Research on the Impacts of Marine Autonomous Surface Ship on the Seafarer's Career and MET

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November 2018

Content

Chapter 1 - Background

Human beings have enjoyed a nearly 5000 years history of using ships as means of transport from ancient canoes to modern vessels. The main four great times are comprised of the raft age, the sailing boat age, the steamboat age and the combustion ship age. Each leap in ship technology may impose a certain impact on shipping industry.

The emergence of Marine Autonomous Surface Ship (MASS) is the result of modern science and technology. Thanks to the rapid improvement of Artificial Intelligence, Information Geographical Systems, environmental information perception, satellite and communication, the Big Data, Remote control, Debugging diagnosis technology, Internet of Things, great progress has been made in recent years. Some major shipping countries and many equipment manufacturers invest a great deal of time, energy and capital to research and develop relevant products and system, just to ensure the precedence. It is reported that the first fully autonomous ship will be put into operation around 2020. Meanwhile, the International Maritime Organization (IMO) begins the legislative research on at 99th Session of the Maritime Safety Committee (MSC).

The operation of traditional ships is based on human, who makes all the decision and operations. In the future, ships can be controlled and operated by machines if Marine Autonomous Surface Ship can reach the level of unmanned control. It can be predicted that the its wider application will bring great change to the shipping industry, and pose great impact to maritime personnel on the post setting, personnel demand, knowledge structure, talent cultivation and etc.

In order to study the implications of MASS on the Seafarer's career, Nautilus Federation and ITF conduct a survey by questionnaires and conclude "it's not surprising that the majority of seafarers (84%) consider autonomous ships as a threat to seafarer's jobs. However, the research report does not tell how the development of MASS affect the seafarer's occupation, nor their impact on MET.

Undoubtedly, each leap in ship development may exert a certain impact on the future career and education of seafarers. By studying the course of ship technological development, the Research attempts to predict the impacts of MASS on the changes of Seafarer's jobs, Seafarer quantities, navigation modes, the knowledge structure of seafarers, maritime education and training, subject setting from the perspective of comparison of ship crew manning, maritime laws and regulations, application of new shipping technologies and psychological analysis.

Chapter 2 - Impact of Ship Development on Seafarer Career

2.1 The Development of Ships

The time-honored history of using ships as a means of transport is almost as long as human civilization. By the power type, it can be divided into four periods: raft age, sailing boat age, steam engine age and internal-combustion engine ship age. With the compelling need of environmental protection, and high air emission control, countries all over the world are vigorously developing pollution-free or less-polluted new energy vessels. With the progress in science and technology, maritime transportation is about to be ushered into a new energy era.

2.1.1 The Raft Age

The history of using rafts as a tool for transportation, hunting and fishing can be dated back to the Stone Age. 3 types of boats are frequently utilized: canoe, raft and planked ship. Moreover, these boats are operated by man and propelled by oars, poles, and sculls.

Table 2-1 Ships at the Raft Age

Type of ships	Feature of ships	Age
canoe	The Canoe is the oldest means of waterborne transportation, which is made by burning tree trunks into hollowed canoes with fire or axes.	The Primitive Times
raft	The raft is the combination of tree trunk, bamboo pole, reed or animal skins so as to float on the water.	The Ancient Times
plank ship	The planks are joined as the ship hull with many reinforcing cabins.	The Bronze Age

2.1.2 The Sailing Boat Age

According to the historical records, sailing boats appeared in ancient Egypt as early as 4000 BC, and came to the heyday from the 15th century to the middle of the 19th century. Later in the early 15th century, Zheng He, a great Chinese navigator, sailed to East Africa, and Columbus discovered the New World at the end of the 15th century, whose journey could not be completed without the so called sailboats. In the history of sailing boat, great contributions have been made in the Mediterranean coastal area, the northern Europe, Western Europe and China. The American Clipper emerged in the middle of the 19th century pushed the sailboat development to climax. Sailboats of different regions are marked with the local characteristics including structure, form and sailing gear.

Table 2-2 Ships at the sailing boat age

Type	Feature	the Age
Ancient Mediterranean sailboat	The sailing boat of Crete is characterized by two raising ends and one square sail in a single mast. The ancient Greek and Roman sailboats were equipped with oars which were only used when they enter and leave ports and dispatch.	2000 B.C.-1600 B.C.
	Ancient Greek sailboat is marked by high free board, good wave resistance and one square sail in a single mast. The two huge oars on the stern act as a rudder. Beyond that, for easier operation, a sail was put to the mast and jib topsail was added to the top of the singled-mast.	
	The ancient Roman sailboat is improved as well. The addition of front and rear jibs makes operation easier.	
Northern and Western European sailboats	The Nordic Viking sailboat can sail far to Greenland and North America, and the ship is navigable for its oak. It totaled about 30 meters long and 6 meters wide, nearly symmetrical in shape with keel and column. Moreover, the board is joined with iron nails. So the single-masted ship with a mast rope and square sail can move smoothly under the crosswind.	9^{th}- 11^{th} century
	Columbus led the Spanish fleet called *Santamaria*, a 28-meter-longsailboat with the displacement of about 200 tons.	1492 A.D.
	Magellan's Spanish fleet: after the 16th century, the displacement of European sailboats gradually increased to 500-600 tons, and the rigging became more and more various. The three-mast ships became increasing popular because of increasing sail area. As the main mast was added with topmast and topsail, the main sail is put with the bottom sail, and adds the jib to the mast, the speed increased remarkably with various sails.	the 16^{th} century
The American Clipper	This high-speed sailboat is originated from America, characterized by fine form, sharp end and high speed. The representatives are the *Ann Markin* in 1833 and the *Great Republic* in 1853.	the 18^{th}-19^{th} century
Chinese sailing boat	Otherwise, the Chinese sailboat was constructed horizontally to form a rectangular shape with a flat bottom. The rudder is on the center line of the stern, at which platforms were created to prevent waves. Its structure is solid owing to watertight cabins and a sail strengthened with bamboo poles. This balanced sails is not only easily operated, but also can resist wind in all directions. In the 15th century, Chinese sailboats lead the way in terms of scale and performance. The representative is Zheng He's treasure ship of the Ming Dynasty.	the Song and Ming Dynasty

2.1.3 The Steamboat Age

Many people sought to apply the steam engine to ships after the invention of the steam engine in the 18th century. In 1807, American Fulton firstly used steam engine to drive paddles on both sides of the ship called Clermont, and sailed smoothly on the Hudson River. From then on, the development of the ship entered a new stage as the mechanical force began to replace manual force.

Table 2-3 The shipping at the Steamboat Age

The progress of steam engine boat	Features	The typical ships
Early steam boast	Early steam boat is equipped with a whole set of riggings, assisted by steam engine. Steam engine is installed on the deck to propel two large wheels.	SS Savannah
Steam engine ship	The theory of beam from the force theory was applied in ship building, adding the longitude and rack. Double hull extends to the load lines, upper deck reinforced with the same structure. After 1850, iron was used the ship building material. After 1880, steel was used.	The Great Eastern
Turbine	Since the 20th century, marine steam turbines have enjoyed continuous advancement, and they are generally used in large high-speed ships marked by light weight, large power, uniform rotation and no reciprocating parts. Up to now, some large-power ships still use steam turbines as their driving force.	The Titanic

2.1.4 The Internal-combustion Engine Ship Age

With the advent of the internal-combustion engine ship, internal-combustion engine ship gradually replaced the steamboat. Compared with steam engine ship, the internal-combustion engine ship enjoys high thermal efficiency, low fuel consumption and smaller size. Since 1911, cargo ships and passenger ships driven by the internal-combustion engine grew steadily, but steamboats still dominated the international merchant fleets by the end of World War II. After the war, with the development of supercharging technology, the low-speed high power diesel machine capacity with a maximum of 50, 000 horsepower was on the increase. So diesel can be applied to large high-speed ships that used to install steam turbines and obtained competitiveness as the adaptability of diesel to inferior oil is improved. For Ro-Ro ships, container ships, ferries and other pertinent types with limited space, the medium-speed diesel with small size and light weight can be used to drive the propeller through the deceleration box. At present, internal combustion engines with different power, featured in low fuel efficiency and compatibility with low-quality oil occupy almost all the market for marine engines. Therefore, the development of ships after World War II is called the Internal-combustion Engine Ship Age.In order to improve the economic benefits of shipping, ship building projected many trends characterized by mega-ship, specialization, high speed, automation and modernization.

Table 2-4 The Ships at the Combustion Ship Age

The trend of the Combustion ship	Features of the Combustion ship	The typical ships
shipping maximization	Tanker ship: the maximal load is up to 56,5000 tons; Container ship: the maximal load is up to 22,000TEU; Cruise: the maximal load is up to 22,0000 tons; Bulk carriers: the maximum capacity reaches 40,0000 tons; Aircraft carrier: the water displacement totals more than 100,000 tons.	Seawise Giant
shipping Specialization	Container ships have basically replaced general cargo ships. Specialized ships developed after World War II, including liquefied natural gas (LNG) carriers, liquefied petroleum gas (LPG) carriers, Ro-Ro ships, barges for direct transportation by river and sea, passenger Ro-Ro ships, cruise ships and etc.	COSCO SHIPPING LEO
high-speed ship	The speed of general cargo ship increased to 18 nautical miles per hour while the container ship can reach more than 20 nautical miles per hour; Non-displacement high-speed passenger ships have been used in short-distance routes and have seen gradual growth, such as hydrofoil and hovercraft.	Beiyou 16 high-speed passenger ship
Automation of ship	Since the early 1960s,the shipping enterprises from various countries have gradually realized the automation of engines, navigation and outfitting in order to reduce the number of crew, improve the working conditions and increase the economic benefit of ship transportation .	—

2.1.5 The New Energy Vessel

With the impact of the global energy crisis and the requirements of environmental protection and sustainable economic development, developed countries and some developing countries all resort to renewable energy in their 21st century strategies. Thanks to the progress of science and technology, the new energy features unique strengths in energy saving and emission reduction, including wind energy, tidal energy, solar energy, nuclear energy, bio-fuel, liquefied natural gas and etc. Beyond that, its application and marketing is sweeping the market of transport.

2.2 Marine Autonomous Surface Ship

As defined by IMO, Maritime Autonomous Surface Ship means a ship, which, to a varying degree, can operate independently without man-machine interaction.

MASS is the product of the development of modern science and technology. In terms of ship power, it still belongs to the Combustion Ship Age, but much developed in the navigation and management intelligence and automation. Significant advancement has been made in the research and testing of MASS with the rapid development of artificial intelligence, Cyber-physical System, environmental information perception, satellite and communication, Big Data, remote controlling, fault diagnosis technology, Internet of things and etc.

The operation of traditional ships is based on man, who makes all the decision and operations. In the future, ships can be controlled and operated by machines if Marine Autonomous Surface Ship can reach the level of unmanned control. It can be predicted that the its wider application will bring great change to the shipping industry, and pose great impact to such things as the post setting, human resource requirements, knowledge structure, talent cultivation and etc.

2.3 The Impact of Shipping Development on Seafarer's Quantity

2.3.1 Principles of Safe Manning

Seafarer refers to all the people serving on ships in coastal and international navigation areas, including the captain. Seafarers are interconnected with ships, responsible for the navigation, management, safety and order. Moreover, the number of ship crew is an important factor that affects the ship safety. Safe manning refers to the number of qualified or experienced seafarers appropriate to the requirements of ship, crew, passengers, cargo, property safety and marine environmental protection.To ensure the safe navigation, several factors should be fully considered concerning safe manning, including the trade the ship engaged in, the length of voyage, the navigation waters, the quantity of the main propulsion power plant and auxiliary machine, the power, the ship scale, the construction and technical equipment of the ship, the full consideration of enough qualified crew available to meet the peak demand, the appropriate rest time of the crew.

2.3.2 Analysis on the development of the number of seafarers

According to the statistics of BIMCO, the number of seafarers increased from 1234000 to 1647500, which increased rate reached 33.5%

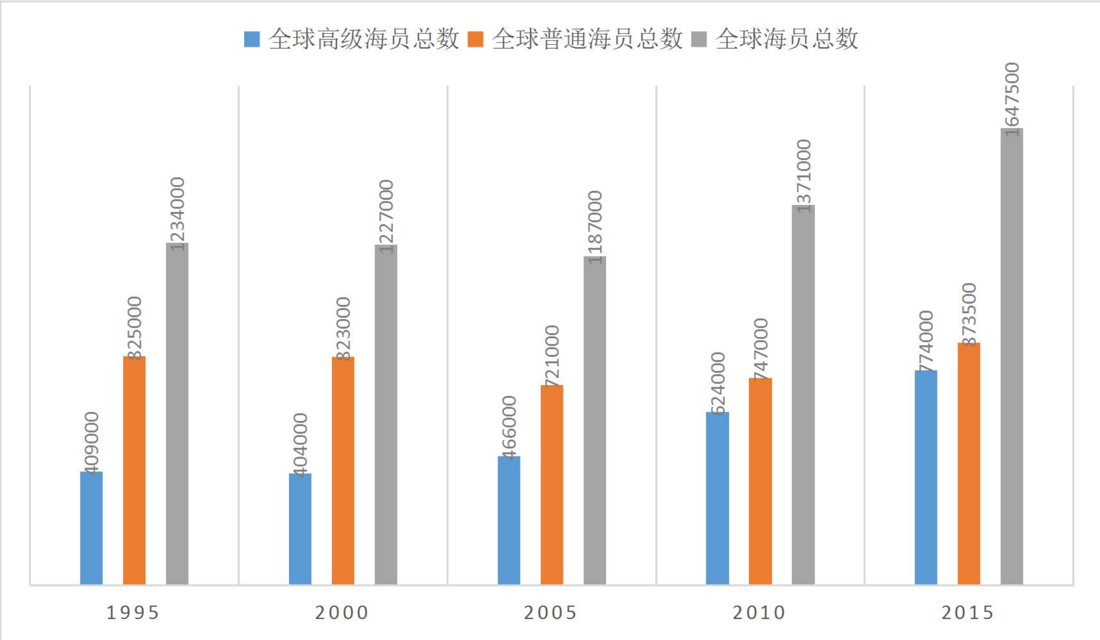

Fig. 2-1 The change of the number of world seafarers from 1995 to 2015

Meanwhile, the development of important science and technology or convention as followings:

In 1993, IMO adopted ISM Convention and published the standard the vessel security management and operation.

In 1994, GPS was adopted fully and provided satellite positioning accurately.

In 1999, GMDSS established a draft about vessel in danger and salvage, and introduce mandatory distress communications.

In 2000, IMO adopted SOLAS Convention about compulsorily install VDR or black box

Table 2-5 The change of the number of world seafarer

Year	No. of senior crew	No. of ordinary crew	No. of crew	The development of important science and convention
1995	409000	825 000	1234000	STCW convention was amended in year 1995
2000	404000	823 000	1227000	
2005	466000	721 000	1187000	In 2004, AIS system was applied on identify the vessel and routing tracking to avoid collision. In 2004, ISPS promoted port safety. In 2006, Maritime Labour Convention 2006 ratified.
2010	624000	747 000	1371000	STCW convention was amended in year 2010. In 2012, ECDIS compulsory application
2015	774000	873 500	1647500	On 20th Aug, 2013, Maritime Labour Convention 2006 was in effect officially

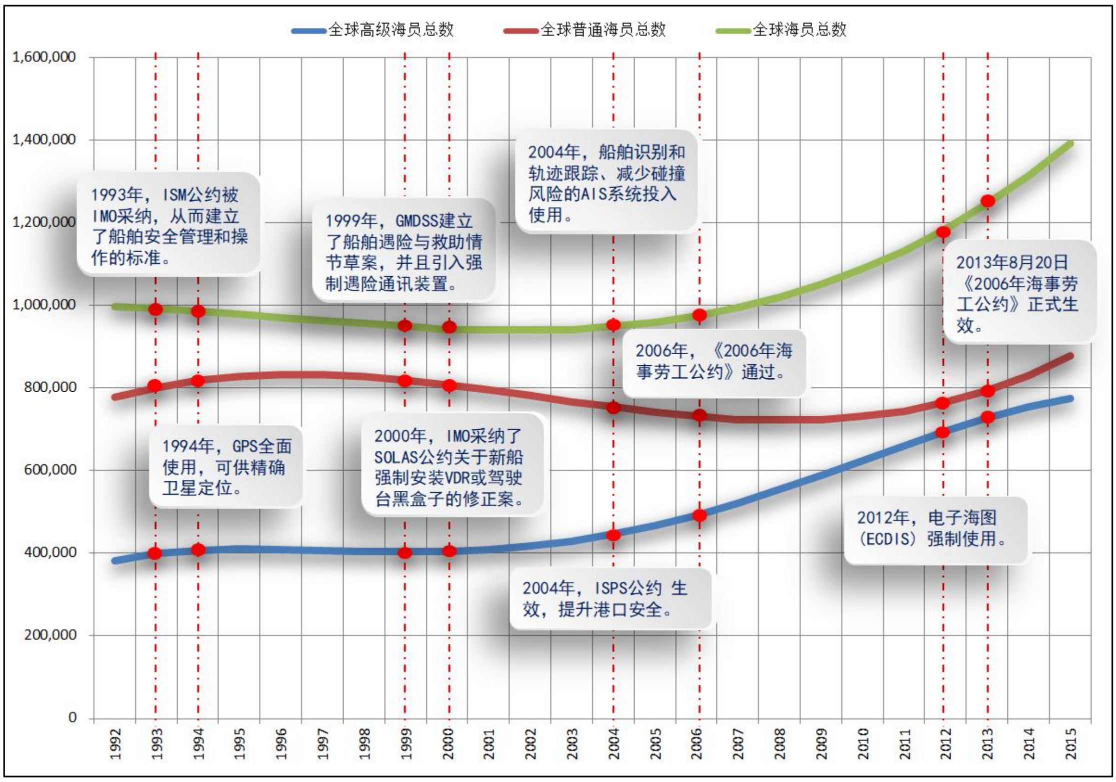

Fig. 2-2 New regulations/New technology and trend of change of seafarers number

1) Shipbuilding and shipping technology play important roles in intensive manning management, but the significant growth of the number of vessels and shipping trade make the gross seafarers increase rather than decline.

1) With the development of the emerging industries, the gross of manning on board vessels is declined, but the number of people working on shipping management, security and service is increasing.

2.3.3 Analysis on the development of vessel manning

Table 2-6 The average number change of the world manning from 1995 to 2005

Year	Total number of worldwide seafarers	Total number of worldwide merchant vessel	Total tonnage (DWT)	The number of average manning	Average vessel deadweight
1995	1234000	28841	671183950	42.78631	23271.87
2000	1227000	30344	732535086	40.43633	24141.02
2005	1187000	31097	839633000	38.17088	27000.45

Table 2-7 The average change of the world manning from 2010 to 2015

Year	Total number of worldwide seafarers	Total number of worldwide merchant vessel	Total tonnage (DWT)	The number of average manning	Average vessel deadweight
2010	1371000	102194	1276137000	13.41566	12487.4
2015	1647500	89464	1749222000	18.41523	19552.24

Remark: Questioning attitude to the conclusion of above table. Review of Shipping has different conclusion on total number of worldwide merchant vessels in 2005-2010 by United Nations Conference on Trade and Development, and about otal number of worldwide merchant vessel in 2010-2015 is totally different.

Evidenced by vessel average tonnage, found that from 1995 to 2015 vessel average tonnage declined significantly in 2010 and is different with the large-scale trend. It has two stages about origin of data sources.

2.4 Influence of ship Development on Seafarers' Post

2.4.1 The seafarers position in raft era.

In the raft era, the seafarers' duties are mainly classified according to boat driving techniques such as paddling, pole support and traction. The number of seafarers is also determined by the size of boat, and there is no specific requirement for seafarers. As canoes and rafts evolve into plank boats or even wooden sailboats, such as paddling, poles, traction, sailing and other sailing techniques become more and more complex, it becomes more and more difficult to rely on one or more people to do too many operations traditionally, and each skills need professional man to operate. Therefore, the roles of seafarers gradually fixed. Further, in shipping practice, the overall quality of seafarers improved greatly compared with the past due to the accumulation of astronomy, hydrology and meteorology and some knowledge closely related to navigation

2.4.2 The seafarers post settings at sailing age.

Ships in the sailing age generally took into account the functions of merchant ships and warships. At that time, seafarers were collectively called seafarers, including officers and professional technicians. Professional technicians include those positions without military ranks. They are collectively called mechanics, and they are divided into woodworkers, divers, repairmen, plug sewers and trumpeters.

2.4.3 The seafarers position in steam boat age.

The seafarers position in steam boat age as table 2-8.

Table 2-8 The seafarers position in steam boat age

Position classification	**Position name**
Officer	Captain, Mate
Deck crew	seafarer
	Boast man assistant
	Picket chief
	Pilot
	Watchman
Engine crew	Engineer
	Electrician
	Boiler
	Fireman
	Coal worker
	Supplier
	cook
Logistics crew	Purser
	Server

	Kitchen staff
	Warehouse staff
	telegrapher

2.4.4 The seafarers post at Internal-combustion Engine era.

Development of shipping technology conditions declined workload on the vessel for crew, and some positions were canceled such as boiler, fireman and so on, which make the number of seafarers decreased.

Table 2-9 Vessel worldwide manning comparison between 1960s and the end of 1980s

	Steaming ships in 1960s	Ships in the end of 1970s	Ships in the beginning of 1980s		Vessel "XianFeng" made by Japan in 1980s
Master	1	1	1	1	1
Chief mate	1	1	1	1	
Second mate	1	1	1	1	
Third mate	3	1		1	
Deck crew without certificate	13	3		6	
Chief engineer	1	1	1	1	1
Second engineer	1	1	1	1	
Third engineer	1	2		1	
Fourth engineer	3			1	
Electrician	1		1		
Bosun	1		1		
Engine crew without certification	9			3	
Maintainer		5			
General crew			4		4
Dual senior officer					4
Server	8	4	2	3	1
Radio operator	1	1	1	1	
Total	45	21	14	21	11

Nowadays, the main positions on Internal-combustion engine ships are prepared according to the vessel minimum safety standard in STCW Convention.

Table 2-10 The situation of vessel manning in diesel engine era

Position	Manning or not	Remark
Master	Yes	
Chief mate	Yes	
Second mate	Yes	
Third mate	Yes	

Chief engineer	Yes	
Second engineer	Yes	
Third engineer	Yes	
Fourth engineer	Yes	
Motor-man	Yes	
Rating	Yes	
Commissar	Yes	Equipped on some vessels
Cook	Yes	
Server	Yes	
Radio officer	Yes	
Telegraph operator	Yes	Canceled
Doctor	Yes	Equipped on some vessels

Chapter 3 - Definition and classification of Marine Autonomous Surface Ship

3.1 Definition and classification of Marine Autonomous Surface Ship

3.1.1 Definition of Vessel

In international law, the existing laws about maritime safety and environment protection are originated from UNCLOS Convention, and SOLAS Convention, COL REG Convention, STCW Convention and other international conventions made by International Maritime Organization, and international customary practices. UNCLOS Convention does not make definition on vessel, but refer to it with two words, ship and vessel. Most researchers consider that unmanned vessel should belong to the vessel in the maritime laws, and UNCLOS Convention also applies to flag state and coastal state of unmanned vessel.

On the other hand, the Conventions adjusting vessel register, maritime safety and anti-pollution make definition to the vessel, for example, UN convention on the Conditions of Registration of Ships defines the vessel as any self-propelled seagoing vessel used in international maritime commerce for the carriage of goods, passengers, or both, but not for vessels with a gross tonnage of less than 500. The definition of vessel in COL REG Convention is any of various types of water craft used or capable of being used as a means of transportation on water, including non-displacement boats, wing-in-ground ships and seaplanes. SUA Convention defines vessel as any kind of craft which is not permanently attached to the sea bed includes power support craft, diving craft or any other floating craft. Convention on the clearance of international ship debris also adopted the similar definition. Based on these maritime conventions, we could know that seaman is not the key component applied to convention. So some researchers hold that unmanned vessel could also enjoys the same rights in the stipulation of UNCLOS Convention in public sea and exclusive economic zone of the right of navigation and the right of innocent passage in territorial sea.

Definitions of vessel above do not contain seaman as key factor and do not exclude Marine Autonomous Surface Ship. Therefore, Marine Autonomous Surface Ship should belong to vessels as defined above.

3.1.2 Definition of Marine Autonomous Surface Ship

Marine Autonomous Surface Ship, MASS in short form. Nowadays, Marine Autonomous Surface Ship is under inventing and testing stage. International Convention and Domestic laws do not give an authoritative definition. In academia, some research constitutions defined Marine Autonomous Surface Ship such as China Classification Society.

The autonomous ship (intelligent ship) understood by the China Classification Society refers to the use of sensing, communication, Internet of things and other technical means to automatically perceive and obtain information and data about the ship itself, the marine environment, logistics, ports, etc. And on the basis of computer technology, automatic control technology, big data technology, intelligent technology, the ships that operate intelligently in navigation, management, maintenance, cargo transportation, etc., in order to make the ships safer, more environmentally friendly and more economical, more reliable. The development of autonomous ship is a gradual process, so the China Classification Society uses the phrase "safer, more environmentally friendly, more economical and more reliable."

Features of Marine Autonomous Surface Ship:

1) With perceptive ability, the ability to perceive the information of the ship itself and the surrounding environment.

2) With memory and thinking ability, that is, the ability to store perception information and manage knowledge, and the ability to analyze, calculate, compare, judge, associate and make decisions with existing knowledge.

3) With learning and adaptive ability, that is, through the interaction of expert knowledge and environment, constantly learn and accumulate knowledge and adapt to the change of environment;

4) With the ability to make decisions, that is, to respond to one's own situation and external environment, to make decisions and guide the on-shore personnel, and even to control the ship.

The term "unmanned ship" refers to a ship that has no crew members on board. Depending on the level of automation, the ship may be operated either remotely by one or more shore-based remote controllers, or in a fully automated mode without human intervention. The level of automation of the operation is not fixed but may change during a single voyage.

In the proposal of related principle about Marine Autonomous Surface Ship in MSC 99th Conference submitted by Japan, the term "unmanned ship" refers to a ship that has no crew members on board. Depending on the level of automation, the ship may be operated either remotely by one or more shore-based remote controllers, or in a fully automated mode without human intervention. The level of automation of the operation is not fixed but may change during a single voyage. Unmanned ship here means the vessel in higher autonomous ability.

In the report of the working Group of the 99th meeting of the MSC, the autonomous ship was defined from the view of legislation, and the autonomous ship is divided into four levels.

IMO defines MASS as a ship that can operate independently of human-computer interaction in some extent.

The object of this study is the influence of autonomous ships on the career development of crew and the maritime education and training. From the view of autonomous ship and crew, we define that MASS refers to a ship that can operate independently of human-computer interaction in some extent, including full autonomous ships with the ability of automatic planning, sailing, autonomous sensing to surrounding environment, and remote-controlled unmanned ships that is no-autonomous sailing and semi-autonomous manned craft that navigates and performs missions in accordance with the built-in procedures.

3.1.3 Classification of Marine Autonomous Surface Ship

It is important to research on the influence of autonomous ship on the career development of crew and the Maritime Education and Training.

Terms of Marine Autonomous Surface Ship as table 3-1

Table 3-1 Vessel terms related to autonomous driving, remote-controlled operation, remote-controlled monitoring and autonomous sailing

Manual navigation of merchant ships	The navigating officer gives the command for the wanted course and speed, either to a helmsman or as an autopilot setting and for bridge navigation of the ship's main engine. The navigating officer has electronic charts and own position and course. A radar system shows other ships' course and speed.
Automatic course steering	Course steering takes place between encoded positions; the ship's autopilot ensures that the ship goes from position A to B.

Decision-support	Decision-support consists in planning a route and speed profile in order to reach a port at a given time with a prediction of the sea and wind conditions underway. More extensive decision-support could consist in guidance for the navigating officer about the performance of an evasive action in narrow waters.
Remotely operated navigation	Remote operation is used about the possibility of remotely operating a point for the autopilot and the effect on the propulsion machinery.
Remote monitoring	Measured values from sensors in, for example machinery spaces, on course and speed are shown in real time in an operation centre ashore or on board another vessel. Full monitoring includes transmission of TV monitoring and radar picture so that the operation centre has sufficient information about the ship and its surroundings to be able to perform remotely-operated navigation.
Partial autonomy	The ship has systems for assessing the situation as well as the consequences and advising the navigating officer about how to react. The navigating officer is not necessarily present on the ship's bridge in person.
Full autonomy	The situation is perceived and assessed and a decision on which action to take is made without any intervention by human beings.

Nowadays, academia researchers have made a variety of classification to autonomous ship when they are making relevant researches according to their own needs. The more authoritative classifications are as follows:

1) Coordinated by Maritime Human Resource Institute (MHRI), the IMO working group, when studying the necessary amendments to the provisions of the STCW Convention relating to autonomous ships, divided the autonomous ships into three cases.

Case 1: Conventional ships with remote control option from shore (seafarers on board)

Case 2: Ships equipped with highly automated bridge/engine watch-keeping system in order for officers/crew to mitigate workload on watch-keeping duties (seafarers on board)

Case 3: Unmanned ships, operated by shore-based remote operator (no seafarer on board)

2) Lloyd's Register of Shipping classifies 7 levels according to Autonomy Level, they are AL0 Manual steering, AL1 Decision supported on board, AL2 Decision supported on board or on shore, AL3 Execution with human being who monitors and approves, AL4 Execution with human being who monitors and can intervene, AL5 Monitored autonomy, AL6 Full autonomy. Classification by Lloyd's Register of

Shipping is based on the difference between used technology and role of operator, and this classification method only relates to navigation. Detailed classification as below table3-2:

Table 3-2 The Autonomy Level of Ships by Lloyd's Register

Description	Operator role
AL 0: Manual steering. Steering controls or set points for course, etc. are operated manually.	The operator is on board or performs remote control via radio link.
AL 1: Decision-support on board. Automatic steering of course and speed in accordance with the references and route plan given. The course and speed are measured by sensors on board.	The operator inserts the route in the form of "way points" and the desired speed. The operator monitors and changes the course and speed, if necessary.
AL 2: On-board or shore-based decision support. Steering of route through a sequence of desired positions. The route is calculated so as to observe a wanted plan. An external system is capable of uploading a new route plan.	Monitoring operation and surroundings. Changing course and speed if a situation necessitates this. Proposals for interventions can be given by algorithms.
AL 3: Execution with human being who monitors and approves. Navigation decisions are proposed by the system based on sensor information from the vessel and its surroundings.	Monitoring the system's function and approving actions before they are executed.
AL 4: Execution with human being who monitors and can intervene. Decisions on navigation and operational actions are calculated by the system which executes what has been calculated according to the operator's approval.	An operator monitors the system's functioning and intervenes if considered necessary. Monitoring can be shore-based.
AL 5: Monitored autonomy. Overall decisions on navigation and operation are calculated by the system. The consequences and risks are countered insofar as possible. Sensors detect relevant elements in the surroundings and the system interprets the situation. The system calculates its own actions and performs these. The operator is contacted in case of uncertainty about the interpretation of the situation.	The system executes the actions calculated by itself. The operator is contacted unless the system is very certain of its interpretation of the surroundings and of its own condition and of the thus calculated actions. Overall goals have been determined by an operator. Monitoring may be shore-based.
AL 6: Full autonomy. Overall decisions on navigation and operation are calculated by the system. Consequences and risks are calculated. The system acts based on its	The system makes its own decisions and decides on its own actions. Calculations of own capability and prediction of surrounding traffic's expected reaction. The operator is

analyses and calculations of its own capability and the surroundings' reaction. Knowledge about the surroundings and previous and typical events are included at a "machine intelligent" level.	involved in decisions if the system is uncertain. Overall goals may have been established by the system. Shore-based monitoring.

3）From the perspective of maritime supervision, the Danish Maritime Authority has divided the autonomous vessels into four grades according to the level of autonomy of the vessels in the research report on "Analysis of Regulatory Barriers for the Use of Autonomous Vessels". They are M, R, RU and A. M stands for manual navigation with automated process and decision support, R stands for remote control vessel with crew on board, RU stands for remote vessel with no crew on board, and A stands for fully automated vessel. The specific classification is shown in Table-3 below (MSC 99/INF.3).

Table 3-3 Autonomous Levels under the Regulation

Autonomy level	**Operator's role**
M: Manual navigation with automated processes and decision support	The operator (master) is on board controlling the ship which is manned as per current manning standards. Subject to sufficient technical support options and warning systems, the bridge may at times be unmanned with an officer on standby ready to take control and assume the navigational watch.
R: Remote-controlled vessel with crew on board	The vessel is controlled and operated from shore or from another vessel, but a person trained for navigational watch and manoeuvring of the ship will be on board on standby ready to receive control and assume the navigational watch, in which case the autonomy level shifts to level M.
RU: Remote-controlled vessel without crew on board	The vessel is controlled from shore or from another vessel and does not have any crew on board.
A: Autonomous vessel	The operating system of the vessel calculates consequences and risks. The system is able to make decisions and determine actions by itself. The operator on shore is only involved in decisions, if the system fails or prompts for human intervention, in which case the autonomy level will shift to level R or RU, depending on whether there is crew on board or not.

Considering that the content of this research is the impact of autonomous vessels on seafarers' career development and maritime education and training, and taking into account the number of vessel manning, the setting of remote control personnel on shore and the maritime education training (including the education and training of the crew of the autonomous vessel on board and the shore remote control personnel), this topic intends to classify the autonomous vessels according to the MSC classification of autonomous vessels. The study was carried out for the following levels:

1) Vessel with process automation and decision support: the vessel is equipped with some systems or equipment that can help seafarers to realize the process automation and decision support of navigation tasks. The navigation decisions of vessels are made by the seafarers themselves, and the information obtained from the outside world only plays a supplementary role in the decision-making of seafarers.

2) Remote-controlled vessel with seafarers: the vessel is equipped with remote control systems or equipment that can help off-board personnel (e.g. personnel on shore or other equipment) complete the task of navigation. The navigation decisions of vessels are made by the off-board personnel, and seafarers are supposed to implement in accordance with the commands by remote-controlled personnel.

3) Remote-controlled vessel without seafarers: the vessel is equipped with remote control systems or equipment that can help off-board personnel (e.g. personnel on shore or other equipment) complete the task of navigation. The navigation decisions of vessels are made by the off-board personnel completely, and there are no personnel on board.

3.2 Status of development of autonomous vessel technology

The development of autonomous vessels involves the integrated application of technologies such as Cyber-physical Systems, Integrated Bridge Systems, environmental information perception, collision avoidance path planning, track control, Internet of Things, cloud computing, big data, sensors, automation technology, network information security, remote control technology, satellite and communication technologies, big data analysis technologies for processing decision support, state analysis and fault diagnosis technologies for equipment and systems and hull condition monitoring and analysis technologies.

3.2.1 Development of key technologies for autonomous vessels

1) Cyber-physical Systems

Cyber-physical systems (CPS) are the integration and interaction between computing processes and physical processes. In other words, it can detect and control the physical process through embedded computer and network, and realize the influence of physical process on calculation process through feedback loop. Different from the traditional concepts of computing system and physical system, it combines the information world with the physical world through self-adaptive and feedback closed-loop control, and mainly considers the performance optimization in function. It is an intelligent technology integrating computing, communication and control technology (3C), which has the characteristics of real time, security, reliability and high performance. Autonomous vessel is a complex, heterogeneous, and highly reliable application system that meets the requirements of CPS. The realization of intelligent needs the support of multi-source isomerism information, such as the vessel's own navigation status, surrounding environment, equipment status, and inter-vessel, vessel-to-shore interaction.

2) Integrated Bridge System

The Integrated Bridge System is an integrated system, which is reflected in various functions such as perfect navigation, driving control, collision avoidance, information centralized display, alarm monitoring, communication, shore station support, navigation management and control automation. It is convenient for the driver and shore-based personnel to observe and manipulate, and optimize the information of each equipment at the same time, so that the Integrated Bridge System can play a greater role in ensuring the safe navigation of the vessel and reducing the personnel cost than when the equipment is used alone. The current IBS has entered the stage of artificial intelligence and mobile internet development, and the new generation of IBS will undergo a major change under the guidance of information technology, network technology, communication technology and computer technology.

3) Environmental information perception

At present, the navigation status information of the channel, other vessels and the vessels can be obtained by means of the existing navigation equipment such as radar, AIS, electronic chart and GPS. The water depth, water flow velocity, wind speed and wind direction are obtained by means of hydrological sensors such as depth sounder, ocean current meter and anemometer. For non-vessel obstacles, laser scanners and radar can also be used for fusion recognition. In the process of environmental perception, the information of different sensors or devices may be redundant, conflicting and missing. it is necessary to realize the reliable identification of the environment by means of information fusion theory.

4) Collision avoidance path planning

When the vessel is sailing, it is necessary to follow the vessel collision avoidance rules. Considering the safety of the collision avoidance path, it is also necessary to consider making the route shorter, more energy efficient and more time-saving. In the early stage, the collision avoidance path planning method based on expert system was widely used. After the 1990s, with the rapid development of intelligent algorithms, fuzzy control, neural networks and artificial potential fields have been used in the field of vessel collision avoidance path planning. However, different intelligent algorithms have their own advantages and disadvantages. The application of multiple intelligent algorithms to avoid collisions has become the development trend of current vessel collision avoidance path planning.

5) Track control

The traditional vessel track control adopts the track automatic rudder method and has experienced four stages: mechanical automatic rudder, PID automatic rudder, adaptive automatic rudder and intelligent automatic rudder. In response to these demands, some advanced control algorithms have begun to be applied to vessel track control, such as Line of Sight (LOS) navigation based on state feedback, Model Predictive Control (MPC) based on optimal control theory method, etc.

6) Internet of Things

Based on the communication network such as the internet and mobile communication networks, the Internet of Things uses the intelligent objects with sensing, communication and computing capabilities to automatically acquire various information of the physical world. It interconnects all physical objects that can be independently addressed, realizes comprehensive sensing, reliable transmission, and intelligent analysis and processing, and constructs an intelligent information service system in which people and things, things and things are interconnected. In the field of navigation, the application of Global Positioning System (GPS), ARPA (Automatic Radar Plotting Aid) radar, AIS, electronic chart display and information system, integrated bridge system, radio frequency identification (RFID), video surveillance and other technical means has made the vessel develop rapidly in the direction of informatization and intelligence. The emergence of the Internet of Things has provided new ideas for the development of autonomous vessels.

7) Cloud computing

Cloud computing is the development of distributed computing, parallel computing, and grid computing. Real-time and dynamic analysis of the massive amount of information collected by a large number of sensing devices at different times during vessel navigation, and the aggregation, splitting, statistics, and backup of such information require cloud computing with elastic growth storage resources and massive parallel computing capabilities as a support.

8) Big data

The application of big data is the process of using the results of big data analysis to provide users with decision-making and mining potential value. Regional or dedicated data monitoring centers have emerged in the shipping industry. For example, international shipping companies such as China Ocean shipping Group have realized the operation status of their vessels on a global scale. Europe's information collaboration service concept for supporting inland navigation, traffic management, transportation management and multi-modal transport - Harmonized River Information Services (RIS) provides users with static information such as electronic maps, laws and regulations, and dynamic information such as vessel registration and vessel position, cargo information, and estimated arrival time.

3.2.2 Development of typical autonomous vessels

The development of autonomous vessels has experienced different stages of development，from the automation of the engine room to the navigation automation of automatic navigation and automatic obstacle avoidance, from the emergence of the of the Intelligent vessel to the automation of the whole vessel automation that takes into account the energy efficiency management, now autonomous vessels are developing into a comprehensive intelligent vessel. At present, the initial results of driverless vessels have emerged.

Table 3-4 Representative Vessels in the Development of Autonomous Vessels

Year	Country/ Region	Vessels	Features
1961	Japan	"Jinhuashan Maru" bulk carrier	engine room centralized control, cab remote control host

1970	Japan	"Starlight Pill" tanker	The control and management of the entire vessel is achieved through various subroutines and interfaces.
1985	China	"Berlin Express" container vessel	Automatic steering system, automatic navigation system, vessel management center, the comprehensive management of the whole vessel is achieved through the computer system.
2008	China	“Tianxiang No. 1” offshore exploration vessel	Intelligent driving, radar search, satellite applications, image processing and transmission
2012	EU	MUNIN	Unmanned vessel
2012	China	Automatic unmanned sampling vessel	Robot control technology, automatic navigation technology, ultrasonic intelligent barrier technology, 3G network / GPRS real-time communication technology. With autonomous navigation, automatic obstacle avoidance, network management and other advantages
2014	UK	"Mayflower" autonomous vessel	Unmanned trimaran sailboat
2016	Finland	"Stella" ferry	Application of advanced unmanned vessel
2016	USA	"Sea Hunter"	Unmanned vessel
2016	China	Unmanned Vehicle	All-weather automatic cruise and hedging, remote reconnaissance operations, professional equipment load piggyback, 360-degree video transmission, voice intercom
2016	Norway	"Hronn" light marine utility vessel	Unmanned vessel
2017	China	"Da Zhi"	Intelligent navigation, intelligent engine room, intelligent energy efficiency management, etc.
2018	Norway	Yara Birkeland	Unmanned, electric, container
2020	Europe	One Sea	Enterprise self-control of marine ecosystem, completely remotely controlled
2020	UK	Rolls-Royce	Remotely controlled unmanned boat
2025	Europe	One Sea	Autonomous commercial operation
2035	UK	Rolls-Royce	Unmanned ocean merchant vessel

In addition, in 2016, Norway established the world's first autonomous vessel test area. In 2018, the offshore test site of the unmanned vessel in Wanshan, Zhuhai, Guangdong Province, was officially launched. Qingdao also began to build a marine autonomous vessel test site. The construction of autonomous vessel offshore test sites will accelerate the process of vessel intelligence and promote the technological development of autonomous vessels.

3.3 Development status of the legal system of autonomous vessels

In view of the rapid development of autonomous vessels, in order to cope with the new requirements imposed by autonomous vessels on international maritime conventions, rules and standards in the future, IMO has gradually begun to develop specifications related to autonomous vessels. The norm-setting work is mainly divided into two steps:

The first step is to review existing IMO rules and regulations, list the specifications and documents to be revised by the International Maritime Organization, and analyze and define how current rules are or aren't accessible to different autonomous vessels, and / or if they would have the possibility of impeding the research and development process of autonomous vessels. (Completed)

In the second step, considering the human factors, technical and operational factors, the analysis will be used to determine the best way to solve the operation of the autonomous vessel.

The 99th meeting of MSC established the Autonomous Vessel Correspondence Working Group to examine the framework of the rules adopted at this meeting, especially the ways and means of solving the problem. The group will report to the conference at the 100th meeting of the MSC (3-7 December 2018).

According to statistics, there are more than 50 IMO legal documents related to autonomous vessels. The International Working Group established by the Committee Maritime International (CMI) selected the conventions that are considered to be most relevant to autonomous vessels in the first phase of the project "Definition of the Scope of Maritime Autonomous Surface Vessels (Quality) Use". These selected maritime conventions require most urgent review, for example, the liability convention does not often regulate the behavior of the master and crew, so it can be analyzed at a later stage. The CMI Working Group recognized the need to review all conventions, but they also realized that work could be and should be done on selected conventions in order to establish a working approach that could be applied to the entire legal and regulatory framework. In the first phase, the CMI International Working Group selected eight maritime conventions for analysis. These eight conventions include:

1) SOLAS – International Convention for the Safety of Life at Sea;

2) MARPOL – International Convention for the Prevention of Pollution from Vessels;

3) COLREG – International Regulations for Preventing Collisions at Sea;

4) STCW–International Convention on Standards of Training, Certification and Watchkeeping for Seafarers;

5) FAL–Convention on Facilitation of International Maritime Traffic;

6) SAR – International Convention for Maritime Search and Rescue;

7) SUA – Convention for the Suppression of Unlawful Acts against the Safety of Maritime Navigation;

8) International Convention on Salvage.

Chapter 4 - Impact of Autonomous Vessels on Seafarers' Post and Quantity

4.1 Comparison and Analysis of Ship Safe Manning

The 1974 International Convention for Safety of Life at Sea have made mandatory provisions on the manning standard of vessels, and the specific manning number is specifically regulated by member states' administrations comprehensively considering such factors as vessel's type, tonnage, technical condition, the capacity of main propeller installation, navigation area, voyage, sailing time, the navigation environment and crew on duty, rest system and other factors.

The development of autonomous ships is certain to influence the ship manning standard and consequently effect on the seafarer's post and number. It is significant to analyze the influence of the typical national current manning standard on seafarer's posts and numbers. This research chooses and analyzes some representative minimum manning standards in China, India, the Philippines, and the Republic of the Marshall Islands, as followed in table 4-1, table 4-2, table 4-3, table 4-4 and table 4-5.

Table 4-1 The Republic of China Ship Minimum Safe Manning Table

<table>
<tr><th colspan="4">Deck Department</th></tr>
<tr><th colspan="2">Types of vessels, shipping area, tonnage or total capacity</th><th>General provisions</th><th>Additional provisions</th></tr>
<tr><td rowspan="2">General vessels</td><td>3000 gross tonnage and above</td><td>The captain, the chief mate, the second mate, the third mate each 1, A/B 3.</td><td>If continuous sailing time is no more than 36 hours, each the third mate and A/B can be reduced1.
If continuous sailing time is no more than 36 hours, each the third mate and A/B can be deducted by 1.</td></tr>
<tr><td>500 gross tonnage and above, but less than 3000 gross tonnage</td><td>The captain, the chief mate, the third mate each 1, A/B 3.</td><td>If continuous voyage time is no more than 36 hours, A/B can be deducted 1 and if continuous voyage time is no more than 8 hours, the third mate can be deducted by 1.</td></tr>
</table>

	200 gross tonnage and above, but less than 500 gross tonnage	The captain, the third mate each 1, A/B 2.	If continuous voyage time is more than 24 hours, the second mate should be added by 1. If continuous voyage time is no more than 8 hours, each the third mate and A/B can be deducted by 1.
	100 gross tonnage and above, but less than 200 gross tonnage	The captain, the third mate each 1, A/B 1	If continuous voyage time is more than 36 hours, the second mate should be added by 1. If continuous voyage time is no more than 8 hours, third mate can be deducted by 1.
	less than 100 gross tonnage	Navigation officer 1 (For the international vessels-captain; For vessels with navigation and engine in one - navigation officer), and A/B 1	If continuous voyage time is more than 8 hours, the driver should be added 1 (the motor-driver is the driver). If continuous voyage time is no more than 4 hours, A/B can be deducted by 1.
Passenger ships	500 gross tonnage and above	The captain, the chief mate, the second mate each 1, A/B 3.	If continuous voyage time is more than 24 hours, the second mate should be added by 1. If continuous voyage time is no more than 8 hours, each the second mate and A/B can be deducted by 1.
	200 gross tonnage and above, but less than 500 gross tonnage	The captain and the second mate each 1, and A/B 2.	If continuous voyage time is more than 8 hours, the second mate should be added by 1.
	100 gross tonnage and above, but less than 200 gross tonnage	The captain and the second mate each 1, and A/B 1.	If continuous voyage time is more than 16 hours, the second mate should be added by 1. If continuous voyage time is no more than 4 hours, the second mate can be deducted.
	less than 100	Captain (For vessels	It is limited to daytime navigation.

		gross tonnage	with navigation and engine in one - navigation officer), and A/B 1	If continuous voyage time is more than 4 hours, 1 second mate (engine and captain in one) should be added.
Engine Department				
All ships	At sea	**Navigation area and engine power**	**General provisions**	**Additional provisions**
		3000 kilowatt and above	chief engineer, second engineer third engineer and fourth engineer each 1, and mechanics undertaking engine watch 3	(1) If the continuous sailing time does not exceed 36 hours, the fourth engineer and mechanic on duty can be reduced each by 1 person. (2) For The AUT-0 automatic engine room, 2 persons of the fourth engineers, third engineers and mechanics undertaking engine watch can be reduced. (3) for the AUT-1 automatic engine room, fourth engineer and mechanics undertaking engine watch can be reduced by 1person each. (4) for the BRC semi-automatic engine room 2 mechanics can be reduced.
		750 kilowatt and above, but less than 3000 kilowatt	Chief engineer, and second engineer each 1, and mechanics undertaking engine watch 2.	If the continuous sailing time is more than 16 hours, each of the fourth engineer and mechanic should be added by 1. (except for automatic engine room and BRC semi-automatic engine room)
		220 kilowatt and above, but less than 750 kilowatt	Chief engineer and fourth engineer each 1, and mechanics undertaking engine	If the continuous sailing time is more than 24 hours, 1third engineer should be added. (except for automatic engine room

			watch 2.	and BRC semi-automatic engine room) If the continuous sailing time is no more than 8 hours, 1 mechanic can be reduced; if the continuous sailing time is no more than 4 hours, 1 more mechanic can be reduced.
		75 kilowatt and above, but less than 220 kilowatt	Chief engineer 1 and mechanics undertaking engine watch 2. (automatic engine room, BRC semi-automatic engine room and navigation and engine in one can be reduced)	If the continuous sailing time is no more than 8 hours, 1 mechanic can be reduced.
		less than 75 kilowatt	mechanics undertaking engine watch 1(For vessels with navigation and engine in one, no requirement)	
	In the port		1 third engineer and fourth engineer (or marine engineer), and 1 mechanics undertaking engine watch(exempted for vessels with navigation and engine in one)	If less than 750 kilowatt, 1 third engineer can be reduced; if less than 75 kilowatt, 1 fourth engineer (or marine engineer) can be reduced; if navigation and engine in one, one more third engineer (or marine engineer) can be reduced.
Passenger Transportation Department				
Passenger ships	According to the rated vessel passenger, it is assigned each 50 passengers with 1 passenger department staff; if the voyage does not exceed 40 nautical miles or the sailing time does not exceed 4 hours, each 100 passengers may be assigned to 1 staff; if the voyage does not exceed 10 nautical miles or the sailing time does not			

	exceed 1 hours, each 150 passengers may be assigned to 1 staff; if the voyage does not exceed 5 nautical miles or the sailing time does not exceed 0.5 hours, each 200 passengers may be assigned with 1 staff; if the voyage does not exceed 5 nautical miles and the sailing time does not exceed 0.5 hours, as well as the rated passenger less than 50, it is not required for passenger department staff.

Table4-2 People's Republic of China Minimum Safety Manning Table for Marine Radio Personnel

Navigation area	GMDSS Equipment	Remarks
A1	Part-time GMDSS limited operator 1	
A2	Full-time GMDSS general operator 1 or part-time GMDSS general operators 2.	
A3 & A4	Duplication	**1** full-time GMDSS general operator or 2 part-time GMDSS general operators
	Single	**1** full-time GMDSS general operator

Table 4-3 Indian Ship Minimum Safety Manning Standard

Type of ship /propulsion power of vessel	Type of manning required	No. Of Manning
Deck department		
Vessels with 3000GT and above	Marine master Class I	1
	Marine deck officer Class II	1
	Marine deck officer Class III	2
	Ratings forming part of bridge watch	3
Engine department		
Vessels having propulsion power of 3000kw and above on international voyages	Marine engineer officer class I	1
	Marine engineer officer class II	1
	Marine engineer officer class III	2*
	Ratings forming part of engineering watch	3*

	*When the vessels is assigned UMS Notation and plying so, then only one Class IV and two ratings forming part of engineering watch will be required.

Table 4-4 The Philippines Ship Minimum Safety Manning standard

Type of ship /propulsion power of vessel	Number	Position	License
Deck department			
2500 GT and above	1	Master	Master Mariner
	1	Chief Officer	Chief Mate
	2	Deck Officer	2nd Mate and 3rd Mate
	3	Rating	Ratings forming part of bridge watch
Engine department			
3000 Kw and above	1	Chief Engine Officer	Chief Marine Engineer
	1	2nd Engine Officer	2nd Marine Engineer
	2	Engine Officer	3rd Marine Engineer and 4th Marine Engineer
	3	Rating	

Table 4-3 The Republic of the Marshall Islands Ship Basic Manning Requirements

Application	Scale
All ships over 8000 GT/3000kw Non-Automated	Master Chief mate Second mate Radio officer/GMDSS Three (3) Able Seamen Two (2) Ordinary Seamen Chief engineer 1st Assistant Engineer 2nd Assistant Engineer 3rd Assistant Engineer Three (3) Oiler/Motormen
Reductions from Basic Manning-Deck	
Vessels over 5000GT but under 8000GT (3-watch ships)	Master Chief mate Second mate Radio officer/GMDSS Four (4) Able Seamen

Vessels over 3000GT but under 5000GT	Master Chief mate Second mate Radio officer/GMDSS Two (2) Able Seamen Two (2) Ordinary Seamen
Reductions from Basic Manning-Engine	
Vessels over 3000kw and certified for unattended operation	Chief engineer 1st Assistant Engineer Two (2) Oiler/Motormen

The above national minimum safety manning tables are based on the current vessel technology, taking into account vessel's type, tonnage, technical condition, the capacity of main propulsion, navigation area, voyage, sailing time, navigation environment and crew watchkeeping and rest system and other factors. With the increasing development of vessel intelligent technology, autonomous vessels are bound to significantly change the technical conditions, and consequently affect the ship manning standards.

Through a comparative analysis of the above-mentioned tables, it can be found that the member states are basically consistent in the specific ship manning, which is mainly due to the mandatory provisions of the Convention on the ship manning standards.

In view of the fact that there is not much difference of ships manning in IMO member states, we selected the most representative general ships of "3000 gross tonnage and above" and "main engine rated at 3000 kW and above" as the research object, and carried out quantitative comparison analysis, in order to get the representative and universal analysis and facilitate the study, and to accurately analyze and predict the impact by remote-controlled ships on the position and number of seafarers.

4.2 Impact of ships with process automation and decision support on the post and number of seafarers

The ship automation can be divided into the automation of ship navigation, the automation of engine room and the automation of loading and unloading operations. The automation of ship navigation is mainly realized through radar, satellite positioning, automatic rudder, trajectory tracking and so on. The automation of the engine room refers to the automatic monitoring, alarm and control of various parameters and working conditions of the main engine and generator, the centralized automatic control and regulation of various auxiliary machines, fire detection and self-extinguishing. It makes the engine room cycle unattended possible and replaces the crew manual operation of machinery and equipment, so as to improve the crew's working conditions. Loading and unloading automation refers to automatic monitoring system of auxiliary boiler, inerting gas, cargo oil pump, valve, liquid level, ship strength and floating state . With the development of ship automation, the labor force is liberated, the workload of the crew is reduced to a great extent, and the crew members are reduced in some positions. The emergence a higher degree of process automation and decision-making support on ships will further liberate the crew's workforce.

The use of ship technology and automated systems has become a reality, with onboard autonomous information systems combined with Integrated Navigation System (INS) and Integrated Bridge System (IBS) to provide the most advanced decision support for captains. Seafarers control the shipboard system on board. In the case of adequate technical support and early warning systems, some operations may be automated, but the standby personnel are ready for manual control.

Ships at this stage are more digital than non-autonomous ships, and crews will rely more on computers and automation technology. This means keeping the crew trained and ready to "monitor the machine" will become as important as the marine engineers on the main engine today, with the difference that their skills need to be expanded to include a certain degree of digitization for working on high-performance computer systems and solving operational problems related to cyber physical systems.

Since the crew manning has been reduced to a considerable extent in the course of ship automation for decades, the number of crew members on board has been generally maintained at around 20 to 30. The ship with process automation and decision support has no obvious impact on the number of crews and the position, but the post has greater requirements for automation, information related knowledge and logical and critical thinking abilities.

4.3 Impact of remote-control ships with crew on post and quantity of seafarers

According to the classification in section 3.1.3 of this report, remote-controlled ships with crew on board should be equipped with two types of personnel, namely, remote-control personnel on shore or other facilities and onboard personnel who perform part of the navigation and management functions. At this time, the ship navigation decision is basically completed by the remote control personnel on the shore or other facilities, and the onboard crew should perform the corresponding duties according to the requirements of the personnel.

In order to accurately analyze and predict the impact of remote-controlled vessels with crew on seafarer’s post and number, we selected the most representative general ships of “3000 gross tonnage and above” and “main engine power 3000 kw and above” as the research object, and carried out quantitative comparison analysis.

For remote-control ships with crew on board, since ship navigation decision of the ship is basically completed by the remote-control personnel on the shore or other facilities, and the onboard crew should perform the corresponding duties according to the requirements of the remote-control personnel, navigators and engineers who are responsible for watchkeeping may be reduced accordingly, but the corresponding onshore remote-control personnel and certain port service personnel should be added accordingly. The ship may not be equipped with the onboard captain and the chief engineer, but be coordinately managed by the shore-based captain. Radio personnel can be replaced by navigator holding GMDSS certificates, which are used in current ocean-going vessels. This configuration can fully meet requirements of the ship's navigation safety and environmental protection. The post settings are shown in Table 4-6 below.

Table 4-6 Remote-control Ships with Crew Minimum Safety Manning Standard

Deck Department			
Types of vessels, shipping area, tonnage or total power		**General provisions**	**Additional provisions**
General vessels	3000 gross tonnage and	2 navigators, 2 A/B	The watchkeeping officer and the AB

	above		can be reduced each by 1 according to the duration of continuous sailing.
Engine Department			
General vessels	Main engine power 3000 kilowatt and above	2 engineers, 1 mechanic	The engineer can be reduced by 1 according to the duration of continuous sailing.
remote-control personnel on shore or other facilities			
General vessels	3000 gross tonnage and above or main engine 3000 kilowatt and above	1 shore-based Captain, 3 shore-based navigators, 5 technical support personnel (including ship machinery technology, sensing technology, communications technology, network security technology and artificial intelligence and other technical personnel 1 each)	

Comparing tables 4-1 and 4-3, the total number of minimum safety manning for current ships with "3000 gross tonnage and above" and "3000 kilowatt and above" is 14, while for the same type of remote-control ships with crew on board, the number of minimum safety manning is at least 16.

Thus, when the autonomous ship develops to the second level, that is, the remote-control ship with crew on board, the personnel required for ship navigation will increase instead of decrease. However, the crew's post will undergo major changes, such as the captain may be converted to a shore-based captain, the chief engineer to a shore-based technician, and the addition of some onshore technical posts, including technical positions such as ship machinery technology, sensing technology, communications technology, network security technology and artificial intelligence and other technical posts.

4.4 Impact of remote-control ship without crew on seafarer's post and number

A remote-control ship without crew means that there are no seafarers on board.

The ship control and operation are carried out in another place,.

Ship navigation depends on four aspects, perception, analysis, decision-making and execution. Onboard crew operate the traditional ship, in essence, in order to complete the above four aspects behaviors, and consequently steer the ship safely and efficiently. The number of the minimum safety manning of the deck department of more than 3000 gross tonnage is 7 (including captain, chief mate, second mate, third pairs 1 person each, 3 seafarers on duty or senior seafarers on duty), and the number of the minimum safety manning of the engine department is also 7 (including chief engineer, first engineer, second engineer and third engineer l, 1 person each, 3 mechanics on duty or senior mechanics on duty). In addition, traditional non-autonomous ships also need to be equipped with full-time a total of about 22 seafarers, including GMDSS radio operator, electricians, electric technicians, chefs and other crew.

For the remote-control ship without crew, its navigation is completed by the no onshore remote-control personnel, instead of depending on the onboard crew,. The shore captain is totally responsible for the shore-based operation. Three onshore navigator are in shifts for the specific operation of ship navigation and technical support personnel patrol to provide technical support. Therefore the number of crew equipped in ships and the types of posts have been greatly reduced.

Table 4-7 Comparison of the crew posts on non-autonomous ships and non-crew remote-controlled ships

	Non-autonomous ships equipped with crew posts	**Post on remote-controlled ship with crew onboard**
Ship department	1) the captain; 2) Deck department: the chief mate, the second mate, the third mate, AB and OS. Among them, the chief mate, the second mate, the third mate are collectively named as navigator; 3) Engine department crew: chief engineer, second engineer and third engineer, fourth engineer, electricians, senior mechanics undertaking watch,	1) Onshore remote-control department: shore-based captains, shore-based navigator, technical support; 2) Port service department: ships berthing or deberthing operators, ship maintenance personnel, pilots.

	and electric technicians. Among them, the chief engineer, second engineer, third engineer and fourth engineer are collectively named as engineers; 4) Radio operators: level 1 radio operator, level 2 radio operator, general radio operators and limited radio operators.	

Function Division of seafarers	1) Navigation; 2) Cargo operation and stowage; 3) Vessel operations and personnel management; 4) Marine engineering; 5) Electrical, electronic and control engineering; 6) Maintenance and repair; 7) Radio communications.	1) Navigation; 2) Cargo operation and stowage; 3) Vessel operations and integrated control 4) Maintenance and repair; 5) Radio communications.
Technical requirements for seafarers functions	1) Management level; 2) Operation level; 3) Support level.	1) Management level; 2) Operation level; 3) support level.

Table 4-8 Seafarers number comparison between marine non-autonomous surface vessels and Remote-control vessels without crew

	Dependence on the seafarers in perception, analysis, decision making and implementation	**Crew manning**			
Marine non-autonomous surface vessels (existing vessels)	100%	**Deck crew**	**Engine Crew**	**Radio operators**	**Support staff**
		Captain, chief mate, second mate and third mate 1 each position. AB 3 persons OS 2 persons	Chief engineer, second engineer third engineer and fourth engineer 1 each position; electricians 1, mechanics undertaking engine watch 2.	First-level radio operator, second-level radio operator, general operator, limited operator.	Chef, etc
		Totally about 22 persons			
Remote-control vessels without crew	0%	Remote-control personnel on shore	Port service personnel		notes
		shore-based captain 1; shore-based navigators 3,	vessel operating personnel, vessel maintenance personnel		Shore-based captain serves as overall

		Technical support personnel 2.			responsible person in shore-based operation. Shore-based navigators control the navigation of vessels, and technical support personnel provide technical support.。
		Totally about 8 persons			

More importantly, working environment of the seafarers has been greatly improved due to the replacement of the seafarers on board with seafarers of Remote-control department on shore. This also normalized the traditional seafarer's occupation characterized by non-fixed working time, danger of living and working place, long-term closure of living and working environment, labor mobility and labor instability.

4.5 Impacts of unmanned vessels on seafarers' post and number

According to the classification of the automation level of MASS by IMO, an unmanned vessel refers to that ship operating system can make decisions, react and act independently. Unmanned autonomous vessels mainly rely on the integration of various sensing equipment, electric drive, propulsion control system, remote control and automation system to complete the vessel navigation operations.

With regard to the impact on seafarers' post and numbers, such marine autonomous surface vessel will have higher requirements for shore-based technical support personnel. When traditional posts of seafarer disappear, new posts will be created. What unmanned vessels need are higher level and well-educated talents to work in the vessel operation center, providing technical support and decision-making for the vessel's navigation and operation.

Table 4-9 Crew manning in unmanned vessels

	Dependence on the seafarers in perception, analysis, decision making and implementation	**crew manning**		
		Shore-based seafarers	**Port service personnel**	**Notes**
unmanned vessels	0%	Shore-based captain 1, shore-based navigator 2. (the vessel is under	vessel operating personnel on vessel arrival and departure, vessel maintenance	Shore-based captains serve as the chief responsible personnel, shore-based

		remote control in case of emergency), Technical support personnel 2-3, voyage data analyst (part time) 1.	personnel。	navigators shall be responsible for the remote operation of the vessel in emergency, and technical support provides for remote technical support.
		Totally about 7 persons		

Chapter 5 - Impacts of marine autonomous surface vessel on maritime education and training

5.1 Impacts of vessels with process automation and decision support on maritime education and training

The operation of vessels with process automation and decision-support remain largely dependent on the operation and management of seafarers, with limited impact on modern maritime education and training. However, as the automatic control system and decision support system are widely applied in this type of vessel, new requirements will be put forward for the knowledge system and training method of education training.

1) The increment of breadth and difficulty of relevant information technology knowledge

With the development of navigation technology, modern navigators need to master more and more new knowledge, especially the knowledge of automation. The navigation technology is firstly automated in the following three aspects: firstly, the automation of navigation means, such as the application of collision avoidance radar and global satellite positioning system; Secondly, the automation of communication means, such as GMDSS application; Thirdly, the vessel's power propulsion plant automation, such as unmanned engine room. This requires modern navigators to master not only the traditional maritime knowledge and technology, but also the new knowledge and technology that are adaptive to the current technical level. In particular, proper education and training should be strengthened in the vessel's automatic control system, equipment and facilities, network security, and so on.

2）Stringent training requirements in areas such as conventions and regulations

With the development of shipping industry, western countries are eager to formulate the worldwide laws and regulations to protect the marine environment, ensure personal safety at sea and standardize the development of shipping industry. From the aspect of the development trend of conventions, its development focus is shifting from regulating equipment and technology to regulating human behaviors. New conventions, new rules, such as the STCW Convention, ISM Rule, and the port state inspection rules formulated according to the port state inspection area memorandum, all turn the focus of the regulations to human behaviors. The development trend of this international legal convention will put forward higher requirements on the quality and behavior of the seafarers, and seafarers competency will be an important criterion to measure the seafarers' seaworthiness in the future.

3）Customized specialized training prevailing

With the rapid development of marine autonomous surface vessels, more and more institutions have invested in the research, development and construction of marine autonomous surface vessels. While the technology is flourishing everywhere, it should not be neglected that a series of self-contained independent vessels will emerge due to the lack of unified technology and standards. These vessels, which are designed and built according to different technical standards, will have their own characteristics in the operation and management. Obviously, the general seafarers training program, especially in the practical skills training, will not be able to meet the requirements of each type of marine autonomous surface vessel for the seafarers' competency. It is an effective way to solve the above problems to carry out customized specialized training for marine autonomous surface vessels with different technical systems. Customized training will be more common.

4）More importance of engineering technology training

With the rapid development of technology, modern vessel equipment and navigation technology, especially marine autonomous surface vessel technology, are changing with each passing day. The seafarer needs to be good at understanding the operation mode of new equipment and new technology, not just the working mode of the seafarers. The logic training of navigation technology is more important, and the seafarers will focus more on science, technology, engineering and mathematics.

5）Strengthened logical and critical thinking training

Artificial intelligence is not the terminator of the seafarers. The application of the decision-making system on the vessel does not change the command relation on the vessel. However, the seafarer needs to consider the way the decision-making system operates, and make critical use of decision-making information.Therefore, more attention should be paid to the cultivation of logical and critical thinking in the future’s seafarers’ training.

6）Increased leadership training

For human resources problems caused by the reduction of seafarers on board, the seafarers need to understand the importance of leadership and interaction. Team integration is important both for a leader and for a follower. Seafarers need receive training to ensure that they understand their strengths, weaknesses, roles and self-awareness through reflections, personal analysis and discussions.

Table 5-1 Knowledge classification and mastery degree of vessel practitioners with process automation and decision support

		Ability			Knowledge					Technology			Sea service experience
		Leadership and communication	Obedience and execution	Psychological stress resistance	Traditional nautical knowledge	Network communication knowledge	Automatic control knowledge	Data mining knowledge	Artificial intelligence knowledge	Autonomous navigation	fault diagnosis	Remote control	
Vessel with process automation and decision support	Management level onboard ship	3	3	3	4	2	2	2	1	1	1	0	Yes
	Operation level onboard ship	2	3	2	3	1	1	1	1	1	1	0	Yes
	Surport level onboard ship	1	3	2	3	0	0	0	0	0	0	0	Yes

Note: mastery degree of knowledge related to marine autonomous surface vessel listed in the above table is different for the personnel in different posts required on different types of vessels.We assign different values to the mastery degree of knowledge listed. 0- no need for grasp , 1- knowing , 2- understanding, 3- familiarity, 4- proficiency.

5.2 Impacts of Remote-control vessels with crew on maritime education and training

When the marine autonomous surface vessels develop to the second level (i.e. the Remote-control vessels with crew), the personnel allocation of the vessels will be greatly changed compared with that of traditional vessels: shore-based Remote-control personnel appeared and the number of the personnel on board was reduced, and the working mode and division of labor will greatly be changed. Maritime practitioners need to complete the learning or practice of relevant knowledge in accordance with the requirements in table 5-1, and meet the corresponding standards of competency.

As can be seen from table 5-2, the knowledge structure required by maritime practitioners on Remote-control vessels with crew members has changed greatly. In addition to the corresponding traditional maritime knowledge, maritime practitioners should master new knowledge and technology related to marine autonomous surface vessel or apply them in practice to different degrees, such as network information knowledge, automation knowledge, information physical system knowledge, big data knowledge, autonomous navigation and collision avoidance technology, remote control knowledge etc, which will have a considerable impact on the future maritime education and training, requiring the future maritime education and training to include the above new knowledge and technology in addition to the traditional maritime knowledge.

Table 5-2 Knowledge classification and mastery degree of vessel practitioners on remote-control vessels with crew onboard

		Ability			Knowledge					Technology			Sea service experience
		Leadership and communication	Obedience and execution	Psychological stress resistance	Traditional nautical knowledge	Network communication knowledge	Automatic control knowledge	Data mining knowledge	Artificial intelligence knowledge	Autonomous navigation	fault diagnosis	Remote control	
Remote–controlled vessel with crew on board	Management level onshore	3	4	3	3	3	3	3	3	4	4	4	Yes
	Operation level onshore	2	4	3	2	2	2	2	2	4	4	4	Yes
	Surport level onshore	1	4	2	2	1	1	1	1	2	2	2	No
	Management level onboard ship	4	3	4	4	2	2	2	2	3	3	3	Yes
	Operation level onboard ship	2	3	3	3	1	1	1	1	3	3	3	Yes
	Surport level onboard ship	1	3	3	3	1	1	1	1	1	1	1	Yes

Note: mastery degree of knowledge related to marine autonomous surface vessel listed in the above table is different for the personnel in different posts required on different types of vessels. We assign different values to the mastery degree of knowledge listed. 0- no need for grasp, 1- knowing , 2- understanding, 3- familiarity, 4- proficiency

5.3 Impacts of Remote-control vessels without crew on maritime education and training

Compared with the Remote-control vessels with crew, the Remote-control vessels without crew are completely dependent on the operation of the qualified personnel on shore. Therefore, the qualified personnel on shore need to have a deeper understanding of the knowledge of network information technology and automation technology, as well as a extensive knowledge reserve to cope with the remote and changeable marine navigation environment.

Table 5-3 Knowledge classification and mastery degree of vessel practitioners on Remote-control vessels without crew

		Ability			Knowledge					Technology			Sea service experience
		Leadership and communication	Obedience and execution	Psychological stress resistance	Traditional nautical knowledge	Network communication knowledge	Automatic control knowledge	Data mining knowledge	Artificial intelligence knowledge	Autonomous navigation	fault diagnosis	Remote control	
Remote-controlled vessel without crew on board	Management level onshore	4	4	4	4	3	3	3	3	4	4	4	Yes
	Operation level onshore	2	4	3	3	2	2	2	2	4	4	4	Yes
	Surport level onshore	1	4	3	3	1	1	1	1	2	2	2	No

Note: **mastery degree of knowledge related to marine autonomous surface vessels listed in the above table is different for the personnel in different posts required on different types of vessels. We assign different values to the mastery degree of knowledge listed. 0- no need for grasp, 1- knowledge , 2- understanding, 3- familiarity, 4- proficiency**

5.4 Impacts of unmanned vessels on maritime education and training

Higher requirements have been put forward for suitable personnel of completely unmanned vessels, which require practitioners to have various knowledge and skills, thus posing new challenges for future maritime education and training.

Table 5-4 Knowledge classification and mastery degree of practitioners on full autonomous vessels

		Ability			Knowledge					Technology			Sea service experience
		Leadership and communication	Obedience and execution	Psychological stress resistance	Traditional nautical knowledge	Network communication knowledge	Automatic control knowledge	Data mining knowledge	Artificial intelligence knowledge	Autonomous navigation	fault diagnosis	Remote control	
Full autonomous vessel	Supervision level onshore	4	4	4	4	4	4	4	4	4	4	4	Yes

Note: **mastery degree of knowledge related to marine autonomous surface vessels listed in the above table is different for the personnel in different posts required on different types of vessels. We assign different values to the mastery degree of knowledge listed. 0- no need for grasp, 1- knowing, 2- understanding, 3- familiarity, 4- proficiency**

Therefore, the impacts of marine autonomous surface vessels on maritime education and training are summarized as follows:

Table 5-5 Knowledge classification and degree of mastery of practitioners on marine autonomous surface vessels

		Ability			Knowledge					Technology			Sea service experience
		Leadership and communication	Obedience and execution	Psychological stress resistance	Traditional nautical knowledge	Network communication knowledge	Automatic control knowledge	Data mining knowledge	Artificial intelligence knowledge	Autonomous navigation	fault diagnosis	Remote control	
Vessel with process automation and decision support	Management level onboard ship	3	3	3	4	2	2	2	1	1	1	0	Yes
	Operation level onboard ship	2	3	2	3	1	1	1	1	1	1	0	Yes
	Surport level onboard ship	1	3	2	3	0	0	0	0	0	0	0	Yes
Remote-controlled vessel with crew on board	Management level onshore	3	4	3	3	3	3	3	3	4	4	4	Yes
	Operation level onshore	2	4	3	2	2	2	2	2	4	4	4	Yes
	Surport level onshore	1	4	2	2	1	1	1	1	2	2	2	No
	Management level onboard ship	4	3	4	4	2	2	2	2	3	3	3	Yes
	Operation level onboard ship	2	3	3	3	1	1	1	1	3	3	3	Yes
	Surport level onboard ship	1	3	3	3	1	1	1	1	1	1	1	Yes
Remote-controlled vessel without crew on board	Management level onshore	4	4	4	4	3	3	3	3	4	4	4	Yes
	Operation level onshore	2	4	3	3	2	2	2	2	4	4	4	Yes
	Surport level onshore	1	4	3	3	1	1	1	1	2	2	2	No
Full autonomous vessel	Supervision level onshore	4	4	4	4	4	4	4	4	4	4	4	Yes

Note: **mastery degree of knowledge related to marine autonomous surface vessels listed in the above table is different for the personnel in different posts required on different types of vessels.We assign different values to the mastery degree of knowledge listed. 0- no need for grasp , 1- knowing , 2- understanding, 3- familiarity, 4- proficiency**

Chapter 6 - Conclusion

1. Through the study on the definition of existing marine autonomous surface vessels, this paper divides the future development of marine autonomous surface vessels into four levels according to the degree of automation of marine autonomous surface vessels. Different levels of marine autonomous surface vessels have different impacts on the future career development of seafarers and the maritime education and training.

1) Vessels with process automation and decision support: vessels are equipped with some systems or equipment that can help seafarers to achieve the process automation and decision support of navigation tasks. The navigation decision-making of vessels is entirely made by the seafarers themselves, and the information obtained from outside only plays a supplementary role in the decision-making of seafarers.

2) Remote-control vessels with crew: vessels are equipped with remote control system or facilities that can help personnel being not onboard such as remote control personnel on shore or personnel of other facilities to fulfill navigation tasks. Vessel navigation decisions will basically be made by personnel being not onboard. In the process of navigation, seafarers should, according to the requirements of remote control personnel, perform corresponding duties.

3) Remote-control vessels without crew: vessels are equipped with remote control system or facilities that can help personnel being not onboard such as remote control personnel on shore or personnel of other facilities to fulfill navigation tasks. Vessel navigation decisions will basically be made by personnel being not onboard and the vessel will be unmanned.

4) Unmanned vessel: the vessel is equipped with the system or equipment that can enable it to accomplish the tasks of navigation autonomously. The navigation decision-making is completed autonomously. There is no crew on the vessel. Control personnel on shore mainly play the role of monitoring the vessel's navigation performance, when necessary, can get involved in controlling the vessel.

2. Impacts of marine autonomous surface vessels on seafarers' post and number

1) The vessel with process automation and decision support has no obvious impacts on the change of seafarers number and posts, but posts have higher

requirements on knowledge related to automation, information technologies and logical and critical thinking ability.

2) For the Remote-control vessels equipped with seafarers, the number of navigators and ratings undertaking navigation watch can be reduced correspondingly, but relevant remote control personnel on shore and certain port service personnel need to be added.

3) The navigation of Remote-control vessels without crew are no longer dependent on the personnel on board, instead it is completed by Remote-control personnel on shore, which greatly reduces the number of seafarers and the types of posts.

4) The unmanned vessel is centered on shore-based technical support personnel. The traditional seafarers' post will disappear and new shore-based posts will be created.

3. Impacts of marine autonomous surface vessel on maritime education and training

1) Vessels with the process automation and decision support are mainly dependent on operation and management of crew, which has a limited impact on modern maritime education and training. As the automatic control system and decision support system of this type of vessel have been applied widely, corresponding learning depth needs to be increased in the existing education training mode.

2) The knowledge structure required by maritime practitioners on remote-control vessels with crew members has changed greatly. In addition to the corresponding traditional maritime knowledge, maritime practitioners should master new knowledge and technology related to marine autonomous surface vessels or applies them in practice to different degrees, such as network information knowledge, automation knowledge, information physical system knowledge, big data knowledge, autonomous navigation and collision avoidance technology, remote control knowledge, etc

3) The remote-control vessels without crew are completely dependent on the operation of the qualified personnel on shore. Therefore, the qualified personnel on shore need to have a deeper understanding of the knowledge of network information technology and automation technology, as well as a extensive knowledge reserve to cope with the remote and changeable marine navigation environment.

4) On the basis of the Remote-control vessels without crew, higher requirements have been put forward for suitable personnel on unmanned vessels, which require maritime practitioners to have various knowledge and skills from management to information technology, thus posing new challenges for future maritime education and training.