the hull would be greatly reduced and the speed improved. Besides, the submerged vessel would be able to avoid adverse weather condition and dense surface traffic.

3.1 Safety of navigation

Today, the responsibility of ship officer is ever increasing because of various navigational duties and paper work throughout the voyage. During coastal voyages, schedules would be even tighter. Frequent port call and prolong hours of navigation in busy coastal water would render stress to the navigating officers. As the number of navigating officers on board is barely sufficient, these stresses could build up as a result of heavy workload causing fatigue and exhaustion.

Furthermore, the navigating officer is often left to remain the sole responsibility on the bridge while requiring to tender to situations that might not be properly perceived and responded to. Although the STCW Convention has imposed stringent competency requirements to the navigating officers, things may go wrong when under constant stress condition. On the other hand, ocean crossing passage is quite the contrary. At sea, workload on navigation is less threatening as there is only little traffic during an ocean passage. Although this could allow opportunity for the navigating officer to relax but there are possibilities that it could also result in low situation awareness.

As a result occasionally accidents such as ship collisions and groundings do occur. Investigation to these accidents reveals that over 80 per cent are caused by human error. Common human factors such as fatigue, error of judgment and low situation awareness often contribute to the cause of marine accidents.

One of the motives behind the research of unmanned vessel is to enhance the safety of navigation and resolve the problem of human errors in maritime accidents. With the introduction of unmanned vessel and autonomous collision avoidance navigational system and because the vessel is to operate without human intervention, it is envisaged that the problem of human error should be alleviated.

3.2 Shortage of seafarer

The supply of ship officers to the shipping industry will not be sufficient in future years. A study by Drewry Shipping Consultants has sounded the alarm that owing to the number of new buildings coming on line and youngsters' reluctance to go to sea, the shortage of ship officers will be worsened in the years to come. The study found that the current moderate shortage for ship officers in the world merchant fleet will not be resolved unless training is increased or measures are taken to address the situation and that the current worldwide supply in the next five to ten years will probably not satisfy future demand for officers.

3.3 Harmful exhaust emission

One of the fundamental motivations to the development of an unmanned vessel is to contribute a more sustainable maritime transport industry by reducing fuel consumption cost and harmful exhaust gas emission.

At present, fierce competition between shipping companies has put a lot of economic pressure on all parties involved in maritime transportation. Cost of bunker fuel being one of the major causes. At the same time, the IMO imposes stringent requirements to ships for reducing of harmful exhaust emission. Whilst the global requirement of 0.50 per cent sulphur cap on exhaust emission will enter into force in 2020, more than 70,000 ships will be affected by the new requirement. This necessity to reduce costs and harmful emissions would cause shipping companies to consider the alternatives of propulsion means such as battery through slow steaming.

3.4 Operation of unmanned vessel

During the initial stage, most of the main control functions such as pre-planning of voyage and choice of routes will still be performed by the SCC. However, on scene navigation control functions such as pre planned actions for collision avoidance and course setting will be taken over by the Sensor System on board. The Sensor System is supported by the radar, high definition visual cameras, LiDAR, thermal imaging and AIC etc.

In principle, the detection functions are based on existing and reliable navigational sensors with the radar still being the main source of information. From a navigational safety perspective, the system must ensure that a single technical failure is not compromise the

whole unmanned ship's capability to meet the safety-critical functions so that the vessel will be constantly operated under all safety parameters.

For routine operation of unmanned shipping, three implementation stages on departure, ocean passage and arrival would be identified. A team of navigation crew will board the unmanned vessel after it completes the ocean passage and approaches to the coastal water of the destination port. The crew will then navigate the vessel in a conventional manner until it arrives the berth. Loading or discharge of cargo will be carried out after berthing. Upon departure, the crew will navigate the vessel away from the busy coastal water to a position where the ocean passage commences. The crew set the vessel to unmanned execution mode for ocean sea navigation under full auto mode and disembark. After that, the ship will sail by itself in unmanned mode until it reaches the coastal water of the destination port.

During the full autonomous mode while at ocean sea passage, status of vessel will be constantly transmitted to shore via satellite communication to enable safe monitoring. The vessel will now proceed on its pre-planned track according to the voyage plan and the environmental data is obtained and monitored by its auto detection sensors such as radar and collision avoidance systems.

The setting and design of the AIC and Sensor System should be based in accordance with the appropriate international legal requirements, such as the International Prevention of Ship Collision Regulations. If a close quarter situation with another vessel is encountered, the Sensor System will recognise the traffic situation and the AIC will respond to it according to Collisions Regulations. Should floating objects or fishing nets be discovered, the vessel will carry out a respective evasive manoeuvre as well.

As soon as a situation is encountered which the Sensor System is not capable of dealing with, human assistance can be sought from the SCC through the AIC. The vessel will be switched automatically into remote control mode and communicate to a shore-side human operator in the SCC via communicate satellites. If required, the human operator will deal with the situation and give direct actions and command to the vessel via the SCC. It is envisaged that the intervention through SCC should gradually reduce, as the auto mode Sensor System are further developed to meet different type of situations.

The concept of the SCC envisages a backup facility in which the unmanned vessel would be operated. Other than autonomous function of the unmanned shipping, the operator might supervise a number of ships of similar types in the SCC. The SCC is to be set up like a full-scale ship's bridge ashore and be executed by a trained operator who may be an experienced master or watch-keeping officer. The role of the SCC is to back-up the safety function of the automatic system on board is to ensure un-predetermine situations are properly dealt with. During the voyage, the navigational processes and relevant actions taken must be recorded and mapped to facilitate future improvement of the system.

3.5 Vulnerability to hijacking control

In the maritime sector, remote control and autonomous navigational system on board the unmanned vessel brings benefits for safety and efficiency such as artificial intelligence components and sensor system, however, as unmanned ships are interconnected through land and satellite networking, it is possible that they would be exposed to cyber threats.

In 2016, after consultation with the members on what maritime cyber security guidelines should look like, the IMO issued the interim cyber security risk management guidelines. These guidelines enable services that are critical for safety and rescue operations, navigation and communication in a physically remote environment to be protected from cyber threats.

Although cyber security attacks on maritime infrastructure have not yet gained critical momentum, a cyber-attack response and prevention plan by first identifying vulnerabilities

are to be maintained. The informational technology and security experts should run regular incident tests to identify weaknesses and strengthen the on board security programme to avoid possible attack from hackers.

3.6 Support of the International Maritime Organisation

In recent years, the IMO has developed guidelines for assessing the risks relating to maritime safety of the autonomous vessels. As the introduction of a concept for unmanned vessels will surely benefit the future development of technology, a thorough review is necessary to identify those hazards which are affected by the operation when these unmanned vessels actually comes into the picture.

Another proposals of IMO's e-Navigation concept is for Automatic Identification System to extend its function to ships in which it would additionally display their intended routes to the SCC or other reception facilities. This service will no doubt be another great benefit to vessel interaction in the development of the AIC of unmanned shipping.

As for the time being, the IMO may consider the introduction of the following measures:

Similar to Traffic Separation Scheme that had been designated in congested traffic water areas, the IMO should consider to designate ocean routes for unmanned vessel. Requirement should be established for member states to register main ocean routes in the Exclusive Economic Zones and High Sea. The designated ocean routes are to be used exclusively for unmanned vessels transiting the sea area under the revised Collision Regulations. Furthermore, for safe operation of the unmanned vessels, special rules and regulations are to be introduced in both surface and submerged conditions.

It is envisaged that future hull structure of unmanned vessels would be designed to fit for both surface and under water navigation. Using battery as its means of propulsion, it is believed that the unmanned vessel should be free from any emission and reduce air pollution to the environment.

3.7 Pros and cons

To summarise, the following are the pros and cons for developing unmanned shipping:

- (1) Pros:
 - elimination of harmful emissions;
 - decrease of human error risk and the resulting associated accidents;
 - reduction of fuel costs;
 - offsetting the expected shortage of seafarers in the future;
 - reduction of total operating expenses; and
 - increase the reliability and efficiency in future sea transport.
- (2) Cons:
 - technology still under development;
 - possible reduction of seafarer jobs;
 - unknown safety risks due to uncertain technology reliance; and
 - vulnerability to computer hackers hijacking control.

4. Legal aspects concerning unmanned ships in Hong Kong

There are major international IMO treaties and Hong Kong legislation that are applicable to the Shipping operations in Hong Kong. To limit the scope of our study, we only confine ourselves with the study of cargo ships engaged on international voyages. If these "unmanned" ships can comply with the local laws and regulation, they can operate in Hong

Kong or if not, the international laws and domestic legislation are needed to be amended with clarifications to cater for “unmanned” cargo ships before these ships can be operated in international waters or in the waters of Hong Kong.

4.1 Master’s role on board ship

The master of a ship has the sole command of the ship but also has all the responsibility concerning all matters that happens to the ship or that requires by the laws and regulations. The maritime legislation considers the master of a ship is a person in charge of the ship, who has ultimate authority and responsibility to make decisions with respect to ship’s health, security, safety and environmental protection matters.

Chapter 1 of the Laws of Hong Kong – Interpretation and General Clauses Ordinance of provides the following: “master”, when used with reference to a vessel, means the person (except a pilot) having for the time being command or charge of the vessel.

Under the International Convention for the Safety of Life at Sea (SOLAS), the master of the ship is required to perform a number of duties related to the ship. The SOLAS and the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL 73/78) conventions are enforced in Hong Kong through Cap.369 and Cap.413 Ordinance, etc. and their subsidiary legislations. These duties and responsibilities are required under SOLAS and the Hong Kong legislation.

The master of the ship is vested with duties, powers, responsibilities or discretions which he is obliged to discharge or exercise for the safe operation of the ship under international treaties and domestic legislation. Do the existing international maritime regulations require that the master or officers or crew necessarily be on board the ship during a voyage or on a sea passage? Some people say without the master or officers or crew on board may render the ship unseaworthy. The unmanned ship may not be able to comply with the Collision Regulations (COLREGs) as the action required for collision avoidance shall, if the circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship. When the traditional role of the master of the ship will not be there and the master’s responsibilities and liabilities will be transferred to other shore-based operators. Compulsory pilotage is another issue that may have an impact on the operation of unmanned ships as compulsory pilotage requirements or regulations vary from port to port.

The IMO has now taken a more proactive and leading role on MASS due to the rapid technological developments in recent years. The Maritime Safety Committee (MSC) and the Legal Committee (LEG) have now agreed on regulatory scoping exercises and gap analysis to see if, where and how unmanned ships will fit in existing maritime conventions and regulations. Furthermore, the impact on the controls of United Nations Sanctions and embargoes on unmanned ships should also be studied by the United Nations and the IMO for the prevention of using the unmanned ships for illegal sea transportation.

5. Conclusions

This paper has demonstrated the potentials of unmanned vessels and its competitive advantages over existing cargo ships. Besides its contribution to reduce fatigue and workload of navigating officers, the improvement of navigational safety by eliminating human errors and reduction of harmful exhaust emission can make shipping safer and more sustainable. However, as the technology is still under development, it is too early for a final evaluation. That said, as the international regulation body, IMO is required to gain acceptance to future unmanned shipping and to designate routes and impose regulations for their safe operation.

Ship category	Level of autonomy	Manned	Method of control	Authority to make decisions	Actions initiated by
Conventional	0	Yes	Automated or manual operations are under human control	Human	Human
Smart	1	Yes/No	Decision support Human makes decisions and actions	Human	Human
Autonomous	2	Yes/No	Human must confirm decisions	Human Software	System System
	3	Yes/No	System is not expecting confirmation Human is always informed of the decisions and actions		
	4	No	System is not expecting confirmation Human is informed only in case of emergency	Software	System

Note: Definitions of the level of autonomy are given in Sec 2, Tab 16

Table I.
Ship categories and
level of autonomy

Table II.
LR Code for
unmanned marine
systems – autonomy
levels

Autonomy Levels (AL)	Manual to Fully autonomous	Description
AL 0)	Manual	No autonomous function All action and decision-making performed manually Human controls all actions
AL 1)	On-board Decision Support	All actions taken by human operator, but decision support tool can present options or otherwise influence the actions chosen Data are provided by systems on board
AL 2)	On and Off-board Decision Support	All actions taken by human operator, but decision support tool can present options or otherwise influence the actions chosen Data may be provided by systems on or off-board
AL 3)	'Active' Human in the loop	Decisions and actions are performed with human supervision Data may be provided by systems on or off-board
AL 4)	Human on the look	Decisions and actions are performed autonomously with human supervision High impact decisions are implemented in a way to give human operators the opportunity to intercede ad over-ride
AL 5)	Fully autonomous	Rarely supervised operation where decisions are entirely made and actioned by the system
AL 6)	Fully autonomous	Unsupervised operation where decisions are entirely made and actioned by the system during the mission

As for Hong Kong, the maritime traffic density in the waters of Hong Kong is high and the traffic patterns in Hong Kong are also complex. The present legal frameworks are also hurdles for unmanned ship implementation. We do not anticipate that unmanned ships could operate within the port of Hong Kong even after IMO has resolved the legal issues. However, with the rapid development of the artificial intelligence system and other control technologies, IMO should re-visit the “Principles of Safe Manning” as adopted by IMO resolution A.890(21) as amended by resolution A.955(23) to take into account the operation of Shore Command Centre and Shore-based Operators and to allow further reduction of the number of crew on board. Only when these international legal framework becomes operational and feasible to the maritime industry, Hong Kong could attempt to consider the autonomous ship application in our waters (Tables I and II).

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