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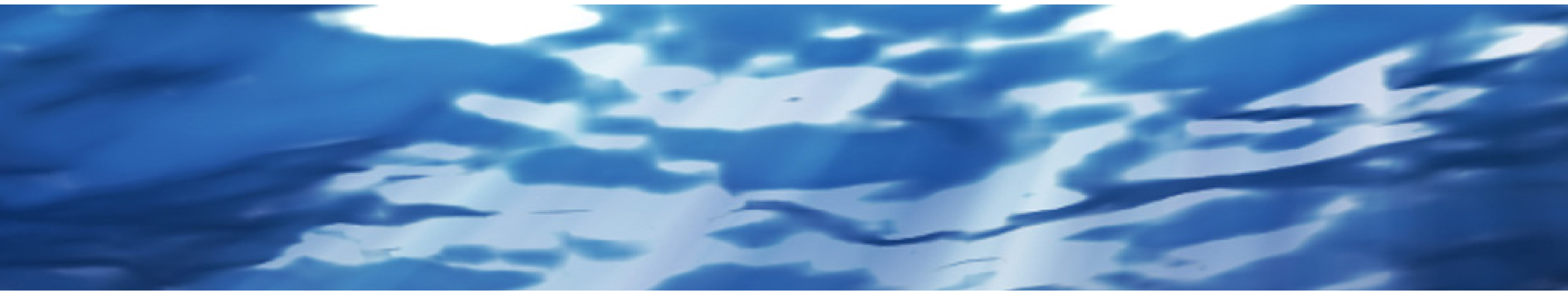
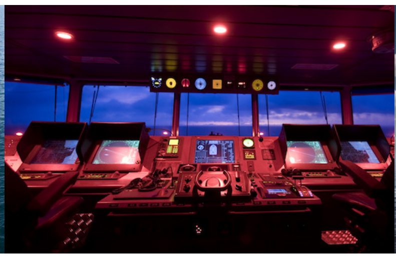
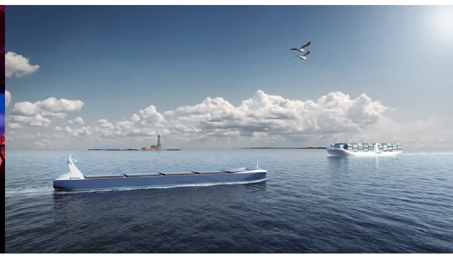


LIGHTHOUSE REPORTS

Gaps in Regulations, Pedagogic Needs and Human/ Automation Interactions in the Shipping Industry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Gaps in Regulations, Pedagogic Needs and Human/Automation Interactions in the Shipping Industry

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Summary

The evolution of the shipping industry toward autonomous vessels has now appeared over the horizon. The rapid push towards the development of smart ships and autonomous vessels has created challenges for many sector stakeholders. Most of the current research efforts have addressed many of the technological challenges such as big data, development and implementation of automated systems and the relocation of personnel from the vessel to shoreside operations centers. However, this evolution has largely ignored the social aspect of this complex sociotechnical system, namely the human element. The scope of this work examines the knowledge gaps in two key areas: the regulatory and pedagogical domains. The report proposes where to focus research activities in order to inform best how decisionmakers and practitioners will enter into this new era of maritime transportation.

The conclusions from this report suggest a development of the existing IMO rules and regulations redefining the Captain's (and other stakeholders) responsibilities in the future. This will be challenging and requires new approaches to regulatory development and standardization across international and national authorities. During this transition period novel ways to manage disruptive technologies must be found and will need to include the end-users of this emerging complex socio-technical system. Further, the basic core competencies will be, to some extent, still valid but competencies, particular non-technical skills, will need to be identified and integrated into recruitment into the vocational academies, and continuing professional education needs.

Sammanfattning

Framtidens "smarta" sjöfart har dykt upp vid horisonten. Den snabba utvecklingen av smarta och autonoma fartyg har skapat utmaningar inom många delar av branschen. Många av de nuvarande forskningsinsatserna har valt att fokusera på många av de tekniska utmaningarna så som "big data", utveckling och implementering av automatiserade system och omlokalisering av personal från fartyg till landbaserade operatörscentraler. Denna utveckling har emellertid i stor utsträckning ignorerat den sociala aspekten av detta komplexa sociotekniska system, nämligen den mänskliga faktorn. Syftet med detta arbete har därför varit att undersöka kunskapsbristerna och framtida forskningsbehov inom två nyckelområden; regelutveckling och pedagogik. Denna rapport föreslår var man ska fokusera forskningsaktiviteter inom dessa områden för att bäst kunna informera beslutsfattare och förbereda de framtida operatörerna som kommer att ingå i denna nya era med sjötransport.

Slutsatserna i denna rapport föreslår en utveckling av befintliga IMO regler och förordningar som omdefinierar kaptenens (och andra intressenters) framtida roll och ansvar. Detta är en utmaning som kommer att kräva nya metoder för att utveckla regelverk och en samsyn mellan internationella och nationella myndigheter. Under denna övergångsperiod behöver det också, för att hantera de omvälvande teknologier som introduceras, utvecklas nya strategier som tydligt inkluderar slutanvändarna i detta framväxande komplexa socio-tekniska system. Vidare är grundläggande nautiska kärnkompetenser fortfarande i viss mån giltiga men kompetenser, speciellt icke-tekniska sådana, behöver identifieras och integreras som en del i högskolorna utbildningar och i den framtida fortbildningen för yrkesverksamma.

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1 INTRODUCTION

The issues of digitalization and automation within the shipping industry have gathered a lot of attention. The need for continued research of these concepts is driven by several factors such as economic sustainability, opportunities for the exploitation of new technologies, improved safety and efficiency of navigation at sea and reducing the environmental impact from shipping (see for example: Lloyd's Register Foundation (2014); Lloyd's Register Foundation (2016). The future research needs to provide attention to several areas like digitalization and autonomy, the concept of smart vessels and a smart fleet, education and training and regulatory challenges (see Figure 1).

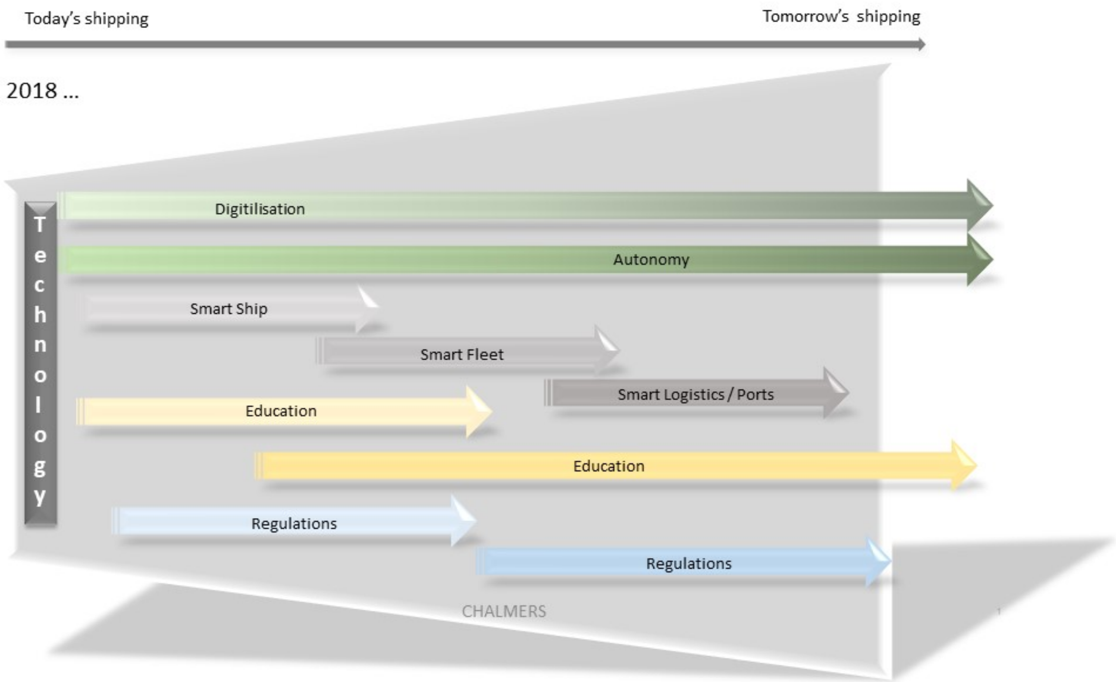

Figure 1. The challenges and research areas in the digitalization of the shipping industry. (attributed to report authors)

The International Maritime Organization (IMO) introduced the implementation of its e-Navigation strategy in 2014 (IMO, 2014). The vision, as defined in MSC 85/26 (annex 20 paragraph 4), was to address navigation systems on board, manage vessel traffic information ashore and create a harmonized communications structure (IMO, n.d.). Several large EU projects have investigated e-Navigation and digitalization from different perspectives and how the introduction of digital tools will affect operators´ performance with regards to safe and efficient navigation of vessels (eg. Sea Traffic Management (STM), MonaLisa, MonaLisa2.0, EfficienSea, EfficienSea II). Other projects resulting from a European research consortium including Chalmers University of Technology have focused on a future autonomous operation of vessels such as the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN, 2016) and the European Defense Agency project Safety and Regulations for European Unmanned Maritime Systems (SARUMS). Following this first discussion on autonomous vessels was the introduction of the concept of smart vessels (Rolls Royce, 2016.). The term ¨smart¨ vessel is broadly used and its definition has yet to be standardized. However, there are common elements consistent within these definitions. For example, a ¨smart¨ vessel can be defined as ¨ a marine asset built with significant degrees of automation in systems, system monitoring and management, and data communications. Automation provides labor-saving methods; human augmentation and error-checking; multiple simultaneous system control and management; and data reporting to enable better and faster decisions. A Smart Ship may have entirely automated, or even autonomous, processes that operate without human intervention¨ (Jorgensen, 2016). Liu and Shang (2017) suggested that a comprehensive definition should include the following four characteristics:

i. *Information fusion*: through the use of sensors, communications, Internet of Things, the Internet and other technical means to establish a ship-wide integrated network system and information intelligence system, so that the ship-to-ship information, data from the ship itself, marine environment, logistics, ports etc. can be fused and integrated.

ii. *Self-assessment and decision-making*: taking the information of the whole ship as the object, using the big data analysis and processing as the means to realize the independent analysis, evaluation, prediction and decision-making optimization ability of the ship.

iii. *Ship-shore integration*: Ship-shore integration: establishment of a ship-shore integrated information platform which can realize ship-shore information interaction, via communication technology.

iv. *Entire lifecycle services*: Through ship-shore integration platform, using onshore resources to monitor, support, manage and control remote vessels, it can provide shipowners with value-added services for assessing vessels or the whole fleet in an entire life-cycle perspective.

As intelligent vessels are developed and progress through the various levels of automation (which are further described in Section 3), each autonomous level will likely demonstrate some or emergence of these characteristics.

At the end of 2017, the China Daily reported that the world´s first smart ship had started its trial voyage (MarineLink, n.d.). The ship was equipped with a marine system with an autonomous learning ability and intelligent operation system. The system is said to analyze real time navigation and meteorological data, pick the best route and alert the crew to hidden dangers in advance. The technical performance of the ships has passed the official assessments from the China Classification Society and Lloyd’s Register of Shipping.

Big Data will change shipping. A press release in June 2018 revealed a cooperation between Stena and Hitachi introducing Artificial Intelligence (AI) into the picture calling it “Cognitive Shipping” Fairplay (n.d.). Yet another press release in August 2018 announced that Samsung Heavy industries was turning to Amazon Web Services, one of the world’s leading cloud provider, to expand their smart shipping capabilities using the breadth and depth of AWS’s services, including machine learning, augmented reality and virtual reality, analytics, databases, compute, and storage (MarineLink, n.d.). August 15th, 2018 YARA announced that, in partnership with the technology company Kongsberg, the Norwegian shipbuilder VARD are to build the first autonomous, electric powered container vessel, Yara Birkeland. The vessel is to be launched in 2020, and gradually move from manned operations to fully autonomous operation by 2022 (YARA, n.d.).

One of the biggest challenges according to stakeholders in the industry is how to manage large data sets and deciding what to do with the data and how operators make sense of it to improve the environmental performance, efficiency and safety. It is strongly believed that over the next 10 to 20 years, the emergence of intelligent/smart ships is going to be the driving force that will determine the competency levels needed from seafarers of tomorrow, the type of ships at sea and ultimately, the future of the shipping industry.

As the industry passes through various levels of smart ships via the integration of digitalized and automated technologies, the challenges of meeting these goals become more obvious. A previous Lighthouse pre-study (Rylander and Man, 2016) examined automation trends in the transportation sector. Most telling were the gaps they identified with respect that technical solutions are not, in all cases, a better replacement of the officer of the watch (see Figure 2).

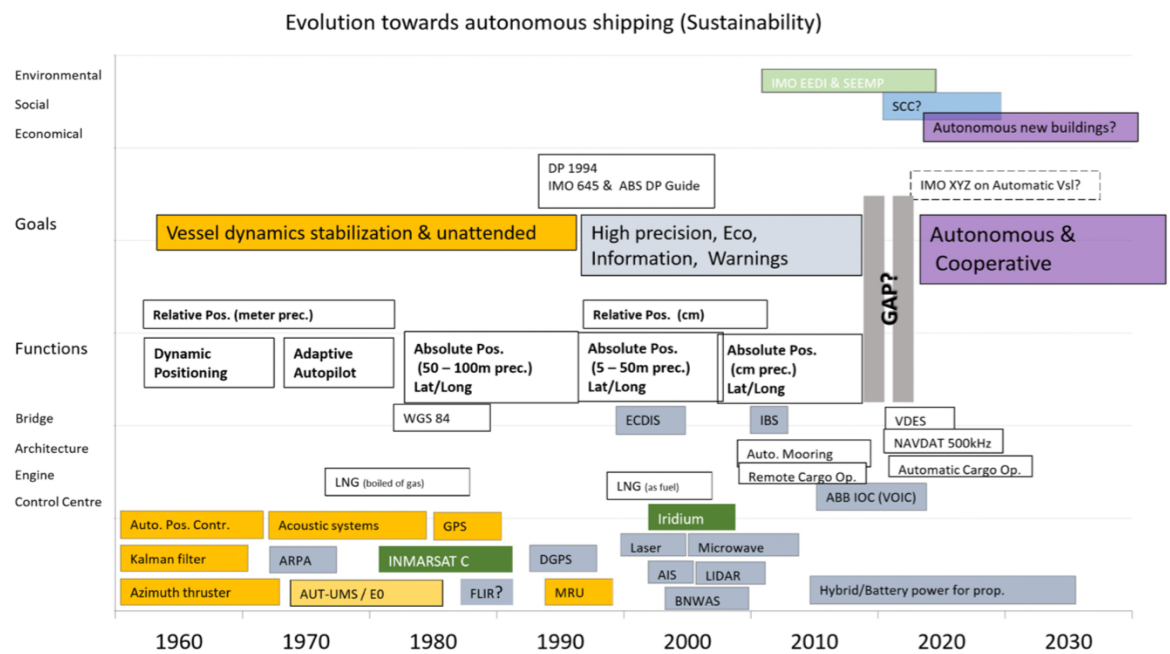

Figure 2 Evolution towards autonomous shipping (Rylander and Man, 2016) (With permission)

Much of the development in autonomous shipping has been done on the technical side. Technologies develop rapidly, some are successful, and some are not. One could enter into an interesting discussion about the gaps in the engineering processes which often exclude the (human) end-user in the development and implementation stage. That is not the focus of this pre-study. However, the most obvious gap is our lack of understanding of the human factor in this complex sociotechnical system where these entities meet (or collide). Human capabilities evolve much slower than the technologies with which they interact. Regulatory oversight and proper education, training and experience are important to make sure technologies and their users are compatible and not set up for failure (i.e. accidents and incidents).

1.1 Objectives

The two main objectives of this pre-study are to identify the human element priorities related to:

- the *Regulatory and Pedagogical gaps* due to the emergence of smart/autonomous vessels.
- the opportunities for both basic and applied research in this era of the smart/autonomous vessels.

2 Background

In the middle of the eighteenth century, the first industrial revolution (IR) took off. The invention of the steam engine started the development of industries, leading to a transition from a farming feudal society to manufacturing industries (Xu, 2018; Prisecaru, 2016). This was followed by the second and third industrial revolution, moving society from a physical labour force into mental efforts (Prisecaru, 2016). These phases of industrial development all created major societal changes and opportunities, which have made major impacts on how we work and live (Schwab, 2017). Partly overlapping the technical advancements made during the 3rd IR, we now are facing the challenges in the 4th IR. It is argued that this revolution is different from the previous ones due to "…emerging technologies and broad-based innovation (that) are diffusing much faster and more widely than in previous ones…" and is different in scale, scope and complexity characterized by a fusion of technologies" (Schwab, 2017).

The shipping industry is traditional and conservative with a slow-moving regulatory body acting in a reactive manner often driven by major shipping catastrophes (Veiga, 2002). However, the 4th IR does not exclude the shipping industry which now is facing a development towards smart and highly automated vessels driven by rapid technology development. The aim of this evolution is a safer and more efficient shipping industry (Xu, 2018; Kobylinski, 2016). The development towards a highly automated operation and monitoring of vessels creates a wide range of challenges (e.g. technological, operational and monitoring of vessels, cyber security, regulatory and legal challenges) (Xu, 2018). This transition will require a development and novel thinking in various areas with a development partly overlapping (Figure 3).

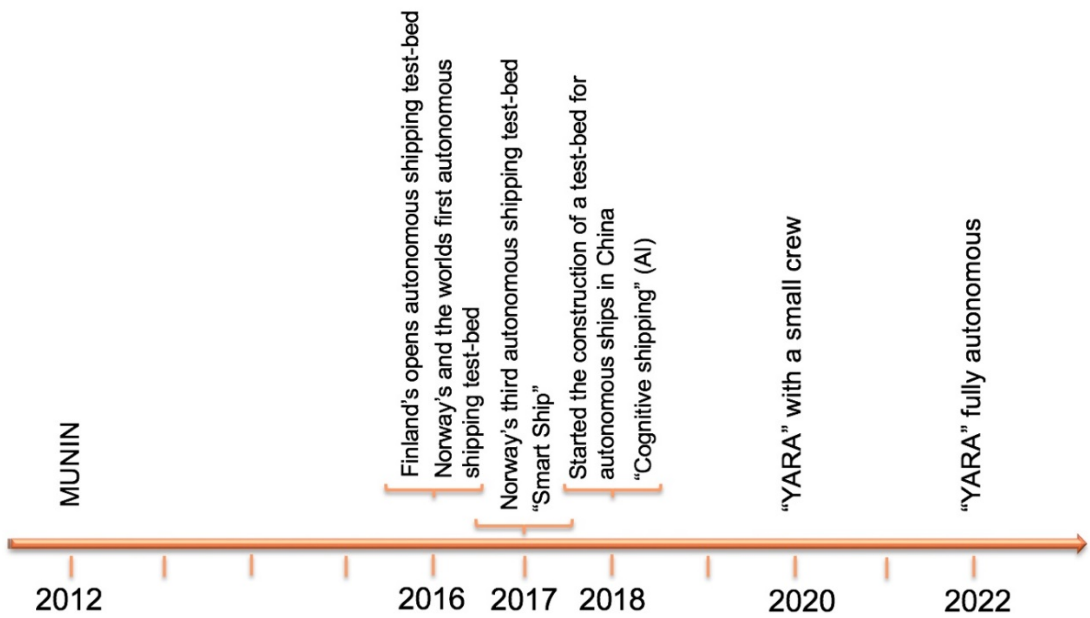

Figure 3. Chronology of the development of autonomous vessels

Brainbridge's "Ironies of Automation" is still cited in scientific circles and discusses the impacts of automation (Bainbridge, 1983). Her concluding sentence in this article "...the irony that one is not by automating necessarily removing the difficulties, and also the possibility that resolving them will require even greater technological ingenuity than does classic automation..." is more valid than ever. When reading industry's response to the challenges ahead created by this digital age, quotations like "redefining shipping" and "transition" become more common (AAWA, n.d.; Rolls Royce, 2016). Areas of discussions are technology, cyber security, regulations and legal challenges together with operation and management of a future fleet port development and logistic (Lloyd´s Register, 2017).

The shipping industry has been subjected to of technical changes for several decades (Lützhöft, 2004; Bloor *et al.*, 2000; Höivold, 1984). The technological developments and its implications on crew performance that the shipping industry has been subjected too and its implications on crew performance is well researched (Lützhöft, 2004; Lundh *et al.* 2016; Conceição *et al.*, 2017). Among the results are evidence of a change in task performance (e.g. new tasks to perform, traditional tasks performed in different ways and a demand for a different vocational skill sets and knowledge). The introduction of new navigational tools on ship bridges is often used as an example to illustrate this development (Lützhöft, 2004; Conceição et.al. 2017). Figure 4 depicts how the number of navigational aids has increased over the years (Conceição et.al. 2017). The purpose for this development has been to improve safety and efficiency, but research has suggested that these technologies can be both counterproductive and ineffective (Lützhöft, 2004).

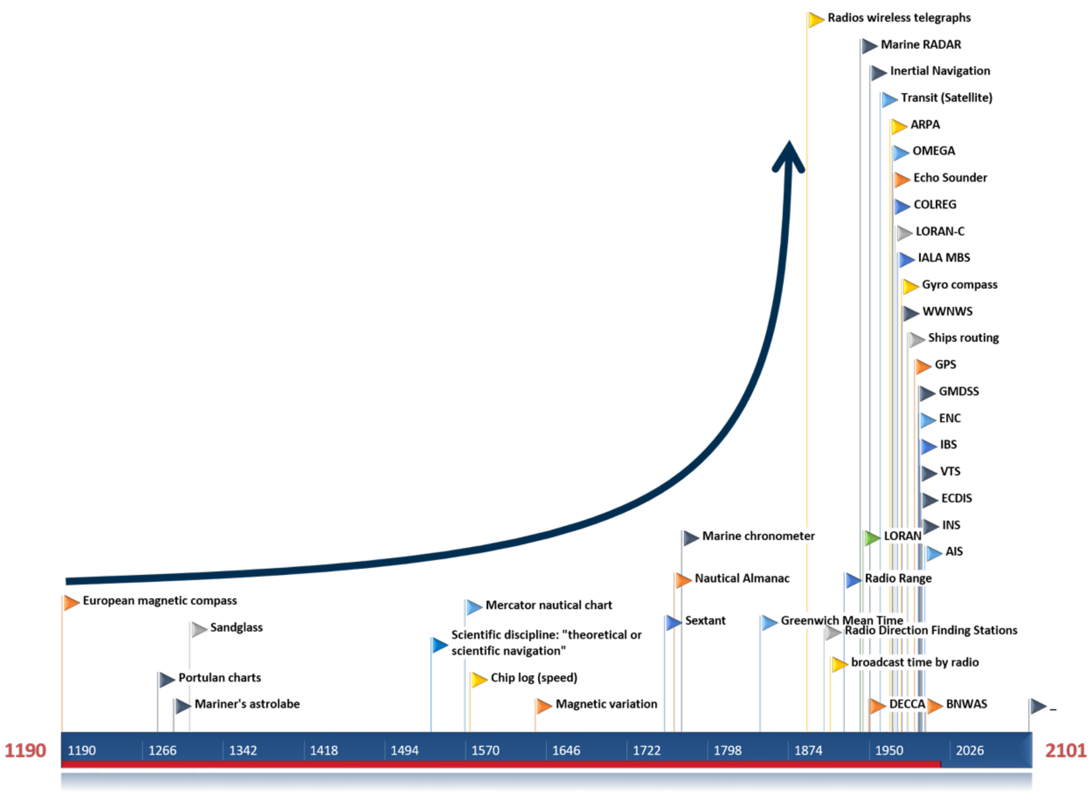

Figure 4. The development of navigational aids (Conceição et.al. 2017) (With permission)

Recently completed and ongoing EU funded research are trying to understand how the introduction of digital tools affects the operators´ performance their relationship to safety and efficiency in the operation of vessels (MonaLisa2.0; Sea Traffic Management (STM); EfficienSea and EfficienSea II). STM aims at "taking maritime transport into the digital age" (STM, n.d.). It focuses on creating a safer, more efficient and environmentally friendly maritime sector. The goals for full deployment of STM resources by the year 2030 is a 50% reduction of accidents, a 10% reduction in voyage costs and 30% reduction in waiting time for berthing, 7% lower fuel consumption and 7% lower greenhouse gas emissions compared to 2015 values.

In 2012 the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) started (MUNIN, n.d.). MUNIN was a part of the 7th framework EU-projects and the idea behind it was to develop and verify a concept for an autonomous ship, which is defined as a vessel primarily guided by automated on-board decision systems but controlled by a remote operator in a shore side control station. The European Defense Agency project Safety and Regulations for European Unmanned Maritime Systems (SARUMS), focused on legal and liability aspects (SARUM, n.d.).

3 State of the art of autonomous shipping

The shipping industry has been subjected to disruptive technology development changing sometimes the whole industry and often affecting the crew and their performance. The technological developments have implied changes in task performance, by adding new tasks and changing existing ones. It has also implied a reduction in the number of crew members on board (Bloor, 2000; Hansson, 1996; Mårtensson, 2006). The first disruptive milestone happened in April 26 1956, when the first container vessel, SS Ideal-X did her maiden voyage which came to be the start of "Intermodalism" and served as the first example of disruptive technology changing the shipping industry. The International Organization for Standardization (ISO) set standard sizes for all containers in 1961 and the ISO standards for containers were published between 1968 and 1970 by the International Maritime Organization. Now the industry is moving into the digital age in the 4th Industrial Revolution (IR) facing a development towards smart and highly automated vessels driven by rapid technological developments. A fully autonomous electric powered container vessel can be a reality in 4 years (YARA, 2018). The transition into highly and fully autonomous vessels will likely change the seafarer as we now know them. The traditional core knowledge described in the STCW Convention will still, to some extent, be valid for the future operators but the question is what else do they need to know and what skill sets do they need to have?

3.1 MASS and Autonomy

Maritime Autonomous Surface Ships (MASS) defines a ship that to varying degrees of autonomy can act independently from human interaction (IMO, 2018). The IMO identified the challenges of autonomous vessels and what issues have to be addressed to embrace the evolution that clearly the shipping and other stakeholders will have to embrace. To clarify, for the purposes of this pre-study the following definitions will be used (Norwegian Forum for Autonomous Ships, 2017):

Automation: The processes, often computerized, that implement a specific and predefined method to execute certain operations without a human controlling it.
Automatic: The system has automation functions that can complete certain operations without human control.
Automatic bridge: Automatic bridge, with crew always on the bridge.
Automatic ship: Ship is supervised by SCC and executes automatic functions.
Autonomy: The system has control functions that can use different options to solve selected classes of problems.
Autonomous ship: Ship with some form of autonomy.

The levels of autonomy are non-hierarchal and are defined as:

- Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated.

- Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location, but seafarers are on board.

- Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.

- Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself. (IMO, 2018).

This pre-study will identify current provisions in an agreed list of IMO instruments and assess how they may or may not be applicable to ships with varying degrees of autonomy and/or whether they may preclude MASS operations¨ and ¨an analysis will be conducted to determine the most appropriate way of addressing MASS operations, taking into account, *inter alia*, the human element, technology and operational factors¨ (IMO 2018).

The list of rules and regulations to be addressed in the MSC's scoping exercise for MASS includes:

- safety (SOLAS)
- collision regulations (COLREG)
- loading and stability (Load Lines)
- training of seafarers and fishers (STCW, STCW-F)
- search and rescue (SAR)
- tonnage measurement (Tonnage Convention)
- special trade passenger ship instruments (SPACE STP, STP)

In this report we examine the human factors elements relevant to SOLAS, COLREG and STCW.

Various organizations have attempted to define the levels of automation within the shipping industry. While classification and description vary, all describe levels which reduce, restrict or eliminate the role of the human operator in the decision-making process (refer to Table 1).

Table 1. Example of levels of automation (Adapted from Lloyd´s, 2017b; HSBA Hamburg School of Business Administration, 2018)

Level of automation			
AL 0	Manual – No autonomous function	All action and decision-making performed manually.	Human controls all actions.
AL 1	On-ship decision support	All actions taken by human Operator, but	Data is provided by systems on board.

		decision support tool can present options.	
AL 2	On and off-ship decision support	All actions taken by human Operator, but decision support can present options.	Data may be provided by systems on or off-board.
AL 3	"Active" human in the loop	Decision and actions with human supervision.	Data may be provided by systems on or off-board.
AL4	Human in the loop – operator/supervisory	Decisions and actions are performed autonomously with human supervision.	At high impact decisions human Operators
AL 5	Fully autonomous (but with rarely supervised operation)	Rarely supervised operation.	Decisions are entirely made and actioned by the system.
AL 6	Fully autonomous	Unsupervised operation.	Decisions entirely made and actioned by the system during the mission.

Certain shipping operations are more suitable for high levels of automation and autonomy. For example, it would be highly unlikely that the Cruise Industry will go to the highest levels of automation due to passenger safety. Paradoxically, the offshore oil and gas (a safety critical industry) will likely be one of the first to go fully autonomous. The journey through the levels of automation will be dynamic but not coordinated, particularly in the short-term.

Further to the definition of levels of autonomy, the Norwegian Forum for Autonomous Ships (2017) provide some nomenclature to describe better the characteristics of these autonomous merchant ships and expand upon the general terms suggested by the MASS report. These different terms will assist in developing operational procedures and future legislation. For consistency purposes, the terms and definitions are cited *verbatim*:

Autonomy Assisted Bridge (AAB) /Continuously manned bridge: The ship bridge is always manned and the crew can immediately intervene in ongoing functions. This will not generally need any special regulatory measures except perhaps performance standards for new functions on the bridge.

Periodically Unmanned Bridge (PUB): The ship can operate without crew on the bridge for limited periods, e.g. in open sea and good weather. Crew is on board ship and can be called to the bridge in case of problems.

Periodically Unmanned Ship (PUS): The ship operates without bridge crew on board for extended periods, e.g. during deep-sea passage. A boarding team enters or an escort boat arrives to control the ship, e.g. through the port approach phase. For regulatory purposes, this would probably be the same as CUS (*See next*).

Continuously Unmanned Ship (CUS): The ship is designed for unmanned operation of the bridge at all times, except perhaps during special emergencies. This implies that there is no one on the ship that is authorized to take control of the bridge, otherwise, the ship would be classified as PUB. There may still be persons on the ship, e.g. passenger or maintenance crew.

4 Regulatory research

One of biggest challenges the industry is going to face is changes and/or additions to rules and regulations governing shipping. Both the International Maritime Organization (IMO) and national maritime authorities will be required to make changes to accommodate the expected changes in training, ship design, safety to name a few.

4.1 Role of International Maritime Organization

The IMO is the United Nations agency responsible for developing and adopting measures to improve the safety and security of international shipping and to prevent pollution from ships. When first formed, technologies and work practices were relatively easily defined, hence making the definition, and adoption of rules to govern a safe and efficient shipping industry (and related activities) relatively straight forward. In this respect, the IMO adopted a rather prescriptive regulatory approach. However, technologies have rapidly proliferated and challenge how humans (and other elements of a highly complex socio-technical system) are supposed to interact with these disruptive technologies. Often, as a result of an accident or incident, amendments to existing regulations and requirements are proposed. These often try to address the causes of the incident (e.g. loss of situation awareness, workload implications or the use of unruly technologies). The blame is often directed at the ¨human element¨ and ignores (or superficially addresses) the root cause(s), often due to poor work organization, training, lack of information transparency or other systemic issues.

4.2 Developing regulatory frameworks

There are three basic approaches to developing rules and regulations (IAEA, 2013):

- Prescriptive
- Performance based
- Goal setting

Traditionally, shipping regulations have been *prescriptive* in nature with the regulating bodies prescribing the acceptance and competency criteria. This approach typically discounts the impacts of changing technologies and technology implementation. A ¨*performance-based*¨ regulatory approach focuses on desired, measurable outcomes; defined results without specific direction regarding how those results are to be obtained.

The most appropriate approach to the regulatory process, that addresses issues of new and/or disruptive technologies, is goal-based (see Figure 5; Bergström, 2018). While the COLREGs and other regulations have not been subject to really major or comprehensive reviews, the vast technological development in recent years and the prospects of MASS becoming a reality will require an IMO regulatory review to ensure that revised and new rules and regulations are fit for purpose. Research-based evidence needs to complement a goal-based approach towards policy and regulation development. Furthermore, the responsibility for demonstrating compliance is given to the operator (company). Thus, the regulator sets operational outcomes and the operator must show how these goals are achieved.

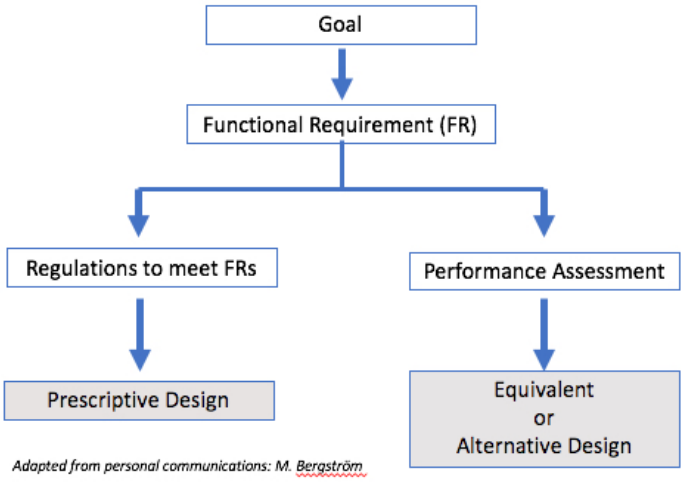

Figure 5. How regulatory expectations are achieved

4.3 Lessons Learned from the Formalization and Adoption of the Polar Code (ABS, 2016)

The IMO formally adopted the safety and environmental parts of the Polar Code at its Maritime Safety Committee (MSC) and Marine Environmental Protection Committee (MEPC) meetings in London, UK (21/11/2014 and 15/ 05/ 2015, respectively). Lead by the IMO, this was the result of an international effort led by the IMO to promote safety and reduce the potential for environmental pollution from the increasing number of vessels operating in Arctic and Antarctic waters. The Polar Code includes many new regulations including elements of ship design, construction, onboard equipment and machinery, operational procedures, training standards, and pollution prevention. In order to achieve this, the IMO employed a goal-based standards framework in its approach to regulatory development. This approach ¨comprised of at least one goal, functional requirements associated with that goal, and verification of conformity that rules/regulations meet the functional requirements including the goals¨ (ABS, 2016). Each part of the Polar Code starts with a goal (outcome) and points to functional requirements which are related to the hazards identified through a comprehensive risk assessment. Then a compliance strategy has to be formulated, often from exiting prescriptive regulations or reference to pertinent international standards. Perhaps this is an approach that should be adopted as stakeholders explore the automation/autonomy needs.

4.4 New regulations or amendments?

Carey (2017) provides a detailed analysis of the legal and regulatory issues surrounding moves towards automation and autonomous shipping. The author contends that international law may prove to be flexible enough to address looming

disruptive technologies and a likely removal of the operator off the vessel. However, these may still require changes to the current regulatory situation.
Some of the significant legal and regulatory issues include (Carey, 2017):

- Lack of human presence on board, particularly the ship's master, may render proposed autonomous vessels unseaworthy (i.e. Hague and Hague Visby Rules) and void marine insurance policies. The proponents of the autonomous ship scheme envisage that the shore-based operator will provide the functional equivalent for the role of the master and chief engineer. In the longer term, it is possible that the ship will become self-learning and operated by artificial intelligence, removing the human element altogether.
- Ability to comply with COLREGs. As the COLREGs currently stand, the autonomous ship will not comply. However, this challenge can be overcome, as evidenced by regular updates by the IMO. More importantly, maybe rules suited specifically for autonomous vessels should be considered.
- Traditional role of the shipmaster will disappear, and the associated legal duties and liabilities will disperse to other actors, likely those that are remotely based on shore.
- Pilotage laws can be port specific and some autonomous vessels will be excluded from berthing

4.5 Specific Regulatory Challenges for Unmanned Ships

It is clear that the industry will face significant challenges in its move toward full autonomy. These challenges are not just technology, digitalization and autonomation in nature, but include:

- Ship Design
- Port Design
- Operator Training
- Safety at Sea
- Developing a Shore Centre concept

Table 2. List of Regulations and Rules that will have to be evolved or replaced (Bergström, 2018)

Source	Regulation/Rule	Description
COLREGS	Rule 5	A ship must always maintain a proper lookout by sight and hearing as well as by all available means appropriated I the prevailing circumstances and

		conditions to make a full appraisal of the situation and the risk of collision
STCW	Ch. VIII, Reg VIII/2	Officers in charge of the navigational watch must be physically present on the navigating bridge or in a directly associated location at all time
SOLAS	Reg. 24	The on-board track control system (autopilot) must enable an immediate switch from automatic to manual control
SOLAS	Reg. 33	The master of a ship is required to assist persons in distress at sea

In Table 2, the following subcommittees have been identified and will likely take responsibility for rules and regulation amendments or substitutions.

- Subcommittee on Navigation, Communications and Search and Rescue (NCSR)
- Subcommittee on Human Element, Training, and Watchkeeping (HTW)
- Subcommittee on Ship Systems and Equipment (SSE)

Table 2 is not exhaustive. For example, environmental and port security regulations may be implicated as vessels become more automated.

5 Pedagocic research

It is important to try and understand the strengths and weaknesses with humans, computer performance and automated processes to optimize their coexistence. This understanding is also important when trying to make qualified estimations of what the future demands on skill set for the seafarers is going to look like. Since the introduction of computers in the late 1970s or early 1980s and the start of the computer revolution our work life has changed (Dorn, 2015). Computer guided production machines made an entrance and devices including computer numerical control (CNC) became common (Dorn, 2015). As the computers became more available and powerful the World Wide Web came to forever change the way we communicate and affected not only the work life but also our social life. These developments initiated a discussion about mass unemployment because of these disruptive technological developments, something that was going to be proved to be wrong. But it did have an impact on the labor market and the necessary skill set. It also created a greater wage gap between workers with and without post-secondary education. However, these apprehensions that failed can be useful lessons learned adding a bit of skepticism into the discussion of the impact on jobs and labor market in the 4th Industrial Revolution. Are we facing a mass unemployment era or will the labor market adjust and create new jobs? We train for the known and educate for the unknown, however the increasingly rapid changes in technology is going to make it hard to keep up with the educational demands.

As discussed earlier, the shipping industry is on the threshold of digitalization which is characterized by rapid technology driven changes which likely is going to change shipping as we know it. However, the core function of shipping is likely to remain a part of the future of shipping, regardless of how it develops (ETF, 2018). The different levels of automation entail different levels of human interference, see Table 1 (Lloyd´s, 2017b). However, "smart" ships will require "smart" crews meaning crews which are trained to manage the changes in technology maintaining a high level of safety, security and performance. The traditional core knowledge will be present, parts may shift ashore, but there will likely be a new focus on managing and monitoring large amounts of data and be able to analyse it. How can Big Data be turned into Small Data? It is not only the process of information that is going to be important, it is also the organization of the crew (on board and ashore) to certify focused and alert crews (HSBA, 2018, ETF, 2018).

However, in line with that core functions of shipping will remain, the core competencies will no doubt to a certain extent also be valid in the future operation of smart and autonomous vessels (VIDEOTEL, 2018). During the transition period towards smart and fully automated vessels, there is a challenge between maintaining the traditional skill set needed to operate older vessels and understanding what skill sets the future operators (onboard and/or ashore) are going to need. IMO through Ashok Mahapatra, Director of Maritime Safety Division, also refers to the need of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers STCW Code to be fulfilled in the digital age (IMO, 2018).

"The skills and competence of seafarers are ensured through the provisions of the 1978 STCW Convention and Code, as amended, which concentrate on the following functions:

- Navigation;
- Controlling the operation of the ship and care for persons on board;
- Cargo handling and stowage;
- Marine engineering;
- Electrical, electronic and control engineering;
- Maintenance and repair; and
- Radiocommunications" (IMO, 2018);

Presently, all Maritime Academies are obliged to fulfil the requirements in STCW Code (IMO, 2011). The requirements in the STCW Code are describing a minimum level of competency. The situation in the shipping industry is however changing fast and the educational requirements described in STCW remain to a large extent traditional. The expected future valid "core knowledge" of navigation and marine engineering in ship's operations, will they in the future be situated on board or in a shore-based control center? The future seafarers will likely need additional skills and the question is what skill set needs to be added? Another question is what new roles or functions not now active in shipping will emerge with changes in the levels of automation.

5.1 Future skill-set for the 4th Industrial Revolution (IR)

The topic of skills necessary in the 4th IR is ongoing and research, in general terms, is trying to understand what future competencies will be necessary (Peters, 2017; Chawis, 2016). The speed and measures of the changes coming in the 4th IR are adding demands to the process of understanding (Xu et al., 2018).
An extensive survey across industries was performed by The World Economic Forum, which aimed at understanding the current and future impact on e.g. skill set in the 4th IR (World Economic Forum, 2016). The result of this survey is summarized in Table 3 and refers to the skill demands anticipated to be necessary in 2020. The results also pointed out what is thought to be a growing skill demand in 2015-2020.

Table 3 Core work-related skills demands in 2020 and predicted changes for 2015-2020 (Adapted from World Economic Forum, 2016)

Core work-related skills	**Scale of skill demands in 2020**	**Core work-related skills**	**Growing skill demand 2015-2020**
Complex problem solving	36 %	Cognitive abilities	52 %
Social skills	19 %	Systems skills	42 %
Process skills	18 %	Complex problem solving	40 %
Systems skills	17 %	Content Skills	40 %
Cognitive abilities	15 %	Process skills	39 %
Resource Management Skills	13 %	Social skills	37 %
Technical Skills	12 %	Resource Management Skills	36 %
Content Skills	10 %	Technical Skills	33 %
Physical Abilities	4 %	Physical Abilities	31 %

The highest ranked core competence (36 %) was complex problem solving skills together with social, process and system skills which all are ranked higher than narrow technical skills. Content skills, cognitive abilities, process skills and critical thinking are thought to be a growing part of the core skills. Schwab (2017) also argues that there are occupations that are most and least prone to automation listing what occupations likely to be “replaced” by automation. Of interest from a shipping perspective, Marine Engineers and Naval Architects rank number 8 on the list for occupations least subjected to changes from the introduction of future automation.

Skills and talent is regarded to be a critical factor in the 4th IR (Schwab, 2017). Blinder (2008) studied similar questions in the 3rd IR and argued that “the nature of education should evolve along with the nature of skills demanded of the workforce” and that “education should be designed with the nature of future jobs in mind”. He continues by arguing that the future development of skill sets needs to emphasize attributes and skills humans are better positioned for than machines, like communication and interpersonal skills, problem solving, learning by doing and experimentation which likely now is more valid than ever.

As of today, humans do have some advantages over machines although the technical developments aim at closing this gap (Table 4) (Groover, 2005). Humans will however likely remain better than machines when it comes to areas like problem solving, creativity and interaction with other humans (Dorn, 2015, page 24).

Table 4 Relative strengths of humans compared to relative strengths of machines (adapted from Groover, 2005)

MAN vs MACHINE	
Relative strengths of humans	**Relative strengths of machines**
Sense unexpected stimuli	Perform repetitive tasks consistently
Develop new solutions to problems	Store large amounts of data
Cope with abstract problems	Retrieve data from memory reliability
Adapt to change	Perform multiple tasks at the same time
Generalize from observations	Apply high forces and power
Learn from experience	Perform simple computations quickly
Make difficult decisions based on incomplete data	Make routine decisions quickly

5.2 Seafarer’s future skill-set

There seems to be an agreement within the shipping industry that human factors competencies will be needed for the crews to meet the future demands in the coming digital age. IMO recently recognized and incorporated this into the revised version of the STCW Code, Manilla Amendments (IMO, 2011). Necessary skills and competencies for leadership, teamwork and managerial issues were added and applied for both navigating and engineering officers. KNect365 (2018) asked 9 different domain experts to discuss the skills seafarers are going to need in the future. The result pointed at soft skills like leadership, personalized lifelong training, management but also the technical skills necessary to use the most modern

equipment were mentioned which align with other industries conclusion. Comments were also made about the challenge of training for future needs as we don't really know what it is going to look like.
More research in this field is clearly needed. The discussions made by different stakeholders in the industry point out that there is a gap between today's skill set and what the future seafarer is going to need. The challenge in this is that we are designing for a future we still don't know what it will look like; we only know it is coming and that it with certainty will need a different skill set, shipping no exception (Schwab, 2017; World Economic Forum, 2015). To try and determine necessary competencies has been researched in different areas (Försvarsmakten, 1996). One perspective considered in military research in Sweden is to compare the action and the competencies required for the task (Figure 6). The utilized competence builds on two pillars, represented by the individual and the task.

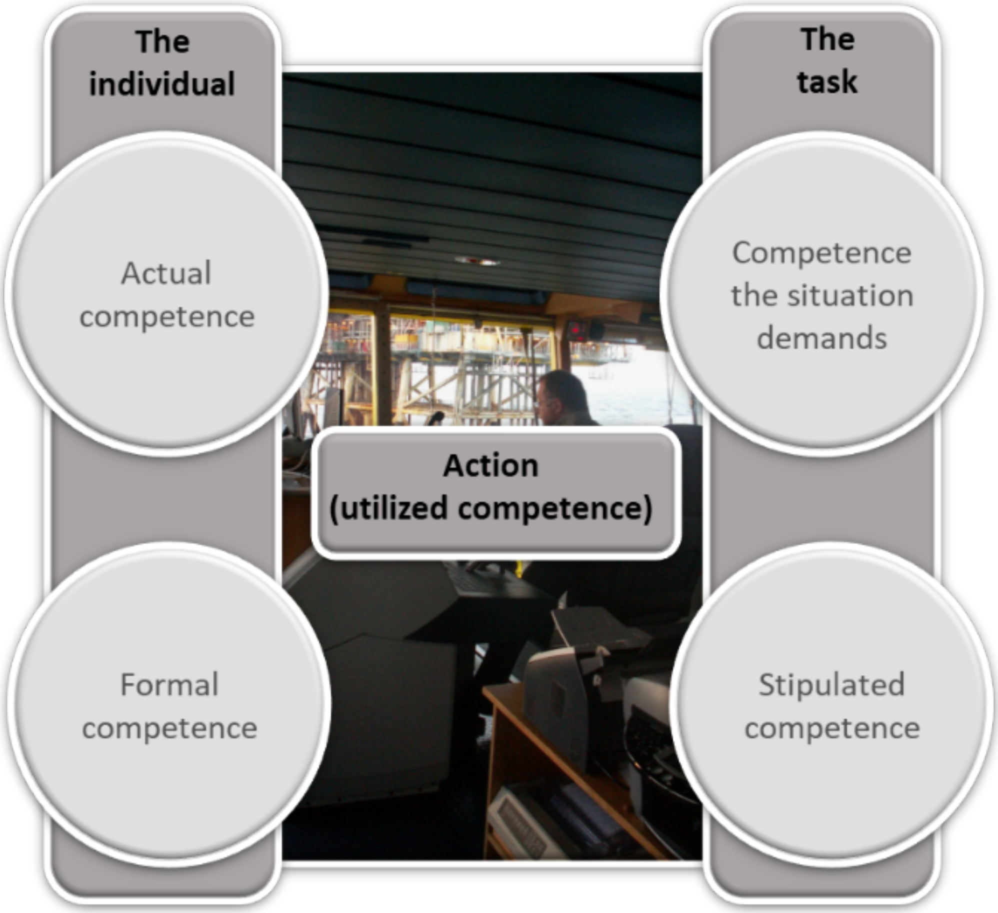

Figure 6. The five dimensions of competence (Adapted from Försvarsmakten, 1996)

Actual competence refers to the individual itself and represent the individuals gathered competence. The formal competence is competence accrued through different educational setups and can be verified by marks, certificates etc. Stipulated competence is the official requirements determining the contents of the education, in shipping represented by STCW Convention.

Rapid changes in technology and systems will likely outpace our understanding of the skills and competencies of tomorrow's maritime professional. Like the aviation and nuclear industries, the world of shipping is evolving into a much more complex and highly organized socio-technical system. Skills and competency directives must become embedded in life-long learning. There will be a need for crystal ball gazing, identifying emerging technologies before they come into practice.
European Transport Workers' Federation (2018) emphasize the importance of a human-centered approach to the digitalization of the shipping industry. They do see a need to maintain certain core competencies but highlight the need of understanding what new skills future seafarers need, to be able to interact with the new system and technology. To achieve this a process of life-long training is necessary. And to ensure the sustainability of the life-long-learning process, cooperation on a European level between the industry, unions, training providers and authorities will be needed.

6 Research challenges and gaps in the regulatory and pedagogical domains

The movement towards fully unmanned, autonomous vessels will create regulatory and training challenges. Most stakeholders have recognized this fact but clearer guidance is necessary to develop systems that are fit for purpose.

IMO rules and regulations will need a complete review. Technology (and hence automation) are evolving very quickly. What are now decision support systems will become decision-making systems. The human factors community recognizes that this might create conflicts with the human operator and could lead to negative operational consequences.

Training of future seafarers will likely evolve in three directions. While the development of technology is moving fast it will take time to phase out older and more conventionally operated vessels. But as the level of automation in general is increasing, retrofitting and technological developments will likely also have an effect on the operation of these older conventional vessels. Shore-based operations will require more competencies. These training directions will not occur consecutively, but in overlapping parallel timelines.

Besides the STCW core skills necessary for a safe and efficient operation of vessels, this skill set will have to be complemented with skills aiming at the management of digital trends and other new near and long-term changes within technology (ETF, 2018). There will also be a need for reorganizing the training. The maritime academies will play an important role and are challenged to understand and keep up with the new technological developments and the associated knowledge requirements.

7 Summary and conclusions of regulatory and pedagogical issues

Overhaul of IMO rules and regulations

- Who carries the Captain's responsibility in the future?
- Do we amend or create new regulations?
- Changing from a prescriptive to a goal-based approach

How are disruptive technologies to be managed?

- New technologies and their automatization must be developed with the end users
- Standardization of design must be a rule

The basic core competencies will, to some extent, be still valid

- Determine what core competences that are valid in the future (all)?
- Finding the right individuals with the necessary core competencies. Are they on board or ashore? Who needs these skills (operating personnel or perhaps the developers)?

Conventionally trained crew

- Short term: What complementary skills are necessary (to manage the retrofitting and update of technology)?
- Long term: How can traditionally educated seafarers be re-skilled?

Future training of crew

- What skill sets are necessary?

The organization of the training

- How should the training be organized?
- Lifelong training, a company responsibility?
- How can new technology be utilized in training purposes?

8 More basic science human factors research opportunities

Other transportation domains have examined the effect of the introduction of automation on human performance. Developing technologies that help operators obtain and maintain situation awareness, provide decision support and help with monitoring tasks have long been in the aviation, nuclear and process engineering domains. More recently these research gaps have been identified in the shipping industry and consequently need to be addressed and solved before, and not after, technology has been put into operations. The introduction of the Electronic Chart Display and Information System (ECDIS) is a perfect example of putting the cart before the horse.

8.1 Human-Machine Interactions

Shipping, logistics and management are going to be performed very differently with the introduction of advanced technologies. Basic research is required to understand use and design, technology and organization, which are essentially about human-technology interactions. It is important to understand the impacts of advanced technologies and probe how digitalization and automation should be designed to not only facilitate information processing (psychology), but also learning and collaborating in their work (sociology) as well as the user-work coupling and development of the global eco-system (ecology). As more automation is designed and introduced, the wide-scope issues established a niche for Human-Computer Interface research, by using shipping as a context, to employ multidisciplinary approaches to understand 1) the way in which technology interacts with us humans and our cognition; 2) their roles in our human social activities; 3) how we are about to proceed by extending our control and shaping the eco-system (Man, 2018).

8.2 Trust in Automation

From a psychosocial perspective, trust can be defined as ¨the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability¨ (Lee and See, 2004). When considering the relationship between humans and technologies, three levels of trust may be defined (Hoff and Bashir, 2015):

- Performance-based trust which is how well an automated system executes a task
- Process-based trust which is based on the operator's understanding of the methods an automated system uses to perform tasks
- Purpose-based trust which is the designer's intended use for an automated system

As the level of automation increases, the trust in the technology to function properly will have to be high (performance-based) in order for the operator to develop a high level of process-based trust. As the operator is likely acting in a supervisory/monitoring capacity, the purpose-based trust must be high. This, unfortunately may be the limiting factor as the designer's intentions (work as imagined) may be different that the operator's (work as done) and unless there is a sufficient amount of transparent information for the operator to obtain and maintain situation awareness, stay in the loop and make critical decisions in a timely manner, unexpected and perhaps catastrophic events will occur. Bainbridge (1983) refers to this as the ironies of automation.

8.3 Shore-Based Control Centre/Remote Operating Settings

If or when unmanned, autonomous vessels become a reality, there will be a slow migration of operators moving from the vessel to the shore side. Both MUNIN (Man et al., 2015) and Rolls Royce (n.d.) have introduced shore-based operations concepts. In both concepts there are technologies which monitor ship systems (i.e. navigation, propulsion, stability, safety, etc.), and provides feedback to a monitoring operator. There are, of course, automated systems (e.g. collision avoidance). In both concepts, the operator monitors several vessels and has the support of a team that can be called upon to assist in decision making if a problem arises. The gap in human factors knowledge are:

- How does the operator obtain and maintain situational awareness?
- How many vessels can an operator monitor safely?
- In an emergency, can the support team assemble quickly and make informed decisions?

From a pedagogical perspective, how should the operator be trained for this position? The operator will need to have the traditional qualifications and certificates, but will require other skill sets. As an analogy, will a competent airplane pilot make a competent air traffic controller and vice versa? From a regulatory perspective, how should the shore center technologies be standardized? For example, all Boeing 737s in service have identical cockpit designs and equipment.

8.4 Instructional and Assistive Technologies

Over the last several decades, approaches to education have evolved considerably and now seem to be technology-driven. IMO has recognized that simulator-based training, for example, is equivalent to some defined shipboard experience for demonstrating competence (STCW, 2010). Simulation, virtual reality (VR) and augmented reality (AR) are commonly used in research and development and allow the end user to assess usability and utility in the design stages.

These technologies can also be used in learning and skill-acquisition. The post-millennial cohort generally are very comfortable with technology. They are early adopters and typically have a steep learning curve because of their lifelong relationship with technology and its hands-on approach to learning (Training, 2018; American Psychological Association, 2010).

These technologies can also be used in an operational setting. AR can support the user's interface with technologies on board. Particularly, if the person is new to a piece of equipment and/or its processes, AR can assist in navigation through the technology, provide decision support and improve response time. There are considerable opportunities for research on the effects of technology on learning.

8.5 Business Models

This is not generally considered to be in the realm of human factors research. However, automation brings the development of smart ships, smart fleets and smart ports. This creates a very complicated socio-technical system. As evidence by the aviation industry, actors must interface, in order to create efficiencies through collaborative decision making, translation/transfer of knowledge and basic information sharing. A good example would be short sea shipping and its intermodal connectivity. A logistically managed movement of goods and reduced port turnaround times will see several economic (i.e. reduced waiting time and efficiency of port infrastructure) and environmental advantages (i.e. slow/green steaming).

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