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ΑΥΤΟΝΟΜΟ ΠΛΟΙΟ - ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΑΝΑΠΤΥΞΗ ΔΕΞΙΟΤΗΤΩΝ ΣΤΑ ΝΑΥΤΙΛΙΑΚΑ ΕΠΑΓΓΕΛΜΑΤΑ

AUTONOMOUS SHIP - EDUCATION AND SKILLS-BUILDING IN MARITIME

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Abstract

Following the continuous technological development and the potential autonomy in the shipping industry, Maritime Autonomous Surface Ships are not just a scenario but feasibility. In this context, the present study reviews the available academic literature on the specific field, including subjects extending from the technical and design requirements and the influencing factors on the operation of the autonomous ship to its possible impacts on the maritime industry. Moreover, the available literature shows the needs in the adaptation of the job requirements and qualifications and the corresponding reformation and creation of proper education and training programs, as well as probable business and operational policy and strategies. Finally, the employed methods in each study are presented. The results of the current paper show that there occurs the ground for further research, mainly in education, but also in the consequences that the autonomous ship will bring.

Keywords: MASS, unmanned autonomous ship, training, education, skills

Περίληψη

Με τη συνεχή ανάπτυξη της τεχνολογίας και την εφαρμογή αυτονομίας στη βιομηχανία της ναυτιλίας, το αυτόνομο πλοίο δεν αποτελεί απλώς μια υπόθεση αλλά μια εφαρμόσιμη ιδέα. Στα πλαίσια αυτά, η παρούσα έρευνα μελετά τη διαθέσιμη ακαδημαϊκή βιβλιογραφία για το συγκεκριμένο τομέα, η οποία επεκτείνεται από τις τεχνολογικές απαιτήσεις για την κατασκευή και τους καθοριστικούς παράγοντες για τη λειτουργία του αυτόνομου πλοίου έως τις επιπτώσεις, που θα προκαλέσει στον κλάδο της ναυτιλίας. Επιπλέον, προσεγγίζει τις ανάγκες για προσαρμογή των απαιτήσεων του ναυτικού επαγγέλματος και την αντίστοιχη διαμόρφωση και δημιουργία των κατάλληλων εκπαιδευτικών προγραμμάτων, καθώς και πιθανή επιχειρηματική και επιχειρησιακή πολιτική και στρατηγική. Τέλος, παρουσιάζονται οι μέθοδοι που έχουν χρησιμοποιηθεί στο σύνολο της σχετικής βιβλιογραφικής έρευνας. Σύμφωνα με τα αποτελέσματα, έδαφος για περαιτέρω έρευνα παρατηρείται κυρίως όσον αφορά στον τομέα της εκπαίδευσης αλλά και σε εκείνον σχετικά με τις συνέπειες, που θα επιφέρει το αυτόνομο πλοίο.

Λέξεις κλειδιά: αυτόνομο μη επανδρωμένο πλοίο, εκπαίδευση, δεξιότητες

1. Introduction

The shipping sector is continuously reacting with technological developments, such as automation and digitalization. Although technology usually provides the chance of improvement in transportation modes, the maritime industry generally seems to have adopted a few technological advancements to develop their sector. Current technological evolution and research have gained grounds that set autonomous navigating seagoing vessels achievable. It is the first time for the feasibility of autonomous unmanned vessels. The main operation methods for unmanned ships are either a remote control, or autonomy, or a combination of the two means as well. Nowadays, in numerous countries worldwide, there are meaningful technical, regulatory, and educational efforts with the purpose of the development of Maritime Autonomous Surface Ships. Automation in the maritime industry will unavoidably affect the shipping governance regulations. The International Maritime Organization (IMO) has included automation in shipping in its deliberation agenda.

Autonomous and unmanned vessels encourage both more reliable and more affordable navigation. Safety in maritime transport evermore remains crucially important. Human error is accountable for 75% or more of all maritime accidents. By reducing or removing crew on board, autonomous ships may lead to elimination or at least a sufficient decrease in human error level. Moreover, the removal of staffed ships may culminate in significant cost savings in accommodations and salaries for the crew, attaining, simultaneously, vessels of less weight, more spare space for transport, and limited fuel consumption. However, it is well-known that changes in technology, practices, and methods not only may decrease several risks and guide to advantages but may also create new challenges. Thus, there exist many arguments about potential remotely operated devices defectiveness or malfunction and the offsets of cost-savings by the cost of purchasing new operating systems and sensors. Nevertheless, overall safety improvement can be gained.

The aims of this study are between exhibiting existing literature and recognizing gaps in main sectors regarding Maritime Autonomous Surface Ship (MASS) by presenting the ones covered and methodologies applied as well. Due to the increasing interest in MASS, there is significant literature approaching various issues of this subject. Several methodologies have been adopted, varying from qualitative to quantitative research approaches, considering different aspects of MASS such as technical and design requirements, influencing factors, business strategies, and others. The present paper focuses on this trend, aiming at presenting an overview of the available research studies through the last decade to identify gaps and new researchable sectors.

In more detail, the paper is structured as follows: In Section 2, based on the available literature, an effort to describe MASS with the view to its technological and design requirements occurs. From the same point of view, current projects on MASS are presented, while influencing factors that must be taken into account are given. Moreover, impacts and expectations in case of application of MASS are referred. Also, some skills and training requirements according to new data are reported. Section 3 introduces the methods for conducting a systematic literature review on the examined issues, the choice and prioritization criteria for studies. Section 4 includes the results of the review, summarized per sector and year as well. Section 5 includes conclusions and a discussion of the results with a focus on areas for further research in this field.

2. Literature Review

According to the International Maritime Organization's definition the **Maritime Autonomous Surface Ship** (**MASS**) is "a ship which, to a varying degree, can operate independently of human interaction" and for regulatory reasons MASS is divided into four degrees of autonomy with potential switching during a voyage, using a dynamic autonomy. These degrees are categorized as follow (IMO 2018):

- MASS degree of autonomy 1 (MASS 1): Ships with automated processes and decision support are included. Seafarers are on board to operate and control shipboard systems and functions; while some operations may be automated. Some systems of this classification level that are found on the existing commercial shipping vessels are Decision Support Systems (DSS) for flooding stability and survivability analysis and emergency response, the unstaffed machinery area in a combination of a centralized management system to notice engineers in case of emergency, automatic excessive bilge level alarms and pumping systems, self-acting conflagration detection and alerts and automatic commencement of emergency generators. (Goerlandt F. 2020)

- MASS degree of autonomy 2 (MASS 2): This framework consists of seafarers onboard and remotely controlled and operated ships from a different location. In this case, an uninterrupted communication and a high degree of integration of monitoring tools at a shore control center with the shipboard systems are required for a successful remote operation and control of the ship.
- MASS degree of autonomy 3 (MASS 3): Remotely operated and controlled ships by a crew based on land and no role for seafarers on the vessel. It is useful to mention that till nowadays there is not enough adeptness or awareness of remotely controlled aftereffects.
- MASS degree of autonomy 4 (MASS 4): This degree refers to fully autonomous ships that would handle all situations by themselves. These vessels are supposed to act on them and decide on strategies independently of human factors, which means a highly public risk and unpredictable social acceptability.

However, it is necessary to clarify that because of the wide-open field of research there are many other terminologies to be used instead of MASS, such as "unmanned ships", "smart or intelligent ships" and "remote and autonomous ships", and alternative classification degrees as well.

Concerning requirements in e-Navigation architectures and latest communication technologies, Hahn, Bolles, et al. (2016), argue that systems shall be competent to merge benefits of a concise situational awareness and be focused on the user, promoting navigation and operations. Further, systems need to get developed independently between them and from other subsystems while they are interacting in data exchange through safe and dependable communication connections. It is important to control the data processing on several criticality levels such as informative, managerial, and safety-related. MASS, moreover, creates new risks in the maritime sector, such as risen cyber security menace, the chance of missing connection with the contact center, or difficulties of performing maintenance throughout voyages.

A study by Chaal et al. proposes a potential framework of a hierarchical control structure of an autonomous ship. This structure consists of the system components, as referred to in the III Code. The IMO, which is responsible for the regulation on international shipping, tops in the control structure. Following the IMO, a coastal, port, or flag state as a member state, implements international regulations to ensure safety in the ship operations. Within the boundaries of the state, a national legislator through implementing international regulations serves as a maritime administrator. Also, that maritime administrator is competent to manage the port, coastal and flag state administration abided by the maritime policy of the state. In the pyramid of hierarchy, the maritime administrator is followed by the inferior controllers, which can be firms and organizations. The latter is assigned to apply national legislation in the field of their activity and function. It is this very function that indicates the proper legal form for each entity according to the maritime administration.

IMO e-Navigation strategy (IMO, 2008) displays an architecture which consists of shore-side and ship-side systems, communicating through links, and support operations such as maintenance, efficiency, security, safety as well as environmental safety. Despite the diverse regulations and standards demanded in the shore-side and the ship-side according to this approach, it is clear that human factor is vital in both sides, a fact that creates unique necessities at the human-device-interface. Most of the projects on MASS involve humans operating the ship in a Shore Control Center (SCC), whose duties may differ from the remote control to supervision.

Despite various projects are working on autonomous ships, in this paper, solely few are picked to be presented below: the Maritime Unmanned Navigation through Intelligence in Network (MUNIN) is an ongoing research on an autonomous ship concept and an assessment of its legal, economic and technical practicability. This project runs by both scientific and industrial partners and co-financed by the European Commission (MUNIN, 2016). Moreover, the ReVolt is an unstaffed, short-sea ship vessel with zero emissions, which is being developed by DNV GL. A model-scale ship 1:20 has been designed and used as a test platform in interplay with the Norwegian University of Science and Technology (NTNU) (Alfheim and Muggerud, 2017). Another partnership, this between Yara and Kongsberg, has led to the Yara Birkeland vessel, the first zero-emission autonomous and fully electric container feeder worldwide. The Yara Birkeland was launched to sea in Romania in February 2020 while it is expected to change from manned operation to fully autonomous by 2022. (Kongsberg, 2020).

Navigation is operated completely by humans over the ages, so it is dependent on individual crew's education and experience. Thus, the subjective navigation factor may drive to collisions, even though humans are more effective in navigating compared to intelligent systems. However, current onboard technologies, such as Global Positioning System (GPS), Radar, and Automatic Radar Plotting Aid (ARPA), come intending to provide further navigation data and lessen failures related to the subjective human nature. The above technologies will lead to an intelligent navigation system that will be able to arrange the near-optimal course for a safe and efficient voyage. In the more distant future, human supervisors will be unnecessary as more intelligent navigation machines will be designed. It is understood that the key to become the autonomous navigation systems entirely applicable is the decrease of the uncertainness level of the intelligent machines compared to human-based navigators (Statheros et al., 2008). Insurance businesses are commonly unwilling to provide cover for these classes of ships for this very parameter (Naeem et al., 2012).

Moreover, approaching the economic domain and especially as regard control, the employers need to measure and monitor both the skills and efforts of the employees on the job and consequently compensate them. The most effective control mechanism is one that explicitly assesses employees at the lowest potential monitoring and measurement costs; the transaction costs. Given that employees agree to act on behalf of the employer. However, significant control obstacles stand in the contractual relationship between employer and employee. Measurement and monitoring can be costly, and their outcomes may be ambiguous. This vagueness occurs due to hidden performance and hidden information. Firstly, it is uncertain if the supervisor misrepresents information, and further, the employer may not identify if employees behave in their duties. These problems arise when there is complexity, as tasks become less visible and the supervisor may not realize the behavior of employees who use complex skills in their jobs. Under such circumstances, it serves more advantages to manage an autonomous ship instead of the common vessel types (Kowtha, 1998).

The choice of an autonomous ship has many more motives. First of all, removing constraints on the ship layout such as deckhouse and crew's accommodation means cost and weight reduction and space increase resulting in higher deadweight as well as more cargo carriage (Jokioinen, 2016). From the same view, smaller hulls can be built to serve short or medium voyages, replacing even other transport modes and offering flexibility to the supply chain (Rødseth, 2017). Furthermore, according to Allianz Global Corporate & Specialty annual review (2017), safer accessibility to likely dangerous seas can succeeded as well as a reduction in the total amount of piracy cases, given that there will be no crew to be utilized for ransom leverage. Unmanned ships may further attend fewer deaths and injuries in case of an accident. Additionally, autonomous ships can positively contribute to green maritime, decreasing fuel consumption or operating on electric battery power.

The Institute of Marine Engineering, Science and Technology (IMarEST) in April 2018 published a report based on a survey and a round-table discussion with 600-plus participants and some industry leaders. Among the survey results, it is worth mentioning that:

- half of the participants claim that they would make the change to remote and autonomous ships.
- the change would be based concurrently on three elements:
  i) improved efficiency
  ii) increased levels of safety
  iii) lowered operational costs.

This statement strengthens by almost an equal number with the prospect of creating a competitive ground for shipping firms adopting autonomous technology. At the same time, over 40% of the respondents believe that the shipping industry is not ready to implement the operation of autonomous ships while there are many obstacles to the full adoption of these operations and that more searches would have to be achieved. Unexpectedly, precisely the same answers are given about the levels of industry efficiency after the replacement of human operators onboard with machines. On the other hand, there are only a few who agree with the point that this change would lead to a safer industry. Worries are born in the most of seafarers, calculated to the 76.06% of the survey participants, about the impact of autonomous ships on their sector because many onboard roles could be relocated to the shore now or in the foreseeable future according to 45.53% of the respondents who agree to this sentence. Finally, approaching the education and skills sector, a total amount of 89.07% of participants demonstrate a need for reformation in the current sea and shore-based training to be ready for the remote operation of autonomous ships. Also, 85% of those surveyed support that seafarers' skills will remain an essential component in the long-term future of the shipping industry and 63.74% that seafarers could be trained to handle the remote operation of autonomous ships.

Wahlström et al. (2015) have tried to recognize related "human factors challenges and opportunities" in remote control in industries that are more familiar with in situ and immediate decision making and operation and compare them to the maritime domain. The chosen industries were cars, subway transit, aviation, container cranes, military and forestry. These challenges and opportunities reported below:

- *Cars*
    - The behavioral adaptation phenomenon might imply seriously weak safety margins as the remote operators are not themselves in any real risk.
    - In lack of manual navigation, skill degradation can follow and that is why would have to be an expert team, with the skill to the traditional seafaring.
    - A need for profound local knowledge in the form of seasoned experts occurs.
- *Subway transit*
    - There is a need for human perception through the shore control center of the implicit purposes of other ships avoiding possible agitators.
    - A must for view sharing between authorities and shore control centers during emergencies arise, for example, the video feed from the vessels.
- *Aviation*
    - Seasickness could eliminate by using autonomous ships.

    - The operators can gain functional specialization while they can be geographically separated.
    - There might notice boredom in the personnel.
    - Accidents may happen during changeovers and handoffs and directly or indirectly might cause episodes.
    - There is an absence of feel of the vessel, meaning engine noise, physical perception of the orientation, and face-to-face weather conditions. This sense could be given to the shore control center allowing new challenges with the combination of different information and reducing the level of boredom simultaneously.
- *Container cranes*
    - At shore control centers, when remotely controlling multiple vessels, the flow of several duties could be remarkable, leading to a continuous reorientation.
    - The issue of the deteriorated sense of spatial dimensions in the video and the need for a stereo vision must be taken into account when in the shore control center design.
- *Military*
    - The autonomous ships and the shore control centers could join a more extensive network of actors, so they would exchange all the accessible data (e.g. video feeds) that could be useful to the authorities in case of crisis.
    - Another matter that has to take into consideration in the shore control center design and its responsibilities is the differentiation between pirates and help-seekers.
    - Provided that the unmanned ships would be meant to take part in rescue actions and be communicative, they have to be characterized by sympathy and compassion towards their surroundings.
- *Forestry*
    - The unmanned vessels need to estimate whether to avoid an object, such as boats or ignore it, such as wood. Furthermore, the shore control center

has to be prepared to assess the ice condition and if an ice breaker may be needed.

In the sequel, a framework based on MASS 3 was created to recognize factors that affect the remotely navigational risk and operational phases that may be experienced. The four operations that were selected were; the voyage planning, the berthing and unberthing, the port approaching and departing, and the open sea navigation. Additionally, regarding the factors, 23 human-related, 12 ship-related, 8 environment-related, and 12 technology-related were identified. Therefore, this paper focuses on human-related ones that provide about 42% of all known factors that impact navigational safety according to the final results. It is also useful to mention that open sea navigation is the phase with the highest amount of risk influencing factors. The 23 human-related risk influencing factors were categorized in the below six groups: 1) cognitive aspect, 2) psychological aspect, 3) errors, 4) situational awareness, 5) experience and training, and 6) cooperation. Then, they were correlated to the four phases of an ocean-going voyage (Fan et al., 2020).

Following the human factor issues, situational awareness is "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1988). Situational awareness is an influential actor for the ocean-going voyage and it may be tough to be sustained sufficient during simultaneous remote control of different ships. Man et al. (2015) study on "human factor issues in remote monitoring and controlling of autonomous unmanned vessels" based on a scenario of a virtual onshore system model noted that there occur differences in situational awareness requirements when relocating the entire monitor and command ashore.

Regarding the differences, they arise from difficulties in attaining adequate situational awareness by the operator. Respectively the gap in organizational hierarchy and regulations also prevent the situational awareness. Reasoning these sentences it could be said that the physical distance from the ship and extra issues related to highly automated conditions and inappropriately structured organizational hierarchy are the obstacles for a sufficient situational awareness. With insufficient situational awareness, a remote operator's psychological gap to the real sea situations may be increased, which can undoubtedly shift out of the loop, and the supervisor might miss to understand vessel sense or preserve harmony. These effects, going on, worsen the performance of the remote supervisor.

Nevertheless, the inadequate situational awareness may be partially counterbalanced by feedback from the vessels, or by good seamanship, which is related to operator experience, skills, education, and training. According to the approach before, if there are inefficient experience, knowledge or skills, weak operator's decisions are expected in a remote or shore control center. So, either seafarers with experience, knowledge, and skills could be hired for the operator position, or sufficient training must be provided. On the other hand, not only proper training but an adaptation and specific technology analysis must be considered for the education of a seafarer to design a harmonic shore control center (Fan et al., 2020).

To emphasize the need for reformation of the maritime education system, Cheng and Ouyang's (2020) study on the development of strategic policy for autonomous ships is summarized below. The decision matrix was chosen as the method for evaluation of cost-benefit, as it constitutes the most simplistic, and offers to the review of programs for maritime education system reformation, autonomous ship technological progress, and autonomous ship legislative amendments. This study established four different assessment indicators: financial resources, time, effectiveness, and administration. Furthermore, survey techniques are used for the evaluation of each assessment indicator. According to the results, the program of autonomous ship technological development held the highest score. However, the program for maritime education system reformation holds the second position over the third one, which belongs to the program for autonomous ship legislative amendments. Consequently, the result indicates the importance of this sector in developing strategic policy. Proper education institutions have to be established to guide the development of the unmanned-ship industry. Technological changes must also be encouraged, especially for the development of autonomous ship monitoring and navigation technology.

It is noticeable that the maritime industry is experiencing high evolution and automation is becoming more popular on ships. With proper design and well-trained staff, automation can be proven valuable in safety and operational performance. Still, with faulty design or misuse by under-trained or untrained staff, automatic equipment can be a contributory reason for collisions. Maritime education and training should take advantage of the significant developments in information technology, computing, and simulation. Ship simulators are more applied in maritime institutions as a worthwhile asset for training methods. This application is also endorsed by the STCW 87/95 Convention. Some fundamental limitations of this technology are simplifications and graphical presentations of machinery systems. As a consequence, a trainee with excellent education of simulator operation can face difficulties, essentially because the schematic presentation and operating system are different from the real one. For this purpose, companies of ship simulators and computer-based training (CBT) applications have established a tridimensional schematic system's design to present a machinery modulation that is potentially closer to actuality. The main challenge in the manufacturing of 3D simulators is to provide precise navigation through the elements of the system. It is likely though to apply zoom procedures for the selected system's elements. Users of 3D simulators can also observe the system's elements from various angles (i.e. front, side, etc) (Žižić et al., 2010).

Automation is probably the most affecting technological evolution to the seafarers' profession both by number and skill as well as shipboard social structure and lifestyle. Inevitably, the passage to shipping automation and the increasing adoption of robotics in shipping will happen. New technologies in the maritime industry make processes more manageable or even reduce the necessity for conducting everyday tasks, thus making some of the common skills unnecessary. Automation on sea-going vessels decreases the need for ratings on deck and engine personnel but raises the demand for officers. As it is evident, new requirements arise when it comes to knowledge and additional skills in managing multiple operations and devices, processing a volume of information, developing new communication skills, and reacting quickly to new challenges and regulations. This reformation must be approached with extreme but trained attention. On one hand, it gives opportunities, challenges and risks, but on the other hand, it obliges efficient actions to be taken instantly to secure that there will not accrue undesirable difficulties, opportunity and financial loss along with anxiety in practice. It can also aid the improvement of the level of shipping services and the skills of the shipping personnel, counter to irreversible failures that it can lead (Frankel, 1983).

It is quite clear that the development of the maritime industry and the technological evolution on-board have improved and they are still in progress. These technologies, such as GPS and ECDIS, relate navigation more to shore. It could be said that the main challenges the seafarers' profession faces globally are the small number of skilled seafaring personnel and the difficulty in the forecast of expected skill needs following the digitization and automation. Additionally to minimum STCW requirements, coming MASS operators will have to improve specific competencies, i.e. knowledge and skills in various fields, such as communication theory and skills, legislation, maths, robotics, and computer science. Hence, another challenge occurs in building training programs that cover these future requirements and needs. Possibly the most desirable education system is within specialized university studies designed for this goal (Lušić et al., 2019). In this scope, mandatory updating courses need to be structured and offered by MET institutions or by mixed agencies.

The entire development of new technologies affects the Maritime Education and Training (MET) method. One of the most significant aims for MET is to build a more scientific and flexible educational background, to enable MET bachelors to adjust themselves rapidly and efficiently to the evolution of new technologies. The main features of MET can be grouped into organizational and operational aspects. Regarding the organizational aspects, it is recommended that MET institutions have to include simulation facilities to offer the experience of reality in a simulated way, computing facilities such as computers, Internet and audiovisual, and workshops and laboratories for cargo handling and diesel engine labs. All the above would help to a "quality system" with "systematic monitoring" and "external audit". On the other hand, the operational aspects of MET have to focus on educational subjects, meaning psychological issues (e.g. leadership and motivation), training ones, skills (physical and mental abilities), and knowledge (awareness of data) as well. The most important subjects that need reformation are automation, data communication, computing, safety, and the environment. In this scope, mandatory refreshing courses need to be structured and offered by MET institutions or by mixed businesses (Mazzarino and Maggi, 2000).

The final selection of technology is dependent on the availability of qualified manning or education for the crew. This is closely related to the choice of flag and rules for manning required by the ship registry. Although IMCO has undertaken an enterprise to set some uniformity (or at least minimum standards of education and manning), there occur yet large variations in requirements, and more importantly, there also are inequalities in the performance and quality of crews.

Moreover, it is essential to determine the source of prospective operators of fully autonomous ships. One thought is that they will be the current onboard administrators, i.e. skilled masters, who will need to complete adequate training courses. But, recruiters can also choose staff that fundamentally trained in remote control processes and have attained sufficient STCW courses. So, the choice is among engine or deck administrators of the highest marine ranks, information engineering staff or technical graduates who will gain additional requalification according to STCW guidelines, or professionals with competent academic degrees who will achieve technoscientific training for autonomous ship operation. The professional development of seafarers is a joint responsibility of maritime academies and training institutions, associations, marine licensing authorities, the International Maritime Organization (IMO), operating firms, and the seafarer. Seafarers' competencies are supervised and maintained either through professional development practices by individuals and their employers, or through marine licensing by regulatory authorities, and the demonstration of accountability for performance according to established disciplines (Žižić et al., 2010).

At this point, it is worth mentioning that the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) in 1978 is one milestone in the development of the seafarer's education sector. The STCW Convention came into effect in 1984 and then it sets minimum qualification standards for masters, officers, and watch personnel on seagoing vessels and the elemental level of education, certification, and watchstanding as well. The newest notable reformations to this Convention are Manila Amendments and were adopted in 2010 and entered into force on 1 January 2012 (IMO, 2011).

Another evidence for the value of education is that the application of training processes represents a meaningful and powerful instrument of development and growth in the business industry which supports the companies in successful interaction in an unstable entrepreneurial environment. In most companies, entrepreneurial and management training projects and human resource growth seem to assume a crucial part in maintaining a firm competitive and profitable. For successful entrepreneurial growth, the management team needs to develop steadily new skills, following corporate development. By training process, the managers' competence may be improved, while the importance of training as a significant factor for the company's growth may be recognized. Investment in management training and development can advocate the firms to proceed with necessary organizational changes to grow up. Though unfortunately, many firms and notably small and medium-sized enterprises (SMEs) do not include training in their business planning procedures, because of limited sources of finance and their priorities in other sectors. Owners of small companies mind training not as an investment but more as a running cost, while managers are more doubtful about the advantages of training. At the same time, SMEs face difficulties to identify and choose the training program they necessitate from the plenty of selections (Evangelista and Morvillo, 1998).

As a result of automation on sea-going vessels, the need for ratings in the engine room and on deck decreases, while the demand for officers increases, driving to a redefinition of their roles and duties. One method of improving the supply-and-demand balance is by retraining ratings with a view to promotion to officer rank. Relevant recommendations were proposed lately by organizations carrying out reforms in maritime labor and retraining projects were submitted in numerous European nations, in some of which (e.g. Germany, Finland, Denmark) ratings form the majority of candidates for office personnel.

On the other hand, individuals' factors occur which determine the zeal for retraining or not. Results of Erez's (1978) study indicate that most of the individuals willing to be retrained were more youthful and more likely to be unmarried than their unwilling counterparts and with a post-primary or nautical academy education, as against a primary or vocational one for the last. However, no more personal data of these two groups, for example, origin and job experience, seems to influence the willingness for retraining.

3. Methodology

In this section, the data collection method implemented for this study is elaborated. The approach of this paper is based exclusively on a review of accessible academic literature. The current academic literature is characterized by extensive research activity and considerable work as regard to Maritime Autonomous Surface Ship (MASS), despite the relatively recent timeline of the introduction of this idea with a thought for development.

Literature was collected through various sources by establishing search criteria linked to technology and communications, human and other factors, and education and training with regard to MASS. To gain access to the most appropriate data and simultaneously restrict the results of the entire search, key-words such as automated/ autonomous/ unmanned/ unstaffed/ intelligent/ remotely-operated/ shore-based ships/ vessels, MASS (Maritime Autonomous Surface Ship), training/ education, certification/ certificates, skills, training method, AI (Artificial Intelligence), and ICT (Information and Communication Technologies) were applied. As it has already been clarified in the literature review section, it was essential to widen the search vocabulary because of the range of research fields and the variety of terminologies.

After that, papers highly relevant to the criteria of the search were chosen for in-depth review. To select the most relevant literature to this study, the following literature sources have been utilized: Science Direct, Palgrave Macmillan, Taylor and Francis online, Emerald publishing, Elsevier, IEEE, official websites, and minutes of international conferences related to the maritime industry. The criteria for paper selection among these research results are that a study or an article is written in English and its subject is related to MASS technology and communications, human and other factors, and education and training. Still, other relevant articles or studies may exist but yet unavailable and they should not be excluded. The reason why those papers are not available is that they might be written in other languages or they have been published in inaccessible sources.

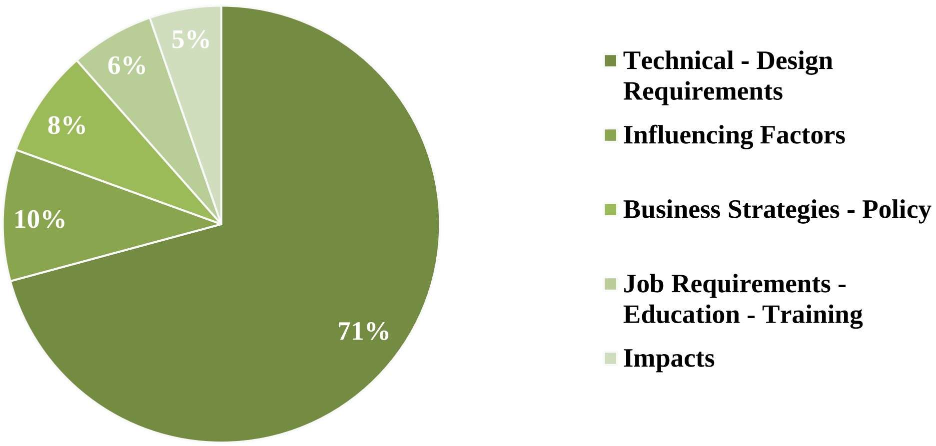
In the beginning, an amount of more than 140 publications was picked. Even though the search tactics were the same during the search process in diverse sources, many articles reported on irrelevant topics, and also the same articles were approached through different sources. Next, the study of these papers separately became necessary. Ultimately, about 115 papers comprising journal articles, reports, and conference minutes composed mainly between 2010 and 2020, were selected as highly appropriate for the objective of this study. In light of these 115 examined papers, it is apparent that influencing factors, business strategies and policy, impacts, and requirements, education and training as well are the most challenging and important sector in the scope of the development of MASS.

This review of the relevant literature assists two purposes. First, it helps to understand and learn about the latest technologies that lead to the future of the maritime industry and their consequences on the job roles and duties in maritime. Secondly, it provides the grounds for the present research by recognizing gaps in the existing literature, which the study intends to address. The review has revealed that there are numerous studies examining MASS and its potential aspects in case of adoption but, therefore there is a limited or even minimum quantity of papers that describe the methods of practice in reforming the existing training programs or regulations. Despite gaps in these specific regards, the literature affords extraordinary penetrations into enhancing knowledge and skills.

4. Results

In this section, an effort to a data analysis of the existing literature occurs on Maritime Autonomous Surface Ship (MASS) during the last decade, namely between 2010 and 2020. For the sake of analysis, all studies are separated into five main domains: (i) Technical and Design Requirements, (ii) Influencing Factors, (iii) Business Strategies and Policies, (iv) Job Requirements, Education and Training, and (v) Impacts. At a first glance, a small number of studies on this topic exist between 2010 and 2017. From 2011 onwards the first approaches to simulation and navigation are noticed, focusing on small vessels. It is also worth mentioning that as regards to the term Maritime Autonomous Surface Ship (MASS) appears in academic research in 2018.

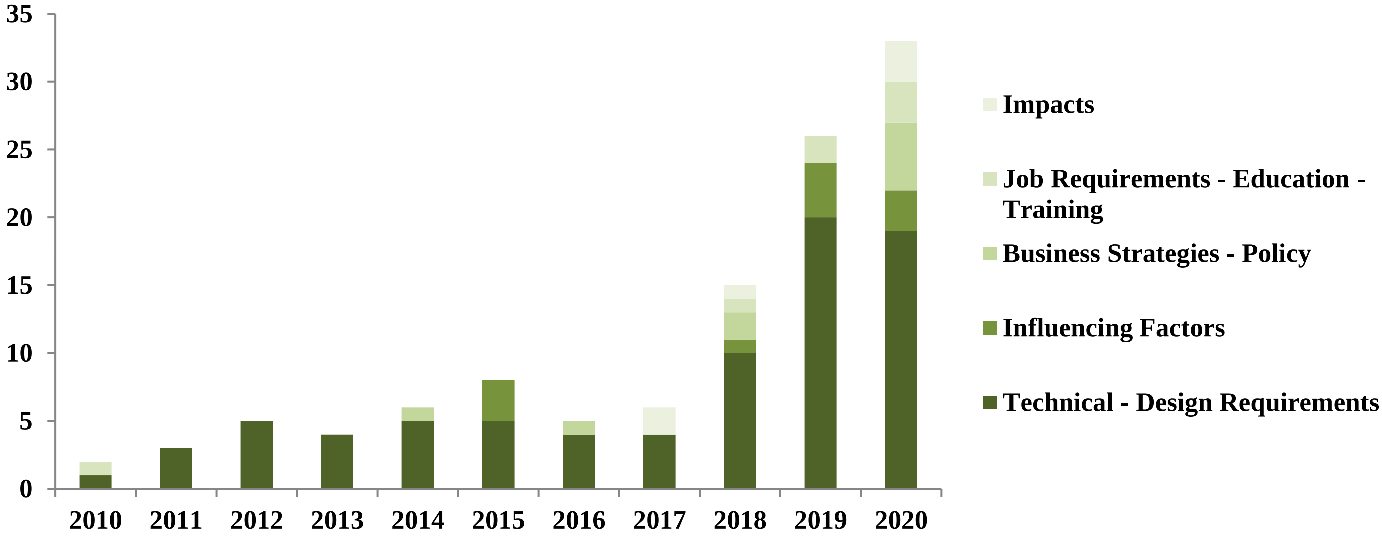
Figure 1 Studies per sector



Source: Author

According to Figure 1, the vast amount of the existing literature concerns the theme of Technical and Design Requirements for MASS. The percentage reaches 71%. The rest of the sectors lag behind in the literature. Specifically, altogether cover a total of 29% of the existing literature. Studies related to Influencing Factors, Business Strategies and Policies, Job Requirements, Education and Training, and Impacts cover 10%, 8%, 6%, and 5% respectively.

Figure 2 Studies evolution per year



Source: Author

Figure 2 illustrates the studies per category as these have defined for the purposes of this study.

As seen one research was performed in **2010** on technological and design requirements and one on job requirements. In the next three years: **2011**, **2012** and **2013**, research is only done on technical issues, numbering three, five and four each year, respectively. In **2014**, five papers were published on technical and design criteria and one on business strategy and policy. In **2015**, a total of eight studies, five on technicality, and three on influencing factors, were estimated. A decline was observed in **2016** to a total of five papers, four articles on technical and design requirements, and one on strategy and policy. Subsequently, four publications on technical and design issues were circulated in **2017** and two were circulated on the effects of autonomous ships. An increasing number of fifteen studies were performed in **2018**, evaluating ten on technical and design requirements, two on business strategies, one on factors that influence, one on impacts, and one on job and training requirements. In addition, twenty studies in the technical sector in **2019** are counted, four on influencing factors, and two on education and job requirements. In **2020** nineteen articles on technical and design requirements, five on business strategies and policy, three on influencing factors, job requirements, training and education, and impacts as well were compiled, that is a sum of thirty-three papers. All the above elements are presented in Table 1.

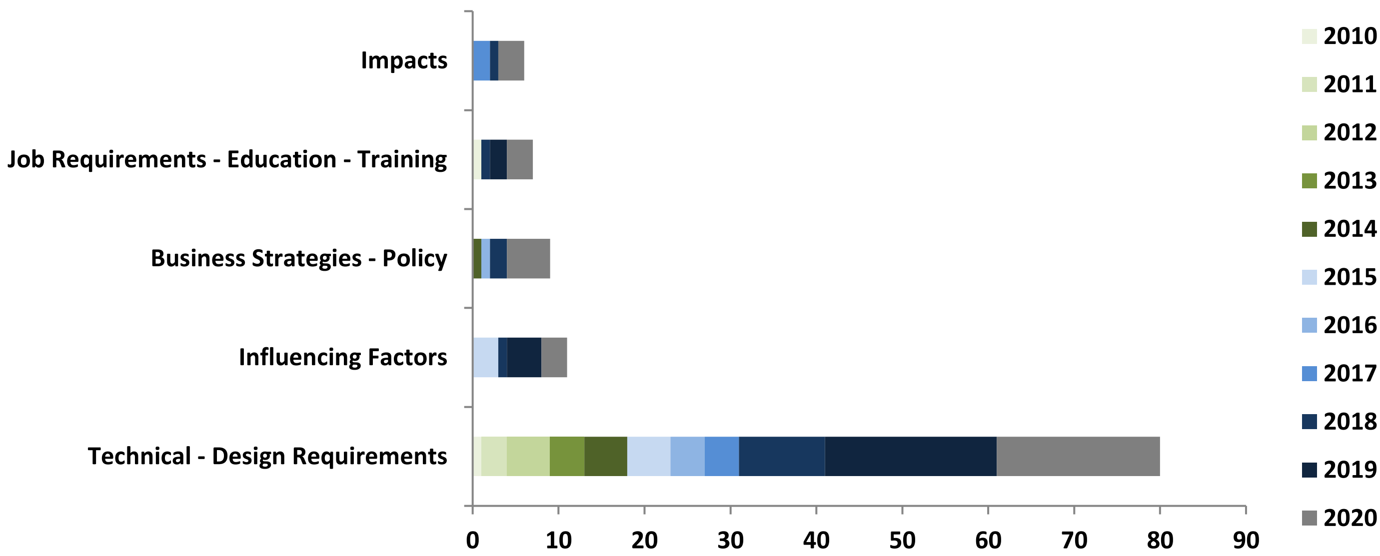
Table 1 Categorization of studies and year

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	**Total/ section**
Technical - Design Requirements	1	3	5	4	5	5	4	4	10	20	19	**80**
Influencing Factors	-	-	-	-	-	3	-	-	1	4	3	**11**
Business Strategies - Policy	-	-	-	-	1	-	1	-	2	-	5	**9**
Job Requirements - Education - Training	1	-	-	-	-	-	-	-	1	2	3	**7**
Impacts	-	-	-	-	-	-	-	2	1	-	3	**6**
Total/ year	2	3	5	4	6	8	5	6	15	26	33	**113**

Source: Author

Once more, it is apparent that the focus of the academic community over the last decade has been the subject of Technical and Design Requirements. The available literature increased significantly in 2017 and has boomed in the last two years. In addition, it is apparent these in these last three years there has been a broader interest in the MASS industry, which different areas of interest. The comprehensive literature on Technical and Design Requirements can determine the feasibility of MASS and provide the seed for further research in other areas. That is why an increasing number of articles on Business Strategies and Policies, on the one hand, and Influencing Factors, on the other, can be observed from 2018 onwards.

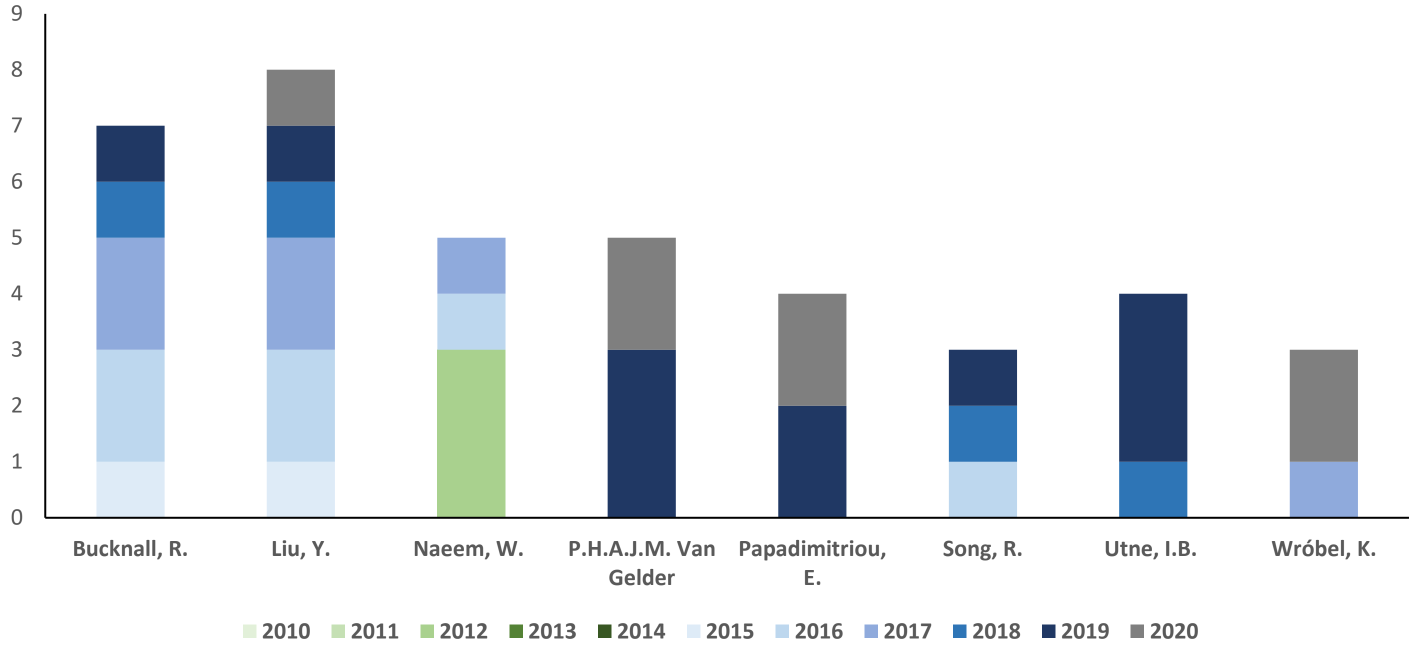
Figure 3 Studies evolution per sector



Source: Author

It is also indicative that in Figure 3 the number of articles published between 2018 and 2020 on Technical and Design issues has reached forty-nine, while in the same period eight studies regarding Influencing Factors and seven regarding Business Strategies and Policy have been issued. The publications in the other fields of interest remain at a low number not only in the last three years but throughout the decade as well. It is probable that the more the literature evolves, more research concerning other aspects of MASS will be conducted, leading to the realization of Autonomy in Maritime.

Figure 4 Studies per author



Source: Author

With regards to the authors, it would be important to refer to the most prolific in the studies of the last decade, as shown in Figure 4. In more depth, eight publications were composed by Liu and several of them co-authored with Bucknall, and Song. These are reported as follows: Path planning algorithm for unmanned surface vehicle formations in a practical maritime environment (Liu and Bucknall, 2015), A multi-layered fast marching method for unmanned surface vehicle path planning in a time-variant maritime environment (Song et al., 2016), The angle guidance path planning algorithms for unmanned surface vehicle formations by using the fast marching method (Liu and Bucknall, 2016), Efficient multi-task allocation and path planning for unmanned surface vehicle in support of ocean operations (Liu and Bucknall, 2017), The fast marching method based intelligent navigation of an unmanned surface vehicle (Liu et al., 2017), Smoothed A* algorithm for practical unmanned surface vehicle path planning (Song et al., 2018), Intelligent multi-task allocation and planning for multiple unmanned surface vehicles (USVs) using self-organising maps and fast marching method (Liu et al., 2019), and Psychophysiological evaluation of seafarers to improve training in maritime virtual simulator (Liu et al., 2020). Naeem is the author of five papers on collision avoidance and COLREGs: A review on improving the autonomy of unmanned surface vehicles through intelligent collision avoidance manoeuvres (Campbell et al., 2012), A rule-based heuristic method for COLREGS-compliant collision avoidance for an unmanned surface vehicle (Campbell and Naeem, 2012), COLREGs-based collision avoidance strategies for unmanned surface vehicles (Naeem et al., 2012), A reactive COLREGs-compliant navigation strategy for autonomous maritime navigation (Naeem et al., 2016), and COLREGs-compliant path planning for autonomous surface vehicles: a multiobjective optimization approach (Hu et al., 2017). Five studies has been conducted by P.H.A.J.M. Van Gelder and three of them by Papadimitriou as well: Global path planning for autonomous ship: A systemic hazard analysis and management process for the concept design phase of an autonomous vessel (Valdez Banda et al., 2019), Influence of environmental factors on human-like decision-making for intelligent ship (Xue et al., 2019), Multi-attribute decision-making method for prioritizing maritime traffic safety influencing factors of autonomous ships' maneuvering decisions using grey and fuzzy theories (Xue et al., 2019), Global path planning for autonomous ship: A hybrid approach of Fast Marching Square and velocity obstacles methods (Chen et al., 2020), and Collision risk measure for triggering evasive actions of maritime autonomous surface ships (Huang and P.H.A.J.M. Van Gelder, 2020). Utne has conducted four articles regarding risk control and human factor: Assessing ship risk model applicability to Marine Autonomous Surface Ships (Thieme et al., 2018), Collision avoidance on maritime autonomous surface ships: Operators' tasks and human failure events (Ramos et al., 2019), Human-system concurrent task analysis for maritime autonomous surface ship operation and safety (Ramos et al., 2019), and Towards supervisory risk control of autonomous ships (Utne et al., 2019). Finally, Wróbel has written the below three studies: Towards the assessment of potential impact of unmanned vessels on maritime transportation safety (Wróbel et al., 2017), A framework to identify factors influencing navigational risk for Maritime Autonomous Surface Ships (Fan et al., 2020), and Identifying research directions of a remotely-controlled merchant ship by revisiting her system-theoretic safety control structure (Wróbel et al., 2020).

Additionally, an effort to present the applied methods for each study has been made. For this reason, special tables have been created to offer a clearer view of the methods.

These tables consist of five major columns. The first column includes the title of each study, the second one the year of composition, and in the third refers to the authors. The last two main columns document the methods, which are divided into two main categories: the Quantitative and the Qualitative ones. The quantitative methods are further subdivided, as shown in the following tables, in (i) Statistics, (ii) Mathematics, and (iii) Simulation. Statistics refers to questionnaires, surveys, and statistical analysis, while Mathematics is mostly about algorithms used for study and experimentation purposes. The qualitative methods therefor include (i) the Literature Review, (ii) the Case Study, (iii) the Interview, or (iv) other.

The following tables indicate that some of the studies only employ quantitative methods. For example, in Table 2’s mentioned study "The review unmanned surface vehicle path planning: based on multi-modality constraint", only Mathematics is used. Qualitative methods are used in other works, as seen in "Components for smart autonomous ship architecture based on intelligent information technology" (Table 2), which is based on Literature Review. Papers using either quantitative or qualitative methods combine more than one sub-method in the same group. For instance, in "Assessing ship risk model applicability to marine autonomous surface ships" (Table 2), both Literature Review and Simulation methods are used to obtain data. It may also be argued that certain studies marked by a degree of further complexity employ both quantitative and qualitative methods. For example, the paper "A rule-based heuristic method for COLREGS-compliant collision avoidance for an unmanned surface vehicle" (Table 2) employs Mathematics and Simulation as components of the research methodology.

With regards to the subject of Technical and Design Requirements, analyzing Table 2 shows how some qualitative or quantitative methods are employed more often than others. Mathematics and Simulation are clearly favored across various studies. When it comes to Influencing Factors and Impacts of MASS, Table 3 and Table 6 indicate that the relative papers seem to favor the literature review as a method on which to base research papers. As far as the theme of Business Strategies and Policy is concerned, Table 4 clarifies that no one method is favored over others. Finally, Table 5 on the subject of Job Requirements, Education and Training, indicates that the academic community most frequently opts for Literature Review and Mathematics.

Adding a cautionary note, it may be argued that the total amount of papers concerning fields other than Technical and Design Requirements is short, and therefore, conclusions on the preference of a certain method over others could be dismissed as premature.

Table 2 Methodology in technical and design requirements studies

Title	Year	Authors	Quantitative Methodology			Qualitative Methodology			
			Statistics	Mathematics	Simulation	Literature Review	Case Study	Interview	Other
Virtual and Augmented Reality for the Maritime Sector – Applications and Requirements	2010	Uwe Freiherr von Lukas				✔			
Automatic Simulation of Ship Navigation	2011	Yanzhuo Xue, D. Clelland, B.S. Lee, Duanfeng Han		✔	✔		✔		
COLREGs-based Collision Avoidance Strategies for Unmanned Surface Vehicles	2011	Wasif Naeem, George W. Irwin, Aolei Yang		✔	✔				
Motion Planning of USV Based on Marine Rules	2011	Jia-yuan Zhuang, Yu-min Su, Yu-lei Liao, Han-bing Sun		✔	✔				
A Navigation and Control Platform for Real-Time Manoeuvring of Autonomous Ship Models	2012	L. P. Perera, L. Moreira, F. P. Santos, V. Ferrari, S. Sutulo, C. Guedes Soares				✔			
A Review on Improving the Autonomy of Unmanned Surface Vehicles through Intelligent Collision Avoidance Manoeuvres	2012	S. Campbell, W. Naeem, G.W. Irwin				✔			
A Rule-based Heuristic Method for COLREGS-compliant Collision Avoidance for an Unmanned Surface Vehicle	2012	S. Campbell, W. Naeem		✔	✔				
Application of Widget-based Consumer Programming Techniques in Autonomous Marine Vehicle Control System Design	2012	Zvonimir Pavlic, Tomislav Lugaric, Sinisa Srbljic, Zoran Vukic		✔					
Ship Trajectory Tracking in Harbour Area by Using Autonomous Tugboats	2012	Van Phuoc Bui, Sang Won Ji, Ji Seong Jang, Young Bok Kim		✔	✔				
A user test of Automatic Navigational Intention Exchange Support System using an intelligent ship-handling simulator	2013	Rina Miyake, Junji Fukuto, Yasuyuki Niwa, Makiko Minami			✔				
Design of a Twin Hull Based USV with Enhanced Maneuverability	2013	Michael Blaich, Stefan Wirtensohn, Markus Oswald, Oliver Hamburger, Johannes Reuter		✔	✔				
Knowledge Discovery Using Genetic Algorithm for Maritime Situational Awareness	2013	Chun-Hsien Chen, Li Pheng Khoo, Yih Tng Chong, Xiao Feng Yin		✔			✔		
Metric Assessment of Autonomous Capabilities in Unmanned Maritime Vehicles	2013	Carlos C. Insaurralde, David L. Lane	✔						
Autonomous Unmanned Merchant Vessel and its Contribution towards the e-Navigation Implementation: The MUNIN Perspective	2014	Hans-Christoph Burmeister, Wilko Bruhn, Ørnulf Jan Rødseth, Thomas Porathe				✔			
Capability-oriented Robot Architecture for Maritime Autonomy	2014	Carlos C. Insaurralde, Yvan R. Petillot			✔		✔		
Development of Collision Avoidance Algorithms for the C-Enduro USV	2014	A. Savvaris, H. Niu, H. Oh, A. Tsourdos		✔	✔				

Table 2 (continued) Methodology in technical and design requirements studies

Title	Year	Authors	Quantitative Methodology			Qualitative Methodology			
			Statistics	Mathematics	Simulation	Literature Review	Case Study	Interview	Other
Neural Anti-collision System for Autonomous Surface Vehicle	2014	Tomasz Praczyk		✔	✔				
Trajectory Tracking of Autonomous Vessels Using Model Predictive Control	2014	Huarong Zheng, Rudy R. Negenborn, Gabriel Lodewijks		✔	✔				
A Real-time Collision Avoidance Learning System for Unmanned Surface Vessels	2015	Yuxin Zhao, Wang Li, Peng Shi		✔	✔				
Development of USV Autonomy for the 2014 Maritime RobotX Challenge	2015	Minju Kang, Sungchur Kwon, Jeonghong Park, Taeyun Kim, Jungwook Han, Jeonghyeon Wang, Seonghun Hong, Yeonjoo Shim, Sukmin Yoon, Byunghyun Yoo, Jinwhan Kim		✔					
Experimental Evaluation of Automatically-generated Behaviors for USV Operations	2015	Ivan R. Bertaska, Brual Shah, Karl von Ellenrieder, Petr Švec, Wilhelm Klinger, Armando J. Sinisterra, Manhar Dhanak, Satyandra K. Gupta		✔	✔				
Path Planning Algorithm for Unmanned Surface Vehicle Formations in a Practical Maritime Environment	2015	Yuanchang Liu, Richard Bucknall		✔	✔				
Ship Seakeeping Operability, Motion Control, and Autonomy - A Bayesian Perspective	2015	Tristan Perez		✔					
A Multi-layered Fast Marching Method for Unmanned Surface Vehicle Path Planning in a Time-variant Maritime Environment	2016	Rui Song, Yuanchang Liu, Richard Bucknall		✔	✔				
A Reactive COLREGs-Compliant Navigation Strategy for Autonomous Maritime Navigation	2016	Wasif Naeem, Sable C Henrique, Liang Hu		✔	✔				
Requirements for e-Navigation Architectures	2016	Axel Hahn, Andre Bolles, Martin Fränzle, Sibylle Fröschle, Jin Hyoung Park				✔			
The Angle Guidance Path Planning Algorithms for Unmanned Surface Vehicle Formations by Using the Fast Marching Method	2016	Yuanchang Liu, Richard Bucknall		✔	✔				
Adaptive Control for a Class of Partially Unknown Non-Affine Systems: Applied to Autonomous Surface Vessels	2017	Ali Haseltalab, Rudy R. Negenborn		✔	✔				
COLREGs-Compliant Path Planning for Autonomous Surface Vehicles: A Multiobjective Optimization Approach	2017	Liang Hu, Wasif Naeem, Eshan Rajabally, Graham Watson, Terry Mills, Zakirul Bhuiyan, Ivor Salter		✔	✔				
Efficient Multi-task Allocation and Path Planning for Unmanned Surface Vehicle in Support of Ocean Operations	2017	Yuanchang Liu, Richard Bucknall		✔	✔				
The Fast Marching Method Based Intelligent Navigation of an Unmanned Surface Vehicle	2017	Yuanchang Liu, Richard Bucknall, Xinyu Zhang		✔	✔		✔		
A COLREGs-based Obstacle Avoidance Approach for Unmanned Surface Vehicles A COLREGs-based Obstacle Avoidance Approach for Unmanned Surface Vehicles	2018	Yanlong Wang, Xuemin Yu, Xu Liang, Baoan Li	✔	✔	✔				

Table 2 (continued) Methodology in technical and design requirements studies

Title	Year	Authors	Quantitative Methodology			Qualitative Methodology			
			Statistics	Mathematics	Simulation	Literature Review	Case Study	Interview	Other
A Two-level Dynamic Obstacle Avoidance Algorithm for Unmanned Surface Vehicles	2018	A. Lifei Song, B. Yiran Su, C. Zaopeng Dong, D. Wei Shen, E. Zuquan Xiang, F. Puxiu Mao		✔	✔				
Adaptive Cooperative Formation Control of Autonomous Surface Vessels with Uncertain Dynamics and External Disturbances	2018	Yu Lu, Guoqing Zhang, Zhijian Sun, Weidong Zhang	✔	✔	✔				
Assessing Ship Risk Model Applicability to Marine Autonomous Surface Ships	2018	Christoph Alexander Thieme, Ingrid Bouwer Utne, Stein Haugen			✔	✔			
COLREGS Based Path Planning and Bearing Only Obstacle Avoidance for Autonomous Unmanned Surface Vehicles	2018	Fuat Beser, Tulay Yildirim		✔	✔				
Components for Smart Autonomous Ship Architecture Based on Intelligent Information Technology	2018	Illkyun Im, Dongryeol Shin, Jongpil Jeong				✔			
Developing a Navigation, Guidance and Obstacle Avoidance Algorithm for an Unmanned Surface Vehicle (USV) by Algorithms Fusion	2018	Hossein Mousazadeh, Hamid Jafarbiglu, Hamid Abdolmaleki, Elham Omrani, Farshid Monhaseri, Mohammad-reza Abdollahzadeh, Aref Mohammadi-Aghdam, Ali Kiapei, Yousef Salmani-Zakaria, Ashkan Makhsoos		✔	✔				
Hybrid Collision Avoidance for Autonomous Surface Vehicles	2018	Einvald Serigstad, Bjørn-Olav H. Eriksen, Morten Breivik		✔	✔				
Smoothed A* Algorithm for Practical Unmanned Surface Vehicle Path Planning	2018	Rui Song, Yuanchang Liu, Richard Bucknall		✔	✔		✔		
Stereo Obstacle Detection for Unmanned Surface Vehicles by IMU-assisted Semantic Segmentation	2018	Borja Bovcon, Rok Mandeljc, Janez Perš, Matej Kristan		✔	✔				
A Systemic Hazard Analysis and Management Process for the Concept Designphase of an Autonomous Vessel	2019	Osiris A. Valdez Banda, Sirpa Kannos, Floris Goerlandt, Pieter H.A.J.M. van Gelder, Martin Bergström, Pentti Kujala							✔
Adaptive Control for Autonomous Ships with Uncertain Model and Unknown Propeller Dynamics	2019	Ali Haseltalab, Rudy R. Negenborn		✔	✔		✔		
Adaptive Fixed-time Control of Autonomous VTOL UAVs for Ship Landing Operations	2019	Kewei Xia, Sangheon Lee, Hungsun Son		✔	✔				
An Affordable and Portable Autonomous Surface Vehicle with Obstacle Avoidance for Coastal Ocean Monitoring	2019	Daniel F. Carlson, Alexander Fürsterling, Lasse Vesterled, Mathias Skovby, Simon Sejer Pedersen, Claus Melvad, Søren Rysgaard				✔			
Case Study - Networked Control for Optimal Maneuvering of Autonomous Vessels	2019	Shuchen Liu, Sylvain Roy, Eloy Pairet-Garcia, Jan-Jöran Gehrt, Friederike Siemer, Christof Büskens, Dirk Abel, René Zweigel		✔	✔		✔		
Cooperative Operation of Autonomous Surface Vehicles for Maintaining Formation in Complex Marine Environment	2019	M.A. Hinostroza, Haitong Xu, C. Guedes Soares		✔	✔				
Digitalizing the Maritime Industry A Case Study of Technology Acquisition and Enabling Advanced Manufacturing Technology	2019	Oda Ellingsen, Knut Einar Aasland					✔	✔	

Table 2 (continued) Methodology in technical and design requirements studies

Title	Year	Authors	Quantitative Methodology			Qualitative Methodology			
			Statistics	Mathematics	Simulation	Literature Review	Case Study	Interview	Other
Experimental Testing and Simulations of an Autonomous, Self-propulsion and Self-measuring Tanker Ship Model	2019	Ameen M. Bassam, Alexander B. Phillips, Stephen R. Turnock, Philip A. Wilson			✔	✔	✔		
Experimental Validation of a Velocity Obstacle Based Collision Avoidance Algorithm for Unmanned Surface Vehicles	2019	Yonghoon Cho, Jungwook Han, Jinwhan Kim, Philyeob Lee, Shin-Bae Park		✔			✔		
Fast Marching Square Method Based Intelligent Navigation of the Unmanned Surface Vehicle Swarm in Restricted Waters	2019	Guoge Tan, Jin Zou, Jiayuan Zhuang, Lei Wan, Hanbing Sun, Zhiyuan Sun		✔	✔				
High Performance Super-twisting Sliding Mode Control for a Maritime Autonomous Surface Ship (MASS) Using ADP-Based Adaptive Gains and Time Delay Estimation	2019	Hossein Nejatbakhsh Esfahani, Rafal Szlapczynski, Hossein Ghaemi		✔	✔				
Intelligent Multi-task Allocation and Planning for Multiple Unmanned Surface Vehicles (USVs) Using Self-organising Maps and Fast Marching Method	2019	Yuanchang Liu, Rui Song, Richard Bucknall, Xinyu Zhang		✔	✔				
Marine Autonomous Surface Ship - Control System Configuration	2019	Tomasz Zubowicz, Krzysztof Armiński, Anna Witkowska, Roman Śmierzchalski		✔		✔			
Model Predictive Maneuvering Control and Energy Management for All-electric Autonomous Ships	2019	Ali Haseltalab, Rudy R. Negenborn		✔	✔				
Optimization of Unmanned Ship's Parametric Subdivision Based on Improved Multi-objective PSO	2019	Shaojuan Su, Jing Han, Yeping Xiong		✔		✔			
Parallel Trajectory Planning for Shipborne Autonomous Collision Avoidance System	2019	Rongwu Yang, Jinsong Xu, Xin Wang, Quan Zhou		✔	✔				
Remote Supervision of an Autonomous Surface Vehicle using Virtual Reality	2019	Mårten Lager, Elin A. Topp	✔		✔			✔	
Study on Optimal Tuning of PID Autopilot for Autonomous Surface Vehicle	2019	Kanako Kobatake, Tadatsugi Okazaki, Masakazu Arima		✔	✔				
Towards Supervisory Risk Control of Autonomous Ships	2019	Ingrid Bouwer Utne, Børge Rokseth, Asgeir J. Sørensen, Jan Erik Vinnem	✔	✔		✔	✔		
Use of AIS Data for Guidance and Control of Path-following Autonomous Vessels	2019	Haitong Xu, Hao Rong, C. Guedes Soares		✔	✔				
A Collision Avoidance Decision-making System for Autonomous Ship Based on Modified Velocity Obstacle Method	2020	Wang Shaobo, Zhang Yingjun, Li Lianbo		✔	✔		✔		
A Systems-based Application for Autonomous Vessels Safety: Hazard Identification as a Function of Increasing Autonomy Levels	2020	Nikolaos P. Ventikos, Adrian Chmurski, Konstantinos Louzis							✔
Adaptive Modeling of Maritime Autonomous Surface Ships with Uncertaintyusing a Weighted LS-SVR Robust to Outliers	2020	Man Zhu, Wuqiang Sun, Axel Hahn, Yuanqiao Wen, Changshi Xiao, Wei Tao		✔	✔		✔		

Table 2 (continued) Methodology in technical and design requirements studies

Title	Year	Authors	Quantitative Methodology			Qualitative Methodology			
			Statistics	Mathematics	Simulation	Literature Review	Case Study	Interview	Other
Adaptive Trajectory Tracking Algorithm of Unmanned Surface Vessel Based on Anti-windup Compensator with Full-state Constraints	2020	Hongde Qin, Chengpeng Li, Yanchao Sun, Ning Wang		✔	✔				
Collision Avoidance for an Unmanned Surface Vehicle Using Deep Reinforcement Learning	2020	Joohyun Woo, Nakwan Kim		✔	✔		✔		
Collision Avoidance Under COLREGS for Unmanned Surface Vehicles via Deep Reinforcement Learning	2020	Yong Ma, Yujiao Zhao, Yulong Wang, Langxiong Gan, Yuanzhou Zheng		✔	✔		✔		
Collision Risk Measure for Triggering Evasive Actions of Maritime Autonomous Surface Ships	2020	Yamin Huang, P.H.A.J.M. van Gelder		✔	✔				
Damage Stability Requirements for Autonomous Ships Based on Equivalent Safety	2020	Jiri de Vos, Robert G. Hekkenberg, Herbert J. Koelman		✔			✔		
Deep Learning for Autonomous Ship-oriented Small Ship Detection	2020	Zhijun Chen, Depeng Chen, Yishi Zhang, Xiaozhao Cheng, Mingyang Zhang, Chaozhong Wu		✔	✔				
Global Path Planning for Autonomous Ship A Hybrid Approach of Fast Marching Square and Velocity Obstacles Methods	2020	Pengfei Chen, Yamin Huang, Eleonora Papadimitriou, Junmin Mou, Pieter van Gelder		✔			✔		
Identifying Research Directions of a Remotely-controlled Merchant Ship by Revisiting her System-theoretic Safety Control Structure	2020	Krzysztof Wróbel, Mateusz Gil, Jakub Montewka				✔	✔		
Intelligent Collision Avoidance Algorithms for USVs via Deep Reinforcement Learning under COLREGs	2020	Xinli Xu, Yu Lu, Xiaocheng Liu, Weidong Zhang		✔	✔				
Maritime 4.0 – Opportunities in Digitalization and Advanced Manufacturing for Vessel Development	2020	Brendan P. Sullivan, Shantanoo Desai, Jordi Sole, Monica Rossi, Lucia Ramundo, Sergio Terzi				✔		✔	
Precise Localization for Achieving Next-generation Autonomous Navigation: State-of-the-art, Taxonomy and Future Prospects	2020	Rathin Chandra Shit				✔			
The Autonomous Navigation and Obstacle Avoidance for USVs with ANOA Deep Reinforcement Learning Method	2020	Xing Wu, Haolei Chen, Changgu Chen, Mingyu Zhong, Shaorong Xie, Yike Guo, Hamido Fujita		✔	✔				
The Review Unmanned Surface Vehicle Path Planning: Based on Multi-modality Constraint	2020	Chunhui Zhou, Shangding Gu, Yuanqiao Wen, Zhe Du, Changshi Xiao, Liang Huang, Man Zhu		✔					
Towards Applicability Evaluation of Hazard Analysis Methods for Autonomous Ships	2020	Xiang-Yu Zhou, Zheng-Jiang Liu, Feng-Wu Wang, Zhao-Lin Wu, Ren-Da Cui				✔			
Towards Shipping 4.0. A Preliminary Gap Analysis	2020	Giuseppe Aiello, Antonio Giallanza, Giuseppe Mascarella				✔			✔
Towards Simulation-based Verification of Autonomous Navigation Systems	2020	Tom Arne Pedersen, Jon Arne Glomsrud, Else-Line Ruud, Aleksander Simonsen, Jarle Sandrib, Bjørn-Olav Holtung Eriksen		✔	✔				

Source: Author

Table 3 Methodology in influencing factors studies

Title	Year	Authors	Quantitative Methodology			Qualitative Methodology			
			Statistics	Mathematics	Simulation	Literature Review	Case Study	Interview	Other
Bayesian Perspective on the Deck Officer's Situation Awareness to Navigation Accidents	2015	George Ad. Psarros	✔	✔					
From Desk to Field - Human Factor Issues in Remote Monitoring and Controlling of Autonomous Unmanned Vessels	2015	Yemao Man, Monica Lundh, Thomas Porathe, Scott MacKinnon				✔			✔
Human Factors Challenges in Unmanned Ship Operations – Insights from other Domains	2015	Mikael Wahlström, Jaakko Hakulinen, Hannu Karvonen, Iiro Lindborg				✔			
Human Factor Issues during Remote Ship Monitoring Tasks: An Ecological Lesson for System Design in a Distributed Context	2018	Yemao Man, Reto Weber, Johan Cimbritz, Monica Lundh, Scott N. MacKinnon			✔			✔	
Collision Avoidance on Maritime Autonomous Surface Ships: Operators' Tasks and Human Failure Events	2019	Marilia Abilio Ramos, Ingrid Bouwer Utne, Ali Mosleh				✔	✔		
Human-system Concurrent Task Analysis for Maritime Autonomous Surface Ship Operation and Safety	2019	Marilia Abilio Ramos, Christoph Thieme, Ingrid Bouwer Utne, Ali Mosleh					✔		✔
Influence of Environmental Factors on Human-like Decision-making for Intelligent Ship	2019	Jie Xue, Zhijun Chen, Eleonora Papadimitriou, Chaozhong Wu, P.H.A.J.M. Van Gelder		✔					
Multi-attribute Decision-making Method for Prioritizing Maritime Traffic Safety Influencing Factors of Autonomous Ships' Maneuvering Decisions Using Grey and Fuzzy Theories	2019	Jie Xue, P.H.A.J.M. Van Gelder, Genserik Reniers, Eleonora Papadimitriou, Chaozhong Wu	✔						✔
A Framework to Identify Factors Influencing Navigational Risk for Maritime Autonomous Surface Ships	2020	Cunlong Fan, Krzysztof Wrobel, Jakub Montewka, Mateusz Gil, Chengpeng Wan, Di Zhang				✔		✔	
A Probabilistic Model of Human Error Assessment for Autonomous Cargo Ships Focusing on Human–Autonomy Collaboration	2020	Mingyang Zhang, Di Zhang, Houjie Yao, Kai Zhang	✔	✔					
Transport Safety and Human Factors in the Era of Automation: What can Transport Modes Learn from each other?	2020	Eleonora Papadimitriou, Chantal Schneider, Juan Aguinaga Tello, Wouter Damen, Max Lomba Vrouenraets, Annebel ten Broeke				✔			

Source: Author

Table 4 Methodology in business strategies and policy studies

Title	Year	Authors	Quantitative Methodology			Qualitative Methodology			
			Statistics	Mathematics	Simulation	Literature Review	Case Study	Interview	Other
Seeking Harmony in Shore-based Unmanned Ship Handling - From the Perspective of Human Factors, What is the Difference we Need to Focus on from Being Onboard to Onshore	2014	Yemao Man, Monica Lundh, Thomas Porathe						✔	
A Navigating Navigator Onboard or a Monitoring Operator Ashore; Towards Safe, Effective, and Sustainable Maritime Transportation: Findings from Five Recent EU Projects	2016	Thomas Porathe			✔				
Autonomous Shipping - Putting the Human Back in the Headlines	2018	Gordon Meadow, Daniel Ridgwell, David Kelly	✔						
Perceptions of Demanding Work in Maritime Operations	2018	Lillian Vederhus, Atle Ødegård, Steinar Nistad, Jon Ivar Håvold	✔						
A Framework to Model the STPA Hierarchical Control Structure of an Autonomous Ship	2020	Meriam Chaal, Osiris A. Valdez Banda, Jon Arne Glomsrud, Sunil Basnet, Spyros Hirdaris, Pentti Kujala					✔	✔	
Development of a Strategic Policy for Unmanned Autonomous Ships - A Study on Taiwan	2020	Hsin-Hung Cheng, Kwan Ouyang	✔						✔
Propulsion Monitoring System for Digitized Ship Management: Preliminary Results from a Case Study	2020	Giuseppe Aiello, Antonio Giallanza, Salvatore Vacante, Stefano Fasoli, Giuseppe Mascarella		✔			✔		
The Effect of Autonomous Systems on the Crew Size of Ships – A Case Study	2020	Carmen Kooij, Robert Hekkenberg		✔					
Towards Shipping 4.0. A Preliminary Gap Analysis	2020	Giuseppe Aiello, Antonio Giallanza, Giuseppe Mascarella				✔			✔

Source: Author

Table 5 Methodology in job requirements and training studies

Title	Year	Authors	Quantitative Methodology			Qualitative Methodology			
			Statistics	Mathematics	Simulation	Literature Review	Case Study	Interview	Other
Effects of Automation on the Training Ships Crew	2010	Leo Žižić				✔			
ICS Study on Seafarers and Digital Disruption	2018	Max Johns (lead author)	✔	✔					
Autonomous Ships and Legal Authorities of the Ship Master	2019	Goran Vojković, Melita Milenković				✔			
Seafarer Market – Challenges for the Future	2020	Zvonimir Lušić, Mario Bakota, Mirko Čorić, Ivica Skoko				✔			
Disrupting Technologies in the Shipping Industry: How will MASS Development Affect the Maritime Workforce in Korea?	2020	Sohyun Jo, Enrico D'agostini	✔	✔					✔
Psychophysiological Evaluation of Seafarers to Improve Training in Maritime Virtual Simulator	2020	Yisi Liu, Zirui Lan, Jian Cui, Gopala Krishnan, Olga Sourina, Dimitrios Konovessis, Hock Eng Ang, Wolfgang Mueller-Wittig		✔			✔		
Shipping 4.0 and Training Seafarers for the Future Autonomous and Unmanned Ships	2020	Gholam Reza Emad, Mohsen Khabir, Mehrangiz Shahbakhsh				✔			

Source: Author

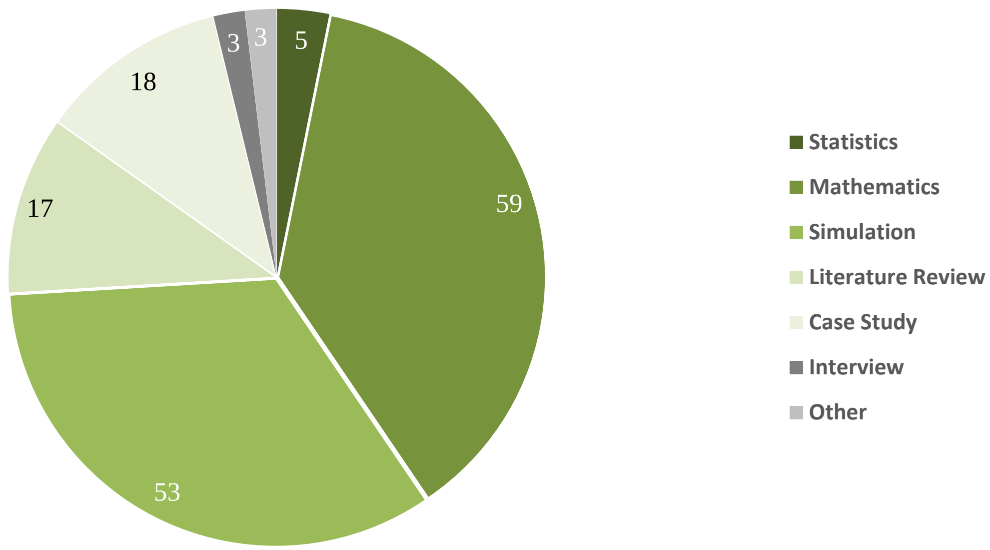
Table 6 Methodology in impacts studies

Title	Year	Authors	Quantitative Methodology			Qualitative Methodology			
			Statistics	Mathematics	Simulation	Literature Review	Case Study	Interview	Other
Analyzing the Economic Benefit of Unmanned Autonomous Ships: An Exploratory Cost-comparison Between an Autonomous and a Conventional Bulk Carrier	2017	Lutz Kretschmann, Hans-Christoph Burmeister, Carlos Jahn	✔	✔					
Towards the Assessment of Potential Impact of Unmanned Vessels on Maritime Transportation Safety	2017	Krzysztof Wróbel, Jakub Montewka, Pentti Kujala	✔	✔					
Introduction to the Special Section on Marine and Maritime robotics: Innovation and Challenges	2018	Marco Bibuli, Enrica Zereik				✔			
Maritime Supply Chains, Chapter 7 - Economic, Social, and Environmental Impacts of Autonomous Shipping Strategies	2020	Martijn Streng, Bart Kuipers				✔		✔	
Maritime Autonomous Surface Ships from a Risk Governance Perspective: Interpretation and Implications	2020	Floris Goerlandt				✔			
Wider Implications of Autonomous Vessels for the Maritime Industry: Mapping the Unprecedented Challenges	2020	Hadi Ghaderi				✔			

Source: Author

Utilizing the data gathered in the Tables 2, 3, 4, 5 and 6, more detailed analysis has been generated to demonstrate the total number of times each method has been used, which includes when it has been used in combination with other methods.

Figure 5 Methods in Technical and Design Requirements studies

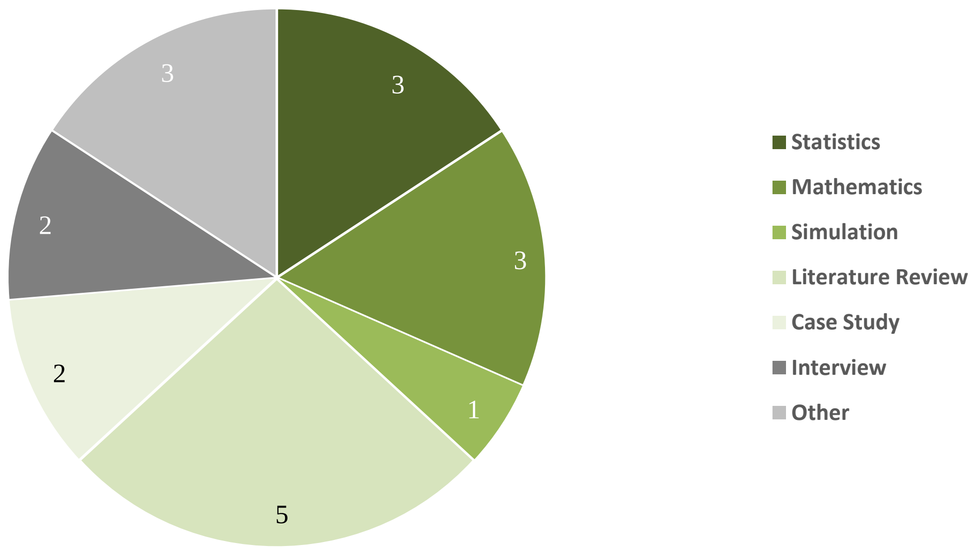


Source: Author

As has already been noted, Mathematics and Simulation are the preferred methods favored by Technical and Design Requirements papers. The Literature Review and Case Study methods follow. The last three are Statistics, Interviews, and other methods (Figure 5).

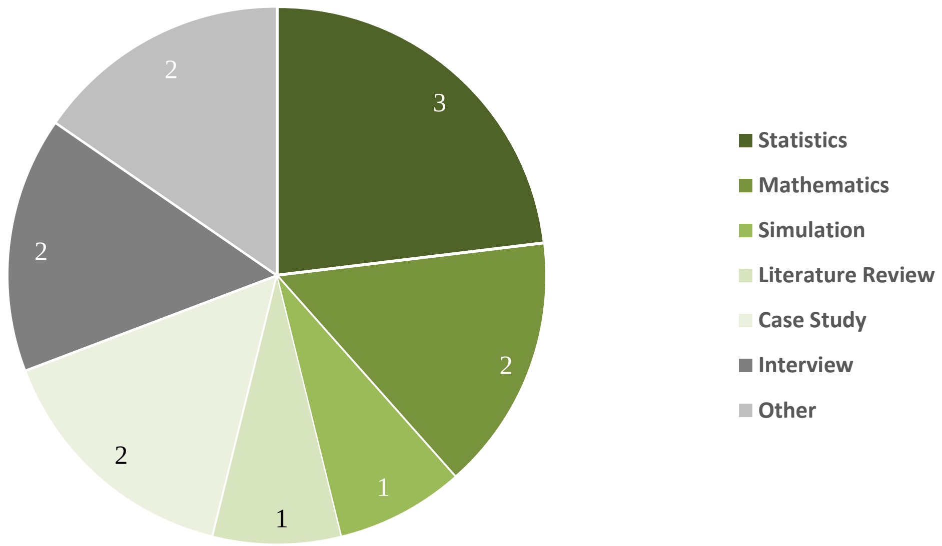
Subsequently, Literature Review is top of the list of methods in Influencing Factors studies, as presented in Figure 6. Statistics, Mathematics, and other methods appear equally three times. Finally, Interviews and Case Studies are employed in two studies, while Simulation only once.

Figure 6 Methods in Influencing Factors studies



Source: Author

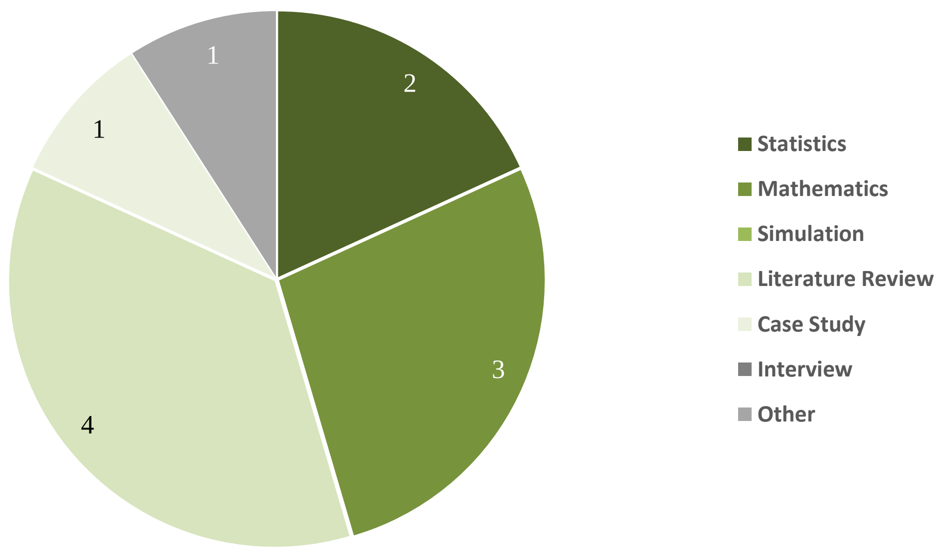
Figure 7 Methods in Business Strategies and Policy studies



Source: Author

Figure 7 shows the methods employed in Business Strategies and Policy papers with Statistics at the top. Mathematics, Case Studies, Interviews, and other methods are found in second place. Simulation and Literature Review are the methods least applied in this study area.

Figure 8 Methods in Job Requirements, Education and Training studies

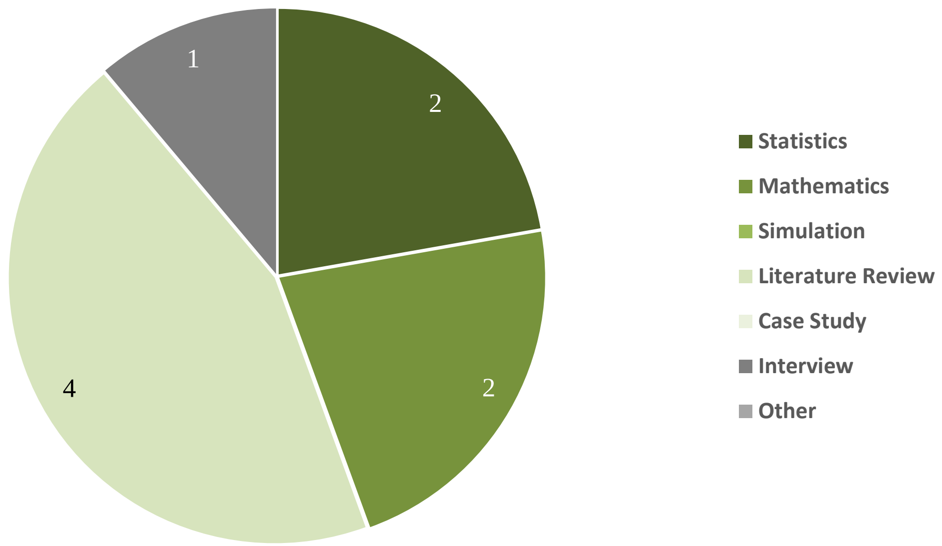


Source: Author

As illustrated in Figure 8, studies on Job Requirements, Education, and Training rely mostly on the Literature Review method. The second and the third most frequent methods, in equal degree, are the two quantitative methods of Mathematics and Statistics. Case Studies and other methods share the last place.

Overall, Figure 9 clearly shows that current studies on MASS Impacts employ fewer methods relative to the other research sectors, and that the most popular method is the Literature Review. To conclude, Statistics and Mathematics have been introduced only twice, while the Interview method has been introduced just once.

Figure 9 Methods in Impacts studies



Source: Author

5. Conclusions

With the constant technological development, unmanned shipping is a conjecture no more; neither a mere object of scientific research lacking the possibility of practical application. More acutely, Maritime Autonomous Surface Ships become all the more tangible. Not only is MASS under development, but the way is open to meet safety and operational standards as well. The effort of researchers to identify and describe technological and design requirements for MASS development through experiments and case studies is not to be overlooked. In the purpose of emphasis of the significance of this effort, it is worth mentioning that many projects concerning MASS are in place. Early studies have revealed several impacts for the users of autonomous ships, such as potentially lower operational costs and higher safety levels, among many other beneficial consequences. That is not to say that MASS comes without repercussions manifested in a variety of areas, such as employment. It is to be added that a relatively small number of papers stress out many factors that may influence the realization of MASS, posing challenges both to stakeholders and scientists. One of the pillars of the risen challenges is based on the subjective and variable nature of personnel who are to operate the MASS. Specifically, Situational Awareness is of profound interest as far as human factors are concerned. Due to the difficulty of harnessing human nature, needless it is to say that the evolution of MASS necessitates the reformation of education and training. Knowledge and experience of the staff already serving for Maritime should undergo adaptation through elaborative training, to effectively meet up the demands deriving from the relocation of the monitoring to the control center ashore, the use of advanced technology systems so on. What is more, the international community plays a capital role, through modifying STCW could ensure a universal minimum of education, qualification, and requirements for seafarers, hence altering the face of Maritime and decisively taking a step towards the future of MASS. Notwithstanding the formation of an effective training program and the implementation of standards through international conventions, seafarer's willingness for training and education is of utmost importance.

It is rather evident than not that the interest in the autonomy of ships escalates in a vivid rhythm. On the other hand, many aspects of MASS are yet unexplored and thus unknown. The full impact of the implementation of MASS cannot be accurately predicted nor the qualification prerequisites for employees of the relevant domain. The academic literature already at hand, however rich may it be, should not be regarded as sufficient for the realization of MASS.

The present study is significant as it summarizes the academic literature regarding the autonomous ship and the employed methods in each paper. Moreover, it stresses that the academic literature concerns mainly five sectors and it reveals the extent to which each sector has been developed. Furthermore, the current paper indicates the gaps that exist in the academic literature in the field of autonomy of ships. What is more, this paper concludes that the sector of MASS impacts and this of job requirements, education and training are researched the least in comparison to others. For all the above this paper may be utilized as a basis for future research on the subject of the autonomous ship.

In this paper, an attempt to present the available studies focusing on Maritime Autonomous Surface Ship and its aspects during the last decade, namely between 2010 and 2020, has been done. The purpose of this research is to illustrate a detailed view of the research that has already taken place and recognize research challenges in the near and distant future as well.

For these reasons, the literature review method has been applied leading to several results via comparative analysis of the available studies. After picking publications through various academic databases, an ultimate total amount of about 115 papers comprising of journal articles, reports, and conference minutes composed mainly in the last decade, were selected for the objective of this study. These papers have been categorized according to specific criteria, such as the subject, the year of composition, the applied methodologies in each study, and the authors. Various tables and figures have also been created to illustrate the extracted results.

Analyzing the academic papers collected and included in this study, it is clear that the interest in this research area has flourished after the year 2017 with articles related mainly to technical and design matters, as well as to business strategies and policies and influencing factors. It is also evident that some authors, such as Liu and Bucknall, are more frequently appeared in studies relevant to autonomous ships with an increasing number of publications. Moreover, the quantitative and qualitative applied methods vary in each research and differ according to the specific research sector.

Regarding fields in need of future research, two have been identified: MASS impacts and job requirements, education, and training on MASS technology. In the former case, only some studies describe how MASS may affect the maritime industry in several ways and potential benefits in different sectors. In the latter case, a few studies are aiming at describing the effect of autonomy on seafarers' job requirements and skills needed and how important is the entire education and training background to be reformed. In both cases, there is significant scope for further research since the application of autonomous ships is still under development. However, it is necessary to clarify that more research on issues on business strategies and policies and influencing factors have yet to be conducted.

Finally, it is useful to mention that there occurs ground for research and studies on new education programs and training materials to cover the needs of MASS or how the existing ones have to be reformed in order to comply with upcoming requirements on seafarers' jobs.

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