University of South-Eastern Norway

Identified Challenges in the Safety Management of Merchant Maritime Autonomous Surface Ships: A Systematic Review of Scientific Journal Publications

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Abstract

Background: While numerous studies have been carried out in the field of safety management of merchant maritime autonomous surface ships, no prior systematic review synthesising their results exists.

Objective: The aim of this paper is to systematically review peer-reviewed journal articles in order to collect all challenges in the safety management of merchant maritime autonomous surface ships identified therein.

Data Sources: Four databases – namely SCOPUS, Academic Search Elite, ScienceDirect and Web of Science – were utilised to search for relevant studies. To find the relevant literature, a Boolean search string combining the following terms was used: Automat*, autonom*, cargo, challeng*, craft*, manag*, marine, maritime, merchant, ocean, overcom*, safe*, sea, ship*, system*, unmanend, vehicle* and vessel*, where the asterisk serves as truncation operator.

Study Eligibility Criteria: Studies were selected to be included in the review if they were published in or after 2008, were published in a peer-reviewed journal, if a full text copy of the article was available, when the article focuses on merchant maritime autonomous surface ships and challenges related to their safety management, when search terms were used in the setting/for the meaning they were intended and if they were a non-duplicate study.

Results: The numerous identified technological, human element related and procedural challenges regarding the safety management of maritime autonomous surface ships were qualitatively synthesised, providing a summary of the results of the available primary research in the field.

Conclusion: Further research is necessary in order to overcome some of the identified challenges and ensure safe operations of maritime autonomous surface ships.

Keywords: *Automated; Autonomous; Challenges; Maritime; MASS; Merchant; Process; Safety Management; Ship; Smart; Surface; System; Systematic Review; Unmanned; Vessel*

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List of Abbreviations

AIC	Automation-Induced Complacency
CASP	Critical Appraisal Skills Programme
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea, 1972
CRediT	Contributor Roles Taxonomy
HVL	Western Norway University of Applied Sciences
IMO	International Martime Organization
ISM	International Safety Management
MASS	Maritime Autonomous Surface Ships
MLC	Maritime Labour Convention, 2006
MSC	Maritime Safety Committee
OT	Operational Technology
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SMS	Safety Management System
SOLAS	International Convention for the Safety of Life at Sea, 1974
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978
USN	University of South-Eastern Norway
VTS	Vessel Traffic Service

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1 Introduction

This chapter aims to introduce the reader to maritime safety management and explain how it is related to general safety management theory. Afterwards, the concept of autonomous shipping is presented and it is argued why the safety of this operation must be properly managed. This leads to the definition of the research conducted in this thesis, where the research question and central terms are defined and possible limitations are listed.

Following the introduction chapter, the methodology of the review is presented in chapter 2. The study design is explained in detail to ensure that the reader has a thorough understanding of the choices made in this paper. Chapter 3 starts with an overview of the principle data extracted from the studies reviewed in this thesis and presents the results of their quality appraisal and risk of bias assessment. In the later parts of chapter 3 the results of the qualitative synthesis of the different challenges in the safety management of merchant maritime autonomous ships identified in the reviewed studies is presented. The results, implications for theory and practice, and the limitations are discussed in chapter 4, before the thesis is concluded in chapter 5.

1.1 Introduction to Maritime Safety Management

Safety management in the maritime domain is largely governed by the International Safety Management (ISM) Code, whose purpose is to provide for the safe management and operation of ships, and for pollution prevention (International Maritime Organization, 2014). The ISM Code requires every company – where a company is defined as the "owner of the ship or any other organization … who has assumed the responsibility for the operation of the ship" (International Maritime Organization, 2014) – to develop, implement and maintain a Safety Management System (SMS), which is broadly defined as a "structured and documented system enabling Company personnel to implement the Company safety and environmental protection policy” (International Maritime Organization, 2014). According to an independent expert group report delivered to the Maritime Safety Committee (MSC), companies that have embraced the ISM Code have experienced “tangible positive effects” (Maritime Safety Committee, 2005), possibly because combining the three core issues of ‘safety’, ‘management’ and ‘system’ in an SMS leads to a systematic control of risk that will prevent accidents from occurring (Li & Guldenmund, 2018). As such, it is argued that continuing research into optimising maritime safety management can lead to further improvements in the field.

While the minimum functional requirements of an SMS have been defined in the ISM Code (International Maritime Organization, 2014), (Grote, 2012) came up with a slightly expanded list based on different literatures in the field of safety management. The differences between the two are highlighted in Figure 1 below.

ISM Code Functional Requirements for a Safety Management System

- Safety and environmental protection policy
- Instructions and procedures to ensure safe operation of ships and protection of the environment in compliance with relevant international and flag State legislation
- Defined levels of authority and lines of communication between, and amongst, shore and shipboard personnel
- Procedures for reporting accidents and non-conformities with the provisions of this Code
- Procedures to prepare for and respond to emergency situations
- Procedures for internal audits and management reviews.

Components of Safety Management according to Grote

- Safety policy
- Safety resources and responsibilities
- Risk identification and mitigations
- Standards and procedures
- Human factors based system design
- Safety training
- Safety performance monitoring
- Incident reporting and investigation
- Auditing
- Continuous improvement
- Management of change

Figure 1: Side-by-side listing of functional requirements mentioned in the ISM Code (International Maritime Organization, 2014) and components of safety management defined by (Grote, 2012).

As the ISM Code is specifically concerned with maritime issues, the inclusion of environmental protection, communication between – and amongst – ship and shore personnel, and international and flag state legislation is a clear distinction to the safety management components identified by Grote. The inclusion of clear goals in the ISM Code requirements can be explained by the headings of these two lists: while the ISM Code has defined functional requirements, Grote has merely stated components of safety management.

While there are only three areas where the two lists overlap with the same wording – i.e. safety policy, procedures and auditing – some areas exist where the wording may be different, but the content can still be understood to be the same. The use of the word "instructions" as compared to "standards" has little practical implication on the safety management. While the ISM Code talks about "defined levels of authorities", Grote choses the word "responsibilities", which too can be understood to have the same effect – it must ensured that everyone involved in the system knows what is expected of him or her. Finally, the consequence of reporting accidents and non-conformities is the same as that of reporting incidents: The organisation must be provided with data in order to learn from previous mistakes.

Safety resources, risk identification and mitigation, human factors based system design, safety training, safety performance monitoring, continuous improvement and management of change are safety management components identified by Grote that are not mentioned in the functional requirements of the ISM Code. On the other hand – in addition to the maritime context related differences discussed above – preparation and response to emergencies as well as management reviews are topics that have been picked up in the ISM Code but were not included in Grote's list of safety management components. The final difference is that while resolution MSC.428(98) identifies cyber risks as threats that must be addressed in safety management systems (Maritime Safety Committee, 2017), Grote's list does not make any such reference.

When looking at safety management in a more general matter, the introduction of maritime autonomous surface ships (MASS) and the associated review of how their safety can best be managed leads to opportunities. When trying to manage safety, many shipping companies still utilise the Safety-I approach (Oltedal & Lützhöft, 2018), which is based on the scientific management theory introduced by Frederick Winslow Taylor at the beginning of the twentieth century (Hollnagel, 2014). While scientific management initially did not consider safety, it was soon used to study how safety could be improved (Hollnagel, 2014). As a result it is widely believed that combining careful planning of work processes with detailed instructions and training improves safety, and that accidents only occur when workers do not adhere to the procedures (Hollnagel, 2014). Safety has therefore historically been managed utilising a "command and control" management style.

While "command and control" was the go-to management style in the early twentieth century, it has been superseded by other management styles in other areas of management, such as quality management (Smith, 2011). Quality managers have discovered that in order to achieve continual improvement not only the manual, but also the mental labour of employees at all levels of the organisation is required (Smith, 2011). As the "command and control" management style reserves all thinking for management and quickly eliminates mental motivation of normal workers (Smith, 2010) it is clearly not a suitable management style to achieve the goal of continual improvement. This issue has been picked up by (Hollnagel, 2014), who has defined the current state of safety management as "Safety-I" and describes that the only way forward in enhancing safety management is by embracing a new way of managing safety that he describes as "Safety-II" and has defined as "the ability to succeed under expected and unexpected conditions alike". Embracing the "Safety-II" perspective leads to the understanding that by studying the ongoing processes in a system – such as planning, communication and cooperation – an understanding can be gained of how these processes support safe operations (Oltedal & Lützhöft, 2018).

While this thesis will only compile the challenges in the safety management of MASS identified in peer-reviewed articles, it does suggest to anyone who will be involved in the drafting of SMS for MASS to thoroughly investigate whether or not a shift to "Safety-II" could increase the level of safety under which MASS can operate. Defaulting to a "Safety-I" approach will restrict operator behaviour, thereby limiting his or her ability to experiment and possibly find innovative, safer solutions (Oltedal & Lützhöft, 2018), which seems like a less than optimal approach when the goal is to safely establish the operation of a novel technology.

1.2 Introduction to Autonomous Shipping

The shipping industry generally agrees that human error is a major contributing factor for most shipping accidents, with a figure of about 60% being stated for all shipping accidents taken together and a significantly larger percentage when only looking at collisions and groundings (Butt, Johnson, Pike, Pryce-Roberts, & Vigar, 2013). This has caused some members of the industry to look at autonomous ships as an opportunity to increase safety, while simultaneously improving the environmental performance and enabling more cost-effective shipping (Vartdal, Skjong, & St.Clair, 2018). While the notion that an increase in automation leads to a reduction of human error has been disputed (Lützhöft & Dekker, 2002) and the human element will still be present in MASS operations (Ahvenjärvi, 2016), various projects have been set up with an aim to make autonomous ships a reality. Examples of such projects are the "Yara Birkeland", the autonomous offshore support vessel "Hrönn", ASTAT at Trondheimsfjorden, as well as two separate projects in China and Japan (Johns, 2018). Research is said to have wielded positive results (Hogg & Ghosh, 2016) and the advancement in technology has even caused the global regulatory body for international shipping, i.e. the International Maritime Organization (IMO), to look into how safe, secure and environmentally sound MASS operations may be addressed in its instruments (International Maritime Organization, 2018).

The IMO has provisionally defined a MASS as “a ship which, to a varying degree, can operate independently of human interaction” (International Maritime Organization, 2018), where “varying degree” refers to degrees of autonomy. The IMO has defined four distinct degrees of autonomy, which are depicted in a non-hierarchical order in Figure 2 below. In this regard it has been highlighted that a MASS is not necessarily tied to a single degree of autonomy, but could instead be operating at several different degrees for the duration of a voyage (International Maritime Organization, 2018). Furthermore, note that “autonomy” does not necessarily mean “unmanned” (Johns, 2018).

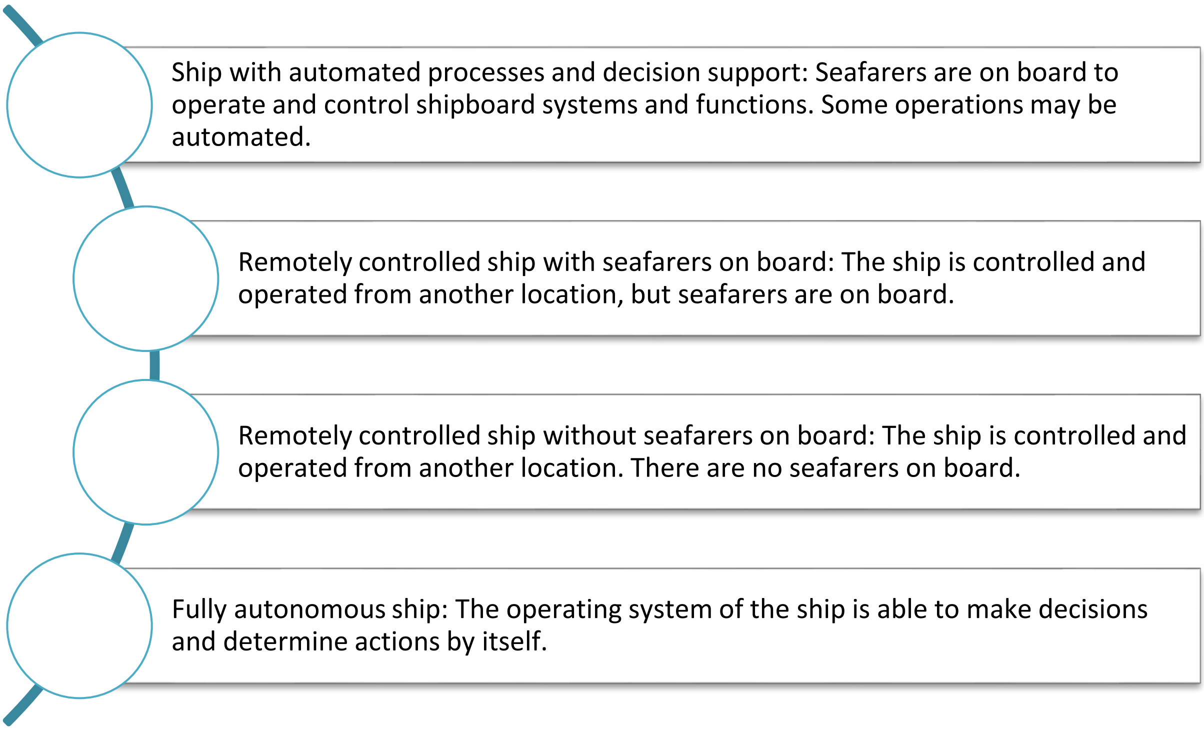

Figure 2: Degrees of autonomy as defined by (International Maritime Organization, 2018).

However, other definitions than those provided by the IMO exist. Classification society Bureau Veritas has defined an autonomous ship as a "ship having the same capabilities as those of a smart ship and including autonomous systems capable of making decisions and performing actions with or without human in the loop", highlighting that "an autonomous ship may be manned with a reduced crew or unmanned with or without supervision". A "smart ship" has thereafter been defined as a "generic term to define a connected ship, capable of collecting data from sensors and having the capacity to process a large amount of data in order to assist the crew during the decision making process", clarifying that "compared to a conventional ship, a smart ship may be manned with reduced crew or totally unmanned with a remote control" (Bureau Veritas, 2017). Another classification society – Lloyd's Register – has decided to use the term "cyber enabled ship" instead of "autonomous ship", suggesting that a cyber enabled ship is provided with cyber-enabled systems which Lloyd's Register defines as "systems installed on board ships that would conventionally be controlled by the ship's crew but which, through recent advances in

IT and Operational Technology (OT), now include the capability to be monitored, or monitored and controlled, either remotely or autonomously with or without a crew on board the ship" (Lloyd's Register, 2017). This notion has recently gained significance as SAE International – a globally active professional association and standards developing organisation in various industries – as decided to add the term "autonomous" to its list of deprecated terms (choosing to utilise the expression "driving automation" instead) (SAE International, 2018). The absence of at least an agreement of the degrees or levels of autonomy – where between four (International Maritime Organization, 2018) and seven (Johns, 2018) distinct degrees/levels have been defined – further exemplifies the issue of the maritime industry lacking clear, universally agreed definitions in this field.

With the IMO being the global regulatory body for international shipping, its definitions will be utilised in this thesis. However, as current IMO regulations consider human involvement to be essential in the decision-making process (Comite Maritime International, 2017), it is assumed throughout this paper that such involvement is provided either by seafarers stationed directly on board or an individual supervising the vessel from shore. While this does not preclude the fourth degree of automation mentioned in Figure 2 above, it does mean that a human must be capable of taking over control of the vessel at any time. This leads to the fact that the SMS for a MASS must also address risks related to human operators being involved in their operation.

1.3 The Need for Safety Management in Autonomous Ship Operation

Given the case that a MASS is larger than 500 gross registered tons, is registered with a flag state and is engaged on international voyages, it will need to comply with the provisions of the International Convention for the Safety of Life at Sea, 1974 (SOLAS)

(Comite Maritime International, 2017). Compliance with the ISM Code is mandated in chapter 9 of the regulation, and as such, an SMS must be in place for any MASS that satisfies the requirements mentioned above.

The need for a separate view on the safety management for autonomous ships is due to the large inherent differences between conventional – manned – shipping and MASS operation. (Grote, 2012) has suggested that safety management should be designed around three attributes of organisations and their environments, i.e.

1. The kinds of safety to be managed: Process versus personal safety.

2. The general approach to managing uncertainty as a hallmark of organisations that manage safety: Minimising versus coping with uncertainty.

3. The regulatory regime within which safety is managed: External regulation versus self-regulation.

It can be argued that each of these attributes is different for MASS compared to conventional ships. While process safety is also considered in the SMS of a conventional ship, their manned operation directly requires a large part of their SMS to be focusing on personal safety. In the case of a MASS the roles are reversed, with process safety being the main concern. Furthermore, while the shipping industry is currently highly proceduralised (Oltedal, 2011), the large amount of uncertainties facing autonomous ship operations and the absence of any seafarers on board able to step in in case something does go wrong might require autonomous ship operators to focus on coping with uncertainty instead of just trying to minimise it. Lastly, while many international regulations will continue to apply to autonomous ships, some well-established conventions will not find application. An example is the International Convention on Standards of Training, Certification and Watchkeeping for

Seafarers, 1978 (STCW) which prescribes qualification standards for masers, officers and watchkeeping personnel but will find no application to shore based personnel charged with navigating the relevant ship (Comite Maritime International, 2017). As a result, autonomous ship operations will depend on self-regulation to a larger extend than their conventionally manned counterparts until the existing conventions are either amended or new regulations for autonomous ships are drafted at IMO level.

As such, it becomes clear that not only will safety management for MASS be mandatory under international conventions, but the approach to this safety management must also change when compared to traditional, i.e. manned ships.

Finally, apart from the legal requirements, safety management can also lead to significant competitive edges for a company. As a strategic process that not only predicts, identifies and addresses operational, procedural, environmental and safety risks before they occur but also corrects deficiencies and performance errors, safety management can play a significant role in enhancing a company's performance (Sheahan, 2017).

1.4 Definition of the Research Field

While research into making autonomous ships a reality has been carried out for some time now, the focus was generally only on overcoming the technological challenges involved (Banda, Ahola, Gelder, & Sonninen, 2018; Man, Weber, Cimbritz, Lundh, & MacKinnon, 2018), leaving a gap in research in the corresponding safety management that needs to be involved. As it is considered most effective to utilise system-engineering tools for the creation of an SMS from an initial stage of a project (Banda & Goerlandt, 2018) and the first autonomous ships could start operation relatively soon, research regarding the safety management of MASS is desperately required.

This thesis therefore aims to summarise the challenges regarding the safety management of MASS identified in existing literature, thereby enabling future research to find suitable ways to address these challenges.

1.4.1 Research Question

The defined research question that this thesis aims to answer is the following: Which challenges in the safety management of merchant maritime autonomous surface ships (MASS) have been identified in peer-reviewed journal articles?

1.4.2 Definition of Central Terms

Challenge: A challenge is a task or situation that tests the ability of something or someone.

Safety Management: Safety management is the process of ensuring that operations are conducted safely. The functional requirements mentioned in the ISM Code (International Maritime Organization, 2014) and the components of safety management defined by (Grote, 2012) discussed in section 1.1 give a less abstract guidance regarding the definition of safety management.

While personal safety issues related to the operation of MASS can be envisioned, MASS operation will largely be concerned with process safety issues (as highlighted in section 1.3). Therefore, this paper will exclusively look into issues related to process safety in the operation of MASS.

Maritime Autonomous Surface Ship: A maritime autonomous surface ship – or MASS – is “a ship which, to a varying degree, can operate independently of human interaction” (International Maritime Organization, 2018).

Merchant: A merchant ship is involved in commerce rather than military activity.

1.4.3 Limitations

The above definition of the research field leads to the following limitations:

- The pool of possible literature to be included in the review is limited to articles published in peer-reviewed journals, thereby ignoring other possible sources of information (e.g. conference proceedings and industry white papers).
- The focus on MASS results in the preclusion of any challenges identified in other areas of automation that may be transferable to MASS operations.
- Further specifying that MASS must be merchant means that papers focusing on military applications are not included in this thesis.
- Focus on process safety results in any challenges regarding personal safety in MASS operations not being included.

2 Methods

This thesis aims to answer the research question defined in section 1.4 above by conducting a systematic review, which is accepted to be a research methodology in its own right (Boland, Cherry, & Dickson, 2017). To the author's knowledge, no systematic review of the challenges in safety management for MASS identified across the different published journal articles has been conducted yet. A completed systematic review in this field will educate readers about the research that has already been carried out in the field and the results of this research. Research gaps can thereafter be identified and – combined with professional judgement – decisions about interventions or necessary changes to policy can be reached. When compared to other types of literature review – such as narrative, rapid and scoping reviews – the transparent and rigorous nature of systematic review methodology and the reduced chance of bias are advantages (Boland et al., 2017) that have led to the systematic review methodology being chosen as the research methodology followed in this paper.

2.1 Study Design

A systematic review is defined as "a review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyse data from the studies that are included in the review" (Moher, Liberati, Tetzlaff, Altman, & PRISMA Group, 2009). To conform with the requirements mentioned in this definition, the thesis was designed using the PRISMA statement (Moher et al., 2009) as a guideline. As this statement recommends the incorporation of a review protocol into the methodology, the work on this thesis began with the drafting of such a protocol – as can be seen in Appendix A – Systematic Review Protocol – utilising an example provided in (Pearson, Field, & Jordan, 2007) as a template. The protocol specifies the objectives, methods and outcomes of primary interest of the systematic review, and can therefore be utilised to promote transparency while also serving as a road map for the review. Changes done to the original review protocol are documented therein.

In order to establish a clear structure, the literature review process utilised by (Snelson, 2016) was utilised in this thesis. It is detailed in Figure 3 below:

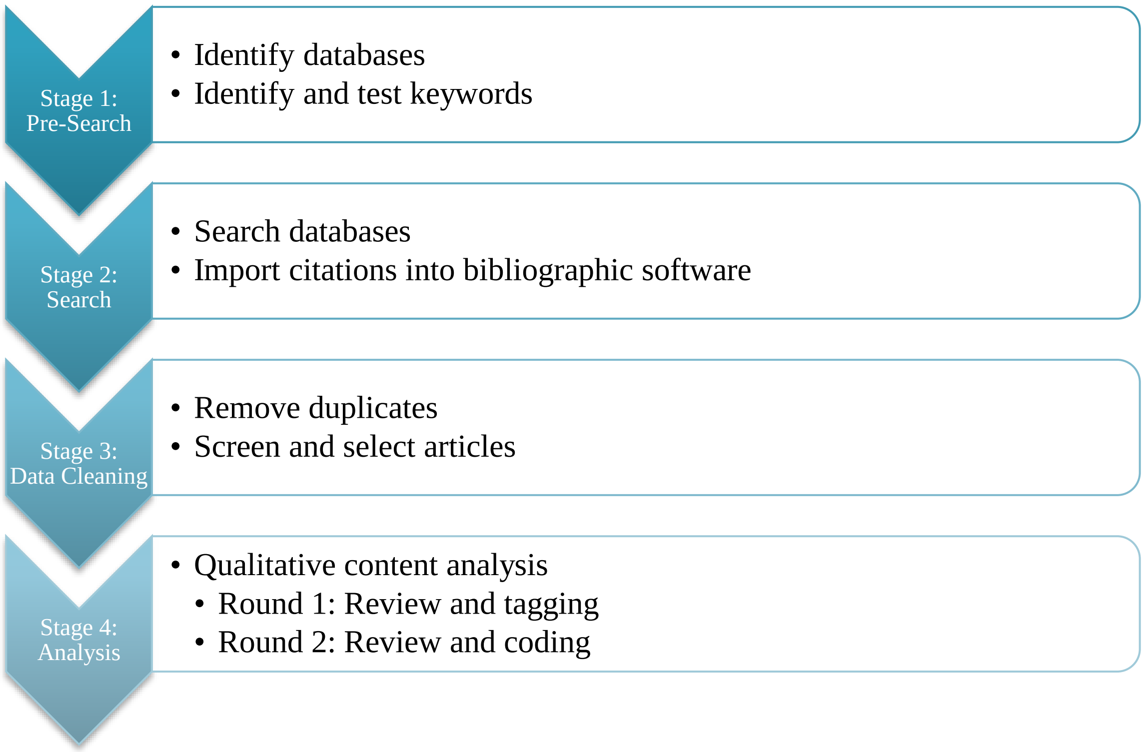

Figure 3: Stages in the literature review process reproduced from (Snelson, 2016).

2.2 Search Strategy

The search strategy of the thesis highlights the approach to both the pre-search-, as well as the actual search stage of the literature review process, as highlighted in Figure 3 above.

In order to identify and choose the databases that will be utilised for searching the literature, the list of relevant databases for maritime studies compiled by the library of the Western Norway University of Applied Sciences was consulted. The list was scanned for databases that would be able to identify relevant peer-reviewed articles. As a result, it was decided to conduct the search using the following databases:

1. SCOPUS,
2. Academic Search Elite via EBSCOhost,
3. ScienceDirect, and
4. Web of Science.

After having decided on which databases to search for literature, the search string was defined. The goal was to define a search string that was precise enough to sufficiently reduce the total number of articles found, while also ensuring that no important literature was filtered out in the process. In order to do so a number of articles that were found during the initial tests of keywords were identified as key articles that must be reproduced by the finally utilised search string. Keywords were combined to form a Boolean search string utilising trial-and-error until the outcome was a search string that resulted in all key articles being identified while filtering out as many unimportant articles as possible. Unfortunately, utilising the same search string in all databases led to the results from three databases being very concise, while one database also finding a large amount of irrelevant articles for the research question at hand. However, an attempt to further specify the search string led to the filtration of relevant articles from the three databases with fewer results and was therefore discarded. The identified preliminary search string was discussed with a senior librarian at HVL and resulted in the identification and removal of overlapping search terms. The result was the search string shown in Table 1 below, that identified all defined key articles while removing as many articles irrelevant for the research question as possible.

Database	**Search string**	**Results**
SCOPUS	(ALL (ship* OR ((vessel* OR vehicle* OR craft*) AND (maritime* OR marine* OR sea OR ocean))) AND (autonom* OR unmanned OR automat*) AND (merchant OR cargo) AND (safe*) AND (manag* OR overcom* OR challeng* OR system*)) AND PUBYEAR > 2007 AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))	779
Academic Search Elite via EBSCOhost	(ship* OR ((vessel* OR vehicle* OR craft*) AND (maritime OR marine OR sea OR ocean))) AND (autonom* OR unmanned OR automat*) AND safe* AND (manag* OR overcom* OR system* or challeng*) AND (merchant OR cargo)	91
ScienceDirect	(ship* OR ((vessel* OR vehicle* OR craft*) AND (maritime OR marine OR sea OR ocean))) AND (autonom* OR unmanned OR automat*) AND safe* AND (manag* OR overcom* OR system* or challeng*) AND (merchant OR cargo)	43
Web of Science	"TS=((ship* OR ((vessel* OR vehicle* OR craft*) AND (maritime OR marine OR sea OR ocean))) AND (autonom* OR unmanned OR automat*) AND safe* AND (manag* OR overcom* OR system* or challeng*) AND (merchant OR cargo))Refined by: LANGUAGES: (ENGLISH)Timespan: 2008-2018. Databases: WOS, KJD, MEDLINE, RSCI, SCIELO.Search language=Auto "	30

Table 1: Search strings and results in four databases.

As can be seen in the search strings for the SCOPUS and Web of Science databases above, the inclusion/exclusion criteria that will be discussed in section 2.3 were included in the search strings where technically possible (i.e. published on or after 2008, in English and in a peer-reviewed journal).

The defined search strings were run on 19 September 2018 in as many database fields as possible. Literature found by running these search strings was complemented by literature found by searching through the reference lists and bibliographies of relevant articles.

2.3 Selection Process

Following the inclusion criteria set in the systematic review protocol of this paper, the following inclusion/exclusion criteria table was created:

	Inclusion criteria	Exclusion criteria
1.	Published in or after 2008	Published prior to 2008
2.	Published in English	Published in another language
3.	Article published in a peer-reviewed journal	Article not published in a peer-reviewed journal
4.	Full text copy of article available	Full text copy of article not available
5.	Article focuses on MASS and challenges related to their safety management	Article does not focus on MASS and challenges related to their safety management
6.	Search terms were used in the setting/for the meaning they were intended	Search terms were used in other setting/for other meanings
7.	Non-duplicate study	Duplicate study

Table 2: Inclusion and exclusion criteria

The sixth inclusion criteria (search terms were used in the setting/for the meaning they were intended) was drafted to exclude papers where the keywords in the search string were used in other settings, or for other meanings than intended. An example of this were articles that were written in the health/medical field and utilised the word “vessel” in another context, as in the use of the term “blood vessel”.

Searching the same search string in four different databases has led to a large amount of articles being found in more than one database, which has resulted in 48 duplications of articles in the final sum of articles. While all 943 of the identified articles were exported to EndNote, the application of the seventh inclusion criteria (non-duplicate study) resulted in the removal of all duplicate studies.

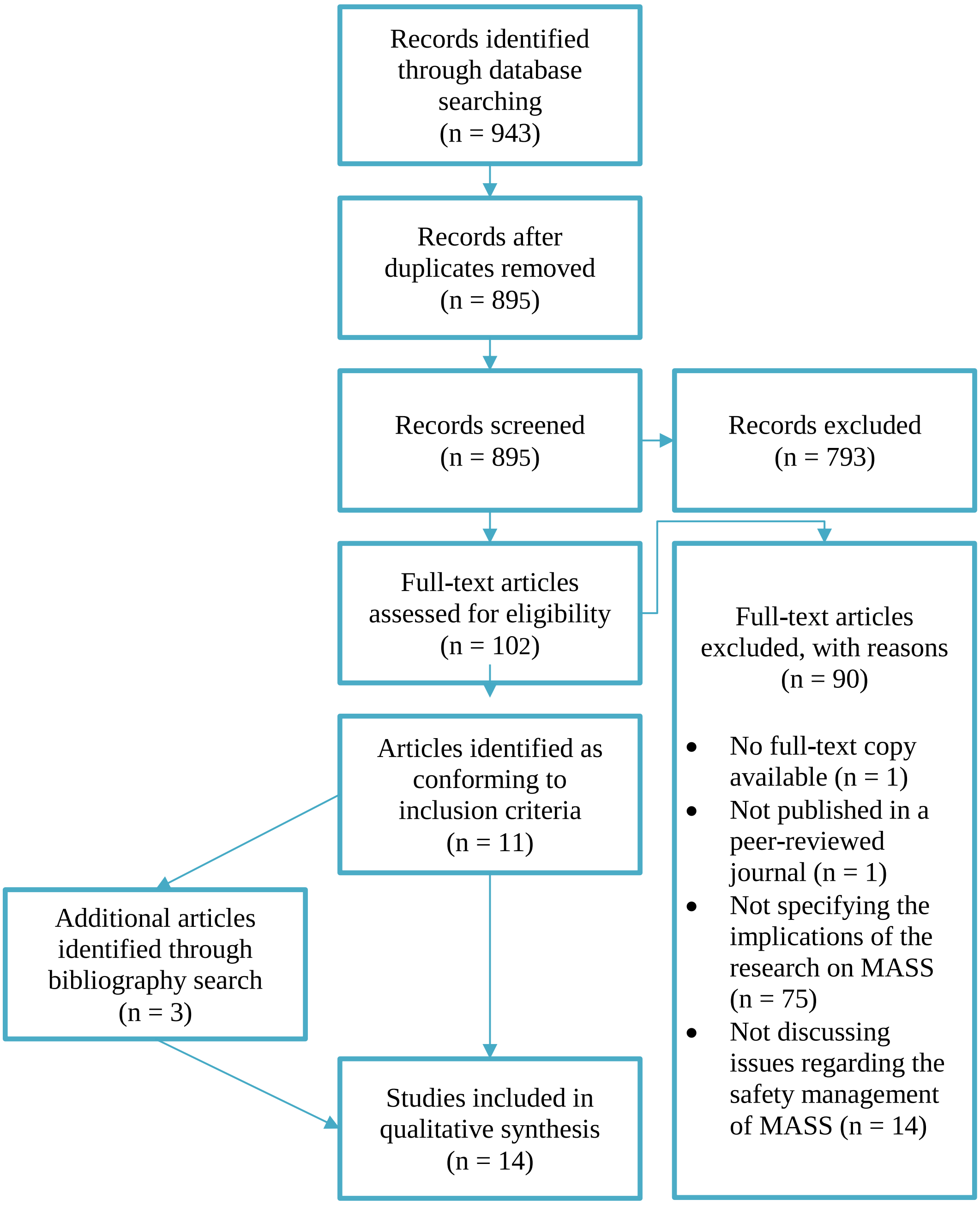

Figure 4: Flowchart of the selection process used in this systematic review.

Figure 4 above – based on the PRISMA four-phase flow diagram (Moher et al., 2009) – is utilised to highlight the selection process used in this systematic review, which was carried out by only one researcher (i.e. the author of this thesis).

The search commenced with the above mentioned database search with the subsequent export of 943 records to EndNote, where 48 duplicate records were removed both by the automatic algorithm and manually. 895 records were initially screened utilising only the titles and abstracts of the papers, followed by 102 articles undergoing a second screening process where the full text of the studies was retrieved and the inclusion/exclusion criteria were applied. The bibliographies of the 11 papers that were deemed to be conforming with the inclusion criteria were screened, which resulted in three additional papers being added to the list of studies that were reviewed in this paper. After the completion of the selection process, the 14 studies highlighted in Table 3 below remained and were included in the qualitative synthesis.

Author(s)	**Year**	**Title**
Acanfora, M., Krata, P., Montewka, J., & Kujala, P.	2018	Towards a method for detecting large roll motions suitable for oceangoing ships
Ahvenjärvi, S.	2016	The Human Element and Autonomous Ships
Burmeister, H.-C., Bruhn, W., Rødseth, Ø. J., & Porathe, T.	2014	Autonomous Unmanned Merchant Vessel and its Contribution towards the e-Navigation Implementation: The MUNIN Perspective
Burmeister, H.-C., Bruhn, W., & Walther, L.	2015	Interaction of Harsh Weather Operation and Collision Avoidance in Autonomous Navigation
Ghaderi, H.	2018	Autonomous technologies in short sea shipping: trends, feasibility and implications
Hogg, T., & Ghosh, S.	2016	Autonomous merchant vessels: examination of factors that impact the effective implementation of unmanned ships
Man, Y., Weber, R., Cimbritz, J., Lundh, M., & MacKinnon, S. N.	2018	Human factor issues during remote ship monitoring tasks: An ecological lesson for system design in a distributed context
Rødseth, Ø. J., & Burmeister, H. C.	2015	Risk Assessment for an Unmanned Merchant Ship
Thieme, C. A., Utne, I. B., & Haugen, S.	2018	Assessing ship risk model applicability to Marine Autonomous Surface Ships
Wróbel, K., Krata, P., Montewka, J., & Hinz, T.	2016	Towards the Development of a Risk Model for Unmanned Vessels Design and Operations

Author(s)	Year	Title
Wróbel, K., & Montewka, J.	2018	A method for uncertainty assessment and communication in safety-driven design - a case study of unmanned merchant vessel
Wróbel, K., Montewka, J., & Kujala, P.	2017	Towards the assessment of potential impact of unmanned vessels on maritime transportation safety
Wróbel, K., Montewka, J., & Kujala, P.	2018	System-theoretic approach to safety of remotely-controlled merchant vessel
Wróbel, K., Montewka, J., & Kujala, P.	2018	Towards the development of a system-theoretic model for safety assessment of autonomous merchant vessels

Table 3: Summary of studies included in the qualitative synthesis.

A visualisation of the different topics covered by the articles removed in the initial screening is visualised in Figure 5 below:

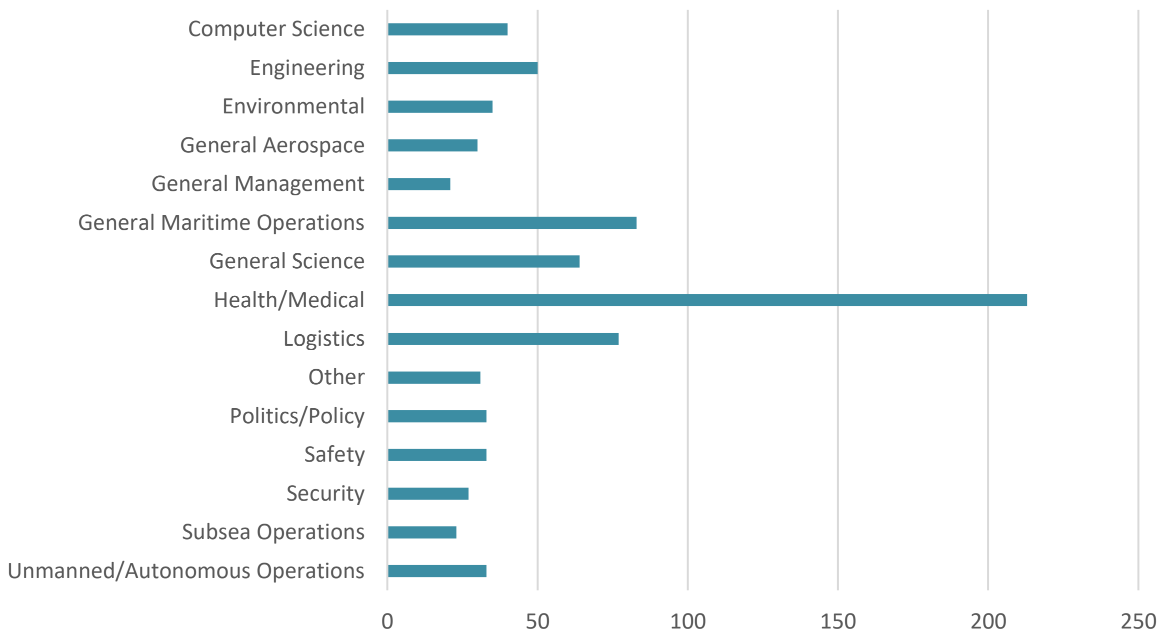

Figure 5: Topic affiliation of articles excluded in the screening process.

Figure 5 highlights that the search string was not sufficiently able to filter out irrelevant literature, as many studies in other research areas utilised the same terms in other settings. An example of such a situation was given earlier in this section. The specific nature of the research question further resulted in a number of articles either covering other automation areas or not focusing on safety management being excluded.

2.4 Data Extraction

The data extracted from each article included author, year, country, study design, outcomes and identified challenges in the safety management of MASS. Data was manually and independently extracted from included studies by one author, i.e. the author of this thesis. The results of this data extraction are provided in section 3.1.

2.5 Quality Appraisal

The methodological quality of the identified studies that met the inclusion criteria were critically appraised using a set of screening questions utilised by (Gillman & Pillay, 2018), which were adapted from the Critical Appraisal Skills Programme (CASP) (Critical Appraisal Skills Programme, 2018).

Screening questions		
1.	Aim/s:	Was the aim of the research clear?
2.	Method:	Was the research methodology used appropriate?
3.	Design:	Did the study design address the aims of the research?
4.	Data:	Did the data collected address the research aim?
5.	Data analysis:	Was the data analysis sufficiently rigorous?
6.	Bias:	Was any bias considered adequately?
7.	Findings:	Are findings clearly stated?
8.	Gap/s:	Have gaps in the literature been clearly identified?
9.	Acceptance:	Can I accept the findings as true?
10.	Value:	Can I apply these findings to my own work?

Table 4: Critical article appraisal questions, taken from (Gillman & Pillay, 2018).

These questions – listed in Table 4 above – aid in considering what the results are, whether or not they are valid and how they may benefit the research field.

In order to get a total quality percentage, points were assigned to the possible answers of “Yes”, “Limited” and “No”. Each question answered “Yes” resulted in a quality percentage increase of 10%, each question answered with “Limited” added another 5%, and each question answered with “No” resulted in no percentage change.

The summary of answers to the screening questions, and the final allocation of quality percentage points is presented in section 3.1.

2.6 Risk of Bias Assessment

As the conduct of a risk of bias assessment is considered to be an important activity in the systematic review process (Moher et al., 2009), this thesis initially tried to utilise the Chochrane Collaboration’s tool for assessment of risk of bias (Higgins et al., 2011) to conduct such an assessment. However, as the articles reviewed in this thesis are inherently different to the articles to which this tool would normally be applied – i.e. the reviewed articles focus on future events while clinical reports focus on trials that have been conducted in the past – it cannot be applied to the literature reviewed in this thesis. Indeed, due to the absence of a suitable risk assessment tool that can be used outside of clinical trials, numerous systematic reviews conducted in the maritime field – e.g. (Ashley, Mangi, & Rodwell, 2014) and (Theocharis, Pettit, Rodrigues, & Haider, 2018) – did not carry out a risk of bias assessment at all.

In this thesis bias is therefore not assessed by utilising a published tool, but by manually looking into the three major categories of risk of bias (Thomé, Scavarda, & Scavarda, 2016), i.e.

1. Publication bias leading to the selective exclusion of relevant studies,
2. Inappropriate research methodology or incorrect methodological applications, and
3. Bias during selective reporting of primary studies.

Risk of bias – classed as either low, unclear or high as clarified in Table 5 – in these categories was assessed for each paper by one person (i.e. the author).

Risk of bias	Interpretation
Low risk of bias	Bias, if present, is unlikely to alter the results seriously
Unclear risk of bias	A risk of bias that raises some doubt about the results
High risk of bias	Bias may alter the results seriously

Table 5: Interpretation of different levels of risk of bias reproduced from (Higgins et al., 2011).

As with the quality appraisal, a total risk of bias percentage was calculated. For each category where the assessment resulted in a high risk of bias, the total risk of bias increased by $33.\bar{3}$ % and for each category where the assessment resulted in an unclear risk of bias, the total risk of bias increased by $16.6\bar{7}$ %. The overview on the risk of bias for the individual categories, and the results of the calculated total risk of bias are presented in section 3.3.

2.7 Synthesis of Results

The process of bringing together the findings from the set of studies included in the systematic review carried out in this thesis is the synthesis of results, which was carried out as a narrative synthesis according to the guidance from (Popay et al., 2006). Such an approach can be utilised instead – or in conjunction – with a statistical pooling approach and "relies on the use of words and text to summarise and explain the findings of the synthesis" (Popay et al., 2006). The outcomes of the study and its methodological adequacy are described, explored and interpreted and in case similarities emerge from the findings, they will be presented as themes with explanations (Enya, Pillay, & Dempsey, 2018).

2.8 Ethical Considerations

According to Elsevier's "Ethical guidelines for journal publication", the following 10 ethics topics should be considered in (Elsevier, 2018):

1. Authorship of the paper
2. Originality and plagiarism
3. Data access and retention
4. Multiple, redundant or concurrent publication
5. Acknowledgement of the sources
6. Disclosure and conflict of interest
7. Fundamental errors in published works
8. Reporting standards
9. Hazards and human or animal subjects
10. Use of patient images or case details

Figure 6: Ethics topics to be considered in academic research according to (Elsevier, 2018).

Authorship of the paper: Elsevier encourages authors to utilise the Contributor Roles Taxonomy (CRediT) author statement as a tool for transparency (Elsevier, 2018). Utilising the CRediT author statement helps in identifying the authors to the work and offering a detailed description of their contributions. The CRediT author statement for this paper is as stated below:

Leif Ole Dreyer: Conceptualisation, Methodology, Validation, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Review & Editing, Visualisation, Project Administration. **Helle Asgjerd Oltedal:** Supervision, Project Administration.

Originality and plagiarism: Any work of others used in this paper is appropriately cited. All used sources can be reviewed in the reference section of this thesis.

Data access and retention: The work carried out in this thesis is a literature review. The articles that were reviewed have been published in scientific journals.

Multiple, redundant or concurrent publication: This paper is an academic thesis written as part of the Master of Science in Maritime Management program at the University of South-Eastern Norway. Elsevier does not regard publication as an academic thesis as “prior publication” (Elsevier, 2018).

Acknowledgement of sources: All sources used in this paper have been properly acknowledged and identified where used in the text. A summary of all cited works is listed in the reference section of this thesis.

Disclosure and conflict of interest: There are no relationships that could be viewed as presenting a potential conflict of interest.

Fundamental errors in published works: If any fundamental error or inaccuracy in this paper will be discovered by the author after publication, the University of South-Eastern Norway will be contacted in order to correct or retract the thesis.

Reporting standards: An accurate account of how the work in this thesis was performed is presented in section 2 of this paper. The objective discussion of the significance of this paper can be seen in section 4.

Hazards and human or animal subjects: The performed work did not involve the use of chemicals, procedures or equipment that have unusual hazards inherent in their use. It also did not involve the use of any animal or human subjects.

Use of patient images or case details: This study was not performed on any patients or volunteers, therefore no patient images or case details were used.

3 Results

This chapter will start by presenting the reader with an overview of the principal data extracted from the articles included in the qualitative synthesis, before going on to assess their quality and risk of bias. The presentation of the results allows the reader to get a better understanding of the background of the challenges identified in these articles, which have been split into technological, human element related and procedural challenges and are presented in the later part of this chapter.

3.1 Study Characteristics

To give the reader an overview of the studies included in the qualitative synthesis of this study, principle data including author, year, country, design and outcomes was extracted and summarised in Table 6 below.

Study	Country	Design	Outcomes
(Acanfora, Krata, Montewka, & Kujala, 2018)	Finland, Poland, Italy	Case study	With the absence of seafarers on board, autonomous ships must have reliable methods for detecting critical operational conditions to be avoided. An alert must be raised when a roll motion starts to develop and an evasive manoeuvre must be executed immediately. This study therefore proposes a method providing for the avoidance of dangerous phenomena involving excessive motions of the ship.
(Ahvenjärvi, 2016)	Finland	Exploratory	The paper highlights that the introduction of autonomous ships does not mean that there is no more human element involved in the navigation process and explores a number of select human factor issues that could be challenging in the safety management of autonomous ships.
(Burmeister, Bruhn, Rødseth, & Porathe, 2014)	Germany, Norway, Sweden	Exploratory	The development of advanced and integrated sensor systems for automated lookout, autonomous navigation systems incorporating the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs) and safe operation in harsh weather, a safe and reliable ship-to-shore communication architecture as well as human-centred design of onshore monitoring stations are regarded as central challenges for MASS.
(Burmeister, Bruhn, & Walther, 2015)	Germany	Case study	Challenges for MASS identified in this paper include the requirement to decide independently how to react to unfavourable weather conditions and how to avoid collisions in accordance with the COLREGs. It highlights cargo care, the transiting of dense traffic and coastal areas, and the large number of interconnected requirements and dependencies in the system as problematic, meaning that different requirements must not be resolved independently. It further highlights that misbehaviour or negligence of other vessels must be taken into account and that a MASS must be able to realise when a departure from the rules is necessary.
(Ghaderi, 2018)	Australia	Exploratory	The paper concludes that new skills and competencies are required to design, build and operate unmanned vessels, and highlights challenges in maintenance, compatibility in navigation support systems and cyber security.

Study	Country	Design	Outcomes
(Hogg & Ghosh, 2016)	Australia	Exploratory	The paper argues that the belief in complete reliability and trustworthiness of automation on ships is unrealistic. Numerous challenges are identified, including in the area of communications, human impact, legislation and standardisation, procedures, cyber security, and maintenance and prevention of technological failure.
(Man et al., 2018)	Sweden	Case study	This study came to the realisation that a shore control centre cannot just copy the design of a conventional ships bridge. Instead, it is argued that ecological interface design should be utilised in order to create a virtual ecology that reflects the constraints in the work domain and supports user-environment coupling.
(Rødseth & Burmeister, 2015)	Norway, Germany	Case study	A number of challenges – combined with some possible solutions – were identified in this paper. Hazards related to the interaction with other ships, errors in detection and classification of small/medium sized objects, detection of objects in low visibility, propulsion system breakdown and heavy weather are highlighted as being challenging to the safety management of MASS as no reliable control mechanisms have been identified yet.
(Thieme, Utne, & Haugen, 2018)	Norway	Theoretical review	This paper highlights that there is currently no appropriate risk model for MASS, which is a challenge for their safety management in itself, because a clear concept of risk is necessary to describe, communicate and manage risk.
(Wróbel, Krata, Montewka, & Hinz, 2016)	Poland, Finland	Case study	The outcome of this paper is that the safety of an unmanned ship as a system is made up of several features, most of which must not be considered separately from others, as the failure of one of the ships' subsystem can trigger a chain of events leading to potentially catastrophic consequences. This is visualised in the Bayesian network they created, which describes relationships between safety issues pertaining to unmanned vessels.
(Wróbel & Montewka, 2018)	Poland, Finland	Case study	The paper allocates levels of uncertainties to risk mitigation measures. Identified areas with particular uncertainties are the involvement of the remote operators, software solutions and the potential for so-called black swans.

Study	Country	Design	Outcomes
(Wróbel, Montewka, & Kujala, 2017)	Poland, Finland	Causal	The results of this paper reveal that the likelihood of an unmanned ship being involved in a navigational accident would decrease, while the extent of consequences – particularly from non-navigational accidents – can be expected to be much larger. Numerous challenges to be addressed in order to allow for the safe operation of unmanned ships are identified in the paper.
(Wróbel, Montewka, & Kujala, 2018a)	Poland, Finland	Case study	The results of this study indicate that ensuring the safety of MASS shall consist of executing various controls on regulatory, organisational and technical plains. As most safety constraint violations can be attributed to technical issues, mitigation of many hazards can be achieved by introducing redundancy to safety-critical systems. Examples of areas that are inherently different to traditional ships are navigation, power generation, fuel management, cargo conditioning and fire safety.
(Wróbel, Montewka, & Kujala, 2018b)	Poland, Finland	Case study	The results of this paper indicate that software development and validation appear to be the parts of the system that are hampered most by significant uncertainties regarding safety performance. By applying a system-theoretic process analysis hazard mitigation measures were identified that can improve the safety performance of MASS. As a result, this paper highlighted a number of challenges related to their safety management.

Table 6: Characteristics and summary of reviewed articles.

3.2 Quality Appraisal

The answers to the quality appraisal screening questions identified in section 2.4 are presented in Table 7 on the next page, and visualised in Figure 7 below.

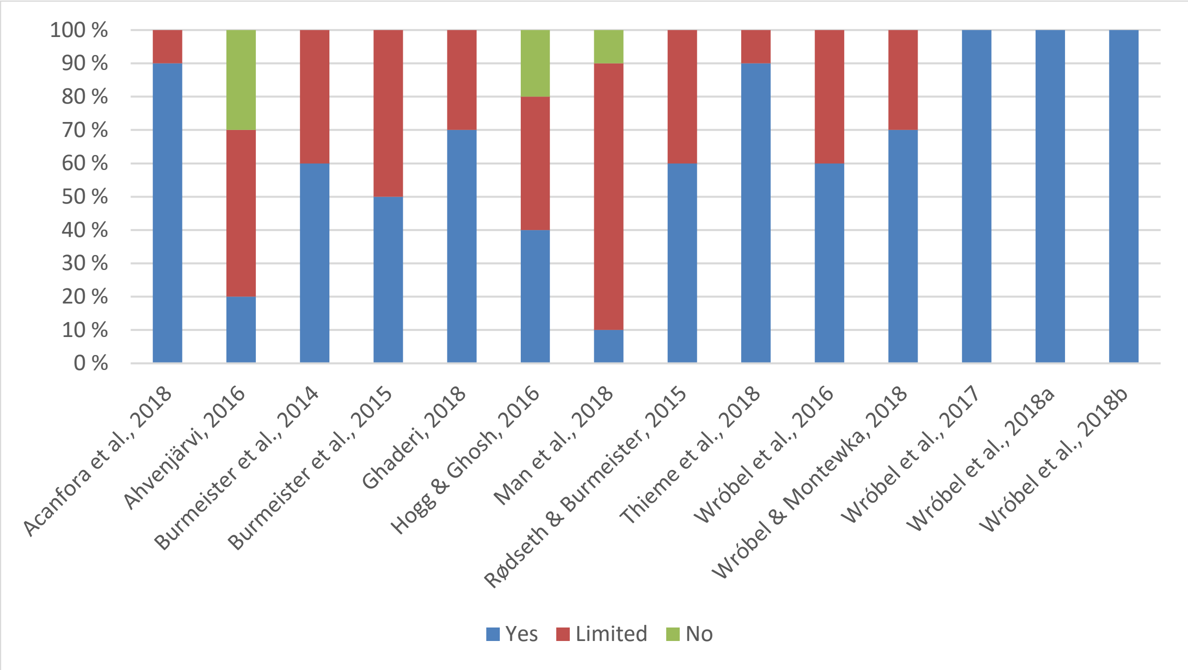

Figure 7: Visualisation of the quality appraisal of reviewed articles.

S/N	Title	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
1	Towards a method for detecting large roll motions suitable for oceangoing ships (Acanfora et al., 2018)	Y	Y	Y	Y	Y	L	Y	Y	Y	Y
2	The Human Element and Autonomous Ships (Ahvenjärvi, 2016)	L	L	L	L	N	N	L	N	Y	Y
3	Autonomous Unmanned Merchant Vessel and its Contribution towards the e-Navigation Implementation: The MUNIN Perspective (Burmeister et al., 2014)	Y	L	Y	L	L	L	Y	Y	Y	Y
4	Interaction of Harsh Weather Operation and Collision Avoidance in Autonomous Navigation (Burmeister et al., 2015)	Y	L	L	L	L	L	Y	Y	Y	Y
5	Autonomous technologies in short sea shipping: trends, feasibility and implications (Ghaderi, 2018)	Y	Y	Y	L	L	L	Y	Y	Y	Y
6	Autonomous merchant vessels: examination of factors that impact the effective implementation of unmanned ships (Hogg & Ghosh, 2016)	Y	L	Y	L	N	N	Y	L	L	Y
7	Human factor issues during remote ship monitoring tasks: An ecological lesson for system design in a distributed context (Man et al., 2018)	L	L	L	L	L	N	L	L	L	Y
8	Risk Assessment for an Unmanned Merchant Ship (Rødseth & Burmeister, 2015)	Y	Y	Y	Y	L	L	Y	L	L	Y
9	Assessing ship risk model applicability to Marine Autonomous Surface Ships (Thieme et al., 2018)	Y	Y	Y	Y	Y	L	Y	Y	Y	Y
10	Towards the Development of a Risk Model for Unmanned Vessels Design and Operations (Wróbel et al., 2016)	Y	L	Y	Y	L	L	Y	Y	L	Y
11	A method for uncertainty assessment and communication in safety-driven design - a case study of unmanned merchant vessel (Wróbel & Montewka, 2018)	Y	Y	Y	L	L	Y	Y	L	Y	Y

S/N	Title	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
12	Towards the assessment of potential impact of unmanned vessels on maritime transportation safety (Wróbel et al., 2017)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
13	System-theoretic approach to safety of remotely-controlled merchant vessel (Wróbel et al., 2018a)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
14	Towards the development of a system-theoretic model for safety assessment of autonomous merchant vessels (Wróbel et al., 2018b)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Key: Y = Yes; N = No; L = Limited											

Table 7: Quality appraisal of reviewed articles.

Taking the data from Table 7, the overall quality level of the different studies can be calculated as discussed in section 2.5. The results are visualised in Figure 8 below.

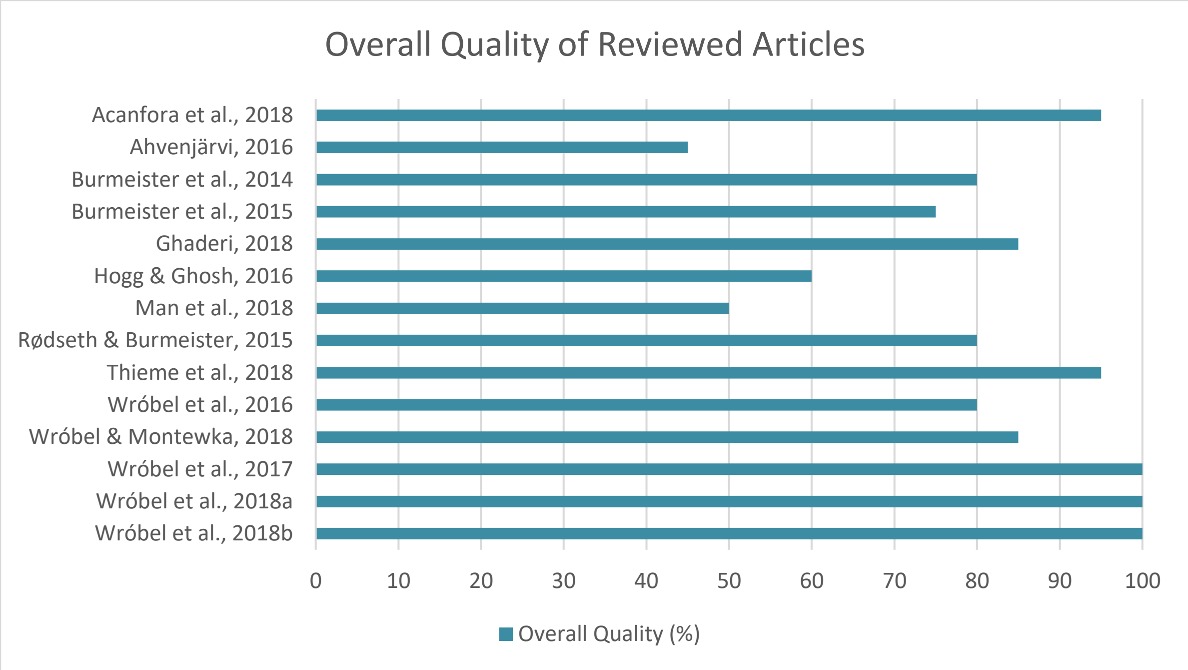

Figure 8: Calculated overall quality of selected studies.

Figure 8 shows that while the quality of the studies by (Ahvenjärvi, 2016), (Man et al., 2018) and (Hogg & Ghosh, 2016) only score an overall quality level of 45%, 50% and 60% respectively, the remaining studies are of high quality.

Due to the subjective and exploratory nature of this research area, it was decided to include the results of these studies in the systematic review anyway. The reader is advised to take the results of the quality assessment into account when assessing the different identified challenges in the safety management of merchant MASS.

3.3 Risk of Bias Assessment

The results of the bias assessment conducted according to the procedure highlighted in section 2.4 are displayed in Table 8**Error! Reference source not found.** below.

	(Acanfora et al., 2018)	(Ahvenjärvi, 2016)	(Burmeister et al., 2014)	(Burmeister et al., 2015)	(Ghaderi, 2018)	(Hogg & Ghosh, 2016)	(Man et al., 2018)	(Rødseth & Burmeister, 2015)	(Thieme et al., 2018)	(Wróbel et al., 2016)	(Wróbel & Montewka, 2018)	(Wróbel et al., 2017)	(Wróbel et al., 2018a)	(Wróbel et al., 2018b)
Publication bias	+	+	+	+	+	+	+	+	+	+	+	?	+	+
Inappropriate research methodology	+	?	?	?	+	?	?	+	+	?	+	+	+	+
Selective reporting	+	−	?	+	?	?	?	+	+	+	+	+	+	+
Key: + Low risk of bias ? Unclear risk of bias − High risk of bias														

Table 8: Risk of bias assessment of reviewed articles.

These results lead to the calculation of the overall risk of bias for each reviewed article as visualised in Figure 9 below.

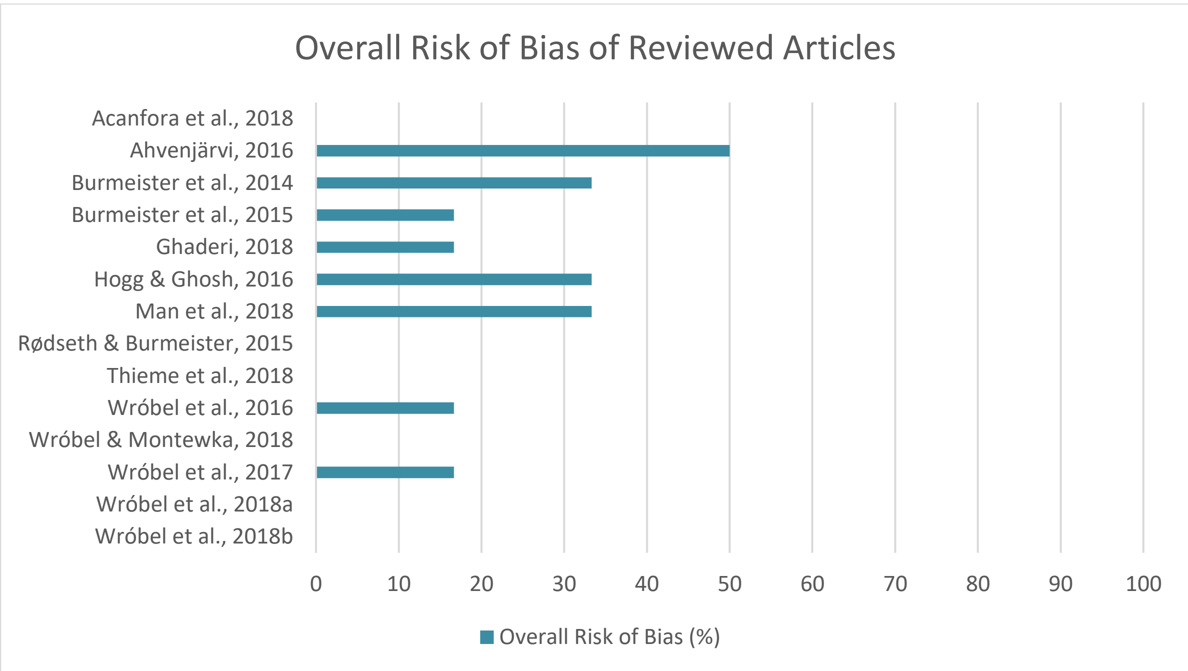

Figure 9: Calculated overall risk of bias of selected studies.

In line with the results of the quality appraisal shown in section 3.2, the results of the risk of bias assessment show promising results. Due to the inherently subjective nature of the articles reviewed, most have some risk of bias. Therefore, the results of all of the papers have been included in this thesis.

3.4 Technological Challenges

As mentioned in the introduction of chapter 3 above, the challenges identified in the reviewed articles have been split into three main groups. This chapter qualitatively synthesises the identified technological challenges, which can be split up into hardware and software.

3.4.1 Hardware

This section presents issues relating to the hardware of MASS, specifically to sensors, communication equipment, fire safety installations, apparatus for rendering assistance and mooring systems.

3.4.1.1 Sensors

A proper safety management system for MASS must ensure that they are provided with an adequate sensor system, in order to measure a variety of different collectable data available on-board a MASS. The importance of the relevant sensors becomes apparent when looking at the consequences of their inadequacy. Due to the lack of “first-hand multi-sensory experience of a living person” (Hogg & Ghosh, 2016), a failure in the sensory system of a MASS would lead to it becoming blind, inevitably leading to it not being able to perform safely and efficiently (Wróbel et al., 2018b). Such an inadequacy of the sensor system could be caused by “sensors’ failures, installed sensors’ inability to measure a required feature, unsuitable sensors being installed or their sub-optimal performance” (Wróbel et al., 2018b), which are all factors that may be mitigated through proper safety management.

The literature generally distinguishes between sensors for sensing the environment outside the vessel (Burmeister et al., 2014; Burmeister et al., 2015; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Thieme et al., 2018; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b), and sensors that measure the current state of the vessel (Burmeister et al., 2015; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b). The following critical areas in which adequate sensor data must be ensured have been identified:

- Lockout (Burmeister et al., 2014; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Thieme et al., 2018; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b).
- External environmental data (e.g. meteorological and oceanographic) (Burmeister et al., 2015; Wróbel et al., 2018a, 2018b).
- Internal stability data (e.g. motion and stress) (Burmeister et al., 2015; Wróbel et al., 2018a).
- Internal system data (Wróbel et al., 2016; Wróbel et al., 2018a, 2018b).

Lookout data refers to any data used for the observation of the sea for hazards, other ships, land, wreckage and distress signals, and is used to prevent collisions and detect persons in distress. When lookout data is combined with external environmental data such as depth readings from the echo sounder, an image of the external environment of the vessel can be constructed. However, to ensure safe navigation, internal stability data must be gathered and analysed as well. By combining external environmental data and internal stability data, dangerous situations that could lead to loss or damage to the ship or its cargo can be either anticipated and avoided, or realised and corrected.

Internal system data refers to data taken from the different internal systems on board, e.g. machinery data, fire sensor data and data to evaluate damage to the ship.

3.4.1.2 Communication

Another hardware challenge related to the operation of MASS is attributed to their capability to communicate. The reviewed literature generally agrees that the communication architecture of a MASS must be safe and reliable and distinguishes between two different types of communication:

1. Ship-to-shore (Burmeister et al., 2014; Ghaderi, 2018; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Thieme et al., 2018; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b).

2. Ship-to-ship (Burmeister et al., 2014; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Thieme et al., 2018).

In the list above, ship-to-shore communication relates not only the communication of the MASS with its shore control centre, but also includes communication with vessel traffic service (VTS), port authorities, pilots etc. Ship-to-ship communication encompasses both communication with other MASS as well as communication with conventional ships.

The architecture of the communication system of a MASS is critical for both safety and security (Wróbel et al., 2016) and requires specialised systems with sufficient redundancy and backup operations (Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Wróbel et al., 2018a). It must be ensured that MASS are provided with the necessary hardware to ensure reliable communication both with the shore control centre (Hogg & Ghosh, 2016; Thieme et al., 2018) and the monitoring and navigational systems used in ports (Ghaderi, 2018), even in regions where only restricted satellite bandwidth is available (Burmeister et al., 2014).

Means for communication with conventional vessels must also be provided (Hogg & Ghosh, 2016), which may prove to be challenging as this type of communication must be catered to humans on the bridges of the conventional vessels.

The uncertainties in the capabilities of the current technical communication solutions available lead (Wróbel et al., 2018b) to conclude that communication – which is considered to be a major part of the whole system – requires further study.

3.4.1.3 Fire Safety

Depending on the type of MASS in question, the design of a technical system capable of preventing or handling fires in all possible scenarios was identified by (Wróbel et al., 2017) to be an extremely difficult challenge. However, as major subsystems of a MASS are heavily reliant on one another, the performance of such a fire protection system has a directly impact the vessels machinery systems and navigational capabilities (Wróbel et al., 2016). Therefore it is concluded that the impact MASS operation has on fire safety must be carefully addressed in their safety management system (Wróbel et al., 2018a).

3.4.1.4 Rendering Assistance

It is pointed out in (Wróbel et al., 2016; Wróbel et al., 2017) that unmanned vessels may find themselves in a situation where they have to assist a conventional vessel that has come in distress. The authors therefore conclude that MASS must be able to assist in the distress response and be able to pick up and accommodate survivors even in the absence of on-board crewmembers. Ensuring that MASS have the required resources available in order to comply with the legislated duty to render assistance (UN General Assembly, 1982) must therefore be regarded in their safety management.

3.4.1.5 Mooring

(Burmeister et al., 2014; Burmeister et al., 2015; Ghaderi, 2018; Rødseth & Burmeister, 2015; Wróbel et al., 2017, 2018a, 2018b) expect a MASS to have a crew for the port-related activities, including departure and approach. In case a MASS operator plans to enter port without having any crew on board, special mooring infrastructure must be provided (Hogg & Ghosh, 2016; Thieme et al., 2018). Such mooring equipment must ensure a safe mooring process for both the ship itself as well as any shore personnel involved in the operation.

3.4.2 Software

The synthesis of the different identified challenges regarding the decision system of a MASS, potential software errors and ensuring cyber security is presented in this section.

3.4.2.1 Decision System

A number of challenges have been identified regarding the decision software that will need to be installed on a MASS designed with a navigation automation system. The two challenges that have been discussed the most is the ability of a MASS to avoid collisions with other traffic in accordance with the COLREGs (Burmeister et al., 2014; Burmeister et al., 2015; Hogg & Ghosh, 2016; Man et al., 2018; Rødseth & Burmeister, 2015; Wróbel et al., 2018b), and the ability to avoid and react to unfavourable weather conditions (Acanfora et al., 2018; Burmeister et al., 2014; Burmeister et al., 2015; Rødseth & Burmeister, 2015; Wróbel et al., 2016; Wróbel et al., 2017).

The primary challenge for a MASS is to ensure that it can principally comply with the COLREGs. This has been fundamentally questioned by (Hogg & Ghosh, 2016) on the basis of them believing that MASS are incapable of mimicking the foresight a human navigator has on the bridge of a conventional vessel. As such, it must be ensured that good seamanship practice is replaced by smart methods and criteria (Acanfora et al., 2018; Wróbel et al., 2018b) sufficient to ensure that MASS can be viewed as complying with the COLREGs.

While the COLREGs theoretically apply to all vessels upon the high seas (International Maritime Organization, 1972), misbehaviour or negligence of other vessels sometimes results in them not being applied in practice. The decision system of a MASS must therefore be able to avoid collisions with other vessels regardless of whether they follow COLREGs or not (Burmeister et al., 2015; Rødseth & Burmeister, 2015).

Another important part for ensuring safe navigation of MASS is the availability of reliable methods for detecting critical operational conditions that need to be avoided, both while planning the route and while monitoring the vessels progress along it (Acanfora et al., 2018). If a MASS encounters rough weather (Burmeister et al., 2014; Burmeister et al., 2015; Wróbel et al., 2016; Wróbel et al., 2017) or conditions that induce excessive motion and/or acceleration, her safety can be compromised. The safety management of a MASS is challenged with ensuring that scenarios that may lead to damage of the ship or its cargo are determined, and then utilised both at the route planning stage and during the voyage execution state (Acanfora et al., 2018). Detection of a potentially dangerous situation during the route planning stage should lead to the route being amended in a way that results in the MASS avoiding potentially dangerous sea areas (Acanfora et al., 2018), similar to how rough weather is avoided by utilising weather routing (Burmeister et al., 2015; Rødseth & Burmeister, 2015). During the voyage, the identification of a potentially dangerous situation should lead to the execution of mitigation actions, such as a change in course and/or speed and the raising of an alert to the shore based controller (Acanfora et al., 2018).

When looking at the two challenges discussed above, it is noted that they cannot be resolved independently, as their commands may be contradicting each other at times

(Burmeister et al., 2015). Decisions made by one system module will inevitably have an effect on another, an example of such an effect being the need for a new route to be provided by the planning module if the control module of the MASS decides that it is necessary to deviate from the initially planned route (Acanfora et al., 2018). It is therefore essential for the safety management of MASS to ensure that a holistic approach is adapted when designing the decision system in order to ensure the collaboration of the different components of the system (Wróbel et al., 2018b). As the proper functioning of the decision system depends on the quality of the input data (Wróbel et al., 2016), a stage where the quality of external- and sensor data is evaluated must be included in the system. Situations in which the indications of two or more sensors contradict each other must be identified and resolved in order to ensure the safe operational conduct of MASS (Wróbel et al., 2018a).

Further challenges that must be resolved include the issue of how a MASS should act in a situation where only really poor alternatives are left and the issue of ensuring that a MASS can adapt to unforeseen situations (Ahvenjärvi, 2016).

3.4.2.2 Software Errors

Even though the reliability and efficiency of the software utilised in MASS is of great importance to their safety (Thieme et al., 2018; Wróbel et al., 2018b), there is a high probability that more or less dangerous software errors are present in their control system (Ahvenjärvi, 2016). This is considered to be a main risk for MASS (Rødseth & Burmeister, 2015). The challenge for safety management is to reveal these errors and correct them before an accident occurs. Proper software development and testing are therefore considered to be critical processes (Ahvenjärvi, 2016) and the introduction of technical standardisation, certification and inspection of the control system is encouraged (Hogg & Ghosh, 2016). Highlighted challenges are the revealing of software errors that are connected with abnormal situations (Ahvenjärvi, 2016) and the reduction of errors by reducing system complexity (Rødseth & Burmeister, 2015). Due to the presence of control algorithms in a large number of MASS system components, a lot of work needs to be done in this area (Wróbel et al., 2018a).

3.4.2.3 Cyber Security

Cyber security is considered critical for the safe operation of MASS and must therefore be addressed in their safety management system (Ghaderi, 2018; Hogg & Ghosh, 2016). While virtually all system components are at risk of an attack (Wróbel et al., 2018a), the communication- and the information technology have been particularly highlighted by (Ghaderi, 2018). As devastating consequences may be expected if a breach in cyber security occurs (Wróbel et al., 2017, 2018b), ensuring the cyber security of MASS poses a major challenge that must be addressed appropriately.

3.5 Human Element Challenges

The second group of identified challenges in the safety management of MASS are those related to the human element. This group is made up of challenges related to training, the effect of technology on the human operator, and human factors based system design.

3.5.1 Training

Ensuring that all persons required to work with the new technology are adequately trained is mentioned as a challenge in a number of different studies reviewed in this paper (Ahvenjärvi, 2016; Ghaderi, 2018; Hogg & Ghosh, 2016; Man et al., 2018; Wróbel et al., 2018a, 2018b). The challenge to ensure proper training not only extents to seafarers (Ahvenjärvi, 2016) and shore-based operators (Wróbel et al., 2018b), but to naval architects (Ghaderi, 2018), technicians and engineers (Hogg & Ghosh, 2016) as well.

While (Man et al., 2018) do not specifically state adjusted training requirements for shore-based operators as a challenge, they do highlight that the required competencies of these operators have not been defined in regulations and that not enough research has been carried out on this topic. (Hogg & Ghosh, 2016) agree that new skills will be required and acknowledge the absence of regulation in this regard, but also highlight the importance of seagoing experience. In this light, they question how the shore-based operator of the future will gain the first-hand experience necessary to become an experienced Master when there are no more opportunities to work at sea.

The realisation of (Wróbel et al., 2018a) that the implementation of operational trainings may have a positive effect on the influence humans have on the safety of MASS serves to highlight that ensuring proper training is a key challenge that needs to be addressed in order to ensure safe MASS operations.

3.5.2 Effect of Technology on Human Operator

None of the papers reviewed suggest that the implementation of MASS will remove the possibility of human error altogether, but the effect that humans will have on MASS have been discussed to a different extent. While (Burmeister et al., 2015; Ghaderi, 2018) suggest that the introduction of MASS holds the potential to ultimately decrease human error, (Ahvenjärvi, 2016; Burmeister et al., 2014; Hogg & Ghosh, 2016; Man et al., 2018; Rødseth & Burmeister, 2015; Thieme et al., 2018; Wróbel et al., 2016; Wróbel & Montewka, 2018; Wróbel et al., 2017, 2018a, 2018b) argue that human factor issues will continue to be of significant importance in MASS operations.

The reviewed literature has identified a number of challenges related to the human factor that need to be managed in order to ensure MASS safety:

- Automation-induced complacency (AIC) results in the operator being unable to detect malfunctions in the system, and is directly affected by the training received, the reliability of the system and the workload experienced (Hogg & Ghosh, 2016). If the operating system of a MASS is reliable, it is likely that the operator becomes over-confident in the system and loses vigilance. This negative effect of automation on the human operator has also been discussed in (Man et al., 2018; Wróbel et al., 2018a).

- Remote supervisory control may lead to out-of-the-loop syndrome (Man et al., 2018) and together with the lack of human connection to the MASS and disappearance of cues in an office-like environment may result in limited situational awareness of the shore-based operator (Ghaderi, 2018; Hogg & Ghosh, 2016; Man et al., 2018; Wróbel et al., 2018a), thereby possibly magnifying the likelihood of an accident occurring (Wróbel et al., 2017). Furthermore, this leads to the inability for the operator to take over control in cases where the automation fails (Man et al., 2018) and has caused (Hogg & Ghosh, 2016) to question the effectiveness of the concept of supervising a MASS from a shore control centre altogether. This question gains more significance because humans are – due to their many limitations – seen as not being suitable for acting as a backup in human-automation interactions (Man et al., 2018).

- It is expected that the cognitive demands in the shore control centre will be higher than on the bridge of a conventional vessel (Hogg & Ghosh, 2016). If improperly managed, this may lead to information overload of the controller (Ghaderi, 2018). It is therefore considered essential for the safety management of MASS to ensure that operators are kept at optimal mental work load levels (Hogg & Ghosh, 2016). In this regard (Man et al., 2018) question if the pre-processing of raw data and flow may aid in reducing the demand of an operators cognitive resources.

- Another negative side effect of MASS implementation is the skill degradation of those charged with their remote supervision (Hogg & Ghosh, 2016; Wróbel et al., 2018a). Necessary steps must be taken to ensure that the shore based operator will retain his or her skills in order to be able to take over control of the MASS when the situation so requires.

3.5.3 Human Factors Based System Design

Depending on the type of MASS in question, the operator may not be present on-board the vessel. This leads to a complete migration of the workspace from ship to shore, which must be duly considered in the design of the shore control centre. The presentation of data in a user-friendly way will be a challenge regardless of the location of the operator.

3.5.3.1 Migration from Ship to Shore

One of the main results of the work of (Man et al., 2018) is the realisation that the ecological changes related to the migration of the working place from ship to shore must be considered when designing the shore control centre. The design of the technology in the shore control centre must be shaped for the new task of remote control and monitoring, meaning that current systems and practices may not simply be transferred to shore (Man et al., 2018). Ignoring the relationship between user and environment when designing the shore control centre may result in interfaces that are not suited for shore-based supervisory work and increase the gap between the demands of the work domain and the capabilities of the operator (Man et al., 2018).

3.5.3.2 Presentation of Data

A substantial amount of interaction between the MASS and its operators may be required at certain stages of a voyage (Thieme et al., 2018). Adapting a user-centred approach results in presenting the necessary data to the user according to his or her goals, tasks and needs (Hogg & Ghosh, 2016) will likely reduce the chance of him or her misinterpreting the data (Wróbel et al., 2017). Utilising user-centred design in human-machine interfaces allows the operator to gain and maintain situational awareness (Ahvenjärvi, 2016; Thieme et al., 2018). Furthermore, it must be ensured that the data required by the operator is presented to him or her in all operating conditions, including unanticipated contingencies. It is in these situations that automation functions may not reveal the true state of the system and provide the least help to the operator (Man et al., 2018). A central alarm management system including prioritisation issues (Burmeister et al., 2014) may aid an operator in these cases, as he or she may not be able to make decisions due to information overflow and bad prioritisation of tasks (Wróbel et al., 2017).

3.6 Procedural Challenges

The final group of identified challenges is related to procedures, which can be related to both contingencies and standard operations.

3.6.1 Dealing with Contingencies

Two different types of contingencies have been identified in the literature. Different challenges have been identified depending on whether a contingency was anticipated or unanticipated.

3.6.1.1 Anticipated

It has been noted in the reviewed literature that even when considerable efforts are expended into ensuring excellent design and performance of MASS, it is likely that at some point a disaster might occur (Wróbel et al., 2017). A number of anticipated contingencies have been identified in the literature, challenging the safety management system to ensure that measures are in place to cope with these contingencies.

- Shore based operators of MASS must anticipate the possibility of communication disconnections and ensure that suitable safeguards are in place in order to cope with such a situation (Burmeister et al., 2014; Burmeister et al., 2015; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Wróbel et al., 2016; Wróbel & Montewka, 2018; Wróbel et al., 2018a, 2018b). Possible fail-to-safe-functionalities that could potentially act as such safeguards have been discussed in (Burmeister et al., 2014; Burmeister et al., 2015; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Wróbel et al., 2018a).

- (Ahvenjärvi, 2016) identifies the situation of multiple and simultaneous sensor faults as a particularly challenging situation for autonomous ships. In fact, the failure of any of the technological equipment on-board the MASS must be addressed in their safety management in order to prevent minor technological failures from causing an error chain that may lead to an accident (Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b).

- While the consequences of a marine accident involving a conventional vessel are usually restricted by the actions of the on-board crew, an unmanned MASS will have to rely solely on the available technology to respond to an accident (Wróbel et al., 2018b). As the operators will be unable to make necessary manual adjustments themselves (Wróbel et al., 2018a), the accident response relies heavily on the designers’ ability to anticipate potential accident scenarios

(Wróbel et al., 2016), as this will decide the response mechanisms that will be provided. While it has been stated that damage assessment and control is likely one of the biggest challenges that safety management for MASS has to face, previous studies have not properly accounted for the absence of humans on board when evaluating response possibilities to MASS accidents (Wróbel et al., 2017).

3.6.1.2 Unanticipated

If a MASS runs into an unanticipated contingency, the operator must be alerted in due time. As it is of utmost importance to ensure that he or she has sufficient time before the situation develops to a point where nothing more can be done to remedy the situation, suitable alert points must be defined (Hogg & Ghosh, 2016; Wróbel et al., 2016). Due to the unanticipated nature of the contingency, this will be a challenging task for the safety management of the MASS.

Regarding the accident response of an unmanned MASS discussed above, the presence of black swans – which are scenarios that for some reason have not been analysed – must be anticipated (Wróbel & Montewka, 2018; Wróbel et al., 2018a). It is therefore unlikely that designers will be able to anticipate all potential accident scenarios in advance. As a result MASS should be designed in a way that ensures a proper level of resilience (Ahvenjärvi, 2016; Wróbel et al., 2017, 2018b).

3.6.2 Standard Operations

The introduction of MASS will have a considerable impact on a number of standard operations of MASS, and numerous procedural challenges to ensuring safe operations of MASS have been identified in the reviewed literature. They have been split into challenges regarding navigation procedures, maintenance, cargo care, risk assessment, safety control and absence of regulations.

3.6.2.1 Navigation Procedures

In the case of a MASS controlled or supervised from a shore control centre a number of challenges regarding the navigation procedures have been identified.

- Utilising the traditional hierarchy of a conventional vessel in a shore control centre may not be suitable. (Hogg & Ghosh, 2016) have suggested that the arrangement of dedicating the captain as the final decision-maker may not be a suitable solution, as he or she will be out of the loop and have difficulty developing proper situational awareness in an emergency. The shift from conventional navigation to MASS operation must therefore be based on a review of manned bridge procedures (Burmeister et al., 2015).

- As the interaction between the operator and the MASS varies depending on the level of autonomy. Procedures must therefore be in place to ensure a safe transition when the operator takes control of the MASS (Wróbel & Montewka, 2018), and that the system and the operator are able to adapt quickly to the new operational mode (Thieme et al., 2018).

- As MASS will continue to coexist alongside other vessels in the foreseeable future, it has been suggested that aspects such as the interactions between conventional ships and MASS must receive more attention in the future (Thieme et al., 2018). One such interaction may be the dangerous utilisation of predictable MASS behaviour by conventional vessels, as humans who have regular contact with automated systems have a tendency to create new and risky habits (Ahvenjärvi, 2016).

- (Thieme et al., 2018) argue that current navigational aids are designed to assist human navigators, and argue that further investigation is necessary to assess if they need to be changed in order to facilitate MASS navigation.

3.6.2.2 Maintenance

The absence of a crew on board an unmanned MASS leads to the realisation that there will be no one on board to carry out any maintenance while the vessel is at sea (Ghaderi, 2018; Hogg & Ghosh, 2016; Thieme et al., 2018; Wróbel et al., 2018b), causing a number of maintenance related challenges (Wróbel et al., 2017). A rigorous preventive maintenance scheme must therefore be developed to ensure that no maintenance of any of the ship components becomes necessary while the unmanned MASS is at sea (Burmeister et al., 2014; Thieme et al., 2018; Wróbel et al., 2016; Wróbel et al., 2018a, 2018b), especially because it has been observed that non-complex hardware problems can propagate a cause major problems (Rødseth & Burmeister, 2015; Wróbel et al., 2016). Ensuring that sufficient backup solutions are available in case of a sub-system failure will be of high importance for unmanned MASS (Thieme et al., 2018).

Depending on the approach chosen to fulfil this goal, a number of different challenges have been identified in the literature. (Hogg & Ghosh, 2016; Thieme et al., 2018; Wróbel et al., 2018b) declare that all MASS components will require extreme reliability. Any maintenance required will have to be carried out in port by specialised personnel (Ghaderi, 2018; Hogg & Ghosh, 2016; Thieme et al., 2018), introducing new implications for both port and ship operators (Ghaderi, 2018). It is even suggested that unmanned MASS will require new propulsion concepts, as conventional diesel engines are in need of frequent maintenance (Thieme et al., 2018).

3.6.2.3 Cargo care

Current designs of MASS suggest that only cargo with low management requirements may be carried on unmanned MASS (Burmeister et al., 2014; Burmeister et al., 2015). In more detail this means that only stable and non-hazardous cargo may be carried on unmanned MASS, and that such cargo may not require maintenance or monitoring during the voyage (Hogg & Ghosh, 2016). However, this view is not shared across all of the reviewed literature. (Wróbel et al., 2016) can see issues arising from self-heating or self-igniting cargo, which suggests that they assume that such cargoes may be carried on board unmanned MASS. (Wróbel et al., 2018b) are more direct in the way that they assume more challenging cargoes can be accommodated if MASS are provided with the right functionalities. Importantly, it must be noted that even if hazardous cargo was banned from being transported on unmanned MASS, undeclared dangerous cargoes may still end up on board (Wróbel et al., 2017). Safety issues regarding the carriage of hazardous cargo must therefore be considered in the safety management of unmanned MASS in any case (Wróbel et al., 2017).

3.6.2.4 Risk Assessment

A number of the reviewed articles focus specifically on assessing the risk and uncertainty involved with MASS operation and highlight the difficulty in establishing a reliable risk model (Rødseth & Burmeister, 2015; Thieme et al., 2018; Wróbel et al., 2016; Wróbel & Montewka, 2018; Wróbel et al., 2017, 2018a, 2018b). However, a clear concept of risk is necessary to describe, communicate and manage risk (Thieme et al., 2018), and make feasible safety recommendations (Wróbel & Montewka, 2018). A number of key challenges that need to be overcome are outlined below:

- There is an acute uncertainty regarding MASS in general, which means that reliable information regarding their actual design and operating circumstances is not available (Wróbel et al., 2016; Wróbel & Montewka, 2018; Wróbel et al., 2017). However, such information must be available if a generic and comprehensive risk model for MASS is to be developed (Thieme et al., 2018).

- Risk models in shipping have traditionally been quantified based on accident and incident data, however due to absence of such data in a MASS context, such an approach is not viable for MASS risk models yet (Thieme et al., 2018). Furthermore, there is no empirical data pertaining to their performance available yet (Wróbel & Montewka, 2018; Wróbel et al., 2018b), and areas that need special attention in the context of MASS operations have rarely been covered in depth in available literature (Thieme et al., 2018). If this absence of reliable data leads to wrong assumptions being made, the assessment may lead to unjustified conclusions and wrong decisions (Wróbel & Montewka, 2018). Circumventing this problem by utilising an existing model to assess risk is also described as questionable (Wróbel & Montewka, 2018).

- The concept of black swans described in 3.6.1.2 above also has direct effects on the risk assessment models for MASS, as the likelihood of their input data being incomplete leads to uncertainties in their outcomes (Wróbel & Montewka, 2018; Wróbel et al., 2018a).

- Due to a lack of an officially defined acceptable risk level, the outcome of the risk models cannot be suitably utilised to assess MASS safety (Wróbel et al., 2016; Wróbel et al., 2017).

3.6.2.5 Safety Controls

Regarding the challenge of ensuring suitable safety controls, it has been noted that approaching the issue systematically from higher organisational levels ensures that hazards are controlled at each point of the system's structure (Wróbel et al., 2018a). However, the challenge of mitigating hazards does not only involve the provision of safe control actions, the safety management of MASS must also ensure that those safety controls are applied at the right time and for the right period of time, and that they are applied in the correct sequence (Wróbel & Montewka, 2018; Wróbel et al., 2018a).

A further challenge is to ensure that safety and cost-effectiveness are suitably balanced (Rødseth & Burmeister, 2015; Wróbel et al., 2016; Wróbel et al., 2018a), as the reduction of cost is one of the most important arguments for MASS (Ahvenjärvi, 2016; Ghaderi, 2018; Rødseth & Burmeister, 2015; Wróbel et al., 2017, 2018a).

3.6.2.6 Absence of Regulations

Due to the absence of a regulatory framework regarding many aspects involving MASS (Hogg & Ghosh, 2016; Man et al., 2018), safety management must ensure that suitable operational procedures are available, relevant training is being organised and that the maintenance of on-board systems is properly managed (Wróbel et al., 2018a).

4 Discussion

This section will review and discuss the findings of the qualitative synthesis of the reviewed articles, will highlight potential areas of further interest and discuss both the implications this thesis has on theory and practice and what limitations it has.

4.1 Review of the Findings

The results presented in this systematic review show that the launch of MASS introduces a number of challenges regarding their safety management. The challenges discussed below were identified as being of high importance for MASS.

4.1.1 Technological Challenges

The main issue for unmanned MASS is the necessity to be able to cope with unforeseen situations in the absence of humans on board. Ensuring proper post-accident response is regarded as being vital for the overall safety of MASS, with damage assessment and control being seen as the most difficult to achieve (Wróbel et al., 2017). Even though (Ahvenjärvi, 2016; Wróbel et al., 2017) have called for resilience to be built into the different components of MASS, nowhere in the reviewed literature is it suggested that viable technological systems to deal with complex fire scenarios or issues related to dangerous cargoes have been developed yet.

The above situation gets even more problematic when considering that the remote operators of the MASS can influence the situation only through the automation means available (i.e. they cannot make any manual adjustments (Wróbel et al., 2018a)) and their ability to impact the situation may even be completely removed if the communication system fails.

As can be seen, the architecture of the communication system of a MASS is critical for its safety (Wróbel et al., 2016). While problems due to limited bandwidth for ship-to-shore communication on the high seas has been discussed (Burmeister et al., 2014), big industrial players such as SpaceX, Google, Boing, Samsung, OneWeb and Facebook are making fast progress in providing high-speed internet to the entire globe (Perry, 2018). Even though this will not remove the possibility of communication failure, it will drastically reduce its likelihood. In the unlikely event that the communication link does fail, suitable fail-to-safe mechanisms must be provided on-board the MASS (Wróbel et al., 2018b). As mentioned in 3.6.1.1 above, possible fail-to-safe-functionalities that could potentially act as such safeguards have been discussed in (Burmeister et al., 2014; Burmeister et al., 2015; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Wróbel et al., 2018a). Communication failure between the MASS and its shore control centre is therefore not regarded as posing a major challenge for the safety management of MASS. However, more work may be necessary to ensure the adequacy of communication between MASS and other ships or VTS (Thieme et al., 2018).

The navigational conduct between MASS and other vessels will be regulated by its decision system. Because of the inherent dependency of MASS operations on software functionality (Thieme et al., 2018), the development and testing of the control software is seen as an extremely critical operation (Ahvenjärvi, 2016). The system is largely dependent on the performance of the sensors installed on the MASS (Wróbel et al., 2016; Wróbel et al., 2018b), and on its ability to assess the quality of input data (Wróbel et al., 2016).

Several different modules will make up the decision system, with the reviewed literature emphasising the importance of the collision avoidance (Burmeister et al., 2015; Hogg & Ghosh, 2016; Rødseth & Burmeister, 2015; Thieme et al., 2018; Wróbel et al., 2017), and the weather routing modules (Burmeister et al., 2015; Rødseth & Burmeister, 2015).

While the parallel cooperation of these modules is critical to detect and avoid critical situations and ensure safe navigation (Acanfora et al., 2018; Burmeister et al., 2015), their interconnected requirements and dependencies must be analysed in order to ensure error free operation (Burmeister et al., 2015). Finally, in order to ensure safety of marine transportation as a whole, MASS must be able to detect and aid any distressed person or persons she may encounters (Rødseth & Burmeister, 2015; Wróbel et al., 2016; Wróbel et al., 2017).

Regarding the above two paragraphs it is understood that the kind of decision system envisioned above, combining “real-time intelligent algorithms for collision avoidance combining multiple vessel situations, dynamic weather conditions and COLREGS compliance is yet to be developed” (Hogg & Ghosh, 2016). This presents an acute challenge for the safety management of MASS, as without such capabilities MASS cannot be safety operated in a number of operational modes.

4.1.2 Human Element Challenges

The reviewed literature has identified that shifting the control of remote-controlled and remote-supervised MASS to a shore control centre comes with the introduction of new risks. It has become clear that the issues that were identified have not been properly addressed yet, which poses an immediate challenge for the safety management.

Common agreement in the literature exist that the design of the shore control centres must be human-centred (Ahvenjärvi, 2016; Hogg & Ghosh, 2016; Man et al., 2018; Rødseth & Burmeister, 2015; Thieme et al., 2018). While it has been proposed that the design of the systems must properly regard the ecological change of migrating the work environment of the navigator from ship to shore (Man et al., 2018), no concrete solutions as to how to solve this problem in practice have been made. While human-centred design and procedures to ensure optimal levels of mental work load of shore based controllers (Hogg & Ghosh, 2016) is considered the only feasible way of helping them gain and maintain situational awareness (Ahvenjärvi, 2016; Ghaderi, 2018; Thieme et al., 2018; Wróbel et al., 2017, 2018a), little is known on how effective this system is in an emergency situation (Hogg & Ghosh, 2016). For anticipated, avoidable accidents a central alert system including a prioritisation module must be designed in order to grab the operators attention and ensure that preventive actions are taken in due time (Acanfora et al., 2018; Burmeister et al., 2014; Wróbel et al., 2016).

Even though some may have initially thought of MASS to eliminate human error (Ahvenjärvi, 2016), (Rødseth & Burmeister, 2015) have observed that in an autonomous underwater vehicle context the most common source of problems is human error. This may be because the backup role in human-automation interactions does not really suit the human operator (Man et al., 2018). Even though human performance problems in remote supervisory control are well known (Man et al., 2018), MASS operations will likely lead to humans in exactly that role. This is an obvious challenge that must be managed.

It is stated that automation-induced complacency (AIC) is affected by the training received by the operator (Hogg & Ghosh, 2016), and a number of other reviewed papers advocate that proper training of personnel can lead to improved safety (Ahvenjärvi, 2016; Ghaderi, 2018; Wróbel et al., 2018a). While industry training requirements are being developed, no legislative requirements exist (Hogg & Ghosh, 2016), meaning that it is still being established what competencies will be required (Man et al., 2018). Training operators of MASS without knowing what competencies will be required to ensure safe operations will likely be a challenging endeavour.

4.1.3 Procedural Challenges

Important procedural challenges that will need to be solved involve the maintenance and security of the MASS. In order to ensure reliability of the different system components a proactive condition monitoring scheme must be developed that ensures that maintenance is carried out before failures occur (Thieme et al., 2018). The knowledge that non-complex errors can lead to major problems (Rødseth & Burmeister, 2015; Wróbel et al., 2016), highlights the importance of such a scheme. As maintenance of the ship and equipment is an explicit part of the ISM Code (International Maritime Organization, 2014), the safety management of MASS is challenged with ensuring the adequacy and reliability of such a maintenance scheme.

As mentioned in section 1.1 above, the international maritime community is becoming more aware of cyber security. (Ghaderi, 2018) has identified cyber security as "the biggest challenge facing the maritime industry", acknowledges its importance to the safe operation of MASS. However, it has been stated that the likelihood of unauthorised control of the ship can be drastically reduced by ensuring proper design of communications, position sensing and on-board control systems (Rødseth & Burmeister, 2015). It therefore becomes clear that as long as cyber security procedures are followed, low risk of unauthorised access to the MASS can be ensured.

4.2 Potential Areas of Further Interest

The author has noted that some potentially challenging areas have not been discussed in the reviewed literature. These are discussed in more detail below.

The type of MASS discussed in (Burmeister et al., 2014) assumes that the decision system of the vessel will only be taking over control of the vessel in deep-sea navigation. It thereby conveniently avoids having to discuss potentially challenging operations such as pilotage, mooring and cargo operations. While the two latter operations have been mentioned in (Hogg & Ghosh, 2016), the challenges related to pilotage of a MASS have not been discussed anywhere. It is likely that there are numerous other conditions and circumstances –

such as ice navigation/navigation in polar waters, STS operations, etc. – where challenges need to be overcome to ensure safe MASS operations. These would all warrant further research.

As long as these operations are not properly considered in a MASS context, it must be ensured that the decision system of a MASS is aware of the limitations to its allowed operations. These must be clearly defined and programmed into the system.

While (Ahvenjärvi, 2016) states that errors due to operator fatigue are not possible in a MASS context, no compelling argument is made that this is the case. While the Maritime Labour Convention, 2006 (MLC) has identified the danger posed by fatigue and has determined minimum hours of rest, these regulations will likely find no application to shore based controllers of MASS (International Labour Conference, 2006). It is therefore argued that without such regulation preventing fatigue, errors due to fatigue may become more likely in the context of a MASS supervised and/or controlled from a shore control centre.

4.3 Implications for Theory and Practice

The collection of identified challenges in the safety management of MASS in section 3 and the review of these findings in section 4.1 show that still a lot of work has to be done in the field of safety management in order to ensure that MASS can be operated safely.

As this is the first systematic review in this academic field, this paper contributes by closing a gap in the available literature and helps researchers in gaining an overview of the challenges that have been identified in academic journal articles in the field of safety management for MASS. It acts as a guide to show where further research efforts are needed in order to ensure the safe and smooth introduction of MASS into the maritime domain.

4.4 Limitations

Being a systematic review, this thesis is affected by two different areas of limitations, namely the limitations of the studies reviewed, and the limitations connected to the systematic review carried out in this thesis itself.

4.4.1 Study Level

The only two reviewed studies that have received a perfect quality and risk of bias rating are (Wróbel et al., 2018a) and (Wróbel et al., 2018b). Therefore, the results of the remaining articles included in the results section of this thesis may be of lesser quality. However, due to the exploratory nature of the research area, these limitations are deemed to be of insignificant nature.

4.4.2 Review Level

A clear limitation of this systematic review is the publication bias, as only articles published in peer-reviewed journals were included in the selection process. This means other material – such as peer-reviewed conference papers or industry white papers – discussing challenges in the safety management of MASS was not included in this thesis.

Furthermore, this paper purposefully did not include papers from other domains such as unmanned aviation, unmanned subsea operations, unmanned cars, and – most notably – military MASS operations. While a lot of work may have been done in those areas that is of acute interest to MASS, transferring knowledge form one field to another is a work in itself. This paper therefore highlights the challenges to the safety management that have been identified specifically in a MASS context and can be utilised to highlight areas where further work is required in a MASS context.

Finally, as mentioned in section 1.4.3, this thesis focused on challenges related to process safety, thereby ignoring any possibly identified personal safety challenges regarding merchant MASS.

5 Conclusion

The aim of this paper was to collect all challenges in the safety management of merchant MASS that have been identified in peer-reviewed journal articles. By conducting a systematic review of a broad spectrum of peer-reviewed journal articles published on or after 2008, the challenges identified in the relevant papers were presented in section 3. It can therefore be concluded that the aim of this thesis was achieved.

Further research work is required not only in order to solve the challenges for maritime safety management of MASS highlighted in this paper, but to investigate other potentially challenging areas that have not been discussed in any of the reviewed papers. Technical, human element related and procedural challenges must be addressed quickly, as the first MASS are planned to be launched relatively soon. Safe operations must be ensured in order to gain the necessary operating permissions from legislators and promote wider acceptance of this new technology in the maritime domain.

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Appendix A – Systematic Review Protocol

Title

Initial: Challenges in the Safety Management of Autonomous Ships: A Literature Review of Scientific Journal Publications

Edited to: Identified Challenges in the Safety Management of Merchant Maritime Autonomous Surface Ships: A Systematic Review of Scientific Journal Publications

Background

While research into making autonomous ships a reality has been carried out for some time now, the focus was generally only on overcoming the technological challenges involved (Banda et al., 2018), leaving a gap in research in the corresponding safety management that needs to be involved. As it is considered most effective to utilise system-engineering tools for the creation of an SMS from an initial stage of a project (Banda & Goerlandt, 2018) and the first autonomous ships could start operation relatively soon, research regarding the safety management of MASS is desperately required.

This thesis therefore aims to summarise the challenges regarding the safety management of MASS identified in existing literature, thereby enabling future research to find suitable ways to address these challenges.

Review questions

Initial: The review seeks to establish, through the available literature, what challenges with regards to the safety management of merchant maritime autonomous surface ships (MASS) exist. The specific review question to be addressed is:

- Which challenges regarding the safety management of maritime autonomous surface ships (MASS) exist?

Edited to: The review seeks to establish, through the available literature, what challenges have been identified with regards to the safety management of merchant maritime autonomous surface ships (MASS). The specific review question to be addressed is:

- Which challenges in the safety management of merchant maritime autonomous surface ships (MASS) have been identified in peer-reviewed journal articles?

Inclusion criteria

Initial: The review will consider all non-duplicate studies published in English in a scientific journal in the last 10 years focusing on MASS and issues related to their safety management.

Edited to: The review will consider all non-duplicate studies published in English in a scientific journal in the last 10 years focusing on merchant MASS and issues related to their safety management.

Search strategy

The search strategy is designed in order to include all possible journal articles complying with the inclusion criteria. It will comprise the following stages:

1. Relevant keywords will be identified, tested and combined to form a relevant Boolean search string.

2. Four databases – namely SCOPUS, Acedemic Search Elite via EBSCOhost, ScienceDirect and Web of Science – will be searched utilising the previously defined Boolean search string.

3. Literature found in step two will be complemented by additional literature taken from reference lists and bibliographies of relevant articles.

The library of the Western Norway University of Applied Sciences has compiled relevant databases for maritime studies. The list was scanned for databases that would be able to identify relevant peer-reviewed articles. As a result, it was decided to conduct the search using the following databases:

5. SCOPUS,

6. Academic Search Elite via EBSCOhost,

7. ScienceDirect, and

8. Web of Science.

Search string, searching all parts of the text	
Intial:	**Edited to:**
(maritime OR marine OR sea OR ocean) AND (autonom* OR unmanned OR automat*) AND (ship* OR vessel* OR craft*) AND (merchant OR cargo) AND safe* AND (manag* OR overcome* OR resolv* OR system*)	(ship* OR ((vessel* OR vehicle* OR craft*) AND (maritime OR marine OR sea OR ocean))) AND (autonom* OR unmanned OR automat*) AND safe* AND (manag* OR overcom* OR system* or challeng*) AND (merchant OR cargo)

Table 9: Initially envisioned and edited search string.

Articles identified by the search will be processed with reference to the PRISMA four-phase flow diagram (Moher et al., 2009). The first step will be the removal of duplicates, followed by the screening of all identified articles based on their title and abstract. Full copies of the remaining articles will be obtained and assessed for eligibility. The remaining articles will be included in the review.

Critical appraisal

The methodological quality of the identified studies that meet the inclusion criteria will be critically appraised using a set of screening questions utilised by (Gillman & Pillay, 2018) that were adapted from the Critical Appraisal Skills Programme (CASP) (Critical Appraisal Skills Programme, 2018). These questions aid in considering what the results are, whether or not they are valid and how they may benefit the research field.

Initial: Furthermore, the assessment of risk of bias in included studies will be carried out using the Chochrane Collaboration's tool for assessment of risk of bias.

Edited to: Furthermore, an assessment of risk of bias in the included studies will be carried out. Such an assessment will be carried out manually by one person (the author) by trying to identify if bias exists in any of the three major categories of risk of bias (Thomé et al., 2016), i.e.

1. Publication bias leading to the selective exclusion of relevant studies,
2. Inappropriate research methodology or incorrect methodological applications, and
3. Bias during selective reporting of primary studies.

Data collection

Following the assessment of methodological quality, data extraction from the articles will be conducted manually. All challenges regarding the safety management of MASS that are identified in the papers will be collected.

Data synthesis

Any challenges regarding the safety management of MASS that have been identified in peer-reviewed journals will be listed in the results section of the thesis in order to give the reader an overview of the state-of-the-art in the research area. Identified and/or suggested ways of tackling these challenges will be listed as well.

All scrutinisation and synthesisisation of the data will be carried out narratively.