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Exploring technical and non-technical competencies of navigators for autonomous shipping

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ABSTRACT
The emergence of autonomous ship technologies has attracted a growing body of academic studies, regulatory discussions and exploration endeavours in recent years. With the introduction of new technology comes the need for the seafarers to be trained in its use. The purpose of this paper is 1) to examine the suitability of the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Table A-II/1 competence framework for navigators under Maritime Autonomous Surface Ship (MASS) operations, and 2) to propose future technical and non-technical competencies that will be needed in autonomous shipping era. A mixed method approach was adopted with collection of both quantitative and qualitative data through a survey instrument developed on the basis of the literature and current STCW Table A-II/1, in which the 66 Knowledge, Understanding & Proficiency (KUP) requirements for navigators were converted into measurement items. Statistical analysis of the data has aided in identifying a list of key technical and non-technical competence requirements for the navigators under MASS operations. The results can be used as an input for revision of the STCW competence requirements and to facilitate the preparation and implementation of novel training frameworks for autonomous shipping.

KEYWORDS
Competence; STCW; autonomy; autonomous shipping; seafarers; MASS

1. Introduction

Shipping industry is often recognized as the lifeline of global economy (Stopford 2009). Over 50,000 merchant ships operate globally to keep the flow of international trade and are manned by over 1.5 million seafarers with representation of virtually every nationality on the globe (ICS 2019). Merchant ships are recognized as high-value assets and some of the technologically sophisticated ships can cost up to 200 million USD while carrying a variety of cargo across the destinations that are necessary and vital to markets worldwide (ICS 2019). Any unexpected event or accident during ship operations could result not only in considerable financial consequences to all stakeholders in the supply chain, but also have the potentials to result in casualties, loss of life, and significant environmental, legal and reputational consequences (Kim, Nazir, and Øvergård 2016; Schröder-Hinrichs, Hollnagel, and Baldauf 2012). Naturally to cater for these issues, shipping community has come up with international frameworks and conventions which dictate various aspects of shipping such as design, operations, manning and training. In this regard, the global maritime authority for

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establishing the standards for safety, security and environmental performance of international shipping is the International Maritime Organization (IMO).

Among other considerations, it is important that the ships are operated by well skilled and qualified seafarers. The training requirements of the industry are oriented towards producing seafarers that can not only operate the ships in an efficient manner, but also give considerable regard to environment and safety. The International Convention on Standards of Training, Certification & Watchkeeping for Seafarers (STCW, 1978 as amended) and its associated Code—as the key instrument of IMO, outlines the qualification standards for officers and ratings for merchant ships globally (IMO 2011). While basic STCW certificates are a prerequisite for any seafarer serving onboard ships, the specific training requirements for different levels of responsibility (i.e., management, operational & support) as well as different ship types and departments are also listed in the STCW Code. STCW in its present form, applies a skill-based framework for training of seafarers. Such framework traces its roots in the apprenticeship model where the seafarer needs to demonstrate the Knowledge, Understanding and Proficiency (KUP) of a set of tasks to be deemed competent for a particular rank (Burke and Clott 2016). The convention has been revised after every few years (1995 & 2010) since its inception to be in line with the contemporary needs of the shipping industry. The need for periodic revision of the STCW Convention and its associated Code can be attributed to changing workplace demands and novel competency requirement with the advent of new technology.

Shipping industry at the moment is undergoing through a wave of increased automation and digitalization (Kitada et al. 2018), interest in autonomous and remotely-controlled ships is growing at a rapid speed globally (Mallam, Nazir, and Sharma 2020; Kim and Mallam 2020). The reasons to support the introduction of autonomous ships ranges from economic reasons through increased efficiency to safety considerations (Brandsæter and Knutsen 2018). Porathe, Prison, and Man (2014) outline four major reasons—improved work environment, cost reduction, reduction of emissions and increased safety—as the drive for adopting autonomous ships. The introduction of autonomous ships also has the potential to result in new modes of ship transportation than the ones existing at the moment.

However, with the new technology comes the need for the seafarers to be trained in its use. Therefore, a natural lag towards the new competence requirements and their implementation in the existing regulations for the shipping industry exists. IMO has launched a regulatory scoping exercise for the potential introduction of Maritime Autonomous Surface Ships (MASS) and defined 4 degrees of autonomous ship operations (IMO 2018), as illustrated in the following Figure 1.

In the context of autonomous ships, the skills and competence that are required for the seafarers in charge of navigational watch i.e. the navigators, is not sufficiently investigated. There is a need for

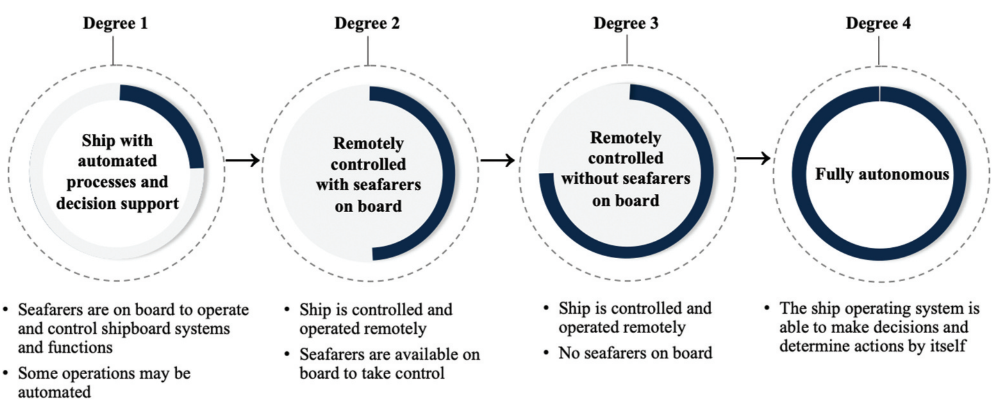

Figure 1. Degrees of autonomy as defined by IMO (adapted from IMO [2018]; Kim et al. 2019).

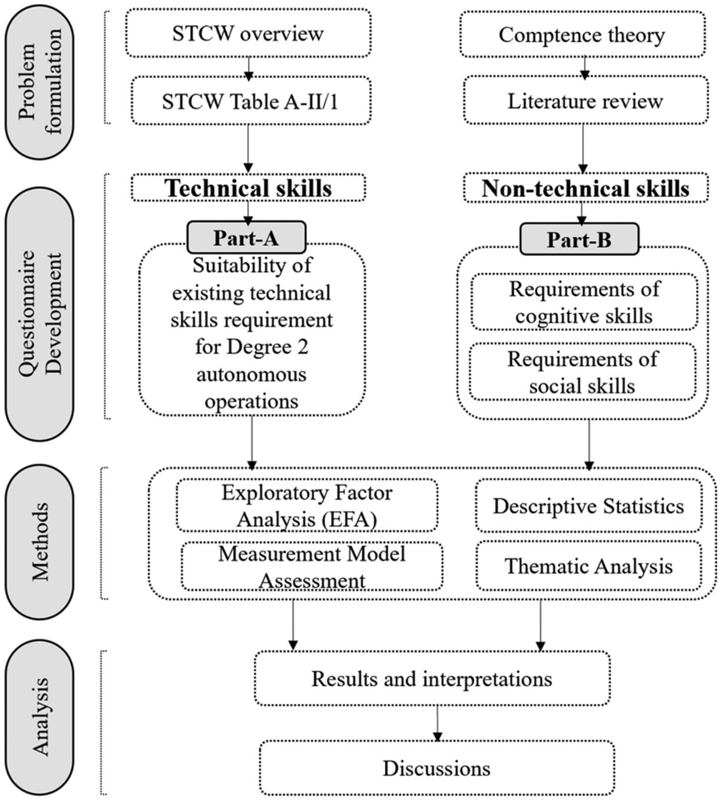

Figure 2. Research flow.

outlining of the needed competencies in order to correspondingly address the novel training requirements of the future navigators (Barsan, Hanzu-Pazara, and Arsenie 2007). It is expected that the STCW convention will be needed to be updated in coming years to catch up with the new operational environments of ships brought on by automation and digitalization. Several recent studies have discussed upon the issues regarding reskilling of seafarers and preparation of Maritime Education and Training (MET) institutes for meeting future competence demands for autonomous ship operations (Wright 2020; Emad, Khabir, and Shahbaksh 2020). However, none of the studies have conducted a detailed and itemized evaluation of the STCW competence requirements along with exploration regarding additional future skills. In this paper, we aim to investigate the suitability of the present STCW requirements (Table A-II/1) for Degree 2 MASS operations as defined by IMO (see Figure 1) and explore the novel future technical and non-technical competencies that will be required for navigators in merchant ships. The remainder of this manuscript is organized as follows—First, the concept of competency, skills requirement of navigators and historic development of STCW convention is elaborated upon. Next, the design of data collection instrument is described along with the data collection and analysis methods. Further, the obtained results are described in light of the selected research questions. Finally, the implications of the study are discussed for the shipping industry along with the future research directions.

2. Theoretical and legal background

There are several definitions and interpretations of the word 'competency' in the literature. A generic definition of competency as given by Oxford English dictionary is—'*the ability to do something successfully or efficiently*' (Stevenson 2010, 355). A more precise definition can be considered as the one given by United Nations Industrial Development Organization (UNIDO) which defines competency as—'*a set of skills encompassing knowledge and attributes which enables an individual to perform a task within a specific function/job effectively*' (Vathanophas and Thai-ngam 2007, 50). The research originating with regards to competency has conventionally described it in relation to the performance of the individual and to its surrounding environment. Woodruff (1993) described competency as '*the set of behavior patterns which are needed to allow the incumbent to perform tasks and functions with competence*'. Whereas Mace (2005) termed it as acquired personal skills which reflect potential ability to provide consistently adequate or high-level performance in a specific job function (Smythe et al. 2014, 60). The outlining and use of competency as a concept can therefore be seen as a part of the process to manage and improve the human performance in a given context through targeted education and training (Hoffmann 1999, 283). In relation to the above definitions, it is worth highlighting the difference between competency and skills. The term competency defines the requirements for the job in a broader context than skills. The terms such as skills, ability and knowledge therefore can be best termed as facets of competency in this regard. A navigator can be termed as competent if he/she can safely navigate the ship across two destinations safely. To undertake this task however, he/she will need a set of skills (e.g., passage planning, radar navigation).

The skills required by the navigators for the operation of ships can be broadly divided into—technical and non-technical skills (Hetherington, Flin, and Mearns 2006; Sharma et al. 2019). The technical skills refer to the knowledge regarding ship operations such as navigation, engine propulsion, cargo handling, maintenance and radio communications. Such skills can be ship specific and also change every few years due to basic changes in ship design and technology advancement. For instance, knowledge regarding use of various bridge equipment such as Electronic Chart Display and Information Systems (ECDIS), Global Positioning System (GPS), Radar, Automatic Radar Plotting Aid (ARPA), Automatic Identification System (AIS) have become paramount for present day navigators. The skills related to the navigational means of the past and the knowledge regarding them has either become obsolete or just present as superficial requirement (e.g. use of sextant to obtain fix) in assessment of competence. The future technical competencies of navigators will therefore, in part depend upon the development of novel navigational technologies and their subsequent adaption by ships.

In relation to the non-technical skills for navigators, the domain itself is relatively less explored by the stakeholders involved in MET. The first Bridge Resource Management (BRM) course for the maritime education and training purposes was launched in 1990s, taking inspiration from the aviation sector's Crew Resource Management (CRM) course (Barnett, Gatfield, and Pekcan 2003; O'Connor 2011). However, the effectiveness of BRM in terms of implementation and the outcomes has been reported variably (O'Connor 2011). Fjeld, Tvedt, and Oltedal (2018) in their review identified five non-technical skills in the research literature related to navigators: (1) situational awareness (2) workload management (3) decision making (4) communication and (5) leadership. It is worth noting that the first three belong to sub-category of 'cognitive skills' and the remaining 2 are classified as 'interpersonal (social) skills'. The investigation of more non-technical skills such as 'mental readiness', 'anticipatory thinking', 'coping with stress/fatigue' and 'seeking advice/feedback' as listed in taxonomy proposed by Yule et al. (2006) would be beneficial. In terms of cognitive skills and their facilitation, appropriate design considerations can help answer some of the concerns (Endsley and Kiris 1995). The acquisition of 'interpersonal' or 'social skills' in contrast would require active intervention in training of navigators.

Traditionally, maritime industry is termed as conservative (resistant to change) and reactive in nature (Mokashi, Wang, and Vermar 2002). The major conventions which regulate the maritime operations at present often originated as the aftermath of large-scale shipping disasters (Schröder-Hinrichs et al. 2013). In this regard, STCW convention is not different. The establishment of STCW was triggered by aftermath of the *Torrey Canyon and Amoco Cadiz* disaster, where the named ships grounded which resulted in the biggest environmental disasters at the time (Schröder-Hinrichs et al. 2013; Parsons and Allen 2018, 24). STCW upon its proposal and implementation initiated common framework for seafarer competence. It replaced the 1936 International Labour Organization (ILO) Officer Competency Certificate Convention (no.53) and was seen as a major step towards ensuring common competency standards worldwide (Morrison 1997). In the few years after its establishment, the shipping community however felt that the STCW 1978 missed its mark. Issues such as vague competence requirements interpreted differently by member states, lack of clarity in standards and continuing number of major shipping disasters meant that the member states signatory to the convention argued for major revisions (Emad and Roth 2008; Schröder-Hinrichs et al. 2013). These prevailing issues called for major revisions to the convention, which was adopted by IMO in the year 1995. The 1995 amendments to STCW marked a major change in the approach of IMO and shipping community with regards to establishment and compliance with safety related regulations in shipping. The member states were now required to demonstrate and outline clear road map of compliance than just being passive signatories as was the case in the past (Parsons and Allen 2018). The framing of regulations also laid emphasis on the importance of the human element within shipping rather than focusing on external provisions as was the norm of its predecessors. The STCW 1995 amendment among other major changes, laid out the Competence-Based Training (CBT) requirements for the seafarers. The competencies associated with specific job roles and profiles were now clearly documented, and the seafarers were required to demonstrate them before receiving certifications for their rank (Lewarn 2002).

The 2010 amendments to STCW continued the emphasis on proactive changes in education and training of seafarers with incorporation of new automation and digitalization developments within shipping. Several key competence requirements were added in this amendment, which were related to modern technologies such as ECDIS, work-rest hours regulations, security training, environmental awareness, and training in non-technical skills such as leadership and teamwork (IMO 2011). Currently, STCW 1978 as amended, in its Table A-II/1 has included 66 Knowledge, Understanding & Proficiency items (KUPs) which specifies the minimum standard of competence for officers in charge of navigational watch on ships of 500 gross tonnage or more (IMO 2011). These KUPs collectively reflect 19 competence themes as illustrated in

Table 1. Competences for navigation officers in operational role as listed in Table A-II/1 of STCW (IMO, 2011, 99–110)

Competence themes
Plan and conduct a passage and determine position
KUP 1 Ability to use celestial bodies to determine the ship' position
KUP 2 Ability to determine the ship's position by use of 1) landmarks, 2) aids to navigation, including lighthouses, beacons and buoys, 3) dead reckoning, taking into account winds, tides, currents and estimated speed
KUP 3 Have thorough knowledge of and ability to use nautical charts, and publications, such as sailing directions, tide tables, notices to mariners, radio navigational warnings and ships' routing information
KUP 4 Ability to determine the ship's position by use of electronic navigational aids
KUP 5 Ability to operate the equipment and apply the information correctly
KUP 6 Have knowledge of the principles of magnetic and gyro-compasses
KUP 7 Ability to determine errors of the magnetic and gyro-compasses, using celestial and terrestrial means, and to allow for such errors

(*Continued*)

Table 1. (Continued).

KUP 8 Have knowledge of steering control systems, operational procedures and change-over from manual to automatic control and vice versa. Adjustment of controls for optimum performance

KUP 9 Ability to use and interpret information obtained from shipborne meteorological instruments

KUP 10 Have knowledge of the characteristics of the various weather systems, reporting procedures and recording systems

KUP 11 Ability to apply the meteorological information available

Maintain a safe navigational watch

KUP 12 Have thorough knowledge of the content, application and intent of the International Regulations for Preventing Collisions at Sea, 1972, as amended

KUP 13 Have thorough knowledge of the Principles to be observed in keeping a navigational watch

KUP 14 Proficient in use of routing in accordance with the General Provisions on ships' routing

KUP 15 Proficient in use of information from navigational equipment for maintaining a safe navigational watch

KUP 16 Have knowledge of blind pilotage techniques

KUP 17 Proficient in use of reporting in accordance with the General Principles for Ship Reporting Systems and with VTS procedures

KUP 18 Knowledge of bridge resource management principles, including 1) allocation, assignment, and prioritization of resources, 2) effective communication 3) assertiveness and leadership, 4) obtaining and maintaining situational awareness, 5) consideration of team experience

Use of radar and ARPA to maintain safety of navigation

KUP 19 Have knowledge of the fundamentals of radar and automatic radar plotting aids (ARPA)

KUP 20 Ability to operate and to interpret and analyse information obtained from radar and ARPA performance, including 1) factors affecting performance and accuracy, 2) setting up and maintaining displays, 3) detection of misrepresentation of information, false echoes, sea return, etc., racons and SARTs

KUP 21 Ability to operate and to interpret and analyse information obtained from radar and ARPA use, including 1) range and bearing; course and speed of other ships; time and distance of closest approach of crossing, meeting overtaking ships, 2) identification of critical echoes; detecting course and speed changes of other ships; effect of changes in own ship's course or speed or both, 3) application of the International Regulations for Preventing Collisions at Sea, 1972, as amended, 4) plotting techniques and relative- and true- motion concepts, 5) parallel indexing

KUP 22 Awareness of principal types of ARPA, their display characteristics, performance standards and the dangers of over-reliance on ARPA

KUP 23 Ability to operate and to interpret and analyse information obtained from ARPA, including 1) system performance and accuracy, tracking capabilities and limitations, and processing delays, 2) use of operational warnings and system tests, 3) methods of target acquisition and their limitations, 4) true and relative vectors, graphic representation of target information and danger areas, 5) deriving and analysing information, critical echoes, exclusion areas and trial manoeuvres

Use of ECDIS to maintain the safety of navigation

KUP 24 Have knowledge of the capability and limitations of ECDIS operations, including 1) a thorough understanding of Electronic Navigational Chart (ENC) data, data accuracy, presentation rules, display options and other chart data formats, 2) the dangers of over-reliance, 3) familiarity with the functions of ECDIS required by performance standards in force

KUP 25 Proficient in operation, interpretation, and analysis of information obtained from ECDIS, including 1) use of functions that are integrated with other navigation systems in various installations, including proper functioning and adjustment to desired settings, 2) safe monitoring and adjustment of information, including own position, sea area display, mode and orientation, chart data displayed, route monitoring, user-created information layers, contacts (when interfaced with AIS and/or radar tracking) and radar overlay functions (when interfaced), 3) confirmation of vessel position by alternative means, 4) efficient use of settings to ensure conformance to operational procedures, including alarm parameters for anti-grounding, proximity to contacts and special areas, completeness of chart data and chart update status, and backup arrangements, 5) adjustment of settings and values to suit the present conditions, 6) situational awareness while using ECDIS including safe water and proximity of hazards, set and drift, chart data and scale selection, suitability of route, contact detection and management, and integrity of sensors.

Respond to emergencies

KUP 26 Ability to take precautions for the protection and safety of passengers in emergency situations

KUP 27 Ability to take initial actions following a collision or a grounding; and ability to assess initial damage and perform control

KUP 28 Appreciate the procedures to be followed for rescuing persons from the sea, assisting a ship in distress, responding to emergencies which arise in port

Respond to a distress signal at sea

KUP 29 Have knowledge of the contents of the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual

Use the IMO Standard Marine Communication Phrases and use English in written and Oral form

(*Continued*)

Table 1. (Continued).

KUP 30 Have adequate knowledge of the English language to enable the officer to use charts and other nautical publications, to understand meteorological information and messages concerning ship's safety and operation, to communicate with other ships, coast stations and VTS centres and to perform the officer's duties also with a multilingual crew, including the ability to use and understand the IMO Standard Marine Communication Phrases (IMO SMCP)
Transmit and receive information by visual signalling
KUP 31 Ability to use the International Code of Signals
KUP 32 Ability to transmit and receive, by Morse light, distress signal SOS as specified in Annex IV of the International Regulations for Preventing Collisions at Sea, 1972, as amended, and appendix 1 of the International Code of Signals, and visual signalling of single-letter signals as also specified in the International Code of Signals
Manoeuvre the ship
KUP 33 Have knowledge of ship manoeuvring and handling, including knowledge of 1) the effects of deadweight, draught, trim, speed and under-keel clearance on turning circles and stopping distances, 2) the effects of wind and current on ship handling, 3) manoeuvres and procedures for the rescue of person overboard, 4) squat, shallow-water and similar effects, 5) proper procedures for anchoring and mooring
Monitor the loading, stowage, securing, care during the voyage and the unloading of cargoes
KUP 34 Have knowledge of the effect of cargo, including heavy lifts, on the seaworthiness and stability of the ship
KUP 35 Have knowledge of safe handling, stowage and securing of cargoes, including dangerous, hazardous and harmful cargoes, and their effect on the safety of life and of the ship
KUP 36 Ability to establish and maintain effective communications during loading and unloading
Inspect and report defects and damage to cargo spaces, hatch covers and ballast tanks
KUP 37 Have knowledge and ability to explain where to look for damage and defects most commonly encountered due to 1) loading and unloading operations, 2) corrosion, 3) severe weather conditions
KUP 38 Ability to state which parts of the ship shall be inspected each time in order to cover all parts within a given period of time
KUP 39 Ability to identify those elements of the ship structure which are critical to the safety of the ship
KUP 40 Ability to state the causes of corrosion in cargo spaces and ballast tanks and how corrosion can be identified and prevented
KUP 41 Have knowledge of procedures on how the inspections shall be carried out
KUP 42 Ability to explain how to ensure reliable detection of defects and damages
KUP 43 Have understanding of the purpose of the 'enhanced survey programme'
Ensure compliance with pollution prevention requirements
KUP 44 Have knowledge of the precautions to be taken to prevent pollution of the marine environment
KUP 45 Awareness of anti-pollution procedures and all associated equipment
KUP 46 Awareness of importance of proactive measures to protect the marine environment
Maintain seaworthiness of the ship
KUP 47 Have working knowledge and application of stability, trim and stress tables, diagrams and stress-calculating equipment
KUP 48 Have understanding of fundamental actions to be taken in the event of partial loss of intact buoyancy
KUP 49 Have understanding of the fundamentals of watertight integrity
KUP 50 Have general knowledge of the principal structural members of a ship and the proper names for the various parts
Prevent, control and fight fires onboard
KUP 51 Ability to organize fire drills
KUP 52 Have knowledge of classes and chemistry of fire
KUP 53 Have knowledge of fire-fighting systems
KUP 54 Have knowledge of action to be taken in the event of fire, including fires involving oil systems
Operate life-saving appliances
KUP 55 Ability to organize abandon ship drills and knowledge of the operation of survival craft and rescue boats, their launching appliances and arrangements, and their equipment, including radio life-saving appliances, satellite EPIRBs, SARTs, immersion suits and thermal protective aids
Apply medical first onboard ship
KUP 56 Awareness of the practical application of medical guides and advice by radio, including the ability to take effective action based on such knowledge in the case of accidents or illnesses that are likely to occur on board ship
Monitor compliance with legislative requirements
KUP 57 Have basic working knowledge of the relevant IMO conventions concerning safety of life at sea, security and protection of the marine environment

(*Continued*)

Table 1. (Continued).

Application of leadership and teamworking skills
KUP 58 Have working knowledge of shipboard personnel management and training
KUP 59 Have knowledge of related international maritime conventions and recommendations, and national legislation
KUP 60 Ability to apply task and workload management, including 1) planning and co-ordination, 2) personnel assignment, 3) time and resource constraints, 4) prioritization
KUP 61 Have knowledge and ability to apply effective resource management, including 1) allocation, assignment, and prioritization of resources, 2) effective communication onboard and ashore, 3) decisions reflect consideration of team experiences, 4) assertiveness and leadership, including motivation, 5) obtaining and maintaining situational awareness
KUP 62 Have knowledge and ability to apply decision-making techniques, including 1) situation and risk assessment, 2) identify and consider generated options, 3) selecting course of action, 4) evaluation of outcome effectiveness
Contribute to the safety of personnel and ship
KUP 63 Have knowledge of personal survival techniques
KUP 64 Have knowledge of fire prevention and ability to fight and extinguish fires
KUP 65 Have knowledge of elementary first aid
KUP 66 Have knowledge of personal safety and social responsibilities

Extrapolating the trends in shipping and taking into account the continuous automation of many functions onboard, some of the existing competence requirements listed above are bound to become obsolete (Sharma et al. 2019; Kim and Mallam 2020). On the other hand, new competence will be required to ensure the navigators are trained for the new job functions.

Furthermore, with gradual introduction of automation technologies onboard ships over the years, many of the ship's functions have already become automated. This has meant that ship owners who are responsible for manning and maintenance of ship would feel suffice to reduce the crew size, as crewing bears a significant cost in day-to-day ship operations (Stopford 2009). However, this has also meant that there are less and less crew onboard performing the duties on ships, but more information elements for the crew to process in a variety of operations. This has contributed to increased cognitive load, and it has been documented that many accidents in shipping have occurred not despite the presence of new technology but rather because of it (Lützhöft and Dekker 2002). The skillsets such as creative thinking, resilience, communication, leadership and management skills, as well as other cognitive and social skills have therefore become increasingly desired in the ship crew, in addition to their updated technical knowledge.

In light of above, the list of competence themes for ship navigators in Table 1 and the important cognitive and social skills as identified in the literature became the basis for designing a survey instrument, which was utilized in data collection and interpretation process of the present study. Table 1.

3. Methods

To adequately model the competence requirements for navigators engaged in Degree 2 MASS operations, a mixed method approach was adopted. This consisted of a quantitative evaluation of the existing STCW competence framework, and a qualitative exploration of future technical and non-technical competencies navigators need to thrive in the era of autonomous shipping. The scope of the study was narrowed down to only include the navigators in operational role and hypothetically engaged in Degree 2 MASS operations scenario as illustrated in Figure 1. The IMO definition of autonomous shipping was used as a reference in the survey due to the international profile of the respondents. The aforementioned 66 KUPs in STCW 1978 as amended were converted into measurement items in a survey, where respondents were asked to rate the extent to which they think that autonomous shipping will impact on these KUPs and their requirement on a Likert scale from 1 (Extremely important) to 5 (Not at all important). The text content of the KUPs were not modified rather, the original text from STCW was followed in order to maintain the originality of the requirements and validity concerns of the study. The questionnaire was digitalized using the platform Qualtrics™, and the link was then sent out to respondents working on international merchant shipping industry through non-random & purposive sampling approach using professional network. The respondents either consisted of active seafarers or individuals working within shipping industry in some capacity. The collected data was exported from Qualtrics™ in the form of MS Excel Comma Separated Value (CSV) data file and was checked for blank and straight lining responses as part of data cleaning and preparation process. 43 cases of blank and 1 case of straight lining responses were found and consequently removed from dataset. A total number of 109 valid responses out of 153 collected responses were therefore registered for the comprehensive questionnaire. Several demographic questions were also included at the end of the questionnaire to facilitate the understanding of survey responses. The demographics data was collected for all the respondents except 2 cases of missing values, where the respondents completed the actual survey but erroneously left out the demographic information. The demographic characteristics of the respondents are summarized inTable 2.

In addition, the respondents were also asked to rate the importance of non-technical skills as identified in literature review about their relevance in Degree 2 autonomous operations. For this purpose, a separate section for non-technical skills was added in the survey questionnaire. The non-technical skills were further divided into cognitive and interpersonal (social) skills. Finally, an open-ended avenue provided in the survey questionnaire enabled the respondents to register qualitative responses about their opinion regarding which future technical and non-technical competencies will be relevant. The survey utilized an anonymous link with no personal information being collected. For the quantitative section, the collected responses were analysed using following software and programs—SPSS™ and SmartPLS™. The questionnaire was designed using 'forced responses' function for the listed KUPs, so that there are no missing values and the respondents had to complete all the answers before proceeding further. The overall research flow is illustrated in the following Figure 2.

The collected responses were analysed using four modes of analysis: (1) Exploratory Factor Analysis (EFA) (2) Measurement Model Assessment (3) Descriptive Statistics and (4) Thematic Analysis. EFA is a multivariate statistical technique for quantitative analyses, which reduces the large number of variables into smaller set of factors that represent the sets of correlated variables (Kilner 2004; Tabachnick, Fidell, and Ullman 2007). EFA allows the researchers to undertake parsimonious analysis, generate theory and also evaluate the construct validity of the measurement instrument (Williams, Onsman, and Brown 2010). The data gathered regarding the evaluation of 66 KUPs were analysed using EFA to allow rigorous analysis for suitability and regrouping for Degree 2 MASS operations. Furthermore, the extracted factor structure from EFA was evaluated using partial least squares structural equation modelling technique for measurement model assessment as

Table 2. Demographic characteristics of the respondents.

Range		Frequency	Percent
Industrial area	Shipping company	75	70.0
	Shipping management company	11	10.3
	Maritime training institute/provider	13	12.3
	Others	8	7.4
Shipping sectors	Wet Bulk (Tanker sector)	57	53.3
	Dry Bulk	8	7.4
	Cargo Liners and Container Ships	20	18.7
	Passenger Liners/Cruise Ships/Ferries	4	3.7
	Other shipping sectors	18	16.9
Year of experience	0–5 years	68	63.5
	6–10	14	13.1
	11–15	7	6.5
	+ 15 years	18	16.9

per the steps given by Hair et al (2019; 2020) to check for consistency, convergent and divergent validity of the indicators.

The qualitative responses gathered through the open-ended section of the questionnaire was subject to a detailed thematic analysis to identify the relevant themes. Braun and Clarke (2006, 79) defined thematic analysis as '*a method for identifying, analysing and reporting patterns (themes) within data*'. In this regard, a theme represents some level of 'patterned' response or meaning within the dataset. The emerging competence themes were categorized and coded. After the coding of emerging competence themes, only those not previously discussed in either STCW competence framework regarding technical skills or in the reviewed literature associated with non-technical skill requirements for navigators were qualified. As a result, any redundant competence theme was excluded. Finally, the data gathered for non-technical skills was subjected to descriptive analyses to better understand and visualize their relevancy as rated by the respondents.

4. Results

In accordance with described research framework, the results are reported in two parts. Part A describes the results regarding suitability of existing STCW competence framework and the requirement of novel technical skills obtained by EFA, measurement model assessment and thematic analysis, whereas Part B describes the descriptive statistics regarding the requirement of novel non-technical competence themes derived through thematic analysis.

4.1. Part-A

A Principal Component Analysis (PCA) was conducted on the 66 questionnaire items with varimax rotation. The Kaiser-Meyer-Olkin (KMO) value (.754), is above recommend value of 0.5 (Hair et al. 2006). Bartlett's test of sphericity was also significant ($p < 0.001$), which indicates a good level of sampling adequacy for the purpose of EFA. 28 KUPs out of 66 have obtained a score of < 2 from the scale of 1 (Extremely important) to 5 (Not important at all), which indicated their high relevance for Degree 2 MASS operations. The authors examined the factor loading of all items and removed the items that did not loaded significantly (<0.5) on any of the major components. Several iterations were run to determine the final factor structure. As given in the following Table 3, the final EFA has given 11 factors with eigenvalue greater than 1, which explained 72.6% of the total variance.

Factor 1 represents the KUPs 1, 2, 3, 6, 7 & 15. Examining the individual KUPs and the original theme as designated in Table 1, the derived competence theme was labelled as—*Position fixing & Watchkeeping*. Factor 2 contained KUPs 38–42, which are originally belonging to the theme—*Inspect and report defects and damages to cargo spaces, hatch covers and the ballast tanks*. Since all but 2 KUPs (37 & 43) were loaded on this factor, the original competence theme was retained after evaluation from the authors.

Comm.* refers to communalities, which indicate the amount of the variance in the variable that has been extracted by the factor solution. Varimax rotation performed to extract factors.

Factor 3 consisted of KUPs 51–54, which overlapped with the original competence theme titled *Prevent, control and fight fires onboard*, therefore the original title was retained. Factor 4 is made up of KUPs 63–66 and overlapped with the theme—*Contribute to safety of personnel and ship*, the original competence theme title was retained. Factor 5 consisted of KUPs 22–25. It has partial overlap with two competence themes, which are—*Use of radar and ARPA to maintain safety of navigation* and *Use of ECDIS to maintain safety of navigation*. Upon examining the individual KUPs that loaded on this factor, the competence theme was labelled as—*Use of radar, ARPA and ECDIS to maintain safety of navigation*. Factor 6 contained the KUPs 58, 60, 61 & 62. They barring for 1 KUP largely fall under the theme—*Application of leadership & teamworking skills* and the original competence theme was retained. Factor 7 consisted of KUPs 44, 45 & 46. It had a perfect overlap with the original competence theme—*Ensure compliance with pollution prevention requirements*

Table 3. Results from Exploratory Factor Analysis (*n*= 109).

No.	Competence theme	Factor description	Loading	Comm. *	Cronbach's α
1	Position fixing & Watchkeeping	KUP 3	.800	.692	.830
		KUP 2	.743	.718	
		KUP 1	.736	.705	
		KUP 6	.701	.646	
		KUP 15	.621	.712	
		KUP 7	.593	.665	
2	Inspect and report defects and damages to cargo spaces, hatch covers & ballast tanks	KUP 40	.748	.747	.849
		KUP 39	.724	.712	
		KUP 41	.689	.724	
		KUP 42	.672	.712	
		KUP 38	.661	.600	
3	Prevent, control and fight fires onboard	KUP 52	.782	.820	.829
		KUP 54	.777	.764	
		KUP 53	.776	.827	
		KUP 51	.620	.590	
4	Contribute to safety of personnel and ship	KUP 63	.780	.683	.851
		KUP 65	.754	.735	
		KUP 64	.680	.747	
		KUP 66	.615	.683	
5	Use of radar, ARPA and ECDIS to maintain safety of navigation	KUP 24	.798	.711	.819
		KUP 22	.738	.770	
		KUP 23	.706	.675	
		KUP 25	.667	.646	
6	Application of leadership and teamworking skills	KUP 61	.809	.772	.823
		KUP 60	.741	.773	
		KUP 58	.678	.666	
		KUP 62	.629	.684	
7	Ensure compliance with pollution prevention	KUP 46	.884	.853	.880
		KUP 45	.841	.832	
		KUP 44	.809	.788	
8	Damage control and distress communication	KUP 28	.812	.796	.753
		KUP 27	.764	.717	
		KUP 29	.635	.642	
9	Application of meteorological information in navigation	KUP 11	.713	.758	.758
		KUP 10	.697	.731	
		KUP 9	.612	.672	
10	Reporting and communication	KUP 31	.788	.782	.622
		KUP 17	.762	.723	
11	Manoeuvring and maintaining seaworthiness of ship	KUP 33	.767	.774	.617
		KUP 47	.686	.789	

and the title was retained. Factor 8 consisted of KUPs 27, 28 & 29, which have an overlap between two of the original themes, namely—*Respond to emergencies and Respond to a distress signal at sea*. Upon examining the individual KUPs, the competence theme was renamed as—*Damage control and distress communication*. Factor 9 consisted of KUPs 9, 10 & 11. After considering the individual KUPs, the competence theme was named as—*Application of meteorological information in navigation*. Factor 10 contained KUPs 17 & 31. Upon examining the individual KUPs the competence theme was labelled as—*Reporting and Communication*. Finally, Factor 11 consisted of KUP 33 & 47. The competence theme was labelled as—*Manoeuvring and maintaining seaworthiness of ship*. A reliability check for the synthesized factors was performed in SPSS™ using the score of Cronbach's alpha as a measure. Cronbach's alpha score provides an indication of internal consistency of the measurement i.e. to which extent the items in the instrument measure the same construct (Tavakol and Dennick 2011). The overall Cronbach's alpha for total scale was 0.923. The Cronbach's alpha for each individual competence theme is shown in Table 3.

For measurement model assessment which is confirmatory in nature, the software package SmartPLS™ was utilized and the results were checked against the guidelines provided by Hair

Table 4. Reflexive indicator loadings, CR and AVE of the measurement model.

No.	Competence theme	Indicators	Loading	CR	AVE
1	Position fixing & Watchkeeping	KUP 3	.733	.853	.498
		KUP 2	.591		
		KUP 1	.508		
		KUP 6	.831		
		KUP 15	.785		
		KUP 7	.733		
2	Inspect and report defects and damages to cargo spaces, hatch covers & ballast tanks	KUP 40	.841	.894	.627
		KUP 39	.747		
		KUP 41	.800		
		KUP 42	.821		
		KUP 38	.746		
3	Prevent, control and fight fires onboard	KUP 52	.884	.908	.712
		KUP 54	.869		
		KUP 53	.860		
		KUP 51	.757		
4	Contribute to safety of personnel and ship	KUP 63	.718	.890	.670
		KUP 65	.865		
		KUP 64	.874		
		KUP 66	.807		
5	Use of radar, ARPA and ECDIS to maintain safety of navigation	KUP 24	.820	.881	.649
		KUP 22	.828		
		KUP 23	.819		
		KUP 25	.753		
6	Application of leadership and teamworking skills	KUP 61	.869	.879	.647
		KUP 60	.844		
		KUP 58	.762		
		KUP 62	.733		
7	Ensure compliance with pollution prevention	KUP 46	.907	.925	.805
		KUP 45	.913		
		KUP 44	.870		
8	Damage control and distress communication	KUP 28	.852	.864	.679
		KUP 27	.793		
		KUP 29	.826		
9	Application of meteorological information in navigation	KUP 11	.878	.863	.678
		KUP 10	.816		
		KUP 9	.773		
10	Reporting and communication	KUP 31	.887	.842	.728
		KUP 17	.818		
11	Manoeuvring and maintaining seaworthiness of ship	KUP 33	.927	.828	.709
		KUP 47	.749		

et al. (2019) for reflexive measurement models regarding item loadings, internal consistency reliability, convergent and divergent validity. The first step in reflexive model assessment pertains to examining the indicator loadings. The following reflexive indicator loadings were obtained for the measurement model which barring for two items (KUP 1 & 2) had values above the recommended value of 0.708 as given in Table 4. These denote the indicator variance that is explained by the extracted factor.

Subsequently, the Composite Reliability (CR) and the Average Variance Extracted (AVE) values were calculated. The CR and AVE values for the factors in the measurement model are also provided in Table 4. The CR values for the extracted factors were ranging between 0.828 and 0.925, considered 'satisfactory to good' as per the guidelines (Hair et al. 2019). The obtained Average Variance Extracted (AVE) values, except Factor 1, were greater than recommended threshold of 0.5 (Hair, Howard, and Nitzl 2020). Finally, the discriminant validity, using the Fornell-Larcker criterion was calculated. As reported in Table 5, square root of each factor's AVE is more than the co-relation coefficient when compared with other factors, indicating the discriminant validity criterion is supported for the measurement model (Fornell and Larcker 1981).

For exploring the new technical skill requirement not covered in the existing competence framework, a section of questionnaire was dedicated to open-ended questions such as 'What

Table 5. Discriminant validity

Factor	1	2	3	4	5	6	7	8	9	10	11
1	**.706**										
2	.298	**.792**									
3	.187	.500	**.844**								
4	.187	.474	.597	**.818**							
5	.366	.359	.215	.206	**.806**						
6	.285	.454	.482	.410	.431	**.804**					
7	.040	.337	.398	.420	.238	.355	**.897**				
8	.230	.437	.392	.380	.378	.322	.338	**.824**			
9	.521	.482	.306	.279	.448	.355	.191	.352	**.823**		
10	.372	.296	.174	.215	.341	.196	.078	.350	.322	**.853**	
11	.194	.304	.201	.160	.419	.341	.221	.279	.338	.298	**.842**

technical competence or skills do you think would be important for future navigators?' The respondents were asked to describe in few sentences of their opinion regarding which skills would be needed and reasons for the same. The qualitative responses were then analysed through iterative thematic coding. Any overlap with existing technical skills or competence themes was discarded and only the unique themes emerging were retained in the analysis. These emerging themes were labelled as the 'additional technical skills' the future navigators will require in addition to the already existing ones as listed in the STCW framework.

In the obtained qualitative responses provided by the respondents, the results indicated that the increasing automation would mean that the future seafarers or navigators should be well versed with relevant IT skills that could facilitate the operations onboard. The respondents described that the elementary knowledge regarding coding, and comprehension of machine learning algorithms will be necessary for the future navigators due to the presence of numerous intelligent decision support systems. The respondents also added that due to further advancement towards engine room automation, it might be the case that the crew compliment onboard is further reduced, and the navigators are also trained for engine room operations or for a basic knowledge thereof contributing to the development of a new hybrid role with equal competence requirement for both navigation and engine operations. Due to potential introduction of complex electronic equipment, a separate competence theme addressing the elementary fault finding and troubleshooting aspects will be necessary to ensure smooth functioning of major operational equipment onboard.

Further, the advent of integrated systems on ships will mean that the navigators or the remote-control operators are well versed with knowledge regarding instrumentation & control and operation of diverse types of sensors as well as their limitations. Lastly, the importance of managing risks when abnormal situation arises due to failure/deviance of system and expertise in cyber security will be paramount in day-to-day operations for autonomous ships.

In summary, five major novel technical competence themes emerged during the thematic analysis, namely—*IT skills, safety & security management skills, knowledge regarding engine room operations, electronic equipment and system integration*. The new technical competence themes are highlighted using the thematic map as illustrated in Figure 3.

4.2. Part-B

The second part of the survey recorded the data regarding the relative importance of listed cognitive and social skills in the reviewed literature under Degree 2 MASS operations. With respect to the non-technical skills, there were relatively few measurement items and each of them received identical scores. Therefore, along with the scores, a measure of proportion was employed to identify which skills are relatively important among the listed. With regards to the cognitive skills, *the ability*

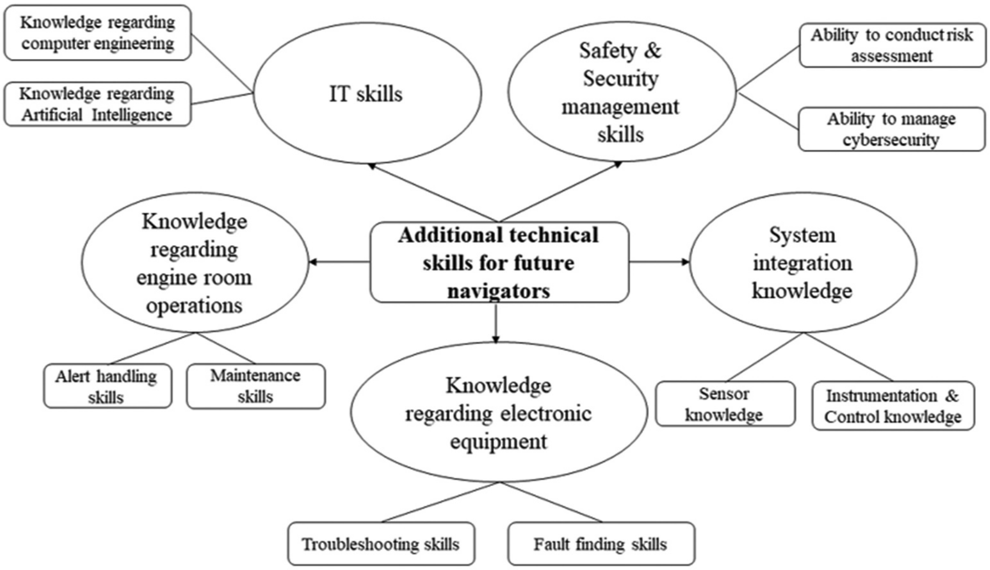

Figure 3. Additional technical skill relevant for autonomous operations.

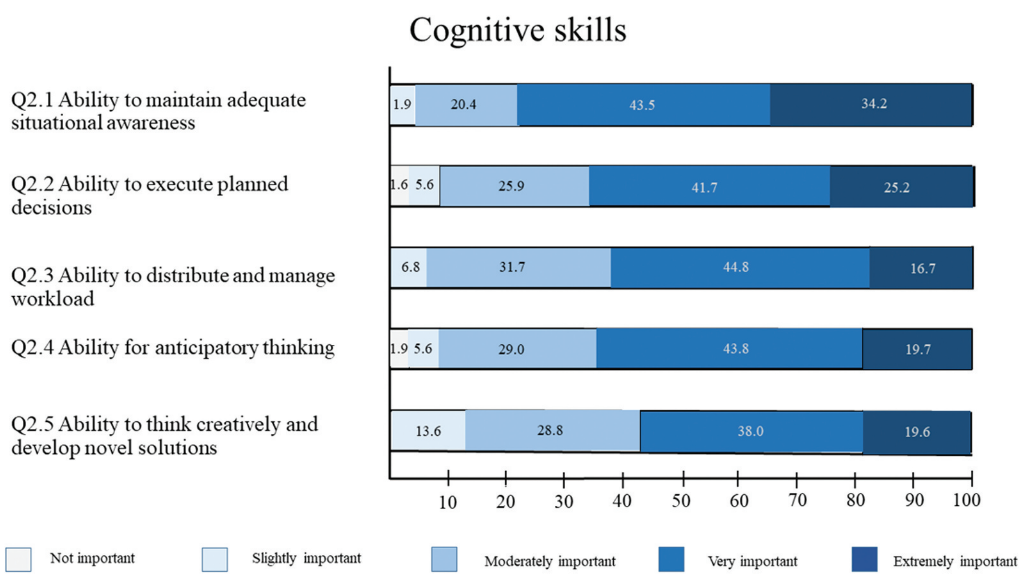

Figure 4. Descriptive statistics for cognitive skills.

to maintain adequate situational awareness obtained the score of 1.90 (most important) also with a proportion of 34.2% which was the highest proportion for *extremely important* category. For the purpose of visualization of this data, Figure 4 illustrates the summative evaluation of 109 responses on each of the cognitive skills.

For social skills, *the ability to take leadership initiatives* received a score of 1.95 and the highest proportion of respondents marking it as *extremely important*—37.5%. Majority of the respondents termed the required social skills as either 'Very important' or 'Extremely important'. This was also found to be the case for aforementioned cognitive skills. For the purpose of visualization of this data, Figure 5 illustrates the summative evaluation of 109 responses on each of the social skills.

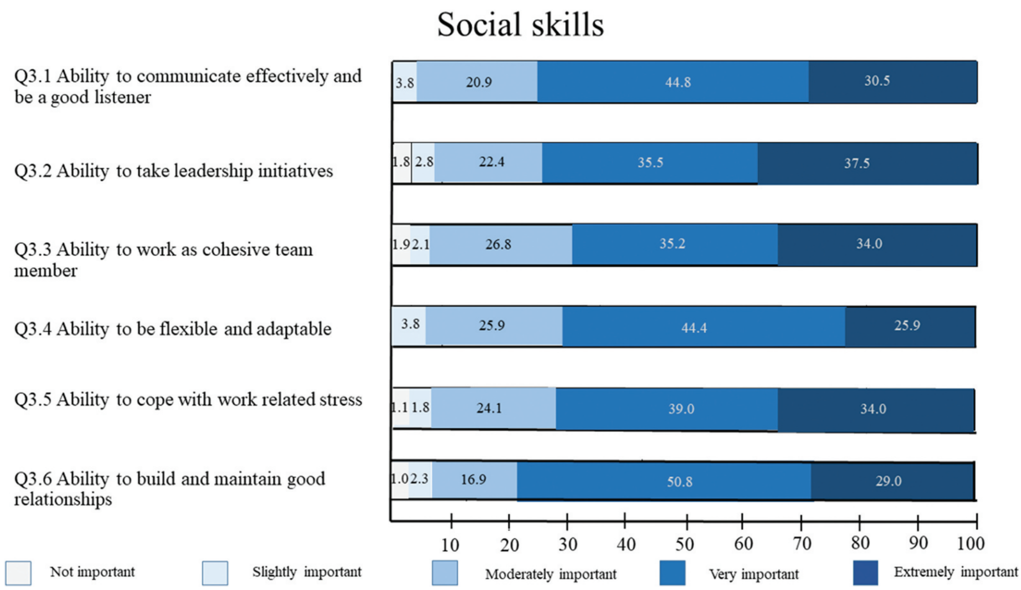

Figure 5. Descriptive statistics for social skills.

For the non-technical skills, an exploratory question—*What non-technical competence or skills do you think would be important for future navigators?* was included in the survey questionnaire to identify competence themes in addition to the ones contained in the questionnaire. As a result, five major themes emerged with regard to cognitive skills namely—*non-routine problem solving, ability for self-regulation, critical thinking, mental readiness and systemic thinking*. Similarly, for social skills, three major themes such as—*ability to establish trust in teams, ability to adapt to cultural differences and negotiation skills* emerged. These emerged themes were labelled as 'additional non-technical skills' for the navigators. The respondents claimed that the due to increased automation and possible reduction to bare-minimum crew members, considerable emphasis to cultivation of non-technical skills is required. This could entail a relatively small team of seafarers onboard or one remote control center tackling many operations related to ship.

In this regard, skills such as self-regulation, critical thinking and non-routine problem solving are particularly important as indicated by the respondents. Further, it was described by the respondents that due to unanticipated situations arising due to hidden properties and interaction between various components within the system, navigators of the future will need to demonstrate considerable mental readiness for handling complex situations and systemic thinking skills. With regards to the existing international nature of shipping industry, characteristics such as ability to earn trust, negotiation and awareness regarding cultural difference between individuals were termed as some of the important social skills to possess. The newly emerged non-technical competence themes are highlighted in a thematic map as illustrated in Figure 6.

5. Discussion

The existing shipping regulations need to be revised or updated in light of the developments taking place with respect to autonomous shipping globally, otherwise they may form a self-limiting regulatory barrier for introduction and adoption of autonomous shipping. The present study intended to target these aspects of autonomous shipping and facilitate improved understanding of regulatory changes that may be required.

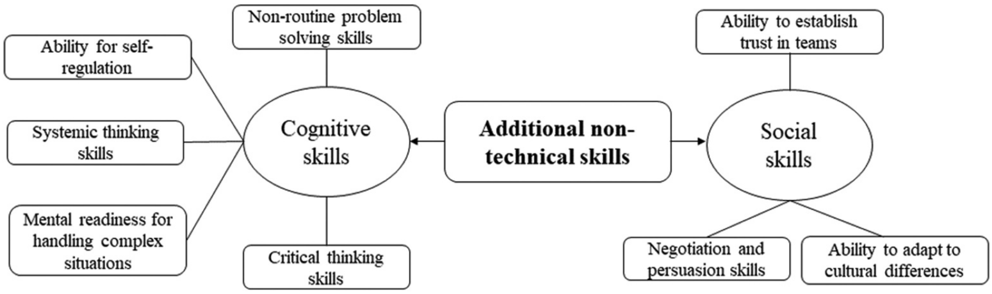

Figure 6. Additional non-technical skills relevant for autonomous operations.

The results derived from analysis provided an insight towards competence requirements for Degree 2 MASS operations and suitability of existing STCW competence framework. As illustrated in the EFA results (Part A), some of the original competence themes were still deemed necessary in the era of autonomous shipping. This to a certain extent is expected as Degree 2 MASS operations, though represents further advancement in ship operations and many shipboard functions, still doesn't amount to 'crew-less' operations. Degree 2 MASS operations, is the next step in the continuum of autonomy leading to completely autonomous ships. Consistent with the definition of Degree 2 MASS operations, the seafarers, are still present onboard to take control if necessary (IMO 2018). However, their roles and as a result, the competence requirement are indicated as more towards supervisory functions and emergency response. This is indicated by the fact that the individual items such as KUP 26 *Ability to take precautions for the protection and safety of passengers in emergency situations* and KUP 27 *Ability to take initial actions following a collision or a grounding*; received the lowest score (most important)—1.48 and 1.51, respectively, in the survey. Some new competence themes as a result of covariance in relevant KUPs also occurred. Emergent competence themes such as—*Position fixing & watchkeeping* and *Damage control and distress communication* among others provide such examples. Several competence themes such as—*Application of leadership & teamworking skills* and *Ensure compliance with pollution prevention* remain relevant. Correspondingly, a modified set of KUPs will be needed to be established in the future for adequately addressing training requirements for different levels of autonomous operations.

The emergent competence themes as derived in Table 3 along with the novel competence themes as illustrated in Figure 3 together address the technical skills as required from future seafarers engaged in Degree 2 MASS operations. There is a marked trend with shift of emphasis from navigational functions that are projected to be automated with time, towards other aspects of ship operations. In this regard, Wróbel, Montewka, and Kujala (2017) had also remarked that with increase in automation onboard, navigational risks such as collision and grounding might decrease and non-navigational risks such as fire, flooding etc will increase. The increased automation and digitalization onboard vessels will introduce vulnerabilities in addition to mere safety. It has increasingly been recognized that merchant ships are becoming susceptible for cyber-attacks. Jones, Tam, and Papadaki (2016) provided scenarios and pointed out the potential weaknesses of various bridge equipment such as ECDIS, GPS, AIS etc. In this regard, the presence of human crew onboard becomes the first line of defence, training and instilling skills for detecting and responding to cyber-attack is relevant for future autonomous operations.

A considerable number of respondents also stressed the importance of acquisition of non-technical skills for autonomous operations. According to Ahvenjärvi (2016), the obvious strength of human element in these complex systems onboard will be their flexibility and creativity. Therefore, adequate exploration regarding non-technical skills in maritime operations and training measures to support them need to be recognized. The qualitative data has indicated that future navigators should engage in systemic thinking competence. This is somehow anticipated as the future systems with deployment of Artificial Intelligence (AI) and automation technologies would mean that the systems will become more and more complex with increasing invisible interactions. It is paramount for the crews onboard to be able to have a holistic and systemic understanding of the systems and its interactions, to be able to comprehend the complexity, to evaluate the interrelations of sub-systems and to subsequently generate the best decisions and course of actions. Furthermore, effective leadership, which is an important element for safe operation today will play an increasingly important role in the autonomous era in order to effectively handle the ship in both normal and abnormal situations. Good leadership correlates with good safety performance, the decisions, attitudes and behaviours of leaders at all organizational levels shape the safety culture and working environment which determines the end results (Flin and Yule 2004; Kim and Gausdal 2017). In the era of autonomous shipping where information flow will determine the decisions and directions, in which ways shipping company and its management could effectively take advantage of the automation technology for safe, reliable and efficient ship operations is a topic worthy of further investigation.

Several limitations of the present research need to be mentioned. First of all, the sample size can be increased to enhance validity and generalizability of the results. Further, challenges with respect to subjectivity can be listed even after rigorous data analysis process conducted, since both labelling the extracted factors during EFA process as well as labelling of competence themes from thematic analysis are subjective in nature. These limitations mean that the results derived should be considered preliminary and further exploration with greater sample size is needed. Future research should be directed in examining the suitability of other competence requirements stipulated in STCW (e.g., Table A-II/2) as well as for roles within other departments in merchant shipping sector such as marine engineer officers. Such investigation carried out by different stakeholders could aid the revision and integration of changes that will be required for the STCW Convention and its associated Code to prepare competent seafarers for the dynamically evolving nature of autonomous shipping.

6. Conclusion and policy implications

Implementation of autonomous shipping technologies has the potential for enhancing safety, efficiency and sustainability performance of maritime industry. However, the regulatory framework for autonomous operations and the investigation for role of human element is in its initial stages. Modelling competences and anticipating the future competence for navigators or operators under plausible autonomous shipping scenarios could be the first stage in preparing for the challenges and opportunities autonomous shipping offers.

Through quantitative and qualitative analysis of a representative sample from the global shipping industry, the suitability of existing STCW competence requirements as well as the new competence themes that will be required under manned and remotely controlled MASS operations were presented in this research. Among the original 66 KUP items, 26 of them were rated by the respondents to be considered as less relevant for future navigators. The 11 competence themes emerged through the statistical analysis, together with the social and cognitive skills derived from the thematic analysis, can be considered as the reference for reskilling of future navigators. The results may contribute to the existing discussions regarding the revision of the STCW convention and its associated codes, in particular the STCW Table A-II/1 to facilitate the preparation and implementation of novel training frameworks for autonomous shipping. The research could aid the curriculum design in MET institutions to equip the trainees with updated skillset for safe and efficient operations. Future research should be directed at investigating the competence requirements for various roles involved in MASS operations.

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