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Rules of the road and the digital helmsman : an analytical review of the COLREG in the context of autonomous ships (Degree-iii)

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RULES OF THE ROAD AND THE DIGITAL HELMSMAN:

An Analytical Review of COLREG in the Context of Autonomous Ships (Degree-iii)

by

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2020

Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me. The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature) :

(Date) : 22 Sep 2020

Supervised by : Dr. Maximo Q. Mejia Jr.

Supervisor’s affiliation : Professor, Director PhD Programme, Associate Academic Dean

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[illegible]
[illegible]

This Sanskrit shloka implies that whatever one obtains from the Guru in the path of enlightenment is not possible from any other sources. The Guru in one's life is a quintessential part to throw light in darkness and awakens the inner core strengths.

I further take this opportunity to express heartfelt gratitude to my alma mater, the WMU for imparting highest standard of education and making me professionally competent to deal with the facts and facets of maritime law and policy making. At the outset, I would also like to extend my earnest thanks to the faculty and staff of the university for continuous support in enhancing my knowledge base and taking care during the unprecedented pandemic times.

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Abstract

Title of Dissertation : **Rules of the Road and the Digital Helmsman: An Analytical Review of COLREG in the Context of Autonomous Ships (Degree-III)**

Degree : **Master of Science**

Disruptive technological innovation is an essential component of the 4th Industrial Revolution (4IR) in the maritime industry. The paradigm shift from conventional ship to autonomous ship/shipping (AS) is driving the maritime fraternity towards a more technologically advanced world. However, this technological transition is likely to pose serious challenges on the provisions of various IMO treaties and significantly the COLREG. This dissertation aims to deliberate whether the existing regulatory framework on collision regulation complement safe operation of Degree-III autonomous ship.

As research & development (R&D) modalities from various countries reveal the ambitious reach and road map to full-fledged AS operation, the IMO as a proponent is also supporting the cause of technological advancement. The purpose of this research will be to bring out the contemporary challenges and underlying issues and establish how COLREG pose as a main challenge. As Deg-III AS necessitates effective coordination between the shore control centre (SCC) and the decision support system, this dissertation will also highlight how the artificial intelligence (AI) is going to be integrated with SCC. The outcome of this research is expected to furnish a detailed gap analysis on the existing technical provisions of COLREG with the perspectives of various member states as being obtained through the scoping exercise conducted by IMO. A rational approach in this research will be adopted to evaluate the criticalities involved with the role & responsibility of SCC operators and subsequent amendments/revision to the existing COLREG.

KEYWORDS : autonomous ship/shipping (AS), COLREG, shore control centre (SCC), artificial intelligence (AI), collision avoidance

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List of Abbreviations

AAWA	- advanced autonomous waterborne applications
AI	- artificial intelligence
AIS	- automatic identification system
ANS	- automated navigation system
AS	- autonomous ship/shipping
COLREG	- Convention on the International Regulations for Preventing Collisions at Sea, 1972
CPA	- closest point of approach
ECDIS	- electronic chart display information system
GPS	- global positioning system
IBS	- integrated bridge system
IMO	- International Maritime Organisation
4IR	- 4^{th} industrial revolution
MASS	- maritime autonomous surface ships
MSC	- Maritime Safety Committee
NUC	- not under command
OOW	- Officer of the Watch
RAM	- restricted in ability to manoeuvre
RoR	- Rules of the Road
RSE	- regulatory scoping exercise
SLOC	- sea lanes of communication
SOLAS	- International Convention for the Safety of Life at Sea, 1974
STCW	- International Convention on Standards of Training, Certification and Watchkeeping, 1978
TCPA	- time of closest point of approach
TSS	- traffic separation scheme
UNCLOS	- United Nations Convention on the Law of the Sea, 1982
VTS	- vessel traffic service

Chapter-1: Introduction

1.1 Background: MASS in realm of Commercial Shipping

The statement that full-fledged operations of maritime autonomous surface ships (MASS) in the realm of commercial shipping is a stone's throw away may not be exaggerated. Potential enablers such as high-speed broadband connections, sophisticated data processing mechanism and big data may contribute in making the autonomous ship/shipping (AS) a commercial reality. Substituting machines and sophisticated sensor suite in lieu of human presence onboard AS will mark exponential changes in the field of shipping. As envisioned, the shipboard automated system will have the efficiency to react to rough weather/sea conditions, less fuel consumption and reduced pollution (Mejia, 2018). The motivation towards AS supplements to the 4th industrial revolution (4IR) as it is likely to induce a paradigm shift in the maritime industry. The rapid development on satellite communication in the 4IR has ensured cheap & seamless communications between the shore authorities and ships at sea and vice-versa. Such technological innovation is expected to result in successful operation of AS in the near future (Kobyliński, 2016). To that extent that AS conceptualisation to real-time operation is concerned, significant contribution and broad initiatives from the industrial, academic and regulatory sides around the world has been reported which is indicative of bringing sea change (Goerlandt, 2020).

The impetus towards becoming more safety conscious, minimising potential accidents due to human error, reduced operating cost and notably enhanced environmental sustainability are driving the maritime fraternity towards technological transition. Although the technological integrant are in-situ for developing AS, various critical and unresolved challenges on the operational, safety and regulatory front still needs to be unravelled. Hence, the factor of safety and uncertainty of operation can only be assessed over time (Liu, 2019).

1.1.1 Autonomy Revolution

The autonomy revolution which some refer to as sea change in the maritime industry is happening around the globe as it has taken shape from theoretical concepts to practical applications. In other industries, especially the aviation, railways and road transport sectors, the autonomy revolution has predominantly overarched the human presence which includes driverless/autonomous cars, autonomous commuter trains with remote monitoring centres, unmanned aircrafts/drones etc (WMU, 2019). Transition to crewless vessel from the present day conventional ship may benefit the shipowner in terms of reduced operating cost but also a optimised global supply chain. Thus, such technological disruption may be considered as an agent to bring out positive outcomes even if it has perceived negative connotations. In making AS to reality, there exist the vested interest from all stake holders/regulators namely the industry, research and development (R&D) institutions, classification societies, insurance firms and the maritime administrations (MARAD) (Pribyl & Weigel, 2018). When the positive side of technical revolution is taken to the count, it shows various perspectives such as emission control or reduction, reduced fuel consumption, human error elimination etc.

To elucidate one of the positive sides, the innovative use of AS for short sea shipping (SSS) by Europe with 40% and US with 37% coastal populace respectively is certainly a motivational factor considering the last-mile freight transport modalities (Munim, 2019). In other words, it can also be inferred that, in the era of autonomy revolution, the shipping industry strives to achieve sustainable development by minimising safety risk, environmental impact and maximising the commercial benefits. Essentially, these three factors are the drivers to march towards autonomy revolution as shown in Figure-1 below:

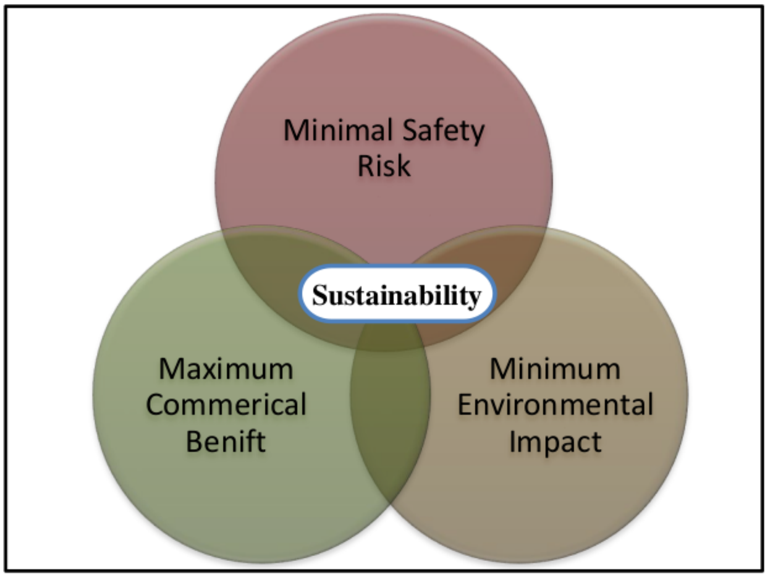

Fig-1: Sustainable Development factors in autonomy revolution, Prepared by author with information adopted from Komianos, 2018.

1.1.2 IMO as Proponent

As a facilitator, the International Maritime Organisation (IMO) has well complemented the advent of AS to the shipping world. It is in the process of aligning the global regulatory measures/framework for AS with a squarely approach and comprehension. The current approach of IMO is to review the existing conventions and regulations taking inputs from all stake holders & regulators and make sure that all regulatory instruments for safe AS operation is in place prior to 2035. Therefore, it is in the process of establishing whether the existing regulations or conventions are applicable or it requires a revision/amendment in coordination with members states, the non-governmental organisation (NGO) and other regulators/stake holders from the maritime industry (Llyod's List, 2019).

The IMO's initiative and approach to embrace AS to the maritime industry falls under the ambit of its six yearly strategic plan 2018-2023, strategic direction (SD)-2 to "*Integrate new and advancing technologies in the regulatory framework*". During the 98th session of the Maritime Safety Committee (MSC) held in Jun 2017, the committee agreed upon to include the issue of AS to its agenda as number of interested member states expressed positive inclination in exploring AS. Thus, the committee decided to conduct a scoping exercise to ascertain safe, secure and environmentally sound operation of AS to be introduced to the IMO instruments. To identify the challenges and opportunities in the maritime domain, primarily four degree of autonomy was coined during the 99th session of MSC in May 2018. Concurrently, the regulatory scoping exercise (RSE) was accorded approval in the 100th session of MSC scheduled in December 2018 and thereafter interim guidelines for conduct of AS trials was also approved during 101st session of MSC in Jun 2019. Although, IMOs perspective to AS reflects its proactive approach to ensure standardisation of its own international instruments, few of the member states and enthusiastic delegates have opposed such approach considering it as premature and irrelevant (Lloyd's List, 2018). Degree of autonomy with respect to operational control of the vessel, human presence onboard and human role as defined by the IMO is shown in Figure-2:

	Level of autonomy	Human presence	Operational control	Human role
Degree 1	Ship with automated processes and decision support	Yes	Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control	Supervision and operation
Degree 2	Remotely-controlled with seafarers on board	Yes	The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions	Backup to manoeuvre, supervise the systems
Degree 3	Remotely-controlled without seafarers on board	No	The ship is controlled and operated from another location. There are no seafarers on board	Monitoring and remote control
Degree 4	Fully autonomous	No	The operating system of the ship is able to make decisions and determines actions by itself	Monitoring and emergency management

Fig-2: Various degree of MASS defined by IMO (Source: Kim et al., 2019)

1.2 Concept of Automation vis-à-vis Autonomy

Automation can be defined as accomplishment of a task mechanically or electrically and often includes use of control system or technology such as stabilising and steering of ships with reduced or minimal human influence whereas autonomy specifies freedom from human intervention/influence when a vessel transits from one place to another (Wright, 2020). It won't be wrong to say that automation is an enabler for autonomy. It is observed that an automated vessel does not have the level of intelligence or independence as an autonomous vessel has and therefore, the human-machine interface will have different functioning in terms of varied degree and level of autonomy (Bhattar, 2019). The shipping industry has witnessed exponential growth in automation in terms of enhancing safety measures, efficient shipboard operations, increment in production and reduction in the operating cost. When the issue of automation is discussed, the interaction between human and machine comes into play and signifies the human-automation relationship (Pazouki et al., 2018). With the advent of AS, the IMO has modelled four degrees of autonomy with clear distinction of human roles/presence as shown in Figure-2. The IMO approach defines degree one with seafarers onboard and the ship being fitted with automated decision support system whereas degree four with highest level of automation in the AS taxonomy will operate with no human presence and capable of taking decisions by itself. Degree two and three both will be controlled from the remote centres however, degree three will be unmanned whereas degree two will have human presence onboard (Kim et al., 2019).

The integrated bridge system (IBS) of a modern day merchant ship is a classic case of automated suite installed onboard with the combination of global positioning system (GPS), electronic chart, echo sounder, engine controls, weather sensors etc. In this case, the level of automation starts with acquiring information, analysis of the information, decision with respect to action selection and eventually action implementation. The IBS comprises separate equipment with separate functioning capable of providing a comprehensive picture of the operating domain and hence, it prompts the duty watchkeeper in navigational bridge to undertake actions as required. On a larger perspective, it is opined that increasing the situational awareness by exploiting automated system, the operator lacks in situational awareness and thus may affect the performance of the individual in pressure-time situation (Ding et al., 2013). When the human-automation relationship is deliberated considering the ship's bridge functions, three key areas are focussed which includes the operational task at hand, real-time situational awareness and the decision making. To further elucidate, the first two aspect, that is the operational task for assisting crew and automated observation is to improve situational awareness may only fall under the ambit of automation whereas the decision making through self-learning by use of artificial intelligence (AI) will denote autonomy (Ringbom, 2019). Figure-3 below explains the three dimensions of key bridge functions in terms of automation and autonomy.

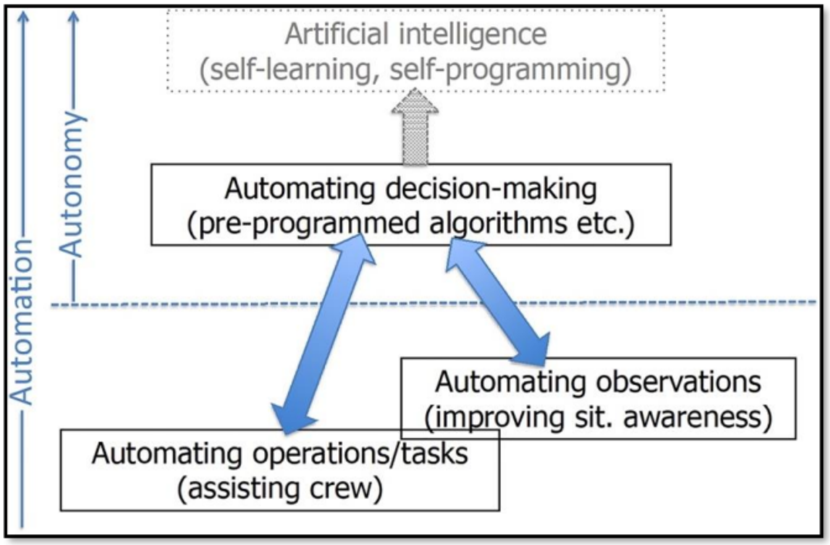

Fig-3: Automation & Autonomy, comparison on key bridge Functions (Source: Ringbom, 2019)

The revolution in autonomy especially in the maritime transport sector, the human-machine interaction are becoming realistic with minimalist human intervention. The key element highlights here is the capability of achieving situational awareness so as the autonomous system in general and the autonomous ships in particular to maintain safe operations at sea. The explicit reason here is, the challenging nature of the algorithm being used to obtain situational awareness and eventually make safe decisions in all circumstances (Brandsæter & Knutsen, 2018). The concept of autonomy is context dependent giving rise to numerous definitions on levels of autonomy. However, it can also be defined keeping the immediate operational task/assignment to count. It is characterised by three principal axes wherein the first being the complexity of operations at hand, secondly the level of manning onboard and lastly the operational profile. The first axis i.e. complexity in operation depends on whether the vessel is operating in sheltered area or open seas considering the prevailing weather/sea conditions and traffic in area. The second axis represents manning level onboard the vessel which signifies whether the vessel is continuously/partially manned or totally unmanned. The last axis represents the operational profile which shows whether the assigned task is completed dependent on the system installed or human intervention is required for accomplishment. Schematic as shown in Figure-4 represents the autonomy variables (Porathe, et al., 2018)

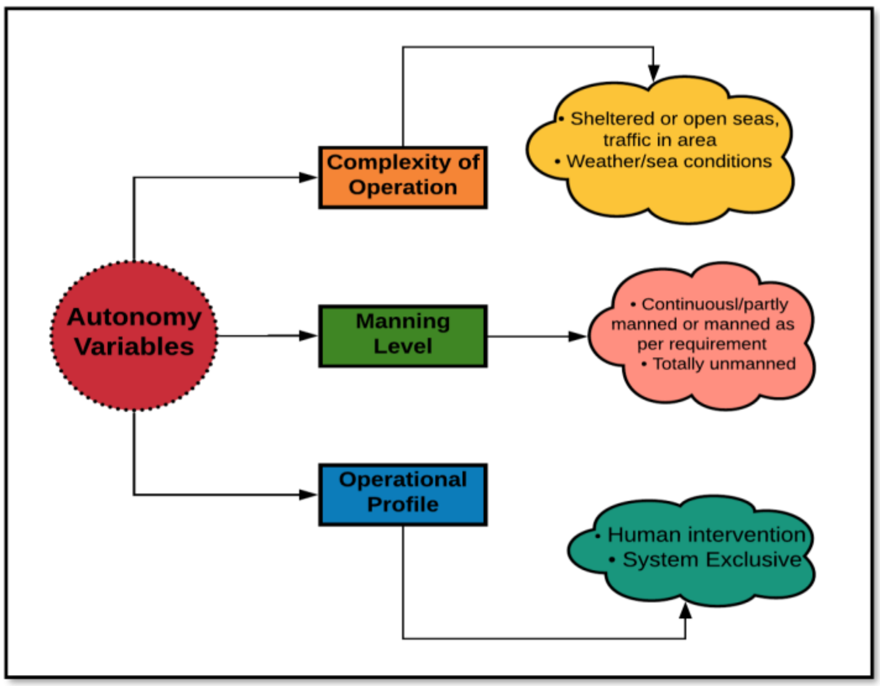

Fig-4: Autonomy variables, Prepared by author with information adopted from Porathe et al., 2018.

1.3 Research objective and Scope

Although AS is a relatively a recent focus area in the maritime industry, many countries have displayed keen interest in adapting to this kind of new technologies. Adoption of such disruptive technology has triggered the responses at the national and international level both to maintain adequate preparedness level in order to mitigate the risks/challenges associated with it. In this regard, IMO as a proponent has been proactively addressing the regulatory challenges to keep law/regulations abreast with the pace of technological advancement. Under the regulation/directives in vogue, the AS operation is limited between adjacent coastal states and within the national waters only. Nonetheless, the practicability operation of AS facts and facets are in initial stages barring the sea trials conducted by few of the countries. So far, very little research has been undertaken pertaining the collision avoidance with respect to Autonomy level-3 as the data and situations of COLREG being explored is mostly conceptual. Hence, the research may be considered as unchartered territory in the context of AS. Challenges arising out of various Rules of the Road (RoR) situations at sea and reaction of human intelligence will be carried out using assumptions of case study. The observation on trials undertaken from various AS projects will also be taken as references as part of the research.

The research objective is to highlight various requirements of the COLREG and to bring out whether degree-III AS warrants any amendment or revision. This research aims at utilising the technical provisions of RoR and establish a correlation with SCC operators task. It is understood that, with significant technological advancement in establishing algorithm for an autonomous ship, issues such as collision avoidance and RoR have rarely been addressed. The study shall also attempt to corroborate the factor of human reliability analysis in regard to the AI system and the SCC functioning. For example, the marine traffic adheres to COLREG wherein restrictions are imposed on a vessel while operating in areas of heavy traffic density or restricted waters. In furtherance, a vessel also obtains inputs on navigational situations and updated information by the vessel traffic services (VTS) to ply risk-free. However, ultimate responsibility lies with the ship's Master or as delegated by the master. The main focus on this research will be to establish potential gap in the COLREG with respect to degree-III AS and ascertain various challenges to the SCC operators. The following research questions will serve as a guide to achieve the research objective:

(a) Does COLREG need to be amended with the potential gap which may include restricted visibility, lights and shapes, definition of master and various collision avoidance situations, if so how?

(b) Determine potential function of SCC operator in case of collision avoidance.

(c) How can the SCC operators undertake their responsibility and assigned duties within the context of COLREG?

1.4 Structure of Study

The research will be divided into six chapters, as follows:

(a) Chapter-1 covers the advent of AS in the realm of commercial shipping as part of the autonomy revolution. It covers the role of the IMO as a facilitator in AS operation especially in terms of reviewing the IMO instruments. It further corelates the concept of automation and autonomy in the maritime industry. It also mentions the Research methodology/approach of the research involved and objective of research along with research questions.

(b) Chapter-2 describes the development strand in autonomous ship operation. It also focuses on current trends and challenges involved and eventually the main challenges. Hand-in-hand, this chapter highlights the development strand in order to establish how various countries have rolled out their plans to achieve full-scale AS operation. Finally, the chapter mentions about the acceptance of AS to the commercial shipping and the reception of such smart technology from different countries and organisations.

(c) Chapter-3 introduces COLREG and briefly discuss various provisions of COLREG. Subsequently, how the existing provisions of COLREG getting affected by introduction of AS will also be discussed. Besides, it also emphasises on the automation transparency[1] i.e. how automation communicates with human and the collision avoidance mechanism.

(d) Chapter-4 emphasises on the functioning of shore control centre (SCC) as the autonomy level-3 AS operation will involve crucial role of SCC operator in manoeuvres and control. It will also briefly examine the human factor and decision support system. Additionally, this chapter will also address the architecture of SCC and the anticipated arrangements of watchkeeping modalities.

(e) Chpater-5 presents a gap analysis considering the facts and facets obtained from Chapter-3 and Chapter-4. Critical analysis on how artificial intelligence (AI) is going to be integrated with the SCC in the perspective of collision avoidance and safe AS operation.

(f) Chapter-6 presents the interpretation and data findings of the research. It will also bring out the summary and eventually recommendations and scope of future research.

1.5 Research Methodology

The research will primarily be undertaken by qualitative research foreseeing probable grey areas on AS operation with respect to existing international conventions and instruments, statutes and resolutions available. The researcher will identify the issues meriting attention/problem areas which is considered essential for the research. Data will be obtained from the literatures on AS and associated disruptive technologies, legal references, research projects etc. AS concepts are largely based on theoretical approach with comparatively less practical data accessible. Until now, the trials of AS have been performed under the supervision of qualified crew and operators onboard. Hence, no real-time experiences has been obtained whilst an AS has

[1] Automation transparency can be defined as how automations ability to affect understanding and prediction of its behavior.

witnessed collision situation or interaction with a manned ship in restricted waters. For research method, the study will also comprehend theoretical analysis (literature-based) in combination with the studies undertaken before with available literature. The approach will focus on discussing the technical provisions of COLREG and identify potential gap/themes. Concurrently, the functioning of shore control centre (SCC) and obligations of SCC operators in terms of collision avoidance will also be brought out. On completion, the potential gaps identified will be corelated with the SCC functioning in regard to Deg-III AS. Figure-5 below shows the diagrammatic representation of research approach and steps followed during the study:

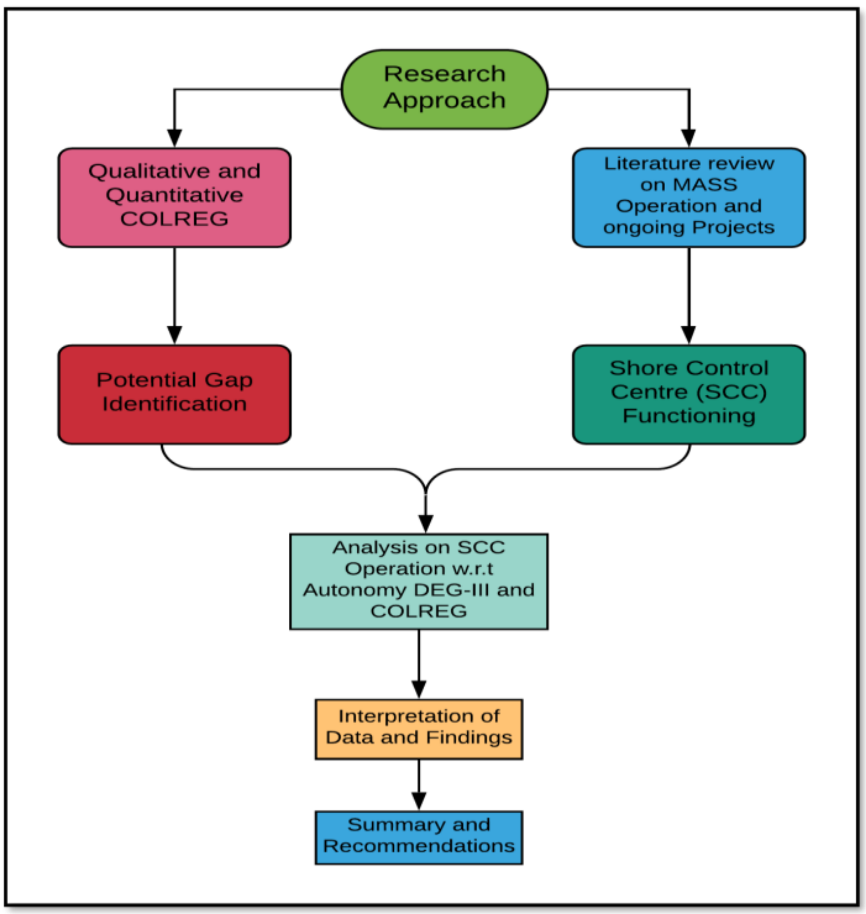

Fig-5: Research approach. Prepared by Author

Chapter-2 : Development Strand

2.1 Current trend and Challenges

The challenges to AS operation are quite complex and dynamic in nature. The advantages of AS operation cannot be explored without addressing the associated challenges and underlying issues. Amongst the many underlying challenges likely to be confronted, the three critical challenges pertaining to operational, regulatory and safety aspects need to be addressed. From the operational point of view, collision sensing and avoidance is considered one of the significant aspect while AS is subjected to high sea operation, docking/un-docking, rough weather/sea conditions and transiting through heavy traffic or multi-vessel/obstacle environment (Weigel & Pribyl, 2020).

Apart from the operational impediments, the regulatory challenges in terms of regulatory intervention is also dependent upon the manning level. The regulatory approach is required to be executed smoothly in order to prevent the existing IMO regulations/instruments from creating in hindrances to the disruptive technology and commercialisation of AS. Various international conventions needs to be amended or revised such as the International Regulations for Preventing Collisions at Sea (COLREG) 1972, the United Nations Convention on the Law of the Sea (UNCLOS) 1982 , the International Convention for the Safety of Life at Sea (SOLAS) 1974/78 and the International Convention on Standards of Training, Certification and Watchkeeping (STCW) 1978 (Blanke et al., 2017).

Lastly, the safety challenge on AS operation envisage safety of ship, cargo, traffic, environment, human being etc. Amongst these serious issues related to safety, it can be contemplated that how an AS without a master will proceed to render search and rescue (SAR) assistance to people in distress which is a mandate as per SOLAS regulations (Ringbom, 2019). To further illustrate, safety of AS in case of emergency situations such as fire and flooding at sea is another significant factor in terms of safety challenges likely to be posed by AS (Kobyliński, 2016). All these three challenges deliberated are somehow connected to each other and need to be resolved before considering practical operation of AS. Schematics representing various challenges are as shown in Figure-6 below:

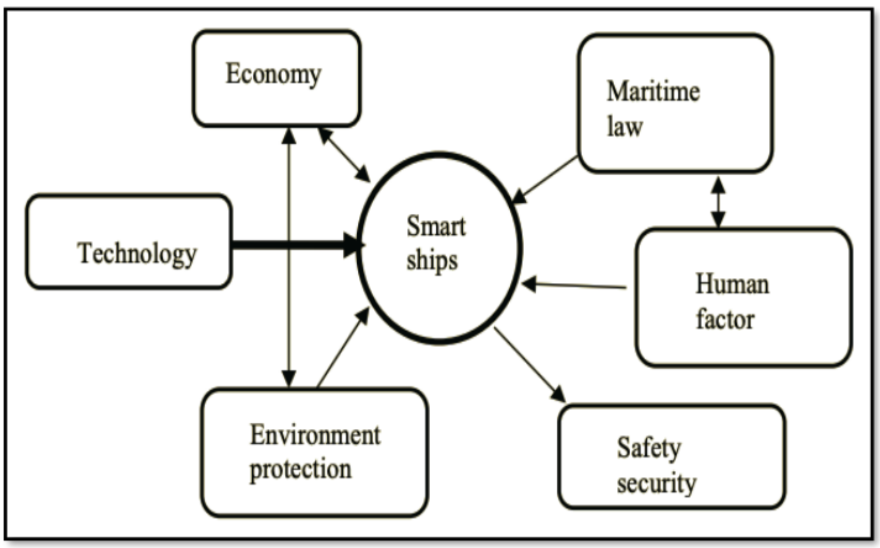

Fig-6: Challenges pertaining to AS operation (Source: Kobyliński, 2016)

2.2 Main Challenges

Regardless of the technological innovation in the shipping industry, collision is still one of the primary reasons for ship loss, sinking of ships at sea and explosion/fire onboard (Allianz, 2020). Besides, latest statistics reveal that collisions contribute to 60% of casualties at sea and 56% of cases of collisions involve breach or violation of COLREG (Liu, 2016). COLREG as an international convention sets out rules based on *good seamanship practices* defining role and responsibility of crew onboard in different collision situations. In the current bridge-watchkeeping scenario, when risk of collision exists, the officer of the watch (OOW) takes adequate and substantive action to keep clear of the vessel in vicinity. Vessel collision at sea is subjected to adherence to *good seamanship practices* under the scope of prescribed collision avoidance rules in vogue. However, this instrument focusses on the decisions taken by humans only and does not mention about AS (Ivanišević et al., 2018).

When a classic case is taken for reference wherein an unmanned vessel is operating in presence of other manned vessels or vice-versa in restricted waters, erratic or incorrect manoeuvres from the unmanned vessel shall create confusion leading to catastrophic situations. Similarly, when only two AS involved in collision situation and no manned vessel is present in the vicinity, both the AS have to take apparent evasive manoeuvres to reveal own intention as there cannot be any real time verbal communication to the other vessel. The apparent actions will only be sensed by the collision avoidance system and monitored from the SCC (Felski & Zwolak, 2020).

2.3 Road map: Making way for AS

The reach and aspirations towards AS is rapidly developing as many organizations/companies are researching and conducting trials on it. The roadmap on AS operation and development strategy includes few of the promising projects in the commercial shipping industry as well as in the military domain. The schematic shown in Figure-7 below shows development strand of AS in the realm of shipping. To name a few, the first ever project Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) funded by the European Union was initiated in 2012 by Norway. This project aims to make the European continent sustainable in shipping and develop real-time solution to make AS operation a reality (MUNIN, 2016). Significantly, the Rolls-Royce led project, Advanced Autonomous Waterborne Applications Initiative (AAWA) funded by Finland in 2013 envisions remotely operated local vessel by 2020 and fully autonomous sea going vessel by 2035 (Poikonen, 2016). In 2013, Another company namely Det Norske Veritas Germanischer Lloyd (DNVGL) in Norway has developed ReVolt, dedicated for SSS in collaboration with Norwegian University of Science and Technology (NTNU) to reduce pressure on land based logistics (DNVGL, 2014).

To take the legacy forward in the pretext of AS development, the Norwegian maritime technology export company, Kongsberg has developed a prototype vessel *Yara Birkeland* and it is anticipated to run fully autonomous by 2022. This project was an outcome of MUNIN project only as part of the Norwegian government initiative (Kongsberg, 2017). On the other hand, the Hrönn autonomous offshore utility vessel is currently under development by the Safe Implementation of Autonomous and Remote Operation of Ships (SIMAROS) project, a collaboration of Automated ships ltd., Kongsberg Maritime AS, DNV GL, Fjellstrand, INMARSAT and the Norwegian Maritime Authority. Other strands in the development include 32 foot driverless passenger ferry by Norwegian university, autonomous harbour ship jointly being developed by Maritime and Port Authority (MPA) of Singapore and Keppel Offshore & Marine Ltd. and the Technology Centre for Offshore and Marine, Singapore (TCOMS), plans to construct a fleet of 250 self-navigating cargo ships by 2025 by a consortium of Japanese companies which includes Nippon Yusen, Mitsui OSK Lines and the shipyard and Japan Marine United (Wright, 2020).

In the military domain, the United States Navy is in the process of inducting *Sea Hunter* after successful trials, an anti-submarine warfare trailing vessel under the Defence Advanced Research Projects Agency (DARPA) (WMU, 2019). Hand-in-hand, the US Navy is also testing two other USVs as part of Pentagon sponsored ghost fleet programme. It has expressed its desire to include such unmanned system to its fleet of integrated force and it is also on the verge of developing concept of operations (CONOPS) for them by 2020 (MAREX, 2020).

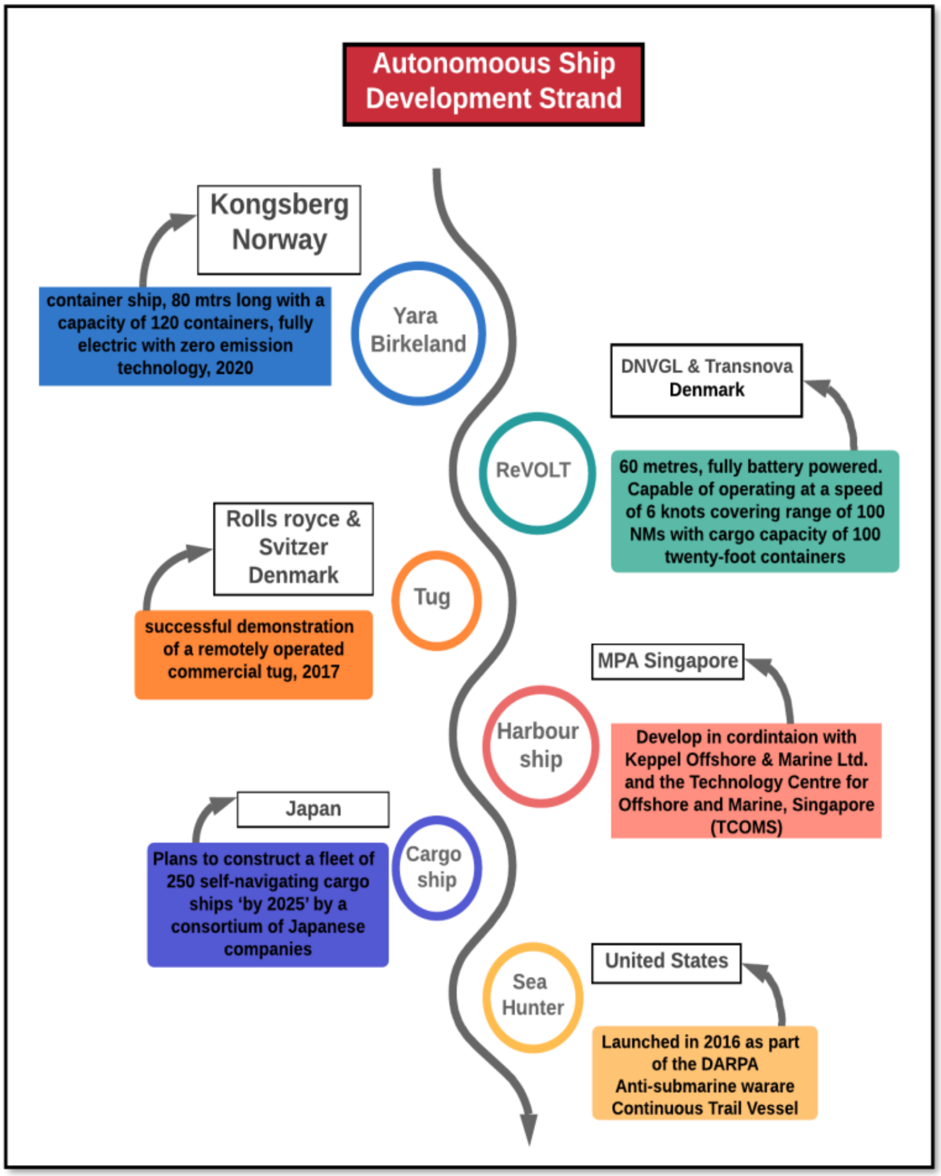

Fig-7: Development strand of AS. Prepared by Author with information adopted from (MUNIN, 2016) (Poikonen, 2016) (DNVGL, 2014) (Kongsberg, 2017) (Wright, 2020) and (MAREX, 2020).

2.4 Literature Review

Literature reviews are based on the existing theory and concepts being developed by various shipping companies and countries. It is highlighted that several initiatives on AS have been undertaken by a few countries in coordination with industry, R&D and academia for developing AS and associated equipment/sensor suite.[2] The trial reports and accessible documents from the researcher will be referred to during the course of this dissertation writing.

Proponents of developing and designing AS are of the opinion that such technological leap in shipping industry will bring positive changes in terms of safety, cleaner environment and safe ocean and overall efficiency in shipping. It is also believed that AS will have cumulative impact on the regulatory framework and international maritime instruments with the rapid transition from human-dependence task to AI. Traditional observance on roles and responsibilities of ship master & crew in discharging their duties as followed in present day will have probably no or limited role with AS in the future (Soyer et al., 2019). Amongst all the potential drives towards AS from the manned conventional ships, the aspect of enhanced safety with no human error is found to be a key motivator. Despite absence of crew onboard, AS will have reliance on shore operators as the SCC will act as safety barrier to avoid a potential collision situation (Abilio Ramos et al., 2019). Additionally, another significant motivational factor for the maritime industry is withdrawal of living spaces and deck house to facilitate additional cargo carrying capacity and also save the shipowner exchequer (Laurinen, 2016). Another, consideration is provisioning of better accessibility to high risk area (HRA) and curtail incidents of piracy as the crew cannot be used as ransom leverage (Allianz, 2020).

An unmanned ship with AI decision-support system is certainly an aspiration with total reliance on uninterrupted sensor performance which is yet to be proven. Such mode of ship autonomy with integrated system suite does not make mention of

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[2] Discussed in Chapter 2.2 ibid

situational awareness below waterline which may lead to catastrophic situations at sea (Wright, 2019). The concept of autonomy here contains a guidance & control system to ensure safe navigation and parallel detection of obstacle. Following this concept, in 2016, the Advanced Autonomous Waterborne Applications (AAWA) exploited developing an integrated control system comprising high definition visual camera, light detection and ranging and thermal imaging considering the regulations for navigation and collision avoidance. It is imperative that developing such high level sensor suite with high degree of expectation is yet to be validated in restricted and unpredictable environment (Li & Fung, 2019).

Developing an advanced autonomous collision avoidance system for AS to safely operate in restricted or constrained waters is demanding. To further amplify, the example of Amsterdam in this case can be cited. In the city of Amsterdam as 25% of the city surface is water, fleet of AS are being used for various purposes which include transporting of goods, garbage, commutation of public, collection of data on water quality and also to ascertain pollution levels in narrow urban canals. In such congested water space, as the decision-making on collision avoidance will be more complicated, it is imperative to augment collision avoidance measures to refrain from collisions at sea with promulgation of necessary amendments to the regulations in vogue (Zhao & Roh, 2019). It is expected that a remotely operated ship will have limitations in evaluating the situational awareness which will affect the decision making capabilities. This decision making capability will be based on the information available on the screen. At present, ships having automated equipment/sensor-suite is utilised as an aid to navigation wherein accuracy of information is corroborated by observing visually. In case of AS degree-III, this mode of validation does not exist (Liu, 2019). Although autonomous shipping is on the verge of becoming a reality by 2025, operation of manned vessel especially the passenger ships, and hazardous cargo carrying ships cannot be ruled out. In such a dynamic scenario, it is apt to claim that AS will be required to co-exist and safely interact with the fleet of manned ships (Burmeister, 2016).

2.5 Acceptance to commercial shipping

Reluctance from few of the shipping company in accepting the smart technology may be the bone of contention. Fear amongst the ship owners and stake holders from the maritime industry may act as an obstacle in accepting AS in the commercial field. Concerns are also observed from the maritime partners that the four levels of autonomy are not prescriptive as it warrants smart security construct from the ab-initio stage so as to avoid unnecessary vulnerabilities to cyber-attack. Cyber-attack may also occur due to high demand of data transfer in AS operation which in turn may affect vessel's safety (Dean et al., 2019). Although such disruptive technology provides potential benefits, public acceptance will be based on reliability of the equipment or technology used. Convincing the stakeholders for adoption of such smart technology on the one hand and likely disgruntlement from the labour organisation, pilot association on the other may act as an hindrance (Pribyl & Weigel, 2018).

The industry is far from united in its views and attitude towards MASS. The International Chamber of Shipping (ICS) has expressed its concern over adoption of such smart technology citing the human element and employability factor of seafarer during the 99th MSC session in Mar 2018. In this regard, the ITF Seafarers' Section Automation Working Group (SSAWG) has also expressed concern especially on the balance between human element and autonomous system (Delfanti et al., 2018). On the contrary, the Baltic and International Maritime Council (BIMCO) has shown keen interest in adopting such smart technology and desires to focus on new competence of seafarers and the need for human relations initiatives to overcome problems such as potential loneliness following the reduction of personnel onboard (Höyhtyä et al., 2017). The shipping world being conservative, acceptance to change warrants overcoming the emotional as well as legal barriers. Issues such as replacing the designation of ship master to SCC operator may be taken as a devaluation to the profession as this profession has high-self-esteem. Reduction of the manning level with increment in autonomy has also been questionable from the seafarers association and trade unions (Kobyliński, 2016).

Chapter-3 : Rules of the Road Vs Artificial Intelligence

3.1 Revisiting COLREG

COLREG convention was designed by the IMO to replace the collision regulation of 1960. It was adopted in 20 October 1972 and entered into force on 15 July 1977. The technical provisions of this convention consist of six parts and total of forty one rules as shown in Figure-8. Additionally, there exist four annexes to this convention which contain specification and characteristics of light and sound signals as required for adherence by the marine traffic. This chapter briefly discusses various provisions of COLREG and presents an analytical study with respect to AS operation.

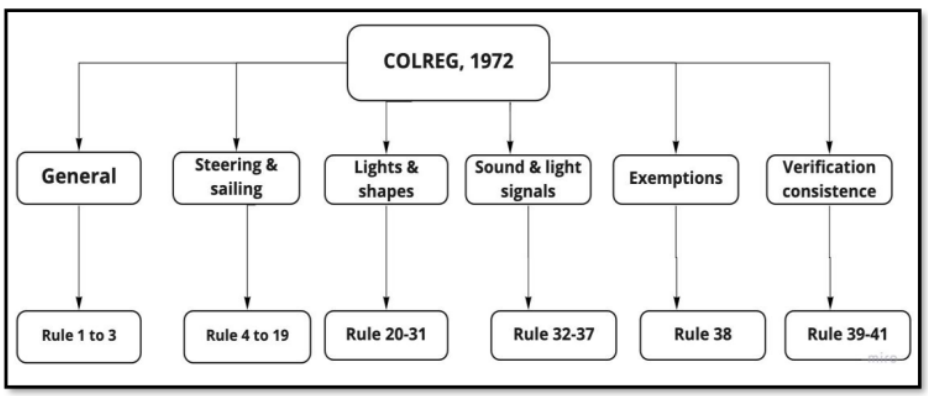

Fig-8: Parts of COLREG. Prepared by author with information adopted from Cockroft & Lameijer, 2012.

It is observed that, the language and legal terminology used in this convention is inconsistent and tend to cause ambiguous interpretation. Thus, attempts to simplify the language for better understanding of the end user (navigator) has also been witnessed (Demirel, 2015). With the increment in number of conventional ships in the merchant fleet, heavy traffic especially on the sea lanes of communication (SLOC) and advent of AS in near future, serious questions are being raised on the compliance and effective application of COLREG by AS.

3.1.1 Part-A General Rules (1 to 3)

Rule-1 of this convention speaks about the application part as it brings out the relevance of these rules to vessels operating at high seas and it also entails applicability of the local or special rule if any made by the state authorities for respective roadstead or harbour. In addition, it brings out installation of additional lights and signals onboard a man of war or fishing vessels promulgated by the government authority of any state. It also covers the exclusive authority of IMO for adopting a traffic separation scheme (TSS)[3] which is a provision under Rule-10 of this convention. Lastly, the application also covers exemptions to specially constructed vessels like a warship or naval vessel in terms of fitment of lights, sound signals or shapes. For example, an aircraft carrier have a masthead light installed off the centre line with reduced separation horizontally.

Rule-2 sets the responsibilities straight on a navigational watch keeper or seaman at watch signifying the ordinary practices exercised by seamen in avoiding a collision situation. To further illustrate, when a vessel is passing through dense fog with non-operational radar, the vessel may not continue to make way and drop anchor if the situation so warrants to be safe and viable. On the other hand, Rule-3 discusses various definitions such as *vessel*, *power driven vessel*, *sailing vessel* etc which has got general application throughout this conventions and also acquaint the end user with the terms used.

[3] IMO Publication *ships routeing* defines TSS as, *a routeing measure aimed at the separation of opposing streams of traffic by appropriate means and by the establishment of traffic lanes.*

3.1.2 Part-B Steering and Sailing Rules (4 to 19)

In this part, Rule-4 states that all rules of section-I (Rule-4 to 10) is applicable irrespective of the visibility conditions. Rule-5 speaks about the inescapable requirement of *Look-out* at all times citing it as an important aspect of collision avoidance. A look-out is expected to be alert and report sighting of any vessel, objects, lights and hearing of any sound or fog signals to the bridge watch keeper immediately. It is imperative that, vessels these days are equipped with advanced equipment and technology like night vision binoculars which acts as an important tool for effective look-out duties. In addition, this rule also emphasises exploitation of the navigational aids (NAVAIDS) namely electronic chart display information system (ECDIS), Radar, GPS etc to apprise the full operational situation at hand (Zhou et al., 2020). The mandatory standards for placing a proper look-out is also mentioned in Part A, Chapter-VIII of the STCW Code.

Safe speed as brought out in Rule-6 envisages various factors to be taken into account namely the weather/sea conditions, visibility, traffic density, radar status etc prior determining the safe speed of a vessel at a given time. To ascertain what can be safe speed, the OOW acts as best on-scene judge to adjust the speed accordingly in order to avoid near-miss situations or collision. On the contrary, Rule-7 mentions timely assessment of the *Risk of collision* if any by the navigational watchkeeper considering effective and proper use of all manual and mechanical means such as radar or compass available onboard (Perera & Batalden, 2019).

Rule-8 covers the actions/measures to be taken to avoid collision wherein the actions are to be taken in ample time anticipating that the risk of collision exist. The enumerated actions as raised in this rule may be alteration of planned course or speed or both and giving allowance to other vessels in vicinity to take individual and substantive action. Rule-9 subjects a vessel with different circumstances such as overtaking a vessel and anchoring while negotiating in a narrow channel whereas Rule-10 refers to TSS and how vessel is subjected to various obligations on a vessel whilst passing through a TSS and the laid down rules to ensure safe passage for self and vessels in vicinity.

Rule-11 states that all rules of section-II (Rule-11 to 19) is applicable to vessels visual to each other and does not apply to vessel which is not in sight or detected by means of a radar. In this section, from Rule-12 to 16 comprise of various steering actions to be adhered to in various RoR situations. To further substantiate, Rule-12 mentions the actions to be taken by two sailing vessels while approaching each other whereas the provisions of overtaking has been specified in Rule-13 especially on the onus between the overtaking vessel and the vessel being overtaken.

On the same pretext, Rule-14 deliberates on terms of head-on situation between two vessels when they meet on reciprocal or nearly reciprocal courses and Rule-15 brings out the essence of action taken by vessels when they cross each other to evade the risk of collision. In such scenario, the vessel which allows other vessel to proceed or keep out of the way is called *give-way vessel* as mentioned in Rule-16 and the other vessel which maintains its course and speed is called *stand-on vessel* and proceeds as planned as stated in Rule-17. In this section, Rule-18 discusses responsibilities between vessels when they operated in tandem. For example the sailing vessel has got the absolute right to keep out if the vessel which is not under command (NUC). Section-III has only one rule that is Rule-19 which reiterates various conditions of vessels operating in area of restricted visibility, vessel not in visual range and importance on utility of radar for timely detection.

3.1.3 Part-C Lights & Shapes (20 to 31)

Rule-20 covers the application in terms of use of various lights and shapes in all weather conditions by the vessels. In the similar way, as discussed in Part-B, Rule-21 talks about various definitions of lights with respect to specifications, positions of fitment and arc of visibility whereas Rule-22 deliberates the varied visibility ranges of lights fitted with respect to length of vessel. Rule-23 incorporates the requirements of exhibiting lights while a vessel is underway depending upon type of vessel and length of vessel. To further facilitate the understanding of a navigator and obviate ambiguity, Rule-24 delineates the requirement of lights when a vessel undertakes towing or pushing operation which is clearly identifiable form another power driven vessel.

A vessel underway with sail and under oars is covered in Rule-25. This rule also mentions the lights to be displayed by small sailing vessels. Rule-26 exclusively covers the distinctive light requirements onboard a fishing vessel with various modes of work like trawling , underway, engage in fishing or at anchor etc. Rule-27 discusses lights to be used by vessels undertaking diving operation, mine clearance operation, NUC, and restricted in ability to manoeuvre (RAM) to facilitate differentiating between vessel undertaking such special operations and avoid closing in. Rule-28 refers to the lights being displayed by vessel constrained by draught (CBD) whereas Rule-29 articulate the prerequisite of lights onboard a pilot vessel. The last two rules in this part namely Rule-30 refers to lights to be used by vessels at anchor and vessels ran aground and Rule-31 mentions lighting requirements of a seaplane.

3.1.4 Part-D Sounds and Light signals (32 to 37)

Rule-32 contains the definitions of sound signal known as whistle and how it is interpreted as long blast or short blast. Rule-33 connotes the equipment prerequisites to generate necessary sound signal specifying vessel length. Amongst all the rules in this part, Rule-34 is often considered quite decisive in terms of the manoeuvring and warning signals used by vessels in various circumstances or RoR situations as we say it. Rule-35 explicitly covers the sound signal requirements when a vessel is operating in an area of restricted visibility and engaged in normal or special operations. In the end of this part, Rule-36 covers making of sound or light signals to seek attentions of vessel nearby and Rule-37 talks about exhibition of necessary signals in case of distress.

3.1.5 Part-E Exemptions (38) and Part-F Verification of consistence (39 to 41)

Rule-38 under Part-E encompasses the exemptions rendered by this conventions to vessels in order allow them to undertake additions or alterations if any with respect to position of light fitment or to evaluate performance check on the sound signalling apparatus. Part-F as adopted in 2013 contains three rules wherein Rule-39 is about definitions, Rule-40 covers the utilisation of agreement by the contracting parties for implementation of the convention and lastly Rule-41 brings out the verification of consistence wherein the dependence of contracting parties on review by IMO is discussed.

3.2 Analytical study of COLREG provisions

The AS operations will adhere to the technical provisions of COLREG unless and until new set of rules are being developed considering various challenges posed by such ship in terms of the machinery/equipment installed, behaviour to various sea/weather conditions, and overall performance to dense traffic or multi-obstacle situations. The question arises here is whether such intelligent ships can be governed by the existing RoR as the maritime front is dominated by manned vessels at present (Kufoalor et al., 2020). This section will undertake analytical study of various technical provisions of COLREG with respect to AS operation and evaluate the criticalities involved.

3.2.1 Responsibility

As discussed earlier, Rule-2(a) of this convention holds a ship captain or the crew responsible to take precautions in normal conditions or special circumstances and mandates to follow the norms followed by the *ordinary practices of a seamen*. However, in case of remotely controlled AS, the question arises here is, "*who will be called as master of the vessel?"* in case of some eventuality or collision reported at sea as the vessel during the passage will pass under the control of various SCC enroute with varied degree of autonomy. Hence, the sense of responsibility to undertake immediate and proactive response will only lie with the system installed onboard and per say responsibilities shouldered by an individual or SCC operator needs to be chalked out (Kufoalor et al., 2020). Subject of legal responsibility may also include the role of SCC operators, software developers and the ship construction and design team. In case of a reported accident involving an autonomous ship, the SCC may not be able to respond to real-time incident and not been able to take suitable actions. Hence, the designated SCC may be held responsible for actions or conduct of an AS. However, AS with automated navigation system (ANS)[4] capable of independent decision making, the shipowner will also have equal obligation irrespective of the type of situation the AS may encounter (Carey, 2017).

Besides, Rule-2(b) allow departure from the rules to avoid imminent danger as adhered by the conventional ship whereas the decision of an ANS may not be prompt as the involvement of SCC will lessen the reaction time to avoid the risk of collision. In a mixed environment, a conventional ship may adhere to the *ordinary practice of seamen* and *good seamanship* but AS may not be subjected to this as it is unmanned. Such trivial issue may further create bottlenecks when an accident is reported by AS and the COLREG is referred to. Hence, it may be established that, responsibilities as brought out in Rule-2 involves a human being for decision making, hence a revision to the COLREG incorporating remote controlled modalities to facilitate legal application of this rule may be considered (Pietrzykowski et al., 2018).

3.2.2 <u>General Definitions</u>

AS can be considered as a power-driven vessel[5] however, it can also be treated as a NUC vessel where there is failure of communication links between the SCC and onboard decision making system or interruption due to technical snag. The AS will be under the command of SCC unless and until it can safely navigate with all the sensor

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[4] *An automated navigation system (ANS) with multiple sensors including a vision sensor, GPS and an electronic-compass was developed. Data from the sensors were fused by a feedback algorithm and the steering angle was calculated based on the fuzzy logic module.*

[5] COLREG, Rule 3(b) defines *power-driven vessel means any vessel propelled by machinery.*

suite, AI system and machineries onboard is intact as defined in article 3(f) of this convention. Alternatively, AS may also be treated as vessel RAM[6] and it will depend upon the autonomy level and the kind of work the vessel is engaged with. AS involved in special operations as brought in Rule-3(g) will only make it a RAM vessel and otherwise it may be a power driven vessel bearing highest level of accountabilities in the echelons of COLREG. Notably, applicability of Rule-3(k) namely *vessels in sight of one anothe*r raises question on AS capability to visually observe another ship in vicinity (Zhou et al., 2020).

3.2.3 Look-out

AS will be monitored and controlled from the SCC wherein the operators employed in the control centre will act as a functional and operational equivalent of ship's crew. However, presence of natural person as *look-out* for proper sight and hearing as per the legal requirements of this convention needs to be addressed. The present provisions may be amended as "every manned vessel" in lieu of the word "vessel" to exempt the AS from the mandatory requirements of placing a look-out or as a carte blanche measure, a separate provisions for AS on the look-out requirements be considered. A computer replacing human eyes to render the sight requirements while hearing modalities may be taken care by the sensor suite for immediate transmission to the SCC in the form of audio. Some academicians are of the opinion that AI is comparatively better than a human being as the likelihood OOW committing mistakes is more than that of AI. The sensors used onboard AS may function way better than a human eye while detecting and identifying any obstruction in restricted visibility or bad weather/sea conditions (Öhland & Stenman, 2017). On the contrary, the trial results on the advanced sensor module (ASM) used in the MUNIN project revealed that human presence is far safer than the sensor module employed for carrying

[6] COLREG, Rule 3 (g) defines *'vessel restricted in her ability to manoeuvre means a vessel which from the nature of her work is restricted in her ability to manoeuvre as required by these Rules and is therefore unable to keep out of the way of another vessel*.

out look-out duties. Such limitations may also be improved by amalgamation with other sensors and using effective & efficient radars (Rylander et al., 2016).

3.2.4 Safe Speed

To be fully compliant with the provisions of Rule-6 of this convention, the ANS needs to comprehend the environmental conditions vis-s-vis ship dynamics. The deciding factors to effect safe speed by an AS will encompass the visibility conditions, traffic density, sensors availability/redundancy, draft, turning diameter, sea state etc. To execute safe speed or maximum allowable speed at a given point of time, AS may require independent determination of time-distance capabilities and other dynamics co-considering look out (Rule-5) modalities to obtain real-time situation (Woerner et al., 2019).

3.2.5 Risk of collision and avoidance action

When the risk of collision is discussed, it is significant to discuss two critical components. Firstly, determining the target contact with continuously decreasing range and compass bearing being fixed and secondly, approaching a bigger vessel or tows (Cockroft & Lameijer, 2012). Onboard an AS, the capabilities of early warning system for giving timely alerts to the SCC and concurrently, prioritising/classifying the contacts in vicinity in terms of range and bearing may facilitate avoiding the collision risk. The minimum safety arrangements onboard AS may be equivalent to or higher than the safety standard of a conventional ship to ensure better preparedness (Zhou et al., 2020). Actions enumerated in COLREG to avoid collision essentially talks about *good seamanship practices* which is presently imparted to the seafarers on the basis of STCW conventions to assess situation of own vessels as well as other vessels. To meet this requirement, the SCC operators may be trained with the norms of STCW to cultivate the good seamanship practices.

3.2.6 Collision avoidance - Crossing situation

Collision avoidance is a significant part as we discuss AS operation involving close quarter situations. It is expected that the decision support system onboard AS is supposed to undertake collision risk assessment similar to the collision avoidance actions undertaken by present day navigator. Assuming that two power-driven vessels are in crossing situation wherein own vessel acts as *stand-on* and the other vessel i.e. the target vessel will be the *give-way* vessel. So, the own vessel has got three zones of navigation in the form of concentric circles as far as the risk estimation is concerned. The first zone is the outermost area known as the general region or safety region, the second zone which is inward to the general zone known as the critical region or caution area and the innermost region is known as the danger zone or danger area where probability of risk of collision is very high. These zones are marked to make sure that the AS has got different levels of alerting mechanism and the collision avoidance system continuously calculate the optimum course and speed suitable to avoid collision as shown in Figure-9 (Nakamura & Okada, 2019).

Further assuming that both the vessels are making way on a straight line and they are proceeding with planned course and speed. Considering that both the vessels have different characteristics/dynamics in terms of work assigned, type, size and other variables, likelihood of respective course trajectory intersection resulting a potential collision situation may not be possible[7]. The trajectory of intersection when passed by both vessels at different times will be considered as safe, however the risk of collision will still exist. With the prevailing practices, the own vessel (*stand-on* vessel) and the target vessel (*give-way* vessel)[8] communicates to each other well in time and convey each other's intentions which may be a matter of concern with collision situations involving AS-AS or AS-manned ship. In furtherance, the possible collision situation is evaluated by taking the compass bearing of each other wherein reduction of range and no changes of relative bearing indicates then risk collision. Hence, in real-time

[7] COLREG, Rule-15 mentions crossing situation in any conditions of visibility.
[8] Discussed under Chapter 3.1.2 ibid

conditions when there is crossing situation, the two vessels involved make sure that they are maintaining the minimum closest point of approach (CPA) which generally falls in the outer end of the danger area/zone. COLREG does not clearly enunciate or clarify details on the crossing situations and it is observed that *good seamanship practices* with the expertise of a navigator has been quite helpful in handling such critical situation allowing the *stand-on* vessel also to react when the *give-way* vessel fails to initiate proper action which may be a significant issue with AS operation (Woerner et al., 2019).

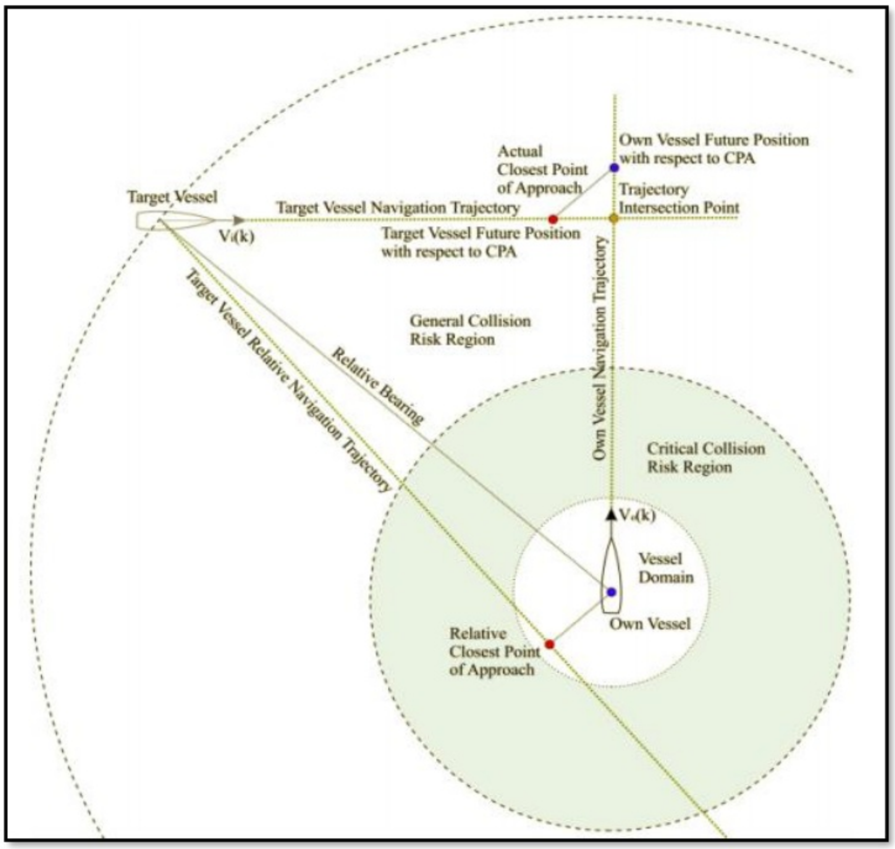

Fig-9: Two vessels crossing situation (Source: Woerner et al., 2019)

3.2.7 Collision avoidance - Head-on & Overtaking situations

Head-on situation (Rule-14) occurs if two ships meet on reciprocal or nearly reciprocal courses and the vessel trajectory meets at one point in a straight line whereas an overtaking situation (Rule-13) occurs if an overtaking vessel comes from more than 22.5 Deg abaft the beam of vessel being overtaken. In both the situations, the vessel has to closely monitor the time of closest point of approach (TCPA) which can be obtained/calculated by knowing the CPA. The TCPA for target vessel is constantly monitored by the bridge watchkeeper so that timely and effective action is taken to avoid the risk of collision. In case of a head-on situation, each vessel turns to their starboard side providing sufficient room to each other and they pass port to port (red to red). While considering the head on situation, it has been previously witnessed that insufficient or inadequate turn (lees than 35 Deg) undertaken by ships has resulted in collision. So, when we consider AS involved in head-on situation, the AS may turn to port considering the best interest to the safety or as decided by the SCC operators which may be in contravention with COLREG or departure from the rule. It is highlighted that the contradiction with COLREG compliance is attributable to the notion of tacit acceptance that it covers all aspects of collision avoidance and the imprecision of the regulation. Hence, this inconsistency may act as an inhibitor to AS operations (Woerner et al., 2016).

Overtaking situations may not be complicated for AS in a mixed environment but then, overtaking situation in multi-obstacle or multi-vessel situation such as overtaking a vessel which is already overtaking another vessel or may be a combination of crossing or overtaking situation will be quite complex and risky as the algorithm or logic used by the decision support system has to prioritise the incidents likely to happen with a precedence as observed during the trials conducted for Telemetron in presence of naval ship, passenger ship and fishing vessel in operating vicinity (Kufoalor et al., 2020). To further facilitate AS operation, the SLOCs or TSS may have a separate lane for AS or dedicated traffic lane in order to decrease risk involved in overtaking situations allowing the vessel to maintain minimum CPA while overtaking another vessel with least interference from other merchant traffic (Porathe & Jan Rødseth, 2019).

3.2.8 Restricted visibility

Restricted visibility[9] implies inability to judge the risk of collision visually due to poor visibility conditions in operating area. Hence, the condition of restricted visibility in regard to AS operation may be alleviated as it will have "computer vision" in lieu of *look-out* for early detection. Thus, AS may not be able to determine by itself the condition of visibility at given point of time. Assuming a hypothetical situation where AS encounters conventional ship in conditions of restricted visibility, the AS can sight the conventional ship whereas vice-versa is not feasible. Hence, this rule may not be applicable to AS because in all probability, the vessel will be insight of one another if at all poor visibility persist in the area of operation (Pedersen et al., 2020).

3.3 Automation transparency & Collision avoidance mechanism

Automation Transparency was not probably a familiar concept but with the 4th IR, it has become a part and parcel of human life. It can be defined as the relationship between human being and automation. In other words, how automation communicates with a natural person in terms of achieving a pre-set objective. The automation transparency may include displaying an additional identification light by AS other than the lights prescribed in current COLREG and revealing the marine traffic of its presence or identity. In the similar manner, AS route planning may also be exchanged with the merchant fleet, the VTS and the security agencies (Coast Guard and Navy) of the coastal states through which the AS is likely to pass, so that situational awareness can be finetuned and all the land based/shore based operators[10] are in sync (Baldauf et al., 2019).

[9] COLREG, Rule-19 Conduct of vessels in restricted visibility
[10] Being discussed in Chapter 4.1.1 ibid

COLREG was drafted for natural person(s) and help them use the rule with judicious reasoning and judgemental skills. The AS needs to follow COLREG and its provision but then vagueness and inconsistency in the rules make it difficult to design collision avoidance system as the parameters for designing such system may vary with different vessel dynamics/characteristics and the operating environment. Hence, its challenging to design a full proof system which is effective irrespective of the vessel dynamics or environmental conditions. The ANS containing collision avoidance algorithms need to differentiate between various RoR situations arising out of two vessels or multi-vessel conditions keeping no room for ambiguity (Rylander et al., 2016).

The collision avoidance mechanism may promptly carry out intelligent route planning and subsequent execution pending directives from the SCC. The key data provider on other vessel details will be the AIS to the advanced senor module in order facilitate the collision avoidance system to initiate necessary action. Although IMO has provided guidelines for operational use of AIS, the issue meriting attention is proper use of AIS by all vessels and mentioning the respective vessel dynamics/particulars so that other vessels in vicinity are not in doubts or ambiguity. Especially, the AS (Deg-III and IV) will not have a human operator available onboard to cross check the target vessel's dynamic/particulars by establishing communication through VHF or other means to corroborate the details. Hence, correct AIS data integration to the sensor module may act as an important tool in deciding own route planning (Porathe, 2020). Few of the additional area to explore may include enhanced use of E-navigation as prescribed by the IMO for better estimation of situational awareness and emphasising the route exchange programme akin to the EU projects such as MONALISA[11], ACCSEAS[12].

[11] MONALISA is a motorways of the Sea project which aims at giving a concrete contribution to the efficient, safe and environmentally friendly maritime transport. This is done through development, demonstration and dissemination of innovative e-navigational services to the shipping industry, which can lay the groundwork for a future international deployment.

[12] ACCSEAS is a 3-year project supporting improved maritime access to the North Sea Region through minimising navigational risk

Thus, generalising the functionality aspect of a collision avoidance system, it may include the sense for timely detection of the barrier/obstacle and immediately linking it with the repository of automatic radar plotting aid (ARPA), Radar and automatic identification system (AIS) so that a complete picture of the operating domain is achieved. Concurrently, the immediate domain plot may be transferred to the SCC for analysis so that situational awareness is optimum. Accordingly, the manoeuvre may be controlled and directed by the SCC operators or else the AS may perform evasive manoeuvre and returns to the planned course and speed on passing the obstruction or area of danger (Bakdi et al., 2020). Hence, designing an effective and efficient collision avoidance mechanism may include the essential determinants as shown in Figure-10:

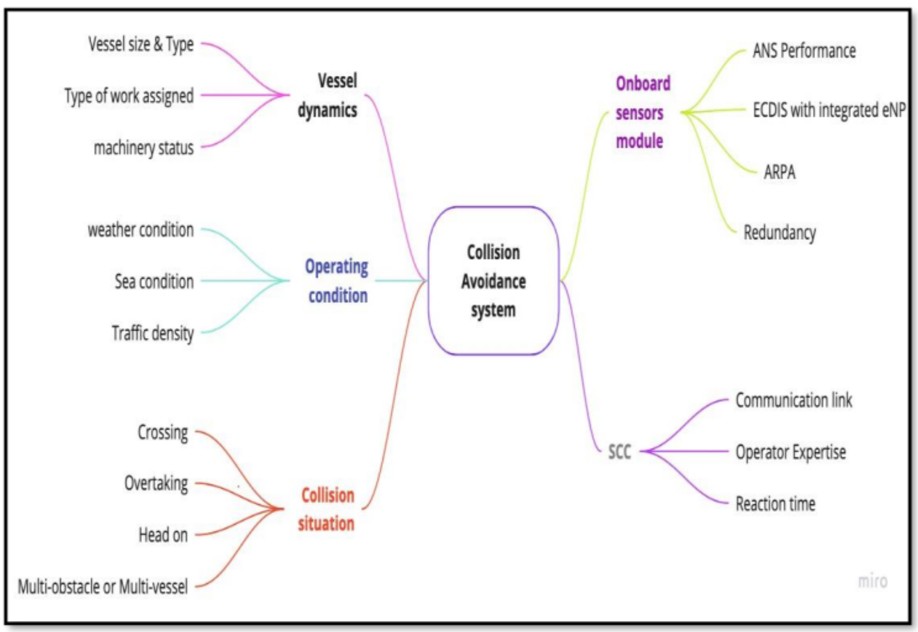

Fig-10: Determinants on designing collision avoidance system. Prepared by author with information adopted from Woerner et al., 2019.

Chapter-4: Shore Control Operations

4.1 SCC Architecture

SCC will play a vital role in controlling AS remotely from a shore-based center with an inventory of sophisticated equipment, sensors and a pool of trained manpower. Relocating the navigator from ship's bridge to shore-based center to carry out supervision and control of more than one ship will be the essence of SCC functioning. Although the decision support system/algorithm will steer the ship without human presence, the SCC operators may have a direct control in case a collision situation develops/anticipated or while the vessel is negotiating through heavy merchant traffic (Rylander et al., 2016). The SCC architecture in terms of equipment/sensors installation and manning requirements may be considered akin to a modern-day conventional ship's bridge. The effectiveness in setting up a SCC may depend upon human redundancy meaning to say that the SCC operators may work as team to evaluate correct situational awareness and cross-check each other's navigational decisions. Such concept of backing-up each other while monitoring/controlling AS remotely may add to achieve the core elements of bridge resource management (BRM)[13] as followed in the conventional manned ship (Barthelsson & Sagefjord, 2017).

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[13] Bridge Resource Management can be defined as the effective management and utilisation of all resources, human and technical, available to the bridge team, to ensure the safe completion of the vessel's voyage.

4.1.1 Connectivity overview

A fully functional SCC may have to establish reliable connectivity with other maritime regulators/partners such as the shipping company, ship agents, VTS, port authorities, the Coast Guard/Navy, pilot etc. foreseeing exchange of timely and accurate information amongst all nodes. With AS being a mobile entity, it will have varied geographical location and may warrant integrating SCC with VTS. From the safety point of view, it is considered essential that SCC may be connected to other organizations in the maritime industry to have better synergy and readily available information. A robust connectivity set up may act as an enabler in terms of dissemination of crucial information and (Kutsuna et al., 2019). Likely overview of SCC connectivity is as shown in Figure-11.

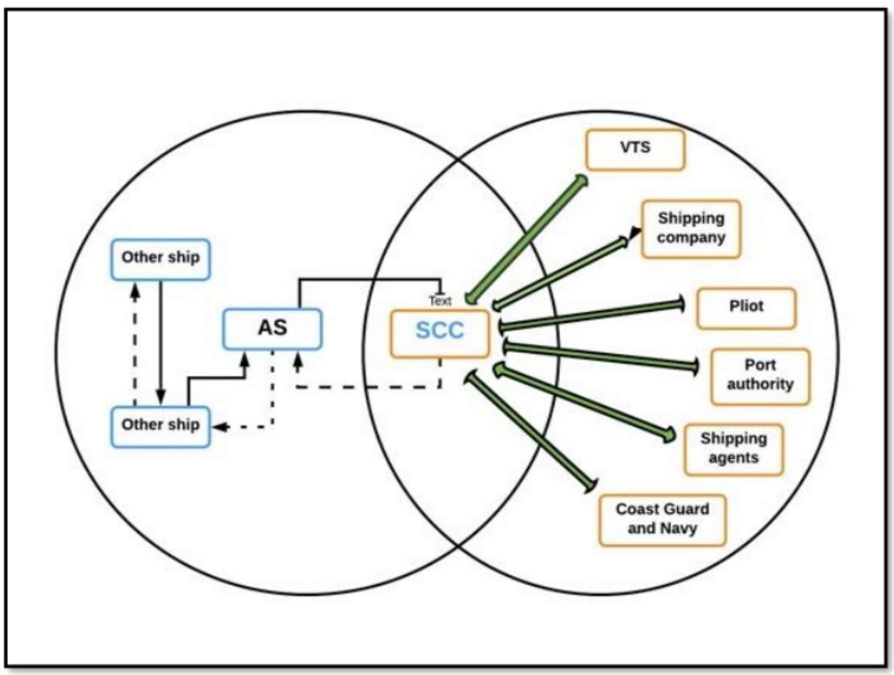

Fig-11: SCC connectivity overview. Prepared by author with information adopted from Rylander et al., 2016.

4.1.2 Technological requirements: AS-SCC functioning

Establishing a robust SCC set up requires strong and reliable technical support. The present technological expertise may not be adequate to support risk free operation of AS. The key technological ingredients of AS-SCC functioning will basically include three things which include firstly, the ship based ANS, secondly, the high-value/performance maritime communication suite and lastly, the shore-based support system. The shipboard ANS terminal is meant for intelligent perception, prompt decision making and its reliable implementation whereas the high-performance communication suite may readily disseminate information in a compressed form from ship to shore and vice-versa. Significantly, the shore-based support system may have to carry out 24x7 monitoring and maintain real time domain picture to ensure that the ship is plying risk free from collision and any other eventuality. The key technological constituents and its utility is as shown in Figure-12 (Yang, 2020):

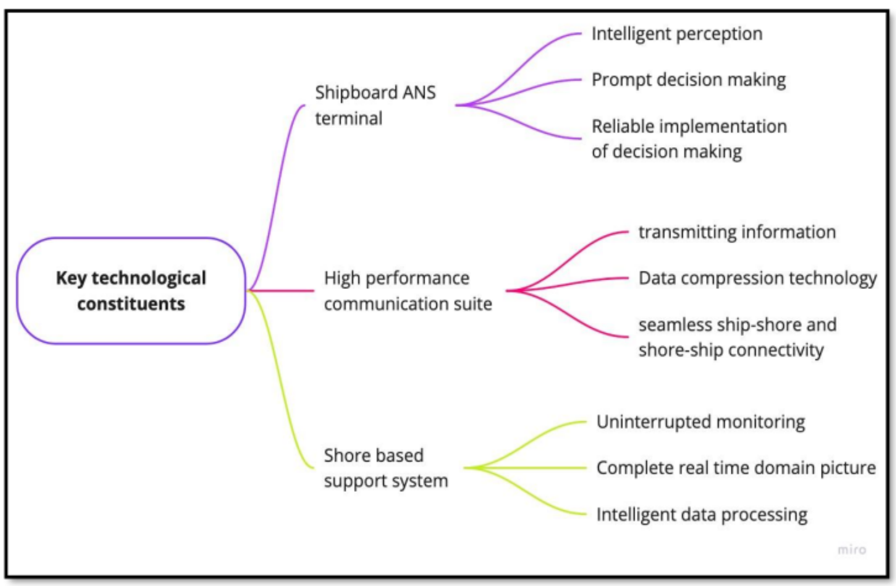

Fig-12: Technological requirements AS-SCC functioning. Prepared by author with information adopted from Yang, 2020.

4.1.3 SCC architecture and Modus operandi

Amongst all the three technological requirements discussed above, the focus here will be on the probable architecture and design of the SCC and the equipment fit in regard to the shore-based support system. The SCC operator console will be the heart of all equipment and sensors. This console will have data inputs from all the nodes which will be processed and fused in furtherance to obtain a real time domain picture at all times. This human-machine interface will clearly delineate the role of human being as operator and the associated machines/sensors. In this interface, the sequence of action will be information acquisition, information integration, prioritising collision risk by the machine and then the verification and approval by the human being and eventually execution by machine and control by machine/operator. Hence, the SCC modus operandi of SCC is anticipated to be quite complex and dynamic (Wróbel et al., 2020).

Presumably, the shore-based system and design will have four essential components. The first component will be high performance two-way communication system with both terrestrial and satellite connectivity. This component will have adequate redundancy catering maintenance and operational availability of the system. The second component will focus on connectivity with the land and sea based actors as reflected in Figure-11 to ensure exchange of data on operational/administrative requirements such as berthing, entry/exit to ports etc. The third component will be the sensor suite installed at the SCC which will provide forecast and feedback on weather/sea conditions in the area of AS operation with the help of a weather & meteorological sensor. In addition, it will also have the facility of remote sensing which in turn will keep the operators informed about the operating environment & navigation situation (course, speed and distance of own vessel). The last component will be the operator or watch keeper’s role. The operator will be solely responsible to prepare a suitable passage plan, feed into the ANS and update as and when required. Additionally, the operator will also have an obligation to continuously feed electronic charts, electronic navigational publication (e-NP), NAVAREA warnings (Wróbel et al., 2020). A schematic depicting SCC operator console architecture is shown in Figure-13 below:

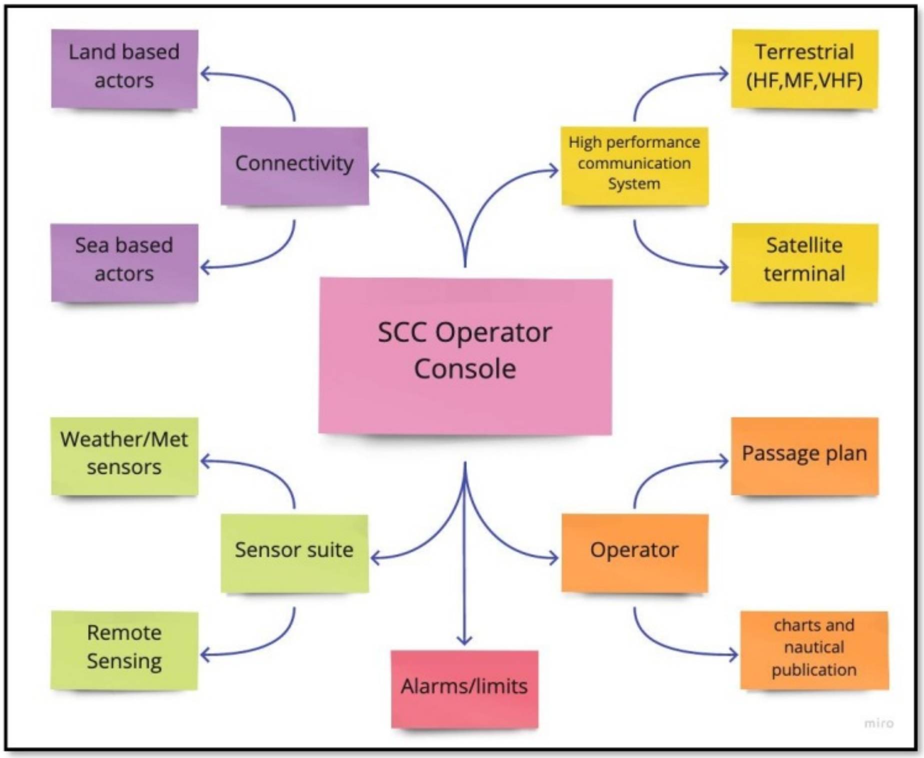

Fig-13: SCC operator console architecture, Prepared by author with information adopted from Barthelsson & Sagefjord, 2017.

4.2 <u>Watchkeeping modality and operator's role</u>

AS will be under the supervisory and operational control of SCC during all phases of the planned voyage. Manning requirements of SCC will be analogous to the bridge watchkeeping and thus, positioning of qualified operators with expertise on navigational watch much like an OOW will be required. The operator's task will be multi-dimensional and more complicated due to the likely architecture of SCC and composite functioning which also array equal or more fatigue related issue. Concurring to the decisions taken by the collision avoidance system of AS and supervising safe manoeuvring in multi-obstacle situation will be a herculean task (Porathe et al., 2014).

The operator's role in discharging his/her duties may be divided into three levels or phases. The first level may be named as "indirect control" wherein updating of passage/voyage plan may be carried out due to several unforeseen navigational situations such as immediate weather warnings, routings to avoid passing through a no go zone like no fishing zone (NFZ) or promulgated area for conduct of military firing/exercise etc. The second level may be called as "direct control" and in this phase giving direct orders to the ANS for a specific manoeuvre by the operator may be considered, for example, dropping anchor to the windward side. The third and most important phase may be called as "force/immediate control" in which, the operator bypass the ANS and takes over the steering control directly to the SCC. This phase may be activated by the operator when risk of collision is imminent and the AS safety is at stake (Brekke et al., 2019).

4.2.1 <u>Evading collision scenario</u>

In ideal condition, AS on detection of collision candidate (CC)[14] will plan out a safe route and divert from the planned path and it is duly monitored by the operator. In actuality, the scenario is different the reason being, from detection of a CC, subsequently evaluating risk and giving precedence to the CC and eventually formulating action plan to avoid collision, considerable time lapse may occur (Kutsuna et al., 2019). In such scenario, the operator with his/her expertise on COLREG may validate the plan of the collision avoidance system or else it may directly take control and execute safest possible manoeuvre to keep the AS away from risk of collision.

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[14] Collision candidate can be defined as pair of ships in an encounter process where their spatiotemporal relationships satisfy certain criteria that has the potential for collision

On assuming that, here the CC may be another AS, conventional ship, floating or fixed object and the risk assessment is high warranting immediate interference of SCC operator. Thus, prompt response and cumulative efforts may be required by the operator evade the collision situation. If the CC is a conventional vessel, then the operator may establish line of sight (VHF) communication and convey its intention so that both the vessels will take independent avoiding actions. On another case, if the CC is a floating or fixed object, the detection algorithm identifies the characteristics of the CC, the operator in turn may corroborate from other vessel in vicinity and directs the AS to procced with safe course and speed. If the CC is an AS, then both the AS will communicate to each other through respective SCC and takes collision avoiding action as deems fit. On the other hand, there may be occasions where the communication link is failed between AS and SCC rendering the operator helpless. In such situations, the probability of risk of collision increases to the maximum as no real-time communication will be feasible (Ramos et al., 2020).

4.2.2 <u>Voyage planning and human interaction</u>

The SCC operator role in ensuring safe operation of AS may depend upon the preparedness level of AS and formulating an operating procedure/check-off list with respect to vessel's readiness prior venturing into sea. The voyage plan may be divided in to four phases namely planning phase, leaving harbour phase, open sea operations and entering harbour phase. In the first phase, the remote operator will undertake a thorough assessment of the sensors, operational availability of machinery/equipment and communication link between AS-SCC and vice-versa, validating navigational way points with a fall-back strategy. After leaving harbour, the SCC operator may have a direct control to manoeuvre the ship out of harbour due to congested traffic and avoid the risk of collision. However, the modality of land based operator connectivity i.e. the with the VTS operator will play a crucial role in ascertaining the traffic density in and around the harbour. The third phase will be the most dynamic phase due to the vessels movement in open seas. In this phase, the SCC operator make sure that the vessel is being monitored while it crosses each pre-defined way points in the voyage plan and due correction may be given when necessary. However, the SCC operator needs to be prompt is assessing the risk of collision and have precision in the situation awareness. The operators may exercise their veto power of taking absolute control of the vessel in case any deviation from the planned strategy is observed (Ramos et al., 2018). Similarly, the last phase namely the entering harbour phase can also be undertaken in an analogous manner like the leaving harbour phase.

Chapter-5: Does COLREG need revisiting?

5.1 Potential gap analysis

It has been the matter of discussion from the regulators/partners and stake holders from the maritime industry, whether COLREG needs to be partially amended or completely revised with advent of AS. Hence, the question arises, is COLREG still fit for the purpose? In this regard, the IMO has been working in coordination with its member states and volunteer organisations (IGOs and NGOs both) in order to derive potential gaps/themes in COLREG and establish a comprehensive regulatory regime for AS operation. The participating member states and organisation have undertaken thorough analysis on each rule of the COLREG considering various degrees of autonomy and submitted their remarks/comments in the GISIS module. The feedback in this module reveal that COLREG compliance by degree-III and IV will pose serious challenges primarily due to switching over of human role from the navigational bridge to SCC operator console (IMO, 2020a).

The likely difficulties to be faced by remotely controlled AS for complying with COLREG may be evaluated by subjecting it to dense traffic scenario. In such situations, the AS will estimate situational awareness and initiates actions/manoeuvres as deem fit to avoid the risk of collision. Assuming that COLREG extant regulation remain unchanged, the preferred manoeuvres will be initiated by the decision support system duly supervised and approved from the SCC. This situation will only allow the SCC operators to interpret as COLREG cannot be altered to a set of quantitative rules (EMSA, 2020). If not revised or amended, the understanding and interpretation of these rules will depend on the decision support system and associated sensors or the SCC operators. Such dependency may also be affected due to failure or erratic reading of the decision support system due to multi-vessel/obstacle situation and response time from the SCC operator to react to a collision situation. Notably, application of COLREG provisions are situation specific[15] wherein developing a decision support algorithm capable of interpretation of all rules at any given point of time may not be feasible (Blanke et al., 2017). The potential gaps/themes in COLREG with respect to degree-III AS are as brought out in sections 5.1.1 to 5.1.6.

5.2 Role and responsibility of Master

Onboard a manned vessel, the bridge team consisting of the navigational watchkeepers or OOW and the helmsman prepare a passage plan considering vessel's safety and likely weather/sea conditions enroute. The same voyage plan in turn is duly verified and approved by the master. Absence of master as a natural person onboard an AS raises uncertainties whether the liabilities will be shouldered by the ship owner/charterer or the SCC operator (Burmeister et al., 2015). The MUNIN and AAWA projects both speculate that the SCC operator will take the relative role & responsibility of master as they will monitor the AS operation, supervise it and take navigational decisions. However, the legal definition of master falls under the ambit of both the international conventions and domestic laws of port state and flag states which extends beyond the navigation and safety of ship. The traditional role and responsibility of a ship master may not be applicable to AS and the SCC operator may not be fully responsible as a traditional ship master (Carey, 2017). In real time situations, the SCC operators may not be able to meet all the obligations supposed to be undertaken by a master of conventional ship.

As per article 94 (b) of UNCLOS, the master of a vessel possesses full charge and in command of the vessel. The master and crew of a vessel needs to have adequate qualification in order to discharge their duties effectively and ensure safety of the

[15] Discussed in chapter-3 ibid

vessel. Besides, article 97 of UNLCOS brings out the disciplinary responsibility of ship master in case of incident of collision or a vessel meeting with some navigational accident. The master also has the onus to report any case of collision and preserve the evidences in the form of charts, log books etc and equipment which may be pertinent during a collision (Cockroft & Lameijer, 2012). Rule-2 of COLREG speaks about the responsibility of a master or crew in case of a close quarter or collision situation. Thus, absence of master or watchkeepers onboard will be chaotic as on-scene evaluation of imminent danger and use of good seamanship practices may create a void in operational decision making. However, argument in favour of the reliability of the decision support system is also observed (Poikonen, 2016). COLREG has been drafted taking into account the maned vessel only to address the core navigational tasks performed by ship crew such as the domain/situation awareness and operational decision-making. These rules have been framed to elaborate a vessel manned with natural persons (human operators) only and the need to take proper and effective collision avoiding action by them (Woerner et al., 2016). In remotely controlled AS, whether SCC operators may be considered as functional equivalent of the vessel crew with same role and responsibility as the vessel crew is assigned with is a matter of concern. Although few of the ongoing projects like AWWA claims that the shore operators with updated training regime may act as functional equivalent of the onboard crew and fulfil obligations as desired from onboard crew (Poikonen, 2016).

The role and responsibility of master as reviewed in the RSE, it is essential to clarify who will act as master when there will be no natural person appointed onboard as master and the vessel will be remotely controlled. For example, the comments rendered by China exhibits the role and responsibility of ship master is considered as a policy issues and recommends to bring out concrete discussions to further establish the role and responsibility of master in the purview of AS operation. In the same lines Republic of Korea is also of the opinion that clarity on the meaning of master along with legal responsibilities needs deliberation and to address this issue as a potential gap. On the other hand, Greece has submitted the comments wherein inclusion in the text analogous to *good seamanship* and extension of master's responsibility to other persons has been emphasised (IMO, 2020b).

5.3 Remote operators' responsibility

On the other hand, it is also presumed that the remote operators while monitoring from a SCC may have less sense of a ship meaning to say real-time experience or physical sensory feeling of a ship. Hence, it may be difficult to sense the external environment factors such as sea/weather condition, roll & pitch, vibrations etc and the ship's reaction to it. This may imply that the tacit knowledge and collision avoiding manoeuvres developed by the navigators onboard a manned vessel is also needed to be mastered by the remote operators (Kim & Mallam, 2020).

When the context of COLREG is analysed, it is observed that the role and responsibility of remote operators may be considered as one of the potential gaps as brought out in the RSE. Rule-5 needs clarification as to what describes a proper *look out* and *by sight* and *hearing* in the back ground of AS. Placing a natural person as a ship's look-out and obtaining frequent verbal reports eases the OOW's approach to evaluate the ship's operating domain and avoid the risk of collision. Uncertainties and queries on the ability of remote operator is also observed whether he/she will be able to undertake duties of look-out in heavy weather conditions and the ability to detect small contacts. In this regard, France and Turkey have expressed their concern on the interpretation of Rule-5 as they believe that this rule requires actual human presence onboard ship to carry out duties of *look-out* and further opines to amend or clarify the COLREG provisions. On the contrary, Brazil has submitted its comment on adjustment and inclusion of definitions of *look-out* taking into account the AS operation and does not specify on amending or revising the convention (IMO, 2020b).

5.4 Collision avoidance action

The human centric wordings and terminology used in Rule-8 includes *good seamanship*, *ample time, large enough* and *readily apparent*. These wordings relate to human element wherein a navigator/OOW utilises his/her own experience and judicious reasoning to effectively undertake actions to avoid collision. These terminologies are subjective requirements to be full-filled by a navigator and it is questionable whether AS will satisfy such requirements (Dean p et al., 2019). Hence, it is considered necessary to redefine the terminologies for automated process and decision support although it may be challenging to programme these requirements into the collision detection and avoidance algorithms onboard AS. Besides, the requirement of passing at *safe distance* also needs to be defined for AS because COLREG presently does not prescribe any rules to avoid collision between AS and conventional ship or between two AS (IMO, 2020b).

When two vessels situation (one manned and other unmanned) is considered, the collision avoidance action onboard AS will be undertaken by the collision avoidance system. However, the SCC operator will take over the control and initiate avoiding action if the collision avoidance system breaks down or the operator feels it necessary to take over control (EMSA, 2020). To further illustrate, a vessel gives way to the other vessel on her starboard side as per Rule-15 whereas a vessel crossing a TSS needs to cross it at right angle to the general direction of traffic flow as per Rule-10 . These two rules may be taken as conflictive due to the respective suggestive action which has resulted into incidents. Nonetheless, human operators onboard use their prudence and take effective action while interpreting such COLREG terminology. Hence, the issue meriting attention will be justifying the human centric terminology by the collision avoidance system or SCC operator so that the manned vessel understands action taken by AS and the collision situation is being avoided (Porathe, 2017).

Assuming that the collision avoidance system to be fully reliable and robust, and capable of achieving intended result, functional equivalent of the human centric terminology as described in the COLREG may be introduced or such as quantifying safe passing distance between two AS or AS and manned ship.

5.5 <u>Collision situations</u>

As per Rule-13, vessel overtaking another vessel take collision avoidance actions while the vessel being overtaken maintain her course and speed.[16] In such scenario, the COLREG mentions two terminologies such as *assume* and *doubt* in section 13(c)[17] which is specifically mentioned for a natural person present onboard to judge and react to collision situations. With AS, defining these terminologies while overtaking situation, anomalies may be created with regard to automated processes. As this rule speaks about seeing the stern light only and not the side lights while considering the situation as overtaking, AS will not be able to sight visually but with a camera only. Hence, the requirement to include the functional equivalent to seeing the stern light in case of AS may be formulated.

In another collision situation i.e. head-on situation(Rule-14)[18] the potential gap in the functional and performance standards that characterise the term *see* with regard to see the other ahead see the masthead lights of other vessel in line, for the purposes of AS operations. Hence, the term *see* in this Rule (para-b) may be clarified or changed considering the automated process. Similarly, crossing situation (Rule-15) also contains lacunae in terms of fulfilling the obligations of *give-way* vessel or *stand-on* vessel by AS. In multi-obstacle or multi-vessel environment, decisions on whether AS assumes the role of a *give-way* vessel or *stand-on* vessel needs to be deliberated.

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[16] Discussed in chapter 3 ibid
[17] When a vessel is in any *doubt* as to whether she is overtaking another, she shall *assume* that this is the case and act accordingly.
[18] Discussed in chapter 3 ibid

While the collision situation cannot be predicted when a vessel is probably not in sight of one another and assuming that the visibility to be around six nautical miles in night. In such conditions, a power driven vessel of at least 50 metres length will exhibit mast head light with a visibility of six miles and stern light with three miles as per Rule-22. So, it can be inferred that the head-on situation and crossing situation exist if at all the distance between the two vessels is equal to or less than six miles (> 6) because at this distance only the clause of *sight to one another* can be full filled. Similarly, in case of overtaking situation risk of collision is estimated if the distance between the two vessel is equal to or less than three miles (> 3) in order to satisfy the clause of sighting stern light. In the current regime of sea-watchkeeping, thus the CPA and TCPA is calculated by the bridge team if potential risk of collision exist and it depends on own vessel manoeuvrability characteristics as well the other vessel's prospect (He et al., 2017). Given such circumstances, the AS may have constraints in estimating whether risk of collision exist or not.

5.6 Conduct of vessels in restricted visibility

Restricted visibility refers to the visibility of human eye in case of a manned vessel. Therefore, *conduct of vessel in restricted visibility* may not be applicable to the AS due to its enhanced computer vision, high performance sensor suite and trained remote operators. Hence, the concept of AS operating in restricted visibility condition may become redundant and applicability of Rule-19 may not be imposed on AS (Zhou et al., 2020). While considering that two manned vessels are operating in restricted visibility, both vessels act independently to avoid risk of collision as both acts as *give-way* vessels. The independent actions involve alteration of course and cognitive use of *safe speed* by the human operator. However, in case of manned-unmanned or unmanned-unmanned interaction, this clause may not be feasible necessitating clarification for the term *vessels not in sight of one another* mentioned in Rule-19(a) (Porathe, 2019).

Rule-19(d) mentions about detection by radar alone which needs clarity because of the advanced sensors and equipment being installed in AS for the decision making process. Besides, Rule-19(e) brings out the sounding of fog signal by another vessel in close quarter situation and the same is heard forward of her own beam by human operators. Subsequently, adequate collision avoidance action is being initiated by both the vessels. Hence, clarity in this regard may also be brought out considering capability of AS in complying with this part of rule. Rule-33(a) brings out manual sounding which again impose difficulties for an unmanned vessel and it may require necessary amendment. In furtherance, the manoeuvring and sound signals used while transiting through area of restricted visibility as prescribed in Rule-34 may also be considered as a potential gap. It is imperative that concerns from countries like Poland have raised questions on the ability of AS to comply with sections (c) (d) and (e) of this rule. Therefore, clarity may be required considering the ability of the SCC operator to hear and correctly apply the required sound signals.

5.7 Lights, Shapes and Sound signal

AS satisfy the criteria of being a power-driven vessel due to its operational feature such as the fitting/installation of propelling machineries in a similar way that of the conventional manned ship. However, identifying AS in presence of others vessels in vicinity may pose difficulties. Installation of an auxiliary light in addition to the lights to be fitted onboard a power driven vessel may be thought upon and incorporated in COLREG Rule-23 as additional text. Correspondingly, to identify an AS in daytime, hoisting of appropriate shape may also be considered (IMO, 2020b).

Chapter-6: Conclusion and Way ahead

6.1 Interpretation and data findings

This research examined the provisions of COLREG[19] with special emphasis to the AS operations and thereafter established the likely functioning modality of SCC and the remote operators.[20] Critical analysis with respect to AS operation affecting various technical provisions of COLREG was carried out. Review of the entire COLREG on rule by rule basis was undertaken thereby ascertaining potential gaps/themes as brought out in chapter-3 and chapter-5 respectively.

The potential gaps/themes identified during the research essentially includes the interpretation issues of the human centric terminology such as *master or crew thereof*, *ordinary practice of seamen, assume, in doubt etc*. as mentioned in the provisions of COLREG and concurrently, the role of SCC operator whilst dealing with various collision situations remotely. It is derived from the analytical study that, some of the terminology contained within the RoR are human centric and requires further clarification in order to avoid ambiguity. It is further observed that this can be most efficiently be carried out with either correct interpretations by the end user or developing equivalences/amendments taking into account the switched over role of master or crew. However, accurate interpretation may be best suited with human presence onboard only. Hence, equivalences or amendments in respect of the terminology may be considered. Probable grey areas of COLREG with respect to AS operation along with justification are as shown in Figure-14 below:

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[19] Discussed in chapter-3 ibid
[20] Discussed in chapter-4 ibid

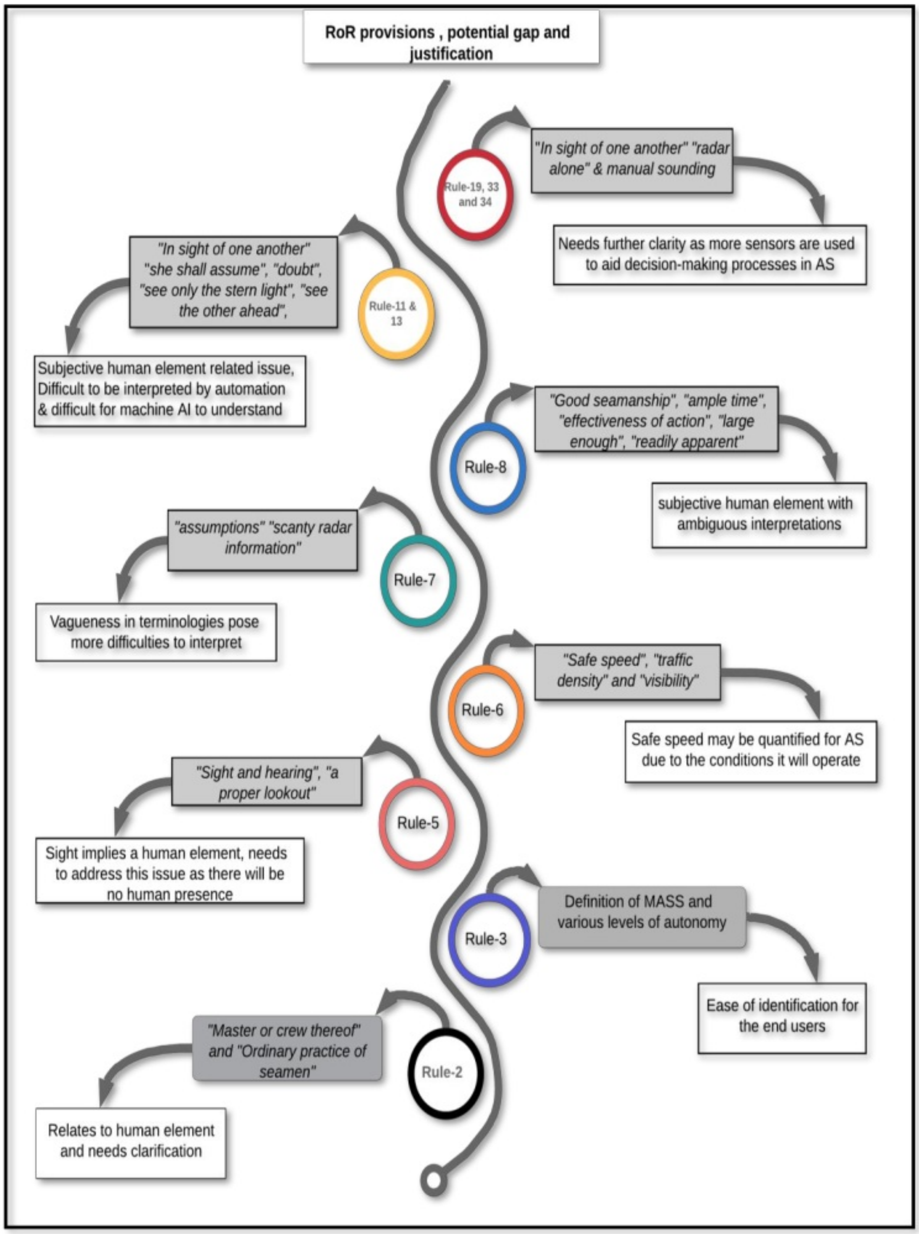

Fig-14: Potential gap analysis of COLREG with respect to AS. Prepared by author with information adopted from IMODOCS/GISIS

Assuming that AS will adhere to all COLREG provisions, the maritime accidents especially collision caused by human error may be avoided. For lawful operations at sea, AS needs to maintain strict adherence to COLREG considering the fact that it will operate in an environment of manned vessels and following the COLREG will be either monitored or controlled by the remote operators. The SCC operator[21] will have a significant role in controlling the ship remotely, but the dependence will be totally on the sensor information and advanced technology being used in the architecture (Naeem et al., 2016).

Inputs gathered from all the sensors installed onboard AS which include engine control, ANS, GPS, LIDAR etc may be transmitted to the SCC in the form of data packets. The data on receipt will be analysed by the remote operators. In case of emergency or multi-obstacle environment, the operators will take over the controls and undertake evasive manoeuvring to avoid the risk of collision. Hence, the reliability of safe AS operation will be completely dependent upon a robust and redundant connectivity set up considering the real time requirements of data transfer and integrity. Therefore, AS and the SCC interdependence and functional relationship will be an essential part while adhering to the COLREG (Chae et al., 2020). Schematic as shown in Figure-15 brings out the functional relationship between AS and SCC:

[21] Discussed in chapter-4 ibid,

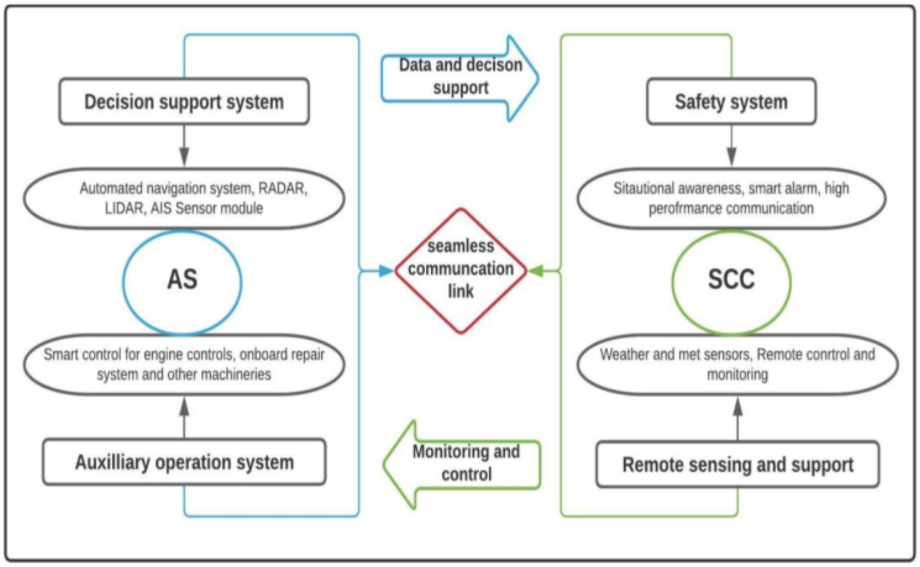

Fig-15 Functional relationship between AS and SCC, Prepared by author with information adopted from Chae et al., 2020.

Although AS will be unmanned (degree-III and IV), the human role cannot be underestimated because the SCC will act as heart of all sensors. Besides, sensor failure or malfunctions, human error can also be possible while managing AS from SCC. The human error issues meriting attention whilst determining the remote operators responsibility in terms of collision aversion is immense. Such trivial issues may include carryover effect[22] due to multiple vessel monitoring at one time, delay is decision making process by the operator due to acclimatization time, lack of situational awareness and not understanding the real-time scenario. For example, a remote operator without sea legs and adequate sea going experience may not able to appreciate sea state-5 and may give hard rudder direction to avoid a close quarter situation is possible. Addressing these issues and reinventing the wheel of AS safety in terms of collision, it may take time for the maritime industry to get familiar (Porathe et al., 2014).

[22] A carryover effect is an effect that carries over from one experimental condition to another. Whenever subjects perform in more than one condition there is a possibility of carryover effects.

In all the four phases of voyage and the probable human interaction[23], the essential factor is the level of understanding of remote operator on the provisions of COLREG may be due to the previous sea experiences and training standards. The expertise and skills of the operator will not only be limited to practical aspect of COLREG but also will envisage the ability to handle delicate system/sensor suite at all situations. The knowledge on the training may also include mitigation of collision risk and developing a mechanism wherein maximum human-machine interface output will be obtained (EMSA, 2020). To justify their assigned roles and responsibilities, the SCC operators need to have background and experience on maritime navigation so that their appreciation to a collision situation or emergency at sea can be effectively handled or otherwise separate training standard may be considered for new entrants with no previous sea going experiences exclusively for AS operations (Dean p et al., 2019).

6.2 <u>Summary</u>

AS is relatively a new concept with no past experiences in the form of case law to establish whether it fits to the frame of COLREG or it warrants some changes to this convention. However, with the development strand[24] and continual research from interested contenders/developers, AS and COLREG functional relationship may be zeroed down. It is highlighted that, the AI technology will govern the AS operation and allow it to comply with the maneuvering rules prescribed in the COLREG, but then strict compliance to all regulations may not be feasible.[25] Concurrently, the issue of developing/programming the collision avoidance mechanism capable of classifying the target contacts as per the requirements of COLREG will be far more challenging especially while detecting small vessels without AIS and floating objects during rough weathers/sea conditions. Another critical area of concern, will be uninterrupted availability of data link between AS and SCC and lack of satellite coverage or blind

[23] Discussed in chapter 4.1.2 ibid
[24] Discussed in chapter 2 ibid
[25] Discussed in chapter 5 ibid

zone in few areas of the world which will eventually affect the SCC operators to make full appraisal of the domain awareness (Soyer et al., 2019).

The transition period of ship design from conventional ships to AS has necessitated revisions/amendments to the IMO instruments to obviate lapses and delay in achieving sustainability in the maritime industry. Amongst all the IMO instruments, COLREG revision/amendments may also be required to establish new standards, role and responsibilities of staff, remote operators, master and bring out clarity in terms of the potential gaps/themes. Revision or amendments to COLREG may only be undertaken in order to satisfy the legal requirements in case of a collision and maritime accident occurred within the scope of COLREG and additionally, to elucidate various responsibilities and requirements under the technical provisions of COLREG (Chae et al., 2020).

Interfacing human skills and machine performance in the form of SCC will take considerable time and efforts. The SCC operator's contribution in ensuring AS safety will be more pronounced because more than one vessel will be controlled at a time and the data inputs from both shore-based and land-based actors[26] will be exhaustive. To make complete appraisal of the collision situation and correlating the information retrieved from the use of AI, the operator will need to have adequate expertise. Notwithstanding, the responsibility of master and crew onboard a conventional ship has been comprehensively brought out, the problem area in this case will be defining master and crew obligation to vessel safety in the context of COLREG. Due to multi-vessel environment and multiple coordination anticipated at one point of time, there will be multi-tasking masters and watchkeepers/crew stationed in SCC. Hence, lines of authority seem blurry and dubious as such changes will be absolutely new to the maritime industry (Wright, 2020).

[26] Discussed in chapter 4.1.3 ibid

In ideal conditions or static/structured environment, AS may operate efficiently, but whenever there will be complex situation like multi-obstacle environment or negotiating a strait with dense traffic, predicting the performance and behavior of decision support system is difficult. In terms of COLREG compliance, it is believed that the decision support system will continuously sense the contacts around the ship's operating domain and initiate best possible collision avoiding action for the AS. In a mixed environment, the target vessel not adhering to COLREG is probable, but AS being compliant to COLREG is highly likely at all times due to the in-situ programming. To this effect, AS may be able to establish CPA for targets operating in vicinity whereas non-compliance from the target will create unwarranted collision situation (Utne et al., 2020). Thus, the remote operator will take immediate control and execute safe manoeuvre. To tackle such critical collision situation, the most significant factor will be availability of communication data link and redundancy so that the situation is well read by the remote operators and react accordingly. However, minute discrepancy of data transfer which may be attributable to communication link failure or sensor malfunctioning from AS to SCC and vice-versa will jeopardize the safety of ship and increase the collision risk.

To conclude, it is important to note that, competence in simultaneous decision making is the core element of COLREG practices by the navigators. Hence, it is paramount that accurate decision is being taken rather deliberating the place of decision. In case of AS operation also, the decisions will be real-time and not pre-programmed. Onboard a conventional ship, the OOW/navigator takes immediate decision from the ship's bridge whereas the SCC operator will take decisions from the SCC corroborating the sensor inputs. The difference here will be the place of decision only. With passage of time and further development on the sensors/equipment suite, training of SCC operators and requisite amendment/revision to the COLREG may bring in synergy in safe AS operations.

6.3 Recommendations

Recommendations on the interpretation and findings of this research revealed several shortcomings and grey areas. Comprehensive and holistic approach to collision avoidance considering the remote controlled AS may include following points:

- Active involvement of all IMO member states and maritime partners to further augment the research efforts on establishing potential gaps/themes analysis and provide value addition.

- Revision/amendment to the COLREG instrument in order incorporate the prerequisites of AS in relation to the human centric terminology and various collision situations. For example defining MASS, role of master and crew taking into account situations where there are no humans as seafarers onboard (Deg-III and IV). Due consideration to the concepts such as inclusion of one additional light with special characteristics or unique sound signal with special characteristics to identify AS in dense traffic area may be given.

- Further enhancing the capacity building amongst the technical giants from the interested member states to develop state-of-art sensors/equipment to be installed onboard AS and the SCC which may include the ANS, decision support system. collision avoidance algorithm etc. In furtherance, tests and trials of these systems may be undertaken at different geographical locations onboard manned vessel simulating various collision situations so that actual response/constraints may be obtained.

- Establish a full-proof communication construct with adequate redundancy and back up in order to facilitate 24x7 communication between AS-AS, AS-SCC, SCC-AS and amongst the designated nodes of shore-based/land-based operators.

- Positioning of experienced navigators/seafarers as the SCC operators and the seafarers may comprise from both deck and technical side. Design of SCC operator console or control room may be planned akin to the real-time bridge architecture. Such design features in SCC simulating the actual sea/weather condition may provide the operator an upper hand in determining quick actions to avoid collision.

- Promulgation of separate timing for AS operations while entering/leaving harbour. Similarly, establishing separate traffic lanes while negotiating in TSS or SLOC may reduce the risk of collision.

- Formulation of safety zone around the operational domain of AS within radius of several miles to ensure minimum CPA is maintained at all times. This in turn will allow the AS and the target vessels in vicinity to appreciate TCPA properly and initiate prompt manoeuvres/actions.

- Validation and exchange of voyage plans with other vessel operators to acquaint each other with their respective planned action akin to the EU projects such as MONALISA and ACCSEAS. Such route exchange programme will reveal the planned action of AS to other merchant fleet.

6.4 Scope for further research

This research keeps various ends of AS-SCC functioning open as it may be a vast area to be explored. It would be interesting to conduct future research by experimenting at various SCC set up at different locations and simulating the collision situations with different traffic density and geographical features. In addition, further research efforts could also aim at analysing the switched-over role of master/crew from a conventional ship to SCC supervisor/operator in AS and thereby deriving the contrast in functioning at two different places with different modus operandi and same objective to avoid the risk of collision. Area of interest as part of further scope may also include how can we expect to produce experienced navigators in the future if AS becomes prevalent.

AS holds great promises for the future of shipping, not least in terms of promoting greater safety at sea. The maritime industry should give careful attention to ensuring that every aspect pertaining to safety and order at sea, such as COLREG, is considered carefully, meticulously and systematically.

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