University of
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Ship Domain in Restricted Waters

A study assessing Norwegian navigators´ perception of safe passing distance to a targeted ship in restricted waters

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Abstract

Collisions at sea is a great threat to the navigational safety. To assess the navigational safety, navigators of ships make use of various criteria. The most commonly adopted ones are two proximity indicators called Closest Point of Approach and Time to Closest Point of Approach. Research suggests that these are insufficient for their intended purpose and generally require a lot of experience from any one applying them, especially in restricted and congested waters. A concept termed ship domain offers an intuitive alternative. The concept is concerned with defining a free space around a ship required for safe navigation and collision avoidance and thus it is a concept aiming at generalizing safe distance. The general problem is that the ship domain is heavily dependent on certain factors known to influence its shape and size, three of which are the type water area, relative bearing to an approaching targeted ship and the own ship´s size. This thesis have investigated the influence of these factors on the ship domain shape and size as perceived by Norwegian navigators in restricted waters in a quantitative, quasi-experimental, questionnaire-based study. It was found, with some caution due to a small sample size, that navigators perceived a ship domain in an increasing manner depending on ship size. The overall influence of ship size on the mean ship domain size could be approximated by a linear regression. The ship domain shape resembled a circle regardless of ship size. It was also found that the relative bearing of a targeted ship had an impact on a perceived safe passing distance. However, there was found no wider systematic differences corresponding to past research and hence some discussion follows this. Finally, future research should consider an empirical approach that considers actual ship navigation so that the results in this thesis can be confirmed. It is also recommended that future research considers a mixed method approach that allows probing for additional information, electing how navigators assess the ship domain.

Acknowledgements

I would like to express my sincere gratitude to my main supervisor, Associate Professor Jarle Løwe Sørensen, for all his support and encouragement. His feedback has been of great importance to ensure a continuous, structured and otherwise positive writing process. My gratitude is also extended to my second supervisor, Professor Kjell Ivar Øvergård who have provided me with much appreciated guidance during the data analysis process. He also introduced me to the field of ship domain research and guided me in the early as well as in the later stages upon completion of this thesis. Finally, I would like to thank my partner Kristin for all her love and support in this rather stressful period of my life.

Preface

This master thesis, henceforth referred to as thesis, is written as a part of a two year master programme at the University of South-Eastern Norway in Maritime Management with specialization Maritime Technical Management. The thesis topic was motivated and initiated by Professor Kjell Ivar Øvergård who formed a collaboration group on the topic of ship domain during the fall of 2017. The group comprised three members: Professor Kjell Ivar Øvergård, Mari Auby Starup (master student) and Johan Øen Strand (master student and undersigned). Mari Auby Starup and Johan Øen Strand have in collaboration and under the supervision of Professor Kjell Ivar Øvergård developed the questionnaire applied herein. The questionnaire was designed for two distinct topics within ship domain research, namely ship domain in open and in restricted waters. The former topic has been the concern of Mari Auby Starup and the latter topic has been the concern of Johan Øen Strand. Beyond designing the questionnaire in collaboration, joint supervision has been received by Professor Kjell Ivar Øvergård pertaining data analysis of the results. There has been no collaboration beyond this. Associate Professor Jarle Løwe Sørensen have since January 2018 been the main supervisor of both Mari Auby Starup and Johan Øen Strand, however, supervision has been provided in individual sessions.

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Introduction

Background

The safety of ships at sea is a top concern in the maritime industry since lack of such poses severe consequences on human lives, damage to the environment and material goods (Soares & Teixeira, 2001). In the case of ship navigation, collisions represents one of the greatest threats to the navigational safety (Vujičić, Mohović, & Mohović, 2016).

The role of human factor in maritime accidents is an important aspect (Chauvin, 2011). A study performed by the Nautical Institute identified human error as the primary cause of collisions and groundings (Gale & Patraiko, 2007). For collisions in particular, the study identified three major human related causes: Poor situation assessment, poor lookout and completely lack of situation awareness, respectively represented in 24%, 23% and 13% of the studied cases (Gale & Patraiko, 2007).

When navigators perform anti-collision maneuvers they do so on basis of applicable regulations and good seamanship (He et al., 2017). The regulations are formally known as the "Convention on the International Regulations for Preventing Collisions at Sea, 1972", short form, COLREG (COLREG, 1972). Good seamanship is frequently understood as the ability to make safe decisions based on professional skill and judgement, learned through first-hand experience (Antonsen, 2009). Thus, navigational situation assessment results from two groups of criteria; regulations and the navigator´s knowledge and experience where the latter group also includes use of navigational systems (Pietrzykowski & Uriasz, 2009).

Many navigational systems exists, however, for collision avoidance in particular, the Automated Radar Plotting Aid (ARPA) is the most widespread on commercial ships (Statheros, Howells, & Maier, 2008). Chin & Debnath (2009) have described the features and application of ARPA as follows: Apart from basic radar functions, ARPA allows for tracking of ships within radar detection range (typically referred to as the targeted ship). The tracking of a targeted ship involves two proximity indicators called Distance at Closest Point of Approach (DCPA) and Time to Closets Point of Approach (TCPA). Respectively, these inform the navigator of the probable distance a targeted ship will pass at the Closest Point of Approach (CPA) and the time required until reaching this point. Navigators typically make use of these as a criterion for assessing the navigational situation and determine necessary collision avoidance maneuvers by defining critical values of CPA and TCPA which reflects a safe distance (Chin & Debnath, 2009).

Other criteria are proposed as alternatives to CPA and TCPA (Pietrzykowski & Uriasz, 2009; Wang & Chin, 2015). Concepts such as Collision Risk Index (CRI), risk level and ship domain are being studied to this end (Szlapczynski & Szlapczynska, 2017). The concept of ship domain is the topic of this thesis and it involves establishing a free space around a ship required for safe navigation and collision avoidance (Zhao, Wu, & Wang, 1993). Goodwin (1975) defined it as *"the effective area around a ship which a navigator would like to keep free with respect to other ships and stationary objects"* (Goodwin, 1975, p. 329). Thus, it is a generalization of safe distance, however, observations show that safe distance is not the same in all directions (Szlapczynski & Szlapczynska, 2017). The concept´s main advantage is that it is intuitively accepted by human beings which makes it an efficient criterion for assessment of the navigational situation and work out evasive actions (Pietrzykowski, Wielgosz, & Siemianowicz, 2012).

Problem Statement

Ship domain is perceived as a more efficient navigational assessment criterion than CPA and TCPA (Szlapczynski & Szlapczynska, 2016). The general problem is that there are many factors influencing its shape and size making it difficult to determine (Wielgosz, 2016). Sources to date are conflicting as to which and how factors need to be considered, let alone what makes up the proper geometrical shape of the ship domain. The cited works are ranging from the need to develop highly complex models based on analytical description of influencing factors and ship domain shape (Wang, 2010, 2013; Wang, Meng, Xu, & Wang, 2009), to far less complex models with only a few essential factors accounted for based on navigators´ assessment of safe passing distance with an approximation process of an elliptical shaped ship domain (Wielgosz, 2016).

The concept of ship domain can enhance navigational safety when it is implemented to shipboard and shore based navigational systems (Pietrzykowski & Uriasz, 2009). However, future research is needed for better insight in essential factors for the ship domain shape and size (Wielgosz & Pietrzykowski, 2012), one of which is ship´s size (Pietrzykowski et al., 2012). Especially there is a need to examine navigators perception of ship domain in restricted waters as few models have been developed for these type of areas (Wang & Chin, 2015). There have been no studies prepared by any Norwegian institution, and it is believed that more researchers should engage in the research field in order to realize ship domain´s potential of enhancing the navigational safety (Baran, Fiskin, & Kisi, 2017).

Purpose of the Study

The purpose of this quantitative, quasi-experimental, questionnaire-based thesis was to examine Norwegian navigators´ perception of ship domain in Norwegian restricted waters. To identify and assess how this is perceived, this thesis has examined navigators´ perception of safe passing distance to a targeted ship approaching from eight different relative bearings and for three different ship sizes of own ship and targeted ship measured in ship´s length overall (LOA). Data was collected using a questionnaire instrument where the participants were to state CPA-values (in decimal of nautical miles) they would feel comfortable having a targeted ship pass that was currently on a collision course with own ship. The scope was limited to Norwegian navigators holding a Certificate of Competency qualifying to serve as officer in charge of the navigational watch, chief mate or ship captain in worldwide trade regardless of ship size. An additional criteria with minimum 12 months of seagoing experience after having finished the shipboard training period was defined to secure that participants had actual experience as navigational officers, not just the required training. Collected data were analyzed using Statistical Package for the Social Sciences (SPSS) version 24. The stated research questions were answered through repeated measure general linear model (GLM) analysis and a Wilcoxon signed- rank test.

Research Questions

To gain insights in navigators´ perception of ship domain in restricted waters, two research questions were prepared. The studied area was the fairway leading to port of Narvik in northern-Norway with own ship placed in GPS position North 68° 20.107´, East 015° 56.229´ sailing at 057°course over ground in 12 knots speed when the participants were asked to state a safe passing distance (CPA-value) to an approaching targeted ship from aforementioned relative bearings and with different ship sizes. The fairway had no traffic separation scheme (TSS) and thus no special COLREGs pertaining to navigation in such area (COLREG, 1972, Regulation 10). The research questions are as follows:

RQ1. What is the general influence of ship´s length overall on the ship domain shape and size as perceived by Norwegian navigators in restricted waters?

RQ2. What is the influence of targeted ship´s relative bearing on a safe passing distance as perceived by Norwegian navigators in restricted waters?

Hypotheses For RQ.1

With reference to RQ1, one hypotheses has been prepared. Studies have shown that ship domain size will generally increase as ship size increases (Pietrzykowski et al., 2012). Thus, it is hypothesized that Norwegian navigators in the selected research area will perceive ship domain size in an increasing manner based on an increase in own ship size measured in length overall:

H1$_0$. The ship domain size will not increase as ship size increases.

H1a. The ship domain size will increase as ship size increases.

Hypotheses For RQ.2

With reference to RQ2, three hypotheses has been prepared. According to the model of Goodwin (1975), the ship domain is larger on own ship´s starboard side compared to its port side. Further, the ship domain is larger ahead of own ship compared to astern of own ship. Hansen et al. (2013) have argued that this is because of different applicable COLREGs for port and starboard encounters of a targeted ship and further that a navigator will be more focused on traffic ahead of own ship than astern of own ship. In sum, this makes the ship domain a geometrical shape around a ship where the boundaries are defined by a curve joining several points on relative bearings from own ship (Pietrzykowski & Uriasz, 2009). The hypothesis that has been prepared with reference to Goodwin´s (1975) model is:

H2$_0$. The ship will be positioned at the geometrical center of its ship domain.

H2a. The ship will not be positioned at the geometrical center of its ship domain.

This can be tested by the two following hypotheses which refers back to the aforementioned relative bearings. It is hypothesized that a navigator, based on the relative bearing of an approaching targeted ship, would like to keep a greater distance to a target on starboard side of own ship compared to port side of own ship. Similarly, a navigator would like to keep a greater distance to a target ahead of own ship compared to astern of own ship. The two hypotheses has been formulated as follows:

H3$_0$. The result of an approaching targeted ship from different relative bearings will *not* make the ship domain larger on starboard side of own ship compared to port side of own ship.

H3a. The result of an approaching targeted ship from different relative bearings will make the ship domain larger on starboard side of own ship compared to port side of own ship.

$H4_0$. The result of an approaching targeted ship from different relative bearings will *not* make the ship domain larger ahead of own ship compared to astern of own ship.

H4a. The result of an approaching targeted ship from different relative bearings will make the ship domain larger ahead of own ship compared to astern of own ship.

Nature of The Study

A quantitative methodology was chosen over qualitative or mixed-methods methodology, as it is suitable to efficiently collect numerical data and test the hypotheses. Besides this, with a quantitative methodology, all aspects of the design may be carefully planned prior to data collection which in turn helps maintain objectivity throughout the research process (McCusker & Gunaydin, 2014).

A questionnaire was used to measure navigators´ perception of a safe passing distance to an approaching targeted ship from eight different relative bearings and three different ship sizes of own ship. Electronic distribution of a QuestBack-based questionnaire was chosen over other quantitative methods. Compared to for example interviews, this instrument offered a time efficient data collection form which secured access to geographically scattered participants (Frankfort-Nachmias & Nachmias, 2008). Participants also tends to be familiar with this format which generally makes them more comfortable responding to it (Cooper & Johnson, 2016). There was no randomization process of participants into experimental and control groups thus making this a quasi-experimental designed study (Harmon, Morgan, & Gliner, 2000). Further, each participant was exposed to all conditions of the variables under study which makes this a within-subject design study (Charness, Gneezy, & Kuhn, 2012).

Significance of the Study

The ship domain has great potential for enhancing the navigational safety (Pietrzykowski & Uriasz, 2009). Acquisition of more knowledge concerning essential factors for the ship domain shape and size in restricted waters with different area parameters than those already studied is recommended for future research (Pietrzykowski et al., 2012). The research field is mainly dominated by Polish and Chinese scientists, and there are no indications of ship domain studies ever undertaken in Norway (Baran et al., 2017). This thesis contributes to the research field on ship domain in a context that has never been studied before, namely Norwegian navigators´ perception of ship domain shape and size as influenced by ship size in restricted waters. It is believed that new researchers can focus the topic and thus eventually improve navigational safety (Baran et al., 2017). As the literature addresses more research, this thesis elicits how navigators perceive the ship domain as a function of important factors and ultimately how they assess navigational safety with respect to collision avoidance. In time, this could complement and improve traditional navigational assessment criteria.

Definition of Key Terms

Ship domain. In this thesis, ship domain is defined as "the effective area around a ship which a navigator would like to keep free with respect to other ships and stationary objects" (Goodwin, 1975, p. 329). A violation of this area is interpreted as a threat to the navigational safety (Pietrzykowski & Uriasz, 2009).

Restricted waters. In this thesis, restricted waters are defined as a type of water area where there is limited space for ship maneuvering due to physical and legal restrictions of the fairway (Wielgosz, 2017). The consequence is that a navigator cannot choose route freely (Pietrzykowski et al., 2012).

Closest point of Approach. In this thesis, the Closest Point of Approach (CPA) is defined as an ARPA radar output-value which displays the predicted distance own ship and targeted ship will pass each other. Navigators makes use of CPA to assess the navigational situation and determine evasive collision actions (Chin & Debnath, 2009). Henceforth, the Closest Point of Approach will be referred to as CPA.

Navigator. In this thesis, a navigator is defined as the officer in charge of the navigational watch, chief mate of captain of the ship as defined in the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW, 2010Reg. II/1, Reg II/2).

Relative bearing. In this thesis, relative bearing is defined as the bearing to ships and objects relative to own ship´s bow which marks 000° to 359° clockwise.

Literature Review

Documentation

This literature review starts by establishing the criticality and causes of collisions at sea as a backdrop to assessment criteria used in collision avoidance. The two criteria are CPA/TCPA and ship domain. It then briefly explains the reason as to why ship domain can be considered a more efficient assessment criterion than CPA/TCPA before central aspects to the concept of ship domain are discussed. The specific aspects that are elicited are factors influencing its shape and size, the different geometrical shapes that can be assumed and methods of its determination. The final part of the literature review forms the basis of the developed research questions.

The literature search process started with a wide search in two databases – google scholar and ScienceDirect. Once the general body of available ship domain literature had been identified, a narrower search in academic peer-reviewed journals began. Two particular journals that provided much relevant literature was The Journal of Navigation and The TransNav, International Journal on Marine Navigation and Safety of Sea Transportation. Several other journals were also used but these were accessed through the aforementioned databases. Key search words were ship domain, restricted water, confined water, collision avoidance.

Navigational Safety and Collision Avoidance

Theoretically collisions should not occur if all ships follows the COLREG (MAIB, 2004). Still, collisions appears to be one of the most frequently occurring accidents in terms of frequency per accident type (Eleftheria, Apostolos, & Markos, 2016).

The European Maritime Safety Agency stated that 50 percent of maritime accidents were of a navigational nature and that collisions constituted 16 percent of them (EMSA, 2017). Furthermore, ship – ship collisions have been found to represent some 50 percent of total risk on the hazard profile of ships navigating in a busy waterway (Mou, Tak, & Ligteringen, 2010). Consequently, collisions represent a great threat to the navigational safety.

Gale and Patraiko (2007) found that 60 per cent of collisions occurred due to human error. Similar findings were supported by Chauvin, Lardjane, Morel, Clostermann, & Langard (2013) who investigated human and organizational factors in maritime accidents. The researchers found that most collisions occurred due to decision errors (82.05 percent), meaning that the decision maker had applied an inappropriate or inadequate plan for the situation. Further, they found that poor visibility and misuse of navigational instruments were major contributing factors as well as lack of situation awareness and poor lookout due to an abundance of other work tasks being carried out while navigating the ship (Chauvin et al., 2013). Given this understanding, safe navigation requires unceasing assessment of the situation in order to identify dangerous situations, however, the associated assessment criteria applied to this end appears to be insufficient (Wielgosz, 2016).

Conceptual Framework

Assessment criteria applied in collision avoidance. The fact that assessing the navigational situation is often viewed in terms of sufficient space separation has led to concept of ship domain (Ying, 2012). Despite offering an intuitive way of assessing this, the concept of safe distance and related CPA and TCPA measures is far more commonly adopted in navigational systems (Szlapczynski & Szlapczynska, 2016). CPA and TCPA´s simplicity in interpretation and implementation to navigational systems is probably the reason as to why they are so widespread (Szlapczynski & Szlapczynska, 2017). They are unambiguous and independent of factors less relevant to navigation (Ying, 2012) and furthermore easily determined because of their simple analytical formulas (Szlapczynski & Szlapczynska, 2016). The main shortcomings of CPA and TCPA compared to ship domain are that they do not take into account crucial elements in assessing collision risk such as the relative bearing to targeted ship as well as the type encounter situation (Szlapczynski & Szlapczynska, 2016). Moreover, they do not take into account other factors influencing safe distance such as ship size (Ying, 2012). Considering practical application, especially in restricted waters, assessment criteria such as CPA and TCPA requires a lot of experience in their interpretation from anyone applying them (Wielgosz, 2016). The aforementioned collision causes can be eliminated or at least reduced by implementation of ship domain to navigational systems as it would enhance navigational safety (Pietrzykowski & Uriasz, 2009).

Ship domain. Conceptually, the definition of Goodwin (1975) is considered the most representative (Wang, 2013; Wielgosz, 2016; Zhao et al., 1993). However, a critical question pertaining the concept´s nature have been raised (Pietrzykowski & Uriasz, 2009). Pietrzykowski and Uriasz (2009) questioned whether it should reflect an area a navigator wants to keep clear of other ships or an area that a navigator actually keeps clear of other ships (the effective ship domain). Zhu, Xu, and Lin (2001) had an interesting discussion on this subject. They held that ship domains as desired by navigators were different from ship domains actually kept by navigators. Respectivley they termed the two concepts subjective and objective domains. They argued that the objective domain was rather a result of a navigator´s desire to maintain a free space around the ship, that is, the subjective opinions of navigators (resulting in a subjective ship domain) had a direct impact on the actual free space that was maintained (the objective domain). Due to this they concluded that the subjective domain was applicaple to assess collision risk and resolve collision avoidance problems whereas the objective domain was better suited for capacity analysis of waterways and such. (Zhu et al., 2001).

A more recent and similar ship domain definition termed declerative ship domain has newly been introduced. In its essence, the declerative ship domain is an area that navigators declare that they want to keep free of other ships (Wielgosz, 2016). Wielgosz (2016) stated that determining the declerative ship domain was motivated by past works which had indicated its declerative nature (Wielgosz & Pietrzykowski, 2012).

Regardless of what kind of definition that is adopted, the ship domain should at some level reflect subjectivity which accounts for the expected result of navigational behaviour (Wang, 2013; Ying, 2012). The basic difficulty lies however in the which and how factors are accounted for in the process of ship domain determination (Wielgosz & Pietrzykowski, 2012). A litterature review on the concept has shown that various ship domain models exists. These models appear in different shapes and sizes, with different factors accounted for, let alone determined by different research methodologies (Szlapczynski & Szlapczynska, 2017). Thus, the next couple of sections will focus on important factors influencing the ship domain, the different geometerical shapes a ship domain can assume and different research methodoligies that can be applied to determine it.

Ship Domain Influencing Factors

The ship domain models of Fujii and Tanaka (1971), Goodwin (1975), and (Coldwell, 1983) generally established the theory behind ship domain (Zhao et al., 1993). Zhao et al. (1993) held that although these researchers had recognized the same factors (especially ship size and type of water area) as influencing the ship domain shape and size, the general theory still lacked an explanation on what truly caused it to exist. The theory of Proxemics was applied to this overcome this limitation (Zhao et al., 1993). The theory of Proxemics is essentially concerned with the study of human spatial behavior (Evans & Howard, 1973), that is, personal space. In turn, personal space can be defined as *" the area individual humans actively maintain around themselves into which others cannot intrude without arousing discomfort"* (Hayduk, 1978, p. 118). Similar to ship domain, personal space is dependent on certain factors such as nationality, gender and familiarity between persons (Evans & Howard, 1973). By drawing a parallel between the two concepts, Zhao et al. (1993) was able to explain why ship domain exists, and also analyze the influencing factors. They argued that since objects such as cars have a magnifying effect on the personal space of a driver, the same would be applicable to a ship and its navigator and thus apt to be considered by the same principles.

The *first* influencing factor is known under the common term of human factor and covers the navigator´s skill and knowledge, nationality, mental and physical abilities (Pietrzykowski & Uriasz, 2009). Although many researchers attempts to capture this element in their research, it is difficult to isolate and analyze it separately from other more easily identifiable influencing factors such as ship size (Ying, 2012). One example were the human factor has been directly accounted for in a ship domain model is the Dynamic Quaternion Ship Domain (DQSD) model (Wang, 2013). Wang (2013) stated that the model accounted for the navigator´s skill, physical and mental abilities in the way that when these states were worsened, the domain shape and size would become more conservative in terms of shape and size. This was described and accounted for by an analytical equation of time varying variables deemed to sufficiently represent navigator´s states (Wang, 2013).

The *second* factor argued as influential is the ship´s size and more specifically its length overall (Zhao et al., 1993). Many researchers have considered this in their models (e.g.Fujii & Tanaka, 1971; Goodwin, 1975; Hansen et al., 2013; Pietrzykowski, 2008; Pietrzykowski & Uriasz, 2009; Wang, 2010, 2013; Wang & Chin, 2015; Zhu et al., 2001). Some researchers also considers the ship length of targeted ship in their models (e.g.Pietrzykowski & Uriasz, 2009; Wang & Chin, 2015; Zhu et al., 2001) and how this makes a navigator keep a greater distance to the target. However, the general influence of ship size is that it has a significant effect on ship domain shape and size, that is, the ship domain increases as ship size increases (Pietrzykowski et al., 2012).

The *third* factor is ship type, e.g. passenger or cargo ship (Zhao et al., 1993). Ship type has been concluded as non-influential per se, but it is rather reflected through a typical length associated with a particular ship type in question (Pietrzykowski & Magaj, 2016) with the aforementioned influence. Rawson, Rogers, Foster, and Phillips (2014) presented a ship domain model for the River Thames which was influenced by ship type. However, it has been argued that ship maneuverability and ship length were subsumed under the concept of ship type in this model (Szlapczynski & Szlapczynska, 2017) and so it had not been considered an individual factor. In sum, the ship type does not influence the ship domain per se, but rather represents certain characteristics (Pietrzykowski & Magaj, 2016).

The *fourth* factor is the type of water area (Zhao et al., 1993). Szlapczynski and Szlapczynska (2017) argued that this is a shared factor among all proposed ship domain models, however, the extent to which it has been considered in previous models are different. This is because a ship domain model can serve different purposes such as capacity analysis of a waterway and collision risk assessment. For example, when a particular model has been aimed at capacity analysis of a waterway, it is usually a specific waterway of interest due to its unique characteristics. When a particular model has been aimed at collision avoidance purposes, it is rather the general characteristics of a waterway that has been of interest, such as open or restricted waters (Szlapczynski & Szlapczynska, 2017). Wielgosz (2017) found that the ship domain is generally larger in open waters compared to restricted waters and further that the shape tended to be slimmer in restricted waters.

The *fifth* factor refers to ship´s speed, and more specifically relative speed (Zhao et al., 1993). The common perception of speed´s influence is that the ship domain size will increase as the speed increases, however, some contradictory findings to this exists (Wielgosz & Pietrzykowski, 2012). Most often, an increase in speed will lead to a bigger ship domain due to increased reaction time (Rawson et al., 2014).

The *sixth* factor is traffic density (Zhao et al., 1993). This influences the ship domain in a similar manner as the type of water way do, that is, less available maneuvering space which leads to a smaller domain (Hansen et al., 2013; Wielgosz, 2016; Wielgosz, 2017).

The *seventh* factor is the relative bearing to a targeted ship which in turn has to do with the psychological burden of COLREG (Zhao et al., 1993). Zhao et al. (1993) argued that due to give-way and stand-on regulations stipulated in COLREG, navigators would impose certain safeguards on themselves in order to comply. The effect is that the ship domain becomes larger on starboard side because encountered ships approaching from this direction would imply that own ship is the give-way vessel and vice versa for port side. Hansen et al. (2013) have also argued that the ship domain is larger ahead of own ship than astern of own ship because of a navigator´s focus of attention depending on the encounter situation. Figure 1 shows the model proposed by Goodwin (1975) which very clearly demonstrates both principles.

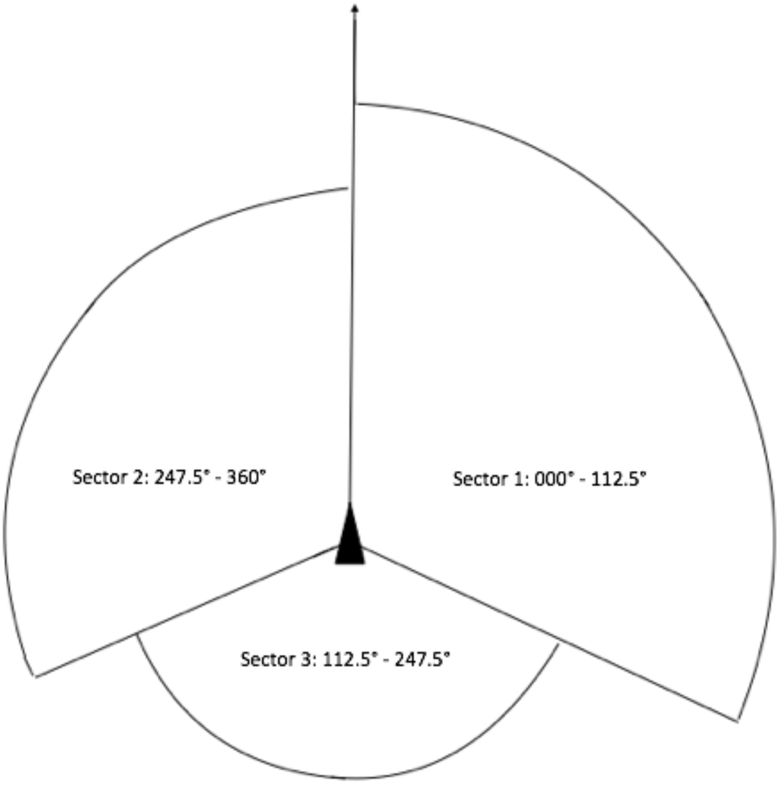


Figure 1. Goodwin´s (1975) ship domain model.

Two factors that was not considered by Zhao et al. (1993) in their Proxemics analysis (though mentioned) are ship maneuverability and weather/visibility conditions. Briefly, ship´s maneuverability, or rather its rate of turn (ROT), have been found to affect the ship domain size (Pietrzykowski, 2008), but the precise impact still lacks a good explanation (Szlapczynski & Szlapczynska, 2017). The effect of weather and visibility conditions are still not well understood (Andersson, 2017; Wang & Chin, 2015), but some findings indicate that the ship domain increases as visibility decreases (Zhu et al., 2001).

Ship Domain Shape

Proposed ship domain models may roughly be categorized as circular ship domains, elliptical ship domains and polygonal ship domains (Wang et al., 2009). In the following a few examples of all of these shapes will be provided along with some considerations that has been made pertaining the ship domain shape by various researchers.

Goodwin (1975) proposed a circular ship domain as earlier shown in figure 1. The researcher accounted for how COLREG makes a safe distance different depending on the target´s relative bearing and proposed a discontinuous circular domain with three sectors of different size. Davis, Dove, and Stockel (1980) deemed the discontinuity impractical since a targeted ship sailing from one sector to another would imply a sudden and unrealistic change in the navigational situation. To overcome this limitation, they smoothed the boundaries so they became continuous and decentralized the ship´s position in order to retain the different sectors for COLREG compliance. Zhao et al. (1993) proposed applying fuzzy domain boundaries on Goodwin´s (1975) model to circumvent some of the same limitations. However, the circular discontinuous domain shape is still criticized for the same reasons as Davis et al. (1980) argued, and some researchers opt for more complex shapes (Wang & Chin, 2015)

Fujii and Tanaka (1971) proposed an elliptical domain for overtaking situations in restricted water with the ship´s position centralized in the sideway direction of the domain. Coldwell (1983) extended this work and defined a ship domain for meeting encounters in restricted waters with the ship´s position decentralized towards port side of the domain. Both models are shown in figure 2 and 3 respectively. Note that Coldwell (1983) only defined half an ellipse due the study´s focus on meeting encounters only.

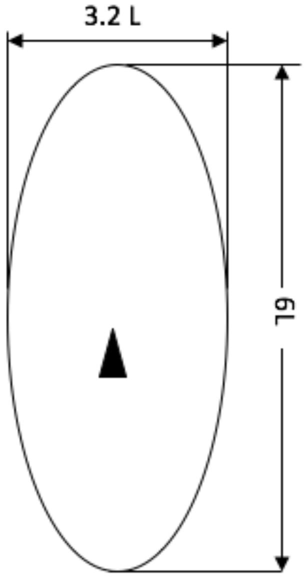


Figure 2. Fujii and Tanaka´s (1971) ship domain model.

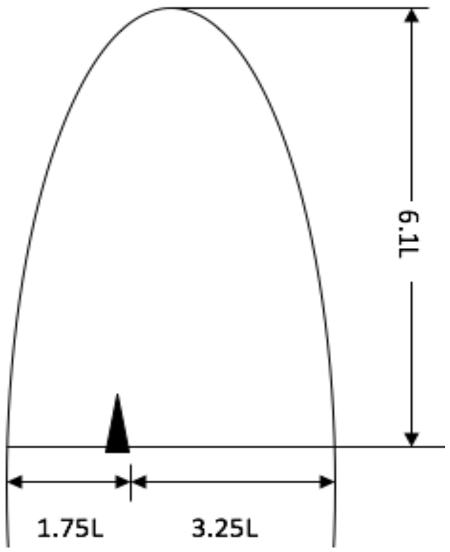


Figure 3. Coldwell´s (1983) ship domain model.

Commenting upon these models, Zhao et al. (1993) concluded that Fujii´s model was not decentralized due to associated COLREGS for overtaking situations which technically allows for overtaking on either side of an overtaken ship. Hansen et al. (2013) obtained similar results but made the aforementioned reflections pertaining what normally could be expected given the influence of COLREG. Szlapczynski and Szlapczynska (2016) argued that the ellipse is the most complex geometrical shape which still allows for simple and quick calculation of domain size as well as decentralization of ship´s position for COLREG compliance. Furthermore, they have argued that the ship domain in fact are ellipses considering past and present empirical research (Szlapczynski & Szlapczynska, 2016).

Wang and Chin (2015) deemed both elliptical and circular domains insufficient. They argued that the elliptical domain involved too many geometrical constraints to sufficiently represent the domain area. As for the discontinuous circular one, they argued it would lead to an undesired and sudden change in the navigational situation. To overcome these challenges the researchers defined a decentralized polygonal ship domain. Since this shape involved fewer geometrical constraints, the researchers claimed the model to be superior of other earlier proposed models. Commenting upon these claims, Szlapczynski and Szlapczynska (2017) argued that the resulting shape of this domain in fact resembled an ellipse.

Pertaining the ship domain shape and influencing factors in general, it should also be mentioned that a ship domain can be shaped like either a sphere, ellipsoid or cuboid which are three-dimensional figures accounting for ship´s draft and air draft (Pietrzykowski & Uriasz, 2009). However, the two- dimensional ship domain which has been emphasized so far is the topic of this thesis.

Ship Domain Methodologies

The methods of determining a ship domain can be divided in three categories. These are; empirical, analytical and expert knowledge methods (Szlapczynski & Szlapczynska, 2017). The choice of method is important because it impacts both the shape and size of ship domains as well as its interpretation (Pietrzykowski, 2008). That is, subjective or objective ship domains (Zhu et al., 2001), or even declarative ship domains (Wielgosz, 2016).

The empirical method was the original method of ship domain determination (Pietrzykowski, 2008; Pietrzykowski & Uriasz, 2009; Szlapczynski & Szlapczynska, 2017; Wang & Chin, 2015). Basically, the method involves recording ship trajectory data and define the domain boundary based on densities of these trajectories (Pietrzykowski & Uriasz, 2009).

For example, Fujii and Tanaka (1971) and Coldwell (1983) defined the domain boundaries at the local maximum of ship trajectories, i.e. where the density was highest. Goodwin (1975) on the other hand defined it at the intersection of where ship trajectories started exceeding the uniform traffic density that could have been expected given the absence of a ship domain. Zhao et al. (1993) commented upon these differences and concluded that they were suitable for different purposes due to this. Goodwin´s (1975) model was deemed better suited for study of collision risk because it was less conservative whereas Coldwell´s (1983) and Fujii and Tanaka´s (1971) model was deemed better suited for traffic capacity analysis. Three inherent weaknesses with the empirical method are: First, it requires a great amount of data. Second, it is difficult to isolate factors and hence analyze their impact. Third, the method leads to an unclear description of the ship domain (Pietrzykowski & Uriasz, 2009). However, pertaining the first weakness, AIS-data can be used to overcome this weakness (Wang & Chin, 2015). Hansen et al. (2013) recently demonstrated how this can be done by utilizing AIS-data from a four year period to determine a minimum ship domain corresponding to a comfortable navigational distance in Danish waters.

The analytical method is recognized by its analytical description of the domain boundary as a function of selected variables (factors) which describes a given ship (Pietrzykowski, 2008). The factors may be such as relative speed, own ship speed and geometrical dimensions (Dinh & Im, 2016). One example of an analytical ship domain model is the Quaternion Ship Domain (QSD) model (Wang, 2010). Wang (2010) stated that unlike other ship domain models which were defined by geometrical shapes, the QSD model was determined by two parameters - quaternion Q and index k. The Q parameter determined the domain size whereas the index k determined the domain shape. The quaternion Q comprised four radii - fore, aft, starboard and port section - which accounted for different factors such as ship´s speed, ship´s maneuverability, COLREG, etc., and the index k added flexibility to the shape. Further, the domain boundaries were made fuzzy to indicate different levels of navigational safety (Wang, 2010). A major challenge with the analytical method is to properly account for relevant factors (Pietrzykowski & Uriasz, 2009). Although the model presented above can be considered highly advanced, the fact that it is purely analytical can be considered a disadvantage because it is limited to the researchers choice in terms of factors accounted for (Szlapczynski & Szlapczynska, 2017).

The expert knowledge method does as it implies utilize the knowledge of navigators (Dinh & Im, 2016). This includes both their procedural knowledge as well their non-procedural knowledge which results from years of experience (Pietrzykowski, 2008; Pietrzykowski & Uriasz, 2009). With this method it is also possible to subject the gathered data from navigators assessment of the ship domain to artificial intelligence tools such as neural networks, that is, machine learning (Szlapczynski & Szlapczynska, 2017). Zhu et al. (2001) were the first one to do this. The researchers gathered questionnaire data based on ship maneuverability, visibility conditions and relative to bearing to a targeted ship and subjected to neural networks where it was generalized and shaped into rules which made up the ship domain (Szlapczynski & Szlapczynska, 2017). Pietrzykowski (2008) used a similar approach for restricted waters, and Pietrzykowski and Uriasz (2009) for open waters. In addition to utilizing machine learning, fuzzy logic was added to represent different levels of navigational safety (Pietrzykowski, 2008; Pietrzykowski & Uriasz, 2009). These two works can be considered extensions and combinations of Zhao et al. (1993) which proposed fuzzy domain boundaries, and Zhu et al. (2001) which proposed neural networks (Szlapczynski & Szlapczynska, 2017). A more recent example of an expert knowledge based domain is the declarative ship domain (Wielgosz, 2016). Wielgosz (2016) stated that gathered questionnaire data where participating navigators were to declare the domain boundary was used to approximate an elliptical shaped ship domain. One challenge with the expert knowledge method in general are to gather a proper amount of data (Pietrzykowski & Uriasz, 2009). Another challenge is that it is bound to be rather subjective and highly dependent on which navigators that are examined (Szlapczynski & Szlapczynska, 2017). However, as previously argued, the subjectivity can at some level be argued as a strength.

Ship Domain In Restricted Waters

So far in this literature review it has been shown that there are an abundance of factors responsible for reflecting the ship domain shape and size, different geometrical shapes that can be assumed and different research methodologies that can be applied.

The number of factors are so great that for practical reasons, usually only a few can be accounted for in the process of domain determination (Wielgosz, 2017). According to experts, critical factors are type of water area, ship´s size and ship´s speed (Wielgosz, 2016). It is particularly important to study the ship domain in restricted waters as few ship domain models have been developed for these types of areas (Wang & Chin, 2015). The ship domain as a navigational assessment criterion is believed to be particularly expedient in restricted waters where a navigator face limitations in terms of maneuvering space due to increased traffic density as well as physical and legal restrictions in the fairway (Wielgosz, 2017). Although some models have been developed for restricted waters, there is still need for future research on ship domain in other area parameters than those already studied to determine the impact on ship domain shape and size (Pietrzykowski et al., 2012).

Pertaining the choice of ship domain methodology, it remains a question as to which is most suitable for domain determination (Pietrzykowski & Uriasz, 2009). However, the analytical and expert knowledge approach is usually preferred when collision avoidance purposes are concerned because they both efficiently allow to isolate and analyze the impact of factors on the ship domain shape and size (Szlapczynski & Szlapczynska, 2017).

Research Method

This thesis has aimed at assessing the influence of own ship´s size on ship domain shape and size as perceived by Norwegian navigators in restricted waters and whether a safe passing distance was perceived differently based on the relative bearing to an approaching targeted ship. This section describes the research methodology applied to this end to enable replication and constructive criticism (Frankfort-Nachmias & Nachmias, 2008, p. 13). Enabling replication implies a thorough description of what has been done, one that allows others to repeat the investigation in an identical manner and in the process avoid unintentional error and deception. Constructive criticism enables others to question various aspects of what has been done and conclusions drawn (Frankfort-Nachmias & Nachmias, 2008, p. 13).

Research Method and Design

The research design was developed on basis of the purpose, research question and hypotheses of this thesis. A quantitative methodology was chosen over qualitative or mixed-methods methodology, as it suitable to efficiently collect numerical data and test hypotheses (McCusker & Gunaydin, 2014). Besides this, McCusker and Gunaydin (2014) stated that with a quantitative methodology, all aspects of the design may be carefully planned prior to data collection which in turn helps maintain objectivity throughout the research process.

In quantitative research there are two main types of design – experimental designs and non-experimental designs (Muijs, 2004). Since not all research in social sciences allows for straightforward application of experiments we find the quasi-experimental design (Frankfort-Nachmias & Nachmias, 2008, p. 114). Although both involves manipulation of at least one independent variable, the latter type does not randomly assign participants to control and experimental groups. Sometimes there is even only one group of participants (Harmon et al., 2000). Such designs where participants are exposed to multiple conditions are known as "within-subject design" (Charness et al., 2012). A quasi-experimental – within-subject design was chosen for this thesis as it was deemed useful to measure how individual navigators perceived ship domain differently depending on the ship´s length overall and targeted ship´s relative bearing. That is, ship domain under multiple conditions.

An electronical distributed survey- instrument was used to measure the perceptions of the population sample. This was chosen over other available data collection methods such as observation or interviews (Frankfort-Nachmias & Nachmias, 2008). The particular type of survey instrument was a questionnaire. The advantages of a questionnaire are that it offers data collection at a low cost, provides a high degree of anonymity for participants, reduces bias since researcher and participant are separated and it can facilitate access to geographically scattered respondents. The disadvantages are that it requires simple and easily understood questions and instructions, it is not possible to probe for additional information, there is little control over who actually fills out the answers and response rates are usually low (Frankfort-Nachmias & Nachmias, 2008, p. 208). Electronical distribution in particular may lead to bias since it tends to favor computer literate respondents (Leedy & Ormrod, 2013). However, it facilitates time-efficient data collection and easy access to participants as it enables online distribution (Wright, 2006). A questionnaire was deemed sufficient to measure the perceptions of the population sample as it allowed to represent critical factors (ship size and relative bearing) for the ship domain shape and size so that the obtained results could be analyzed in relation to the stated research questions and hypotheses. See questionnaire development-section below for further clarification.

Population

The population being the aggregate of all cases that fit a defined specification (Frankfort-Nachmias & Nachmias, 2008, p. 163) was defined as Norwegian navigators holding a Certificate of Competency qualifying to serve as officer in charge of the navigational watch, chief mate or captain in worldwide trade regardless of ship size. More specifically, the population was defined as navigators having finished minimum 12 months of practical shipboard training according to the competency requirements as defined in the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW, 2010Reg. II/1, Reg II/2). An additional inclusion criteria of 12 months of seagoing experience after having completed the mentioned training was also defined to secure that participants had actually served as officer of the navigational watch, not just completed the required training.

Sample Design and Sample Size

Sample design relates to drawing a representative sample from the population and how this is done can be divided in two categories – probability and nonprobability designs (Frankfort-Nachmias & Nachmias, 2008, p. 167). Respectively they mean that it is possible to specify a certain probability of including a population member to the sample and vice versa. Probability design is the strongest with respect to obtaining a representative sample since ideally all population members could have had equal chance of being included. However, probability design is not always feasible for practical reasons such as lack of an exhaustive list of population members (Frankfort-Nachmias & Nachmias, 2008, p. 167). Obtaining a list of all population members as defined in this thesis was deemed highly unlikely. The cost in terms of time and resources needed to aggregate such a list was a serious discouraging factor and so a nonprobability convenience sample design was chosen. In more practical terms this means that the sample was drawn from population members conveniently available to the researcher (Frankfort-Nachmias & Nachmias, 2008, p. 168). A list of graduated students in nautical science at the University College of Southeast Norway containing e-mail addresses was primarily used to this end. All persons contained in the list had graduated in the period between 2010 – 2014 and would theoretically fulfill the requirements of the defined population. Social media was also used extensively to target the population. This was done by establishing contact with former colleagues (all of whom were or still are navigators) of the researcher of this thesis. The other master student who conducted research on ship domain in open waters and applied the same questionnaire used a similar approach. Demographic questions in the applied questionnaire ensured the possibility to weed out respondents not fulfilling the requirements of the defined population.

Calculation of an appropriate sample size is a common task in research(Barlett, Kotrlik, & Higgins, 2001). The sample size generally depends criteria such as a predefined accepted significance level (p-value used for rejection), statistical power, expected effect size and standard deviation in the population (Kadam & Bhalerao, 2010). The actual calculation can be done by free computer software such as for example G*power 3.13 analysis (Faul, Erdfelder, Buchner, & Lang, 2009). While significance level and statistical power is often determined by convention, the expected effect size is commonly benchmarked against other related studies (Kadam & Bhalerao, 2010). Unfortunately, such effect size could not be obtained for the study in this thesis and so calculation of an appropriate sample size was not done. However, since an increase in sample size leads to a boost in statistical power (Nuzzo, 2016), an arbitrary sample size of 200 participants was set as a goal.

Research area. The selected research area for this thesis was the fairway leading to the port of Narvik. Own ship´s given GPS position was North 68° 20.107´, East 015° 56.229´, sailing at 057° course over ground and 12 knots speed when the participants were asked to state CPA-values corresponding to a comfortable passing distance of an approaching targeted ship from eight different relative bearings and for three different ship sizes. The closest land mass (an island) is roughly 1.6 nautical miles from this position and so it was considered restricted waters. Further, the researched area had no Traffic Separation Scheme (TSS) and thus not any special COLREGs (COLREG, 1972, Rule 10) that would make a participating navigator question the likelihood of an approaching targeted ship from either of the relative bearings. The port of Narvik is one of Norway´s largest in terms of sea freight transport, with for instance 5, 422, 602.00 tons of goods (11.4% of total amount of sea freight transport to and from any Norwegian port) transported to and from the port in fourth quarter of 2017 (SSB, 2018).

Questionnaire Development

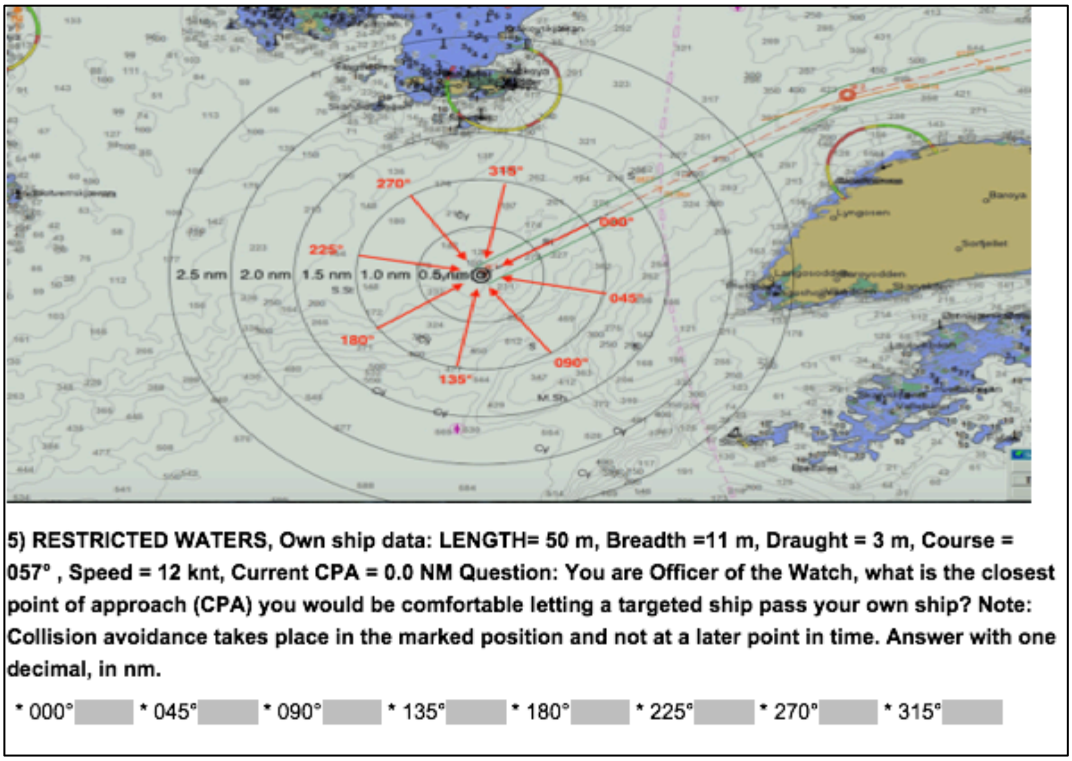
A literature search with the aim of finding a validated ship domain instruments that could measure the opinion of the population sample was executed through Google scholar and a database called Science Direct. The search in these two databases ultimately lead to a search in more maritime focused peer-reviewed journals. The Journal of Navigation and The TransNav, International Journal on Marine Navigation and Safety of Sea Transportation was two journals with many ship domain articles. After having completed the search, no readily available instruments could be obtained and consequently a questionnaire based solely on available ship domain literature had to be developed. A description of a questionnaire used to determine declarative ship domains in restricted waters (Wielgosz, 2016) particularly offered valuable input in this process. Wielgosz (2016) stated that the questions in the applied questionnaire related to passing distance to a targeted ship during an anti-collision maneuver with a ship approaching from eight different relative bearings: 000°, 045°, 090°, 135°, 180°, 225°, 270° and 315°.

The questionnaire applied in this thesis was developed and distributed together with one other master student that conducted research on ship domain in open waters (Mari Auby Starup). Collaboration on developing and distributing the questionnaire was done for two reasons. First, ship domain in open and restricted waters are conceptually the same thing and so collaboration ensured a second opinion on important ship domain aspects that was found in literature. Second, it was deemed likely that the same population members would have been targeted to a great extent (due to similar contact networks) should two separate questionnaires have been distributed. Thus, one single questionnaire was considered an advantage. Some pitfalls are however associated with this choice. It is particularly question order and context effects that may materialize in such respect. The effects basically imply that an answer to one question may influence the answer to the subsequent if the topics are related (Lewis-Beck, Bryman, & Futing Liao, 2004). It is likely that this was the case in the applied questionnaire.

The questions contained in the questionnaire related to a desired passing distance to a targeted ship approaching from eight different relative bearings; 000°, 045°, 090°, 135°, 180°, 225°, 270° and 315° that was currently on a collision course (CPA=0.0 nautical miles) with own ship. Demographic questions were also added. The questionnaire comprised five categories in total. In order of appearance they were: Questionnaire cover letter with an informed consent form, questionnaire instruction, questions for ship domain in open waters, questions for ship domain in restricted waters and demographic questions.

The questionnaire instruction provided a general description on the concept of ship domain and that the aim was to investigate navigators assessment a ship´s domain. A description of own ship (which they were to imagine they were the navigator of) and targeted ship´s characteristics was provided. The ships were stated to be equal and equipped one becker-rudder, one propeller, one bow-thruster and both ships were sailing at 12 knots speed. A picture with eight arrows pointing towards own ship was provided along with information stating that the arrows represented relative bearings and headings of the targeted ship as a demonstration of the questions to come. Further, since this could be interpreted as eight different ships approaching at the same time, participants were explicitly informed that each approach (arrow) was to be treated individual from the other.

The ship domain questions per se were graphically represented by a screenshot from an Electronic Chart Display and Information System (ECDIS), that is, a navigational chart with own ship´s GPS position represented by an icon. Figure 4 shows one question from the questionnaire for restricted waters. The wording were similar in all questions for both open and restricted waters, and so the example represents the other questions as well.



5) RESTRICTED WATERS, Own ship data: LENGTH= 50 m, Breadth =11 m, Draught = 3 m, Course = 057° , Speed = 12 knt, Current CPA = 0.0 NM Question: You are Officer of the Watch, what is the closest point of approach (CPA) you would be comfortable letting a targeted ship pass your own ship? Note: Collision avoidance takes place in the marked position and not at a later point in time. Answer with one decimal, in nm.

* 000° * 045° * 090° * 135° * 180° * 225° * 270° * 315°

Figure 4. Questionnaire example for restricted waters.

The arrows as described was drawn on top of the navigational chart pointing towards own ship. Range rings for each 0.5 nautical miles was also drawn on top of the chart to easily communicate the scale distance to land. The latter modification was only done for the restricted waters category in the questionnaire. For open waters a simple bar-scale in nautical miles was used for the same purpose. Participants were asked to state one CPA-value in nautical miles with one decimal for each relative bearing they would feel comfortable having the targeted ship pass. This was repeated three times for ship domain in open waters and three times for ship domain in restricted waters with changed ship size for each question. The same ship sizes were used for open and restricted water questions. Table 1 shows an overview of the size parameters that was used. Henceforth, the ship sizes will be referred to according to their LOA only.

Table 1. Overview of ship sizes under study

Size Parameter	Size 1	Size 2	Size 3
Length overall (LOA)	50 meters	100 meters	200 meters
Breadth	11 meters	20 meters	32 meters
Draught	3 meters	5 meters	10 meters

The final category, demographic questions, asked for gender, age, nationality, years of seagoing experience, rank onboard the ship (e.g. captain), type of certificate, and which type of ship the participant had experience with. 55 questions had to be answered in total to complete the questionnaire. That is, three ship sizes with eight relative bearings for both open and restricted waters and seven demographic questions (6 x 8 + 7).

The questionnaire instrument was developed in several stages. In the first stage a simple draft was drawn by hand with a targeted ship approaching from eight different relative bearings. The draft was presented to a certified navigator were the person was asked to give feedback pertaining missing information that could facilitate a navigator´s qualified opinion on stated questions. The feedback session was in the form of an informal phone conversation. The person suggested information on rudder and propeller characteristics of both involved ships, statement of weather conditions (e.g. good visibility/daytime), current CPA of targeted ship and speed information. Current CPA of targeted ship was especially emphasized because this provided an unequivocal statement of the current situation. All proposals were implemented after discussion on practical issues with the other master student.

The second stage was to overcome challenges in effectively representing the type of area the predefined ships were navigating in. Another issue, pertaining the purpose of this thesis, was to find an area that could sufficiently represent navigation in restricted waters. An

ECDIS screenshot and the fairway to Narvik was chosen as previously described. The selected area was coordinated with a third master student who probably will conduct research on ship domains utilizing AIS- trajectory data in the future. The reason as to why it had to be coordinated was to enable future comparison of ship domains as desired by navigators versus what is revealed through AIS-data. The selected area was deemed sufficient to this end.

In the third stage a complete draft made on the online survey platform questback© was sent to two persons with academic experience for feedback. Changes pertaining readability and interpretation of the questions were suggested and implemented. In addition, it was suggested to visually show the respondents how close the ship was navigating to the coast line. Aforementioned range rings were added for this purpose.

In the fourth stage the questionnaire was distributed to 10 individual navigators to test it. This was followed up with a phone conversation to one of the selected navigators, again in the form of an informal phone conversations. No changes to the questions per se were suggested, however, some concerns to provide the participants with the ability to go back and forth in the questionnaire instrument was expressed and implemented. The test results were deemed sufficient and distribution through questback© began. The entire questionnaire as distributed is attached in appendix A of this thesis.

Operational Definition of Variables

Ship size and relative bearings were defined as the primary independent variables for ship domain in restricted waters. Aforementioned demographic questions served two purposes. Firstly, they enabled a description of the sample. Secondly, it made it possible to weed out participants which were not fulfilling the population requirements as it has been described.

CPA-values. CPA-values were defined as the dependent variable. It was considered continuous as such and the participants were to state CPA-values they deemed safe having a targeted ship pass for three different ship sizes and for eight different relative bearings. Participants were instructed to answer in nautical miles with one decimal (e.g. 0.5 nautical miles).

Ship size. Ship size and particularly ship´s length overall was considered an ordinal variable with the predefined ship sizes as specified in table 1 on page 36. Each participant had to state CPA-values for all different ship sizes to complete the questionnaire.

Relative bearing. The eight aforementioned relative bearings were considered ordinal variables. It was defined as the bearing from own ship to targeted ship measured from own ship´s bow. This implies that for example 000° was defined directly ahead of own ship whereas 180° was defined as directly astern of own ship. Each participant had to state CPA-values for all different relative bearings to proceed to next question.

Gender. Gender was considered an dichotomous variable and termed male and female. Gender information was collected to enable description of the sample.

Nationality. Nationality was considered a nominal variable and participants were to state their nationality in letters. Stated nationality was used to weed out those not fitting the population requirements, that is, not Norwegian.

Age. Age was considered a continuous variable and participants were to state their age in numbers. Age information was collected to enable description of the sample.

Years of seagoing experience. Years of seagoing experience was considered a continuous variable and the participants where to state the number of years they had been sailing as certified navigators. Years of experience was used to weed out those not fitting the population requirements and to enable description of the sample.

Rank. Rank was considered a nominal variable and participants were to state their current rank onboard. Rank information was collected to enable description of the sample.

Type of Certificate. Type of certificate was considered an ordinal variable. Certificate information was collected to weed out those not fitting the population requirements and to enable sample description. The certificate types were termed STCW Deck Officer Class1, Master Mariner, STCW Deck Officer Class 2, STCW Deck Officer Class 3, STCW Deck Officer class 4, STCW Deck Officer Class 5 and none of the above. The first four certificate types were in the population requirement (STCW, 2010Reg. II/1, Reg II/2). Henceforth, the different certificates will be referred to as class 1, class 2, class 3, and class 4.

Experience with ship types. Experience with ship types was considered a nominal variable and participants were to state ship types they had experience with. This was used to describe the sample. The different ship types were categorized as: Passenger ferries, Cruise ships, Tankers, Container ships, Offshore vessels, Bulk Carriers, Fishing vessel, Large Sailing vessels, Naval ships and None of the above. It was possible to state multiple ship types.

Data Collection and Processing

Aforementioned list of graduated students was primarily used to target the population. The particular manner in which this was done was to contact all persons contained in the list through their personal e-mail addresses. A short text was formulated in the e-mail informing each contacted person of the questionnaire´s purpose and the responsible persons for the questionnaire. The e-mail was formulated in Norwegian since it was assumed that all receivers spoke Norwegian. A link to the questback-questionnaire was attached in the e-mail. The e-mail was distributed on February 26th (2018) with a reminder sent on March 7th (2018).

Social media was also used to target the population. This was done by establishing personal contact with a request to respond to the questionnaire. Only a brief description similar to the one in the distributed e-mail was given with a link to the questback-questionnaire. 274 respondents were contacted in total.

All collected data was locally stored on the personal computer of Mari Auby Starup (the other master student) as an excel spreadsheet. This file was in turn sent to the researcher of this thesis and locally stored on a second computer.

Data cleaning was initially done in the excel-spreadsheet containing raw-data. Irregularities in use of both commas and periods had to be corrected as some respondents had used commas when stating CPA-values whereas others had used periods. All values were corrected to commas since this was interpreted as numbers in the applied analysis software. However, it must be emphasized that decimal numbers are reported with period herein. Some participants had also stated CPA-values without decimals. This ultimately lead to the question of whether the unit was in meters or nautical miles. Participants with such answers were completely removed from the data set due to this ambiguity. One respondent had also answered with a short explanatory text when stating CPA-values. The text was deleted and only the numbers were left in the excel spreadsheet readily for analysis. Nine foreign respondents were also deleted along with five respondents with less than one year of experience. After completion of data cleaning, 53 participants remained.

The excel spreadsheet was ultimately imported to Statistical Package for Social Sciences (SPSS) version 24 for analysis. Some minor changes pertaining labeling of variables was done to make them better suited for analysis. Stated CPA-values were labeled by the area (open or restricted), ship length and relative bearing they belonged to. For example, R_50m_000° denoted CPA-value for restricted water with ship size= 50 meters LOA at 000° relative bearing. Demographic variables where participants were to check off alternatives was labeled with numbers. For gender, 0=Male, 1=Female. For certificates, 1 = Class 1, 2 = Class 2, 3 = Class 3, 4 = Class 4. For experience with ship types, 0 = No, 1 = Yes for the different ship types in question.

Analysis

The analyzed data-set was split in two between the researcher of this thesis and the researcher of ship domain in open waters. CPA-values pertaining restricted waters along with all collected demographic data were subject to analysis herein.

Demographics. Collected demographic information was used to describe the sample. This was done by descriptive statistics of the sample. Frequency, mean and standard deviation was calculated for participants´ age and years of experience. Frequencies of gender, ranks, type of certificates, and type of experience was also calculated in number of sample units and percentages that represented each item.

Descriptive statistics. Stated CPA-values for restricted waters were subjected to frequency analysis in SPSS. 10th percentile, 25th percentile, means, 75th percentile, 90th percentile of stated CPA-values for all relative bearings and all ship sizes were calculated. The primary purpose of this was to enable a visual representation of the obtained ship domain shape and size for further discussion. This was done by exporting the obtained results to excel and generate spider charts and tables of descriptive statistics. Histograms showing frequency distributions of stated CPA-values for all ship sizes and relative bearings were also made in SPSS to assess the distribution of the obtained results. The distributions´ normality was tested by means of a Kolmogorov-Smirnov test of normality.

Inferential statistics. All stated CPA-values were analyzed by means of repeated measure general linear model (GLM) analysis to assess the within-subject effects ship size and relative bearing. This was chosen because the GLM analysis matched the research design. Partial eta squared (η_p^2) served as the measure of effect size as this is obtained from GLM analysis in SPSS version 24. Cohen´s (1988) classification of effect sizes pertaining partial eta squared was used to interpret the magnitude of these. According to this classification, $\eta_p^2 > 0.02$ is considered a small effect size, $\eta_p^2 > 0.13$ is considered a medium effect size and $\eta_p^2 >$

0.26 is considered a large effect size (Cohen, 1988). A linear regression analysis using ship size as covariates and mean ship domain as dependent variable was also done to further assess ship sizes impact on the ship domain size. A Wilcoxon signed-rank test for paired samples was used to test the hypotheses that the domain would be larger on starboard side of own ship compared against port side of own ship (H3a), and larger ahead of own ship compared against astern of own ship (H4a). Wilcoxon signed-rank test is the nonparametric equivalent of a t-test which can be used when the assumption of normal distribution is not met (Hinton, 2014, p. 197). To test the hypotheses, separate variables for all three ship sizes corresponding to starboard, port, astern and ahead of own ship were computed. The mean value of stated CPA-value for relative bearing 045° and 090°($(\bar{x}\ 045^\circ + \bar{x}\ 090^\circ)/2$) was used as indicator for starboard side, 270° and 315° ($(\bar{x}\ 270^\circ + \bar{x}\ 315^\circ)/2$) for port side, 135°, 180° and 225° ($(\bar{x}\ 135^\circ + \bar{x}\ 180^\circ + \bar{x}\ 225^\circ)/3$) for astern and 000° ($\bar{x}\ 000^\circ$) ahead of own ship.

Assumptions

The first assumption was that eight different relative bearings where participants were to state CPA-values corresponding to a safe passing distance would be sufficient to assess ship domain shape and size. The second assumption was that the chosen research area sufficiently described navigation in restricted waters. The third assumption was that the obtained results pertaining stated CPA-values in fact reflected the opinion of skilled navigators, meaning that the population requirements were sufficient.

Delimitations

Many factors influence ship domain shape and size, however, ship size, speed and type of water area are considered key factors (Wielgosz, 2016). Among these only ship size and type of area was investigated herein. Relative bearing was also considered a factor, however, this was rather viewed as an inherent characteristic of the entire concept since observations have shown that safe distance is not the same in all directions (Szlapczynski &

Szlapczynska, 2017). The reason as to why speed was not investigated (although mentioned in the questionnaire instrument) was two-fold. Firstly, it would have required more questions because at least two different speed relations would have to be represented. This was undesirable because it was believed that this would put a higher workload on participants and hence fewer would have participated. Secondly, the design of the study did not facilitate speed to be sufficiently represented as it is questionable to what extent participants actually can relate to this through a questionnaire. The scope was further limited to expert knowledge assessment of ship domain as perceived by Norwegian navigators and Norwegian restricted waters with no TSS. Norway was relevant because literature indicates that no studies have ever been undertaken in this country´s context before (Baran et al., 2017).

Beyond what has been hypothesized herein, other factors and ship domain methodologies could have been considered. However, some of the most critical factors has been investigated here. The expert knowledge approach was chosen because it allowed to investigate ship domains as desired by navigators (Dinh & Im, 2016) which in turn is relevant for collision risk assessment (Zhu et al., 2001). As previously argued, it is also an efficient method to isolate and assess the impact of influencing ship domain factors. The other factors and ship domain methodologies was beyond the scope of this thesis because it would have required additional time and resources to complement what has been done.

Reliability and Validity

Reliability refers to the consistency of a measuring instrument (Frankfort-Nachmias & Nachmias, 2008, p. 154). In this thesis, reliability refers to consistency of measures of CPA-values on different relative bearings across three different ship sizes. That is, consistency of measures on the concept of ship domain. The reliability was tested by calculation of Cronbach´s alpha using SPSS where it was calculated for CPA-values of each relative bearing separately across the three ship sizes (e.g. 000° for 50 meters LOA, 100 meters LOA and 200 meters LOA. The outcome of the test is presented in the results section.

Validity is essentially concerned with the question of whether the intended in fact is being measured. Three different aspects of this are subsumed under the concept of validity, namely content, empirical and construct validity (Frankfort-Nachmias & Nachmias, 2008, p. 149). With respect to this thesis, it is particularly certain issues referring to a part of the content validity aspect, the face validity, that will be addressed. Briefly, the applied questionnaire instrument was as previously argued carefully developed according to peer-reviewed ship domain articles. Furthermore, the questionnaire instrument has been developed in collaboration with subject matter experts (the navigators that were consulted via telephone) and tested before it was distributed in full scale. Thus, it is believed to have face validity. However, some issues will be discussed in the limitations section towards the end of this thesis.

Ethical Assurances

Several steps were taken to ensure that the conducted research was executed in line with ethical principles. First, an evaluation of the necessity to apply permit to collect data from the Norwegian Center for Research Data (NSD) was considered. The following considerations were made: Since the data collection process generally did not require any participant to state any information that would make them identifiable as individuals, NSD application was deemed unnecessary. However, since online questionnaire distribution involved sensitive data such as IP-addresses and e-mails from contacted participants, the hidden identity function in Questback was used to ensure anonymity. QuestBack states the following pertaining this function: "*When hidden identity is used in surveys, no identifiable information, such as browser type and version, internet IP address, operating system, or e-*

mail address, will be stored with the answer. This is to protect the respondent's identity" (Questback, 2018).

Second, a questionnaire cover letter with an informed consent form was added. The cover letter informed the participants of the persons responsible for the questionnaire (three persons) with full name and contact information. Furthermore, participants were informed within which institution and faculty the research were being conducted in, let alone that participation was voluntary and anonymous. Participants were explicitly informed that their identity would be hidden and a link to the previously cited questback-statement was provided to put participants at ease that anonymity would be guaranteed.

Results

This section will, without discussion to relevant literature, report on the outcome of the analyses as described in the previous section. The results are organized in the following subsections: Demographics, descriptive statistics and inferential statistics.

Demographics

Table 2 on next page shows the demographic profile of participants. 53 participants made up the sample and a majority of these were males (86.8%). Roughly 60% were aged 31 to 50 years old whereas about 30% were 30 years old or younger ($\overline{x}$ = 36.21; SD = 10.07). All participants stated to have more than one year of seagoing experience. About 47% had 1 to 5 years of experience and about 53% had more than 6 years of experience ($\overline{x}$ = 8.94; SD = 8.527). All participants stated to be of Norwegian nationality. About 79% of the participants served as either chief mate, 1st mate, 2nd mate or 3rd mate whereas 17% served as captains and two participants as pilots. Although only 17% actually served as captains, 47.2% of the participants stated to possess the highest certificate class (class 1) which means that they theoretically could have been captains. 30.2% stated to possess class 2 certificate, 20.7% stated to possess class 3 certificate and only one participant stated to possess the lowest certificate class (class 4) in the defined population. It was possible for the participants to state multiple ship types they had experience with. Tankers and offshore vessels were most frequently represented. Respectively 47.2% and 43.4% of the participants stated to have experience with these types. Following came passenger ferries and naval ships which 28.3% of participants stated to have experience with. As for the rest of the ship types, only a minority stated to have experience with these. Three participants also stated to have experience with either of the defined ship types.

Table 2. Demographic profile of participants

	N	Percent		N	Percent
Gender			**Certificates**		
Male	46	86.8%	Class 4	1	1.9%
Female	7	13.2%	Class 3	11	20.7%
Total	53		Class 2	16	30.2%
			Class 1	25	47.2%
Age			Total	53	
23 – 30 years	16	30.2%			
31 – 40 years	25	47.2%	**Experience with ship type**		
41 – 50 years	7	13.2%	Passenger ferries	15	28.3%
51 – 60 years	2	3.7%	Cruise ships	8	15.1%
>61 years	3	5.7%	Tankers	25	47.2%
Total	53		Container ships	4	7.5%
			Offshore vessels	23	43.4%
Years of Experience			Bulk carriers	6	11.3%
1 – 5 years	25	47.2%	Fishing vessels	8	15.1%
6 – 10 years	13	24.5%	Large sailing vessels	6	11.3%
11 – 15 years	7	13.2%	Naval ships	15	28.3%
>16 years	8	15.1%	None of the above	3	5.7%
Total	53		*(Several types possible)*		
Nationality					
Norwegian	53	100%			
Total	53				
Rank					
Mate (1st,2nd ,3rd)	28	52.8%			
Chief Mate	14	26.4%			
Captain	9	17%			
Pilot	2	3.8%			
Total	53				

Descriptive Statistics

Calculated 10th percentiles, 25th percentiles, means, 75th percentiles and 90th percentiles of stated CPA-values for the eight different relative bearings and for the three different ship sizes formed the basis of the obtained ship domains in this thesis. Figure 5, 6 and 7 on the next pages show spider charts of the ship domain shape and size for three different ship sizes. Table 3, 4 and 5 shows the actual values of the descriptive statistics as this is not easily observed from the figures per se. Finally, figure 8 and table 6 shows mean ship domain for all ship sizes. All values of the descriptive statistics are in nautical miles (nm). The remainder of this subsection will be a brief discussion on the face value of the descriptive statistics.

Ship domain for ship size = 50 meters. A visual inspection of means in table 3 on next page shows that the domain is slightly larger on starboard side of own ship (045° and 090°) compared to port side (270° and 315°) of own ship. Further, the domain is larger ahead of own ship (000°) compared against astern of own ship (135°,180°, 225°). The 10th percentile values shows that below 10% of stated CPA-values are less than 0.1 nm for all relative bearings. The 25th percentile values shows that CPA-values for starboard and port side of own ship are equally 0.2 nm and larger than all other 25th percentile values. The 75th percentile values are 0.5 nm for all relative bearings whereas the 90th percentile values shows more irregularities. Below 90 % of all stated CPA-values are greater on starboard side and port side of own ship compared to ahead and astern of own ship which are equally 0.5 nm. Figure 5 on next page shows a spider chart of the descriptive statistics. By visual inspection and considering mean values, the domain resembles an off-centered circle with own ship´s position slightly shifted towards the domain´s lower left section. The 10th and 75th percentile domain also resembles circles but with the ship positioned at domain´s center. The 25th and 90th percentile domains are both more peculiar shapes. As such, the 25th percentile domain is generally larger on port side of own ship and the 90th percentile domain is larger on starboard side of own ship.

Table 3. Descriptive statistics for ship domain shape and size. Ship size = 50 meters LOA.

Relative bearing	10th percentiles (nm)	25th percentiles (nm)	Means (nm)	75th percentiles (nm)	90th percentiles (nm)
000°	0,100	0,125	0,3566	0,500	0,500
045°	0,100	0,200	0,4028	0,500	0,880
090°	0,100	0,200	0,3858	0,500	0,760
135°	0,100	0,100	0,3274	0,500	0,500
180°	0,100	0,150	0,3066	0,500	0,500
225°	0,100	0,175	0,3358	0,500	0,500
270°	0,100	0,200	0,3840	0,500	0,760
315°	0,100	0,200	0,3764	0,500	0,700

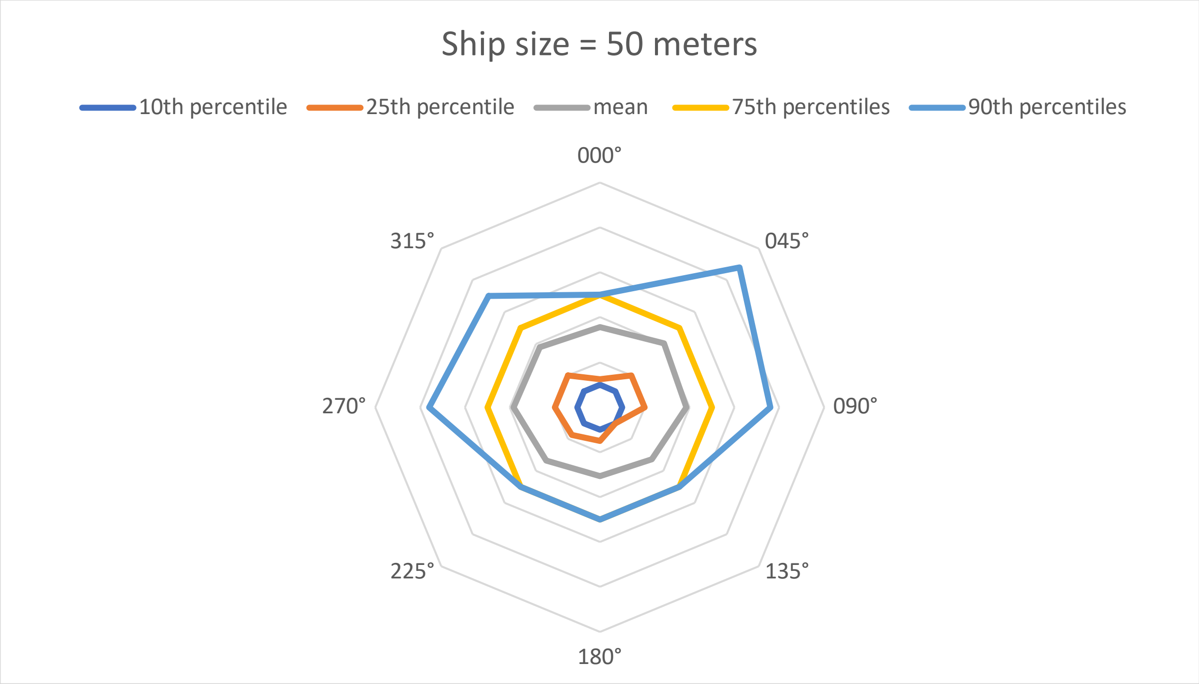


Figure 5. Ship domain shape for ship size = 50 meters LOA

Ship domain for ship size = 100 meters. A visual inspection of means in table 4 shows that the domain is slightly larger on starboard side of own ship (045° and 090°) compared against port side (270° and 315°) of own ship. Further, the domain is larger ahead of own ship (000°) compared against astern of own ship (135°,180°, 225°). The 10th percentile values are 0.1 nm for all relative bearings and the 25th percentile values are 0.2 nm for all relative bearings. The 75th percentile values shows that below 75% of stated CPA-values are larger on the starboard and port side of own ship compared to all the other relative bearings which are equally 0.5 nm. The 90th percentile values shows that below 90% of all stated CPA- values are greater for 090°, 045°, 000°,315°, 270° compared to 135°, 180° and 225°. Figure 6 shows a spider chart of the descriptive statistics. By visual inspection and considering mean values, the domain resembles an off-centered circle with own ship´s position slightly shifted towards the domain´s lower left section. The 10th and 25th percentile domains also resembles circles but with the ship positioned at the domain´s center. The 75th percentile domain has a more blunted shape with ship´s position slightly shifted towards the domain´s left section. The 90th percentile domain resembles more of an elliptical shape, however, a rather oval one with ship´s position slightly shifted towards the domain´s lower left section.

Table 4. Descriptive statistics for ship domain shape and size. Ship size = 100 meters LOA

Relative bearing	10th percentiles (nm)	25th percentiles (nm)	Means (nm)	75th percentiles (nm)	90th percentiles (nm)
000°	0,100	0,200	0,4415	0,500	1.000
045°	0,100	0,200	0,4925	0,700	1.000
090°	0,100	0,200	0,4547	0,650	0,800
135°	0,100	0,200	0,4179	0,500	0,760
180°	0,100	0,200	0,3755	0,500	0,760
225°	0,100	0,200	0,4217	0,500	0,760
270°	0,100	0,200	0,4509	0,600	0,800
315°	0,100	0,200	0,4736	0,700	1.000

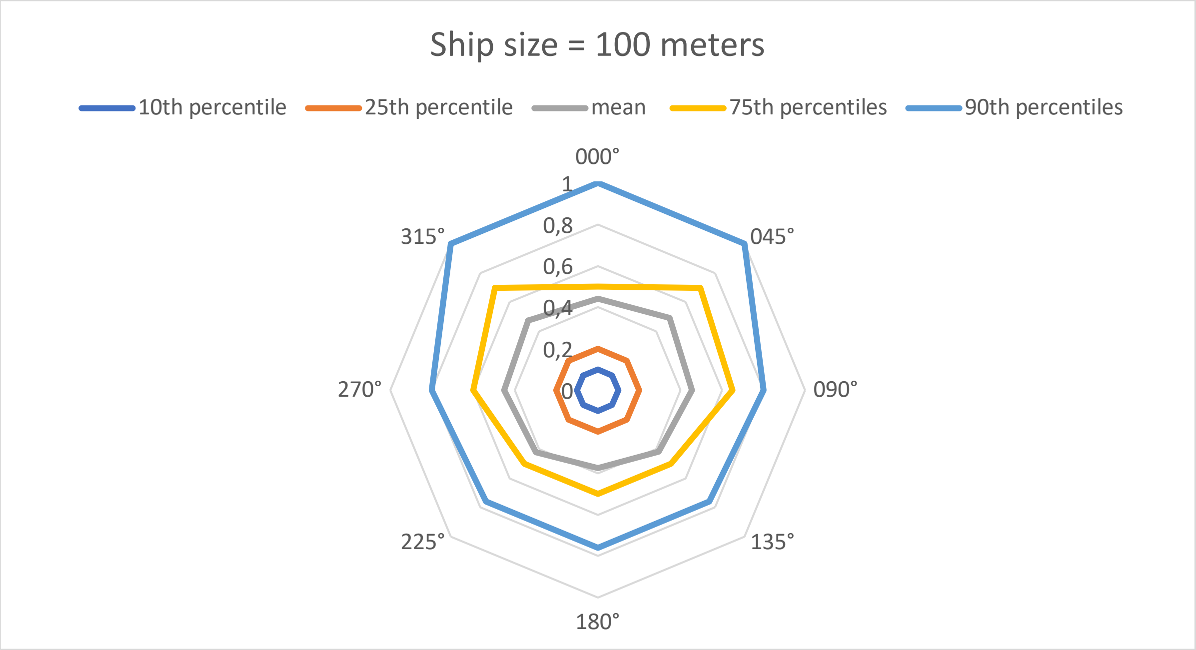


Figure 6. Ship domain shape for ship size = 100 meters LOA

Ship domain for ship size= 200 meters. A visual inspection of means in table 5 shows that the domain is slightly larger on starboard side of own ship (045° and 090°) compared against port side (270° and 315°) of own ship. Further, the domain is larger ahead of own ship (000°) compared against astern of own ship (135°,180°, 225°). The 10th percentile values are 0.2 nm for all relative bearings whereas 25th percentile values are 0.3 nm for all relative bearings except for 180° which is 0.2 nm. The 75th percentile values shows greater CPA-values for 090°, 045°, 000°, 315° and 270° (abeam and ahead of own ship) compared to 135°, 180°, 225° (astern of own ship). The 90th percentile values are 1.0 nm for all relative bearings. Figure 7 shows spider charts of the descriptive statistics. By visual inspection and considering mean values, the domain resembles an off-centered circle with own ship´s position slightly shifted towards the domain´s lower left section. The 25th and 75th percentile domains both resembles circles but with the ship shifted towards domain´s lower section and lower *left* section respectively. The 10th and 90th percentile domains are centered circles.

Table 5. Descriptive statistics for ship domain size. Ship size = 200 meters LOA

Relative bearing	10th percentile (nm)	25th percentile (nm)	Means (nm)	75th percentiles (nm)	90th percentiles (nm)
000°	0,200	0,300	0,6000	0,800	1.000
045°	0,200	0,300	0,6585	0,800	1.000
090°	0,200	0,300	0,6415	0,800	1.000
135°	0,200	0,300	0,5642	0,675	1.000
180°	0,200	0,200	0,5179	0,650	1.000
225°	0,200	0,300	0,5472	0,700	1.000
270°	0,200	0,300	0,6047	0,800	1.000
315°	0,200	0,300	0,6415	0,800	1.000

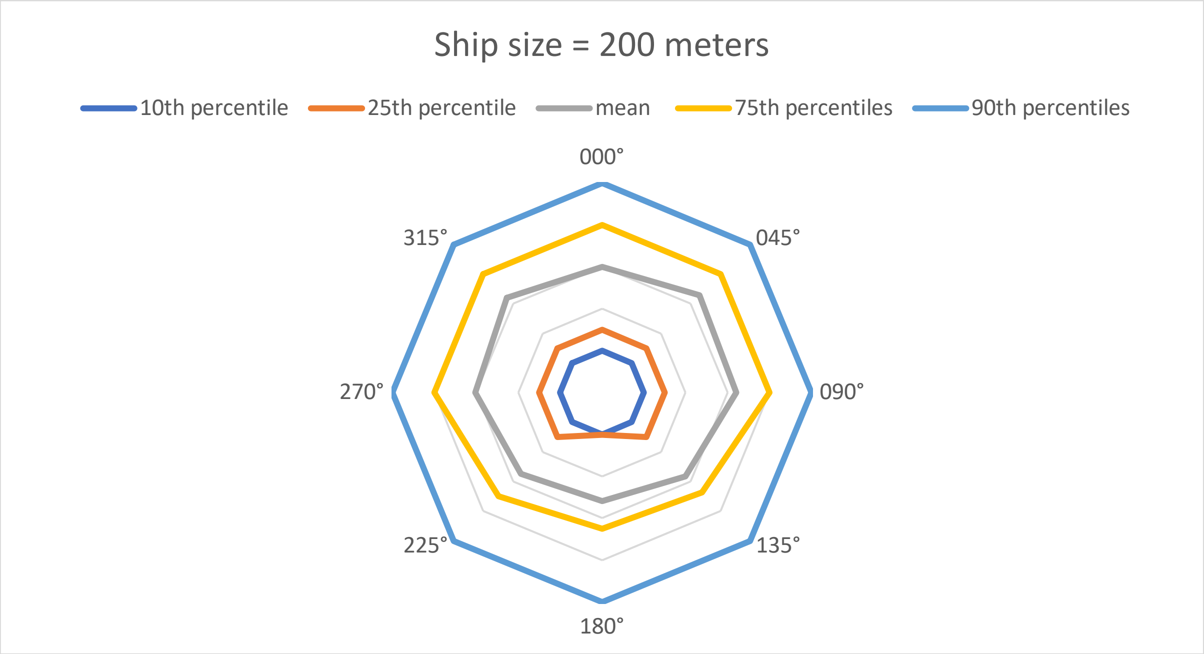


Figure 7. Ship domain shape for ship size = 200 meters LOA

Mean ship domain for all sizes. Table 6 comprise mean values for all ship sizes. That is, the same values as presented in the previous tables. It can be observed that mean values are not similar for all sizes. By visual inspection, means for ship size = 50 meters are smaller than ship size = 100 meters which in turn are smaller than ship size = 200 meters. This can also be observed in figure 8 where it is clearly shown that mean ship domain have increased with an increased ship size. Further, note that the gap between ship domain for ship size = 200 meters and ship size = 100 meters appears to be twice the gap as from 50 meters to 100 meters.

Table 6. Mean ship domain for all ship sizes

Relative bearing	50m (nm)	100m (nm)	200m (nm)
000°	0.3566	0.4415	0.6
045°	0.4028	0.4925	0.6585
090°	0.3858	0.4547	0.6415
135°	0.3274	0.4179	0.5642
180°	0.3066	0.3755	0.5179
225°	0.3358	0.4217	0.5472
270°	0.384	0.4509	0.6047
315°	0.3764	0.4736	0.6415

Figure 8. Mean ship domain shape for all ship sizes.

Scale reliability. Cronbach´s alpha was calculated to test the reliability. According to Frankfort-Nachmias and Nachmias (2008, p. 25), an alpha greater than 0.7 can be considered an acceptable level. Table 7 shows the outcome of the test which has measured correlation for each relative bearing across the different ship sizes. A very high correlation was found for all relative bearings ($\alpha > 0.7$), indicating that there was a consistency on the measurement of a ship domain as a construct.

Table 7. Cronbach´s alphas for relative bearings across ship sizes.

Relative bearing across ship size 50, 100 and 200 meters	Cronbach´s alpha
000°	0.969
045°	0.955
090°	0.945
135°	0.914
180°	0.906
225°	0.935
270°	0.944
315°	0.945

Frequency distribution. The three next pages shows histograms with frequency distributions of stated CPA-values. They are organized with eight individual histograms for each ship size. That is, one histogram for each relative bearing. Figure 9a-h shows frequency distribution for ship size = 50 meters, figure 10a-h shows frequency distribution for ship size = 100 meters and figure 11a-h shows frequency distribution for ship size = 200 meters.

Figure 9a-h. Histograms with CPA-values for ship size = 50 meters

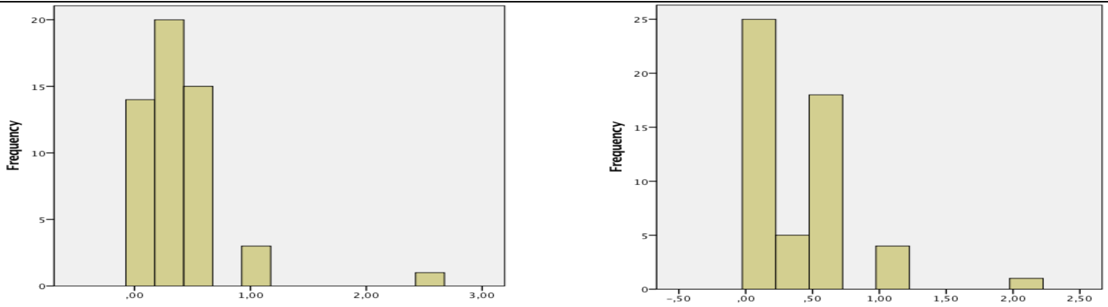


Figure 9a. Histogram for 000°. Ship size = 50 meters (x̄ = 0.36; SD= 0.379). The distribution deviates from normal with skewness 3,826 and kurtosis 19.603.

Figure 9b. Histogram for 045°. Ship size = 50 meters (x̄ = 0.40; SD = 0.341). The distribution deviates from normal with skewness 2.324 and kurtosis 8.191.

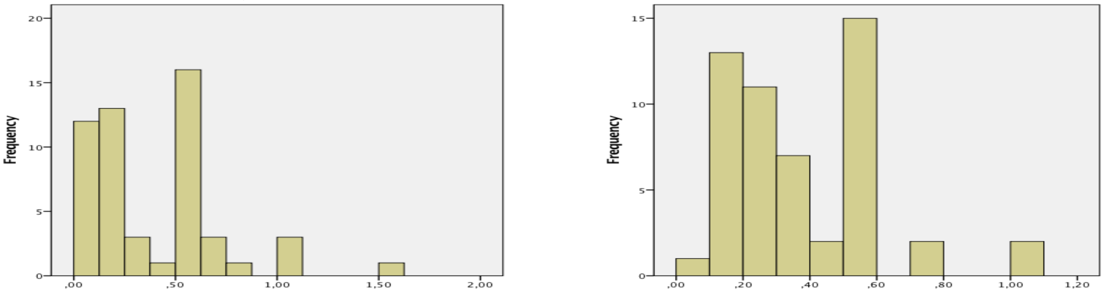


Figure 9c. Histogram for 090°. Ship size = 50 meters (x̄ = 0.39; SD = 0.295). The distribution deviates from normal with skewness 1.465 and kurtosis 2.874.

Figure 9d. Histogram for 135°. Ship size = 50 meters (x̄ = 0.33; SD = 0.222). The distribution deviates from normal with skewness 1.077 and kurtosis 1.271.

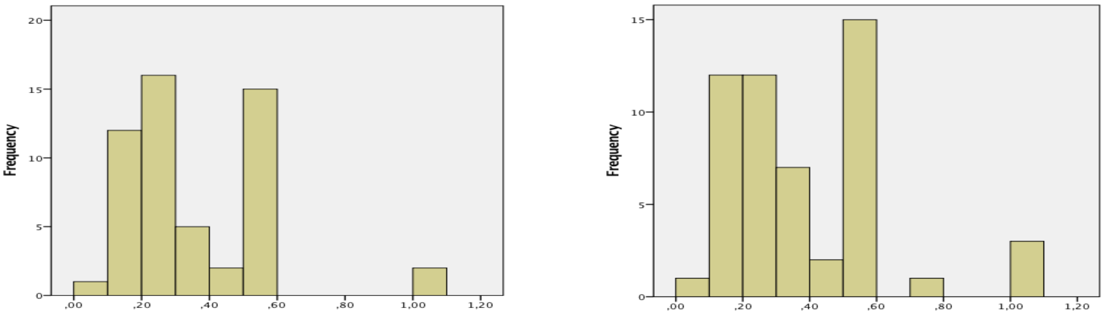


Figure 9e. Histogram for 180°. Ship size = 50 meters (x̄ = 0.31; SD = 0.210). The distribution deviates from normal with skewness 1.364 and kurtosis 2.464

Figure 9f. Histogram for 225°. Ship size = 50 meters (x̄ = 0.34; SD = 0.233). The distribution deviates from normal with skewness 1.245 and kurtosis 1.626

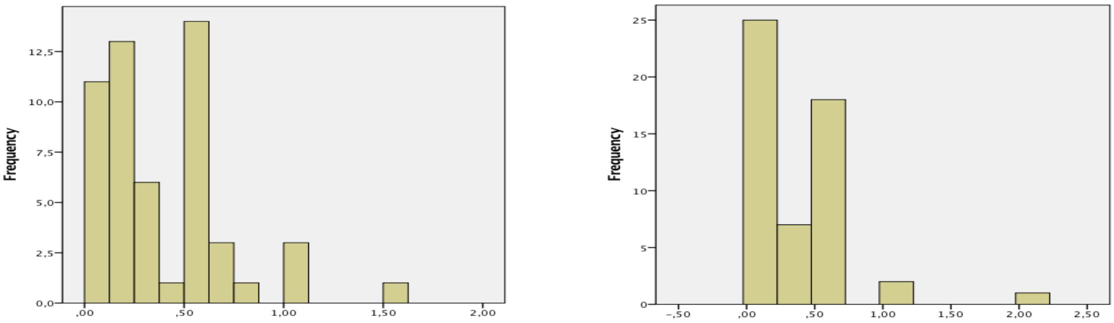


Figure 9g. Histogram for 270°. Ship size = 50 meters (x̄ = 0.38; SD = 0.293). The distribution deviates from normal with skewness 1.532 and kurtosis 3.046

Figure 9h. Histogram for 315°. Ship size = 50 meters (x̄ = 0.38; SD = 0.317). The distribution deviates from normal with skewness 2.890 and kurtosis 12.504.

Note: All distributions show a deviation from normal as ascertained by a Kolmogorov-Smirnov test of normality ($p < 0.001$ for all distributions).

Figure 10a-h. Histograms with CPA-values for ship size = 100 meters

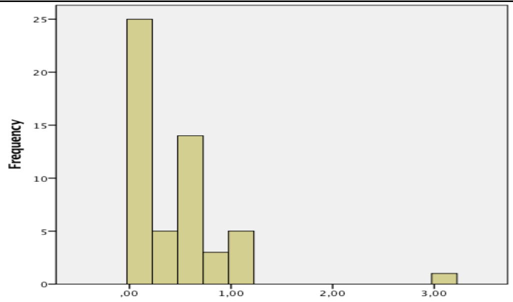


Figure 10a. Histogram for 000°. Ship size = 100 meters (x̄ = 0.44; SD = 0.459). The distribution deviates from normal with skewness 3.595 and kurtosis 18.085.

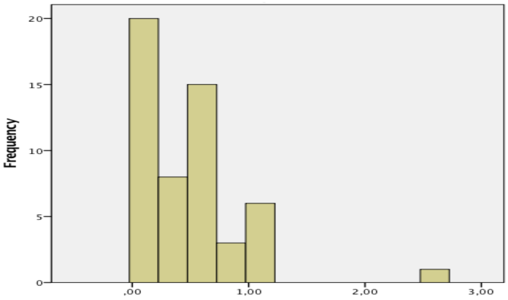


Figure 10b. Histogram for 045°. Ship size = 100 meters (x̄ = 0.49; SD = 0.409). The distribution deviates from normal with skewness 2.477 and kurtosis 10.041.

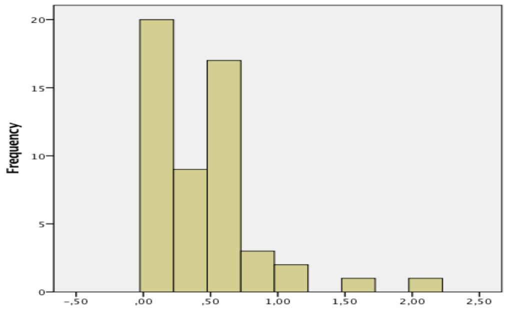


Figure 10c. Histogram for 090°. Ship size = 100 meters (x̄ = 0.45; SD = 0.359). The distribution deviates from normal with skewness 2.072 and kurtosis 6.297.

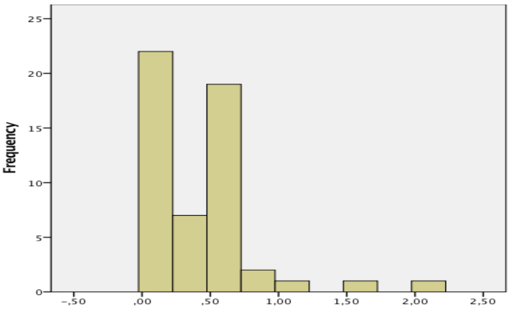


Figure 10d. Histogram for 135°. Ship size = 100 meters (x̄ = 0.42; SD = 0.345). The distribution deviates from normal with skewness 2.518 and kurtosis 8.837

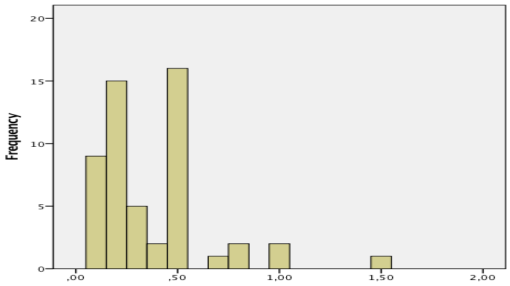


Figure 10e. Histogram for 180°. Ship size = 100 meters (x̄ = 0.38; SD = 0.276). The distribution deviates from normal with skewness 1.756 and kurtosis 4.441.

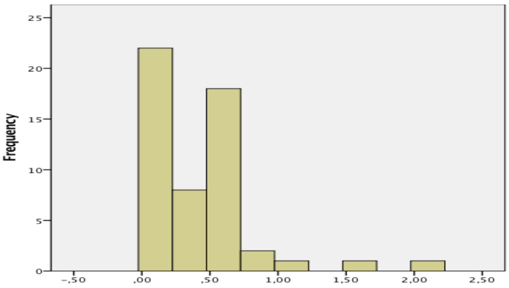


Figure 10f. Histogram for 225°. Ship size = 100 meters (x̄ = 0.42; SD = 0.354). The distribution deviates from normal with skewness 2.451 and kurtosis 7.955.

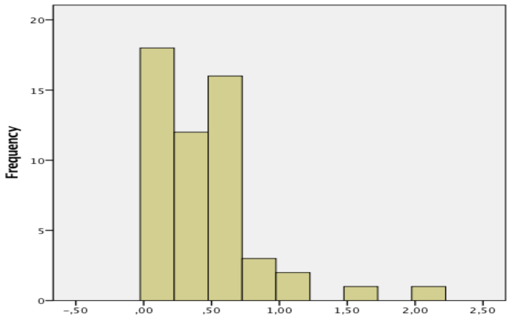


Figure 10g. Histogram for 270°. Ship size = 100 meters (x̄ = 0.45; SD = 0.364). The distribution deviates from normal with skewness 2.122 and kurtosis 6.109.

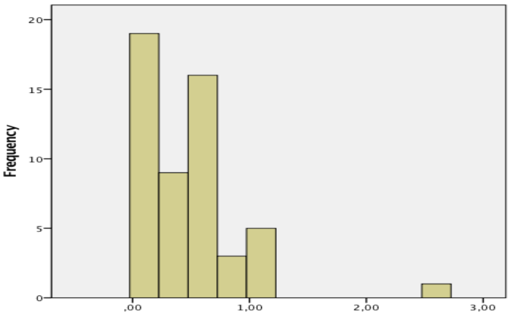


Figure 10h. Histogram for 315°. Ship size = 100 meters (x̄ = 0.47; SD = 0.401). The distribution deviates from normal with skewness 2.731 and kurtosis 11.599.

Note: All distributions show a deviation from normal as ascertained by a Kolmogorov-Smirnov test of normality ($p \leq 0.001$ for all distributions).

Figure 11a-h. Histograms with CPA-values for ship size = 200 meters

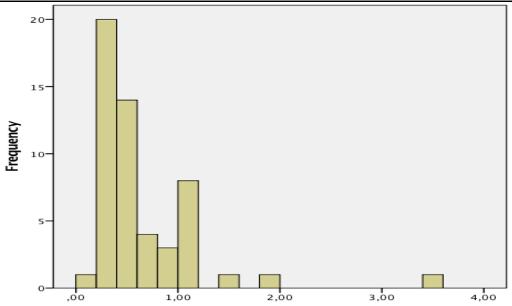


Figure 11a. Histogram for 000°. Ship size = 200 meters ($\bar{x}$ = 0.60; SD = 0.538). The distribution deviates from normal with skewness 3.382 and kurtosis 15.930.

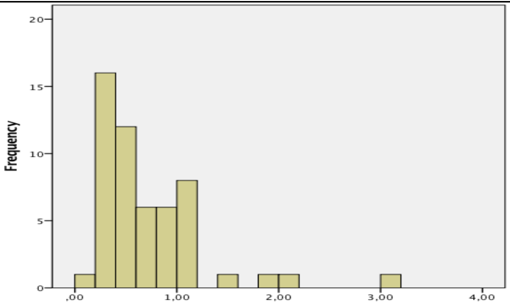


Figure 11b. Histogram for 045°. Ship size = 200 meters ($\bar{x}$ = 0.66; SD = 0.516). The distribution deviates from normal with skewness 2.360 and kurtosis 7.845.

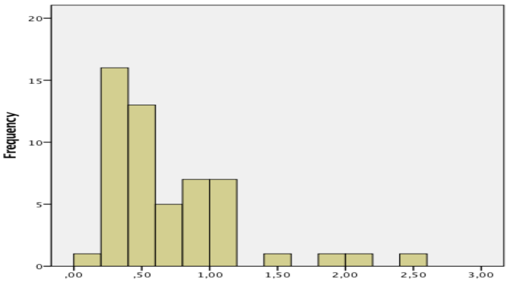


Figure 11c. Histogram for 090°. Ship size = 200 meters ($\bar{x}$ = 0.64, SD = 0.474). The distribution deviates from normal with skewness 1.916 and kurtosis 4.678.

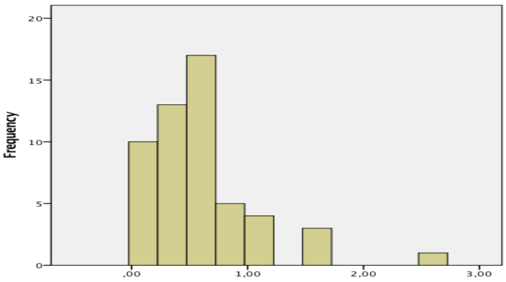


Figure 11d. Histogram for 135°. Ship size = 200 meters ($\bar{x}$ = 0.56, SD = 0.435). The distribution deviates from normal with skewness 2.344 and kurtosis 7.163.

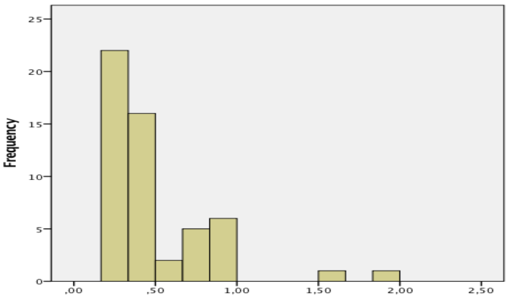


Figure 11e. Histogram for 180°. Ship size = 200 meters ($\bar{x}$ = 0.52, SD= 0.366). The distribution deviates from normal with skewness 1.937 and kurtosis 4.907.

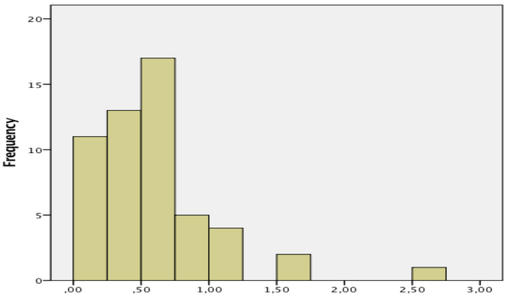


Figure 11f. Histogram for 225°. Ship size = 200 meters ($\bar{x}$ = 0.55, SD = 0.418). The distribution deviates from normal with skewness 2.549 and kurtosis 8.882.

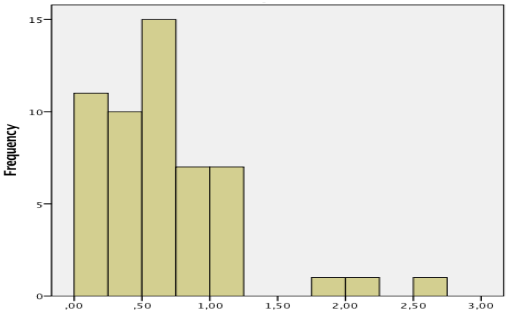


Figure 11g. Histogram for 270°. Ship size = 200 meters ($\bar{x}$ = 0.60, SD= 0.464). The distribution deviates from normal with skewness 2.138 and kurtosis 5.816.

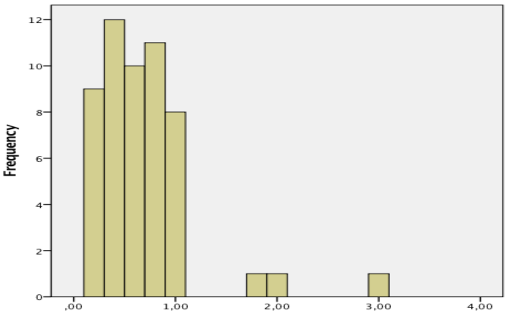


Figure 11h. Histogram for 315°. Ship size = 200 meters ($\bar{x}$ = 0.64; SD= 0.505). The distribution deviates from normal with skewness 2.538 and kurtosis 9.049.

Note: All distributions show a deviation from normal as ascertained by a Kolmogorov-Smirnov test of normality ($p < 0.001$ for all distributions).

Inferential Statistics

All collected data of stated CPA-values were subject to a repeated measure general linear model (GLM) analysis. The Greenhouse-Geisser correction was used to correct the degrees of freedom for independent variables and error terms as Mauchly´s test of sphericity was found to be significant for all independent variables in question: Ship size ($X^2{}_2 = 35.687$; $p < 0.001$), relative bearing ($X^2{}_{27} = 315.180$; $p < 0.001$), ship size x relative bearing ($X^2{}_{104} = 692.497$; $p < 0.001$).

Effect of ship size. A 3 x 8 repeated measure GLM analysis (ship size x relative bearing) was used to test the effects of within-subject factors on stated CPA-values. A large effect for ship size was found (sphericity not assumed, $F_{1.330,\,69.182} = 44{,}434$; $p < 0.001$; $\eta_p{}^2 = 0.461$). With reference to hypothesis H1a, the ship domain clearly increased with increasing ship sizes, see table 8.

Table 8. Estimated marginal means for effect of ship size.

Ship size	Mean (SE)	95% CI
50 meters	0.359 (0.036)	0.287, 0.432
100 meters	0.441 (0.049)	0.344, 0.538
200 meters	0.597 (0.061)	0.475, 0.719

A linear regression using ship size as covariates and mean ship domain as dependent variable found that ship size explained 87% of variation in ship domain size ($R^2 = 0.87$). The fit to data was very good ($F_{1,\,22} = 147.696$; $p < 0.001$). The ship domain size could be approximated using a linear regression:

$$\bar{x} \text{ of ship domain} = 0.281 + 0.00158 * \text{ship size} \qquad (1)$$

Figure 12 on next page shows the linear regression line as described by equation 1:

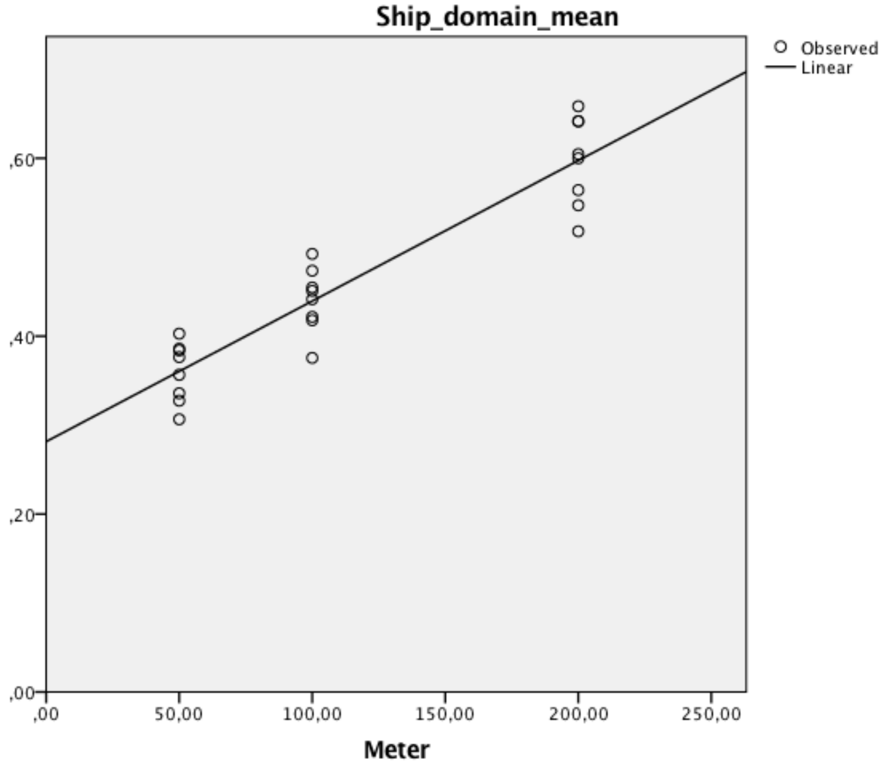


Figure 12. Regression line for mean ship domain size.

Effect of relative bearing. A small effect for relative bearing was found (sphericity not assumed, $F_{3.083,\ 160.331} = 4,888$; $p = 0.003$; $\eta_p^2 = 0.086$). A pairwise comparison with Bonferroni correction showed that relative bearing 045° ($\bar{x}$ =0.518; SE = 0.056) was significantly larger than relative bearing 135° ($\bar{x}$ = 0.436; SE = 0.044), relative bearing 180° ($\bar{x}$ = 0.400; SE = 0.037) and relative bearing 225° ($\bar{x}$ = 0.435; SE = 0.044). Table 9 shows the pairwise comparison of 045° against 135°, 180° and 225°.

Table 9. Pairwise comparison, 045° against 135°, 180° and 225°

Relative bearing	Mean diff ($\bar{x}$ 045° - $\bar{x}$ relative bearing) (SE)	95% CI	p
135°	0.081 (0.023)	0.005, 0.158	0.027
180°	0.118 (0.035)	0.004, 0.232	0.035
225°	0.083 (0.025)	0.000014, 0.166	0.050

Effect of ship size and relative bearing. The interaction effect ship size x relative bearing was not significant (sphericity not assumed, $F_{4.960,\,257.936} = 1.503$; $p = 0.190$; $\eta_p^2 = 0.028$).

Differences in stated CPA-values, starboard compared against port. To test the hypothesis that the ship domain will be similar to Goodwin´s (1975) model (H3a), a pairwise comparison of distances to starboard (045°, 090°) and port of own ship (270° 315°) was done. Table 10 shows the descriptive statistics and the outcome of a Wilcoxon signed- rank test for paired samples. A nonparametric alternative to the t-test was used due to the deviation from normality in the data set. The face value of the descriptive statistics indicates a difference as hypothesized, however, it cannot be inferred that it is so due to the outcome of the Wilcoxon signed-rank test. Consequently, H3a has to be rejected, see table 10 below.

Table 10. Pairwise comparison, starboard against port

	Mean (SD)			Wilcoxon signed-rank test for paired samples	
Ship size	Starboard	Port	Mean diff	Z	p
50 meters	0.394 (0.32)	0.380 (0.30)	0.014	- 0.924	0.356
100 meters	0.474 (0.38)	0.462 (0.38)	0.012	- 0.680	0.497
200 meters	0.650 (0.49)	0.623 (0.48)	0.027	- 1.047	0.295

Differences in stated CPA-values, forward compared against aft. To test the hypothesis that the ship domain will be similar to Goodwin´s (1975) model (H4a), a pairwise comparison of distances forward of own ship (000°) and astern of own ship (135°, 180°, 225°) was done. Table 11 shows the descriptive statistics and the outcome of a Wilcoxon signed- rank test for paired samples. A nonparametric test was used for the same reason as above. The face value of the descriptive statistics indicates a difference as hypothesized, however, it cannot be inferred that it is so due to the outcome of the Wilcoxon signed- rank test. Consequently, H4a has to be rejected, see table 11 below.

Table 11. Pairwise comparison, forward against aft

	Mean (SD)			Wilcoxon signed-rank test for paired samples	
Ship size	Forward	Aft	Mean diff	Z	p
50 meters	0.357 (0.38)	0.323 (0.21)	0.034	- 1.686	0.092
100 meters	0.442 (0.46)	0.405 (0.36)	0.037	- 0.725	0.469
200 meters	0.600 (0.54)	0.543 (0.40)	0.057	- 0.428	0.668

Discussion

This section discusses the outcome of the results. The first subsection will be dealing with the ship´s size influence on ship domain shape and size (RQ1.) The second subsection will be dealing with the effect of targeted ship´s relative bearing (RQ2). The third subsection will be dealing with limitations and the fourth subsection with recommendations for future research.

Effect of Ship Size on Ship Domain Shape and Size

A significant effect of ship size on the ship domain was found in this thesis ($p < 0.001$). In fact, a quite large fraction of variation in the data set could be attributed to ship size ($\eta_p^2 = 0.461$). The general effect was that the ship domain was perceived in an increasing manner as hypothesized and that it was possible to approximate the mean overall ship domain size by a linear regression depending on ship size. The face validity of this finding is high based on logical reasoning that a navigator would judge safe distance depending on ship size. More importantly, it support the findings of, among others, Pietrzykowski et al. (2012), Wielgosz (2016) and Goodwin (1975) who have all stated that ship size significantly influences the ship domain in both open and restricted waters. Unfortunately, none of these researchers have explicitly reported the outcome effect in terms of an effect size, nor a specific relationship such as for example a linear regression (specifically with respect to the influence of ship size). The obtained results in this thesis are not comparable to either of these researchers´ findings in terms of exact dimensions as they have been obtained in other areas, with other ship sizes and different methodological approaches. However, a judgement on the general characteristic influence can be made. For example, Pietrzykowski et al. (2012) concluded in a work specifically dedicated to investigate the effect of ship size in restricted waters that navigators on smaller ships tended to maintain a smaller domains than those on bigger ships. Another observation was that the domain shape appeared to be similar for ship sizes under study (three ship sizes). The applied method of ship domain determination was similar to Fujii and Tanaka´s (1971) method of domain determination which has been described earlier, however, it was based on simulation rather than actual ship navigation (Pietrzykowski et al., 2012). These general findings coincide with the general findings in this thesis – a significant effect of ship size and the shape appeared to be similar for all sizes. That is, for all sizes except the 90th and 25th percentile domains for ship size = 50 meters. These two peculiar shapes could probably be attributed to a few extreme values within the mentioned percentiles due to a small sample size. By visual comparison of the domain shape obtained in this thesis to the domain shape in Pietrzykowski et al. (2012) (minimum, mean and maximum domains for three ship sizes), it becomes clear that they are not at all equal as those are far slimmer and have irregular domain boundaries. The irregular boundaries were stated to be due to several close quarters situations on starboard side of the ships whose domains were determined during the experiment. However, this does not explain the deviation in terms of apparent slimness of the obtained domains in this thesis. This is an important question because the expected result of a ship domain in restricted waters are found to be smaller but also slimmer compared to open waters (Wielgosz, 2017) and not circular. Hence, this makes it possible to question the expediency of applying a questionnaire to determine ship domains. This is because one ought to question the extent to which a static scenario represents actual ship navigation (Wang & Chin, 2015). But as it has been previously argued, subjective opinions were of interest in this thesis. Regardless of this, a similarity in terms of apparent shapes can be observed when the shapes in this thesis are compared to Wielgosz´s (2016) declarative domains. Although these shapes were stated to be elliptical due to an approximation process of gathered questionnaire data, a visual inspection reveals that they were actually quite close to resembling circles. Given the certain similarities to this thesis´ study, it might be postulated that declarative domains are bound to become relatively oval shapes compared to domains which has been determined by other methods. At a general note, Campbell, Fiske, and Helson (1959) stated that a scientific method contributes a great deal to the measurement of a construct, implying that different methods yields slightly different results and similar methods tends to yield similar results. As for ship domain shapes in particular, Szlapczynski and Szlapczynska (2017) have stated that the obtained domain shape in fact are usually a result of the applied method and should not be emphasized beyond the impact of different influencing ship domain factors. In sum, the obtained ship domain shape has face validity, though it deviated slightly from the general body of ship domain models, but not from declarative domains, nor Goodwin´s (1975) model which is circular.

Effect of Targeted Ship´s Relative Bearing

A visual inspection of the descriptive statistics indicated different mean values for all relative bearings considering all ship sizes in question. The GLM analysis also showed a significant effect of relative bearing ($p = 0.003$) with a small effect size ($\eta_p^2 = 0.086$). As shown in the results section, the significant effect was materialized as a difference between relative bearing 045°, 135° 180° and 225° where CPA-values for 045° were significantly larger than the three latter. A closer investigation by a Wilcoxon signed-ranks test revealed no systematic difference with reference to hypotheses H3a and H4a. This finding deviates from the common understanding that the domain should be larger for own ship´s starboard side compared to port side as well as larger ahead of own ship compared to astern of own ship (Goodwin, 1975). As presented in the literature review, this is ultimately a result stemming from the psychological burden of COLREG (Zhao et al., 1993) and a navigator´s focus of attention (Hansen et al., 2013). Based on this, the outcome seems rather ambiguous, especially considering a significant effect of relative bearing (albeit small) but no wider systematic difference. Especially, the face validity of this finding seems rather low and consequently a rejection of the hypotheses H3a and H3a should be taken with a certain skepticism. See subsection limitation below for further clarification.

Limitations

This thesis has limitations which in the following will be addressed: *First,* the scope was limited as the data were gathered from only one static scenario accounting for only a few factors known to influence the ship´s domain. The reasoning behind the chosen factors and method of ship domain determination can be read in the subsection delimitations comprised in the method section of this thesis.

Second, the fact that a questionnaire was used to measure the opinion of Norwegian navigator´s perception of ship domain ought to be questioned. It can be regarded a limitation since face-to-face data collection surely would have facilitated a more nuanced representation of navigators´ opinions on ship domain with a possibility to probe for additional information. As indicated by the discussion above, especially pertaining RQ2, it is reasonable to highlight a few issues regarding the face validity aspect of the applied questionnaire. Essentially, this would be a question as to what an extent the questionnaire accurately captured the variables ship size and relative bearing within the greater entity of ship domain. The outcome of the analyses for hypotheses H3a, and H4a pertaining RQ2 produced a somewhat contradictory finding, at least in terms of statistical significance. This might suggest that the questionnaire was unable to precisely measure participating navigators´ opinion on safe passing distance (in sum, yielding a ship domain) as a function of a targeted ship´s relative bearing. However, that is not to say that the participating navigators were unaware of the different COLREGs pertaining the relative bearings, but perhaps that the questionnaire may have poorly communicated what it was truly concerned with. It should not be ruled out that more explanatory information contained in the questionnaire could have facilitated a navigator´s right state of mind when responding to it. Judging by the outcome of hypothesis H1a, the same cannot be said for ship size as the domain clearly increased with an increased ship size. In sum, it is reasonable to question to what an extent the questionnaire captured relative bearing as a variable. However, in defense of the applied questionnaire and as previously argued, its design was deeply rooted in relevant ship domain literature. Besides, the descriptive statics indicated a difference as hypothesized and moreover, there was an effect of relative bearing. Thus, this could be an issue related to the next paragraph´s discussion.

Third, the sample size was rather small. This could be an issue since the standard error of the mean is a function of standard deviation and sample size (a small sample yields a large standard error) (Hinton, 2014). Since the standard error is a measure of how close the sample statistics are to the population parameter (Allen, 2017), a large standard error would imply less accuracy in estimated means. In terms of confidence intervals, it implies that they become wider because they are calculated on basis of standard error (Frankfort-Nachmias & Nachmias, 2008). Judging by for example figure 5 on page 49 for ship size 50 meters, it can be observed that 10th and 25th percentile values at some relative bearings are equal which in turn demonstrates a certain vulnerability to outliers in the data set and less accurate estimates further from the mean values. A small sample size also decreases the test´s statistical power and increases the chance of a type II error which implies failing to identify a genuine effect (Hinton, 2014). However, the repeated measures design which was used in this thesis boosts statistical power (Charness et al., 2012) because the error of scores are between condition and without individual differences between participants (Hinton, 2014). That is, each participant is his/her own control group. In sum, the results must be interpreted with some caution, but the effect is unlikely to have been highly detrimental.

Fourth, the GLM analysis assumes normal distribution (Hinton, 2014). It was clearly demonstrated in the results section of this thesis that the assumption was not sufficiently met and consequently some bias may have been produced. On the other hand, it has been argued that it is residuals that must meet normality and not the distribution of variables per se (Hoffmann, 2004). Regardless of this, some researchers argues that a GLM analysis is actually quite robust against non-normal distributions (Snijders, 2011). Further, some researchers also argues that non-parametric tests seldomly needs to be considered and recommend parametric tests in general (Rasch & Guiard, 2004). Rasch and Guiard (2004) argued in particular that the Wilcoxon signed rank test is rarely is rarely better than a t-test. A Wilcoxon signed rank test was earlier mentioned used to test hypotheses H3a and H4a herein. A comparison with the same variables in a paired samples t-test showed that all confidence intervals comprised zero ($p \geqslant 0.124$). In practical terms, this mean that the same would have been inferred regardless of which statistical test that had been used. In sum, it is unlikely that the effect of using a GLM analysis could have had a severely detrimental effect on the results.

Recommendations for Future Research

There is need for future research. It is recommended that the sample size is increased to further boost statistical power. Further, with reference to the expert knowledge method as one of three ship domain methodologies, it is particularly meaningful that a mixed methods approach is considered for future research. This would allow to probe for additional information that guides navigators when assessing a ship domain. In order to confirm and generalize the results of this thesis, future research also needs to consider an empirical ship domain methodology which would allow to investigate ship domains in a real-world context with actual ship navigation. This needs to be done in the same geographical area as this thesis has been concerned with to capture area specific peculiarities and so that ship domains as desired by navigators can be compared to those actually maintained by navigators.

Conclusion

Research question one was: *“What is the general influence of ship´s length overall on the ship domain shape and size as perceived by Norwegian navigators in restricted waters?”*. Based on the observations, and with some caution due to a small sample size, it may be concluded that Norwegian navigators perceived the ship domain in an increasing manner as a function of ship size measured in length overall. The overall increasement could be approximated by a linear regression where the mean ship domain size is a function of a ship´s length overall. Further, the shape resembled a circle regardless of ship size. Research question two was: “*What is the influence of targeted ship´s relative bearing on a safe passing distance to own ship as perceived by Norwegian navigators in restricted waters?* “. Based on the observations, and with caution due to a small sample size, it may be concluded that the relative bearing of a targeted ship had an impact on a perceived safe passing distance. Specifically, that navigators would like to keep a greater distance to a targeted ship approaching from 045° compared to 135°,180° and 225° relative bearing. However, further analysis revealed no wider systematic influence of an approaching targeted ship´s relative bearing with reference to the expected outcome that the ship domain would be perceived as larger ahead of own ship compared to astern of own ship as well as larger on starboard side of own ship compared to port side of own ship. Thus, given a somewhat ambiguous outcome, it is meaningful that future research is extended and continued to investigate navigators´ perception of ship domain closer. It is also important that future research considers actual ship navigation in the process of ship domain determination so that the results in this thesis can be compared to actual navigational practice.

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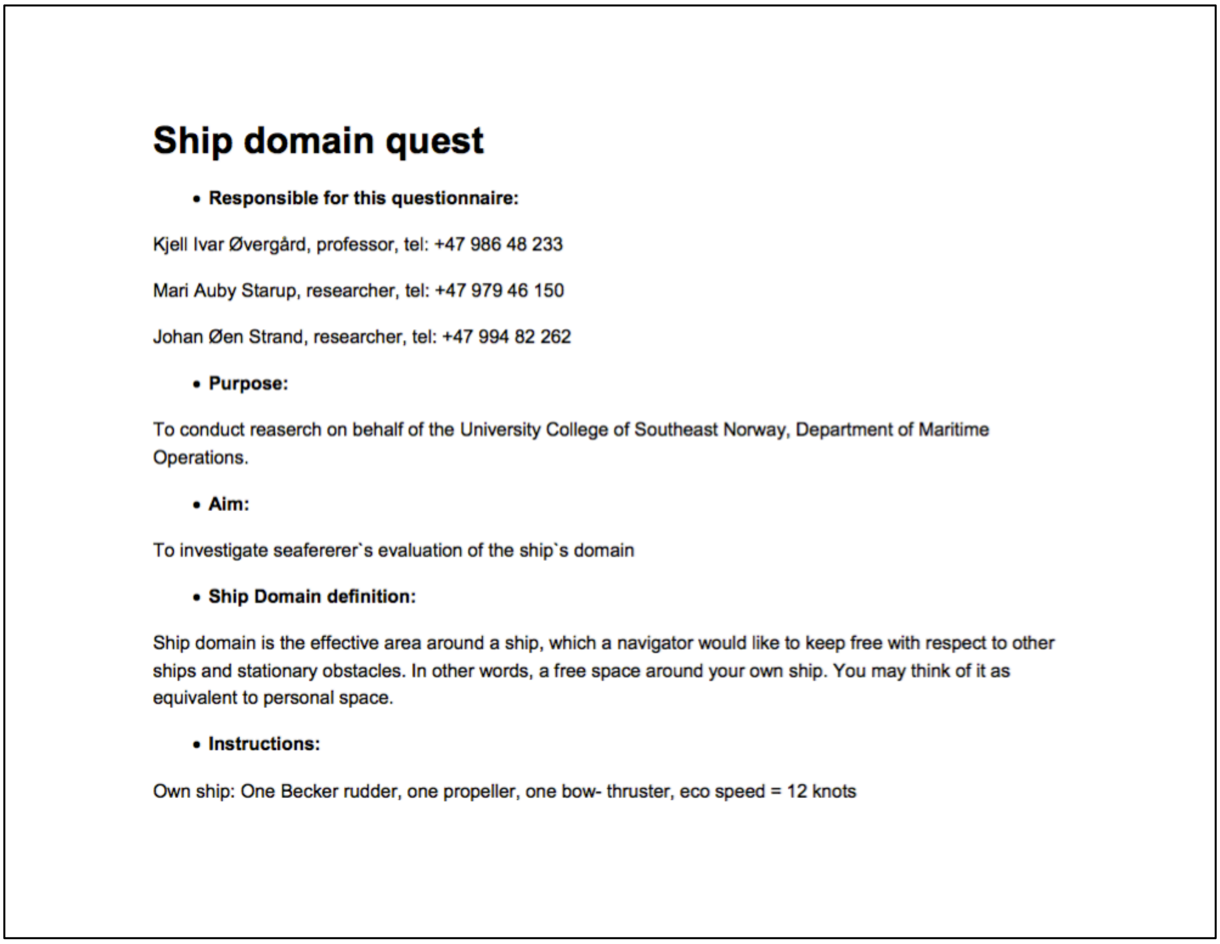
Appendix A: Ship Domain Questionnaire Instrument



Ship domain quest

- **Responsible for this questionnaire:**

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Mari Auby Starup, researcher, tel: +47 979 46 150

Johan Øen Strand, researcher, tel: +47 994 82 262

- **Purpose:**

To conduct reaserch on behalf of the University College of Southeast Norway, Department of Maritime Operations.

- **Aim:**

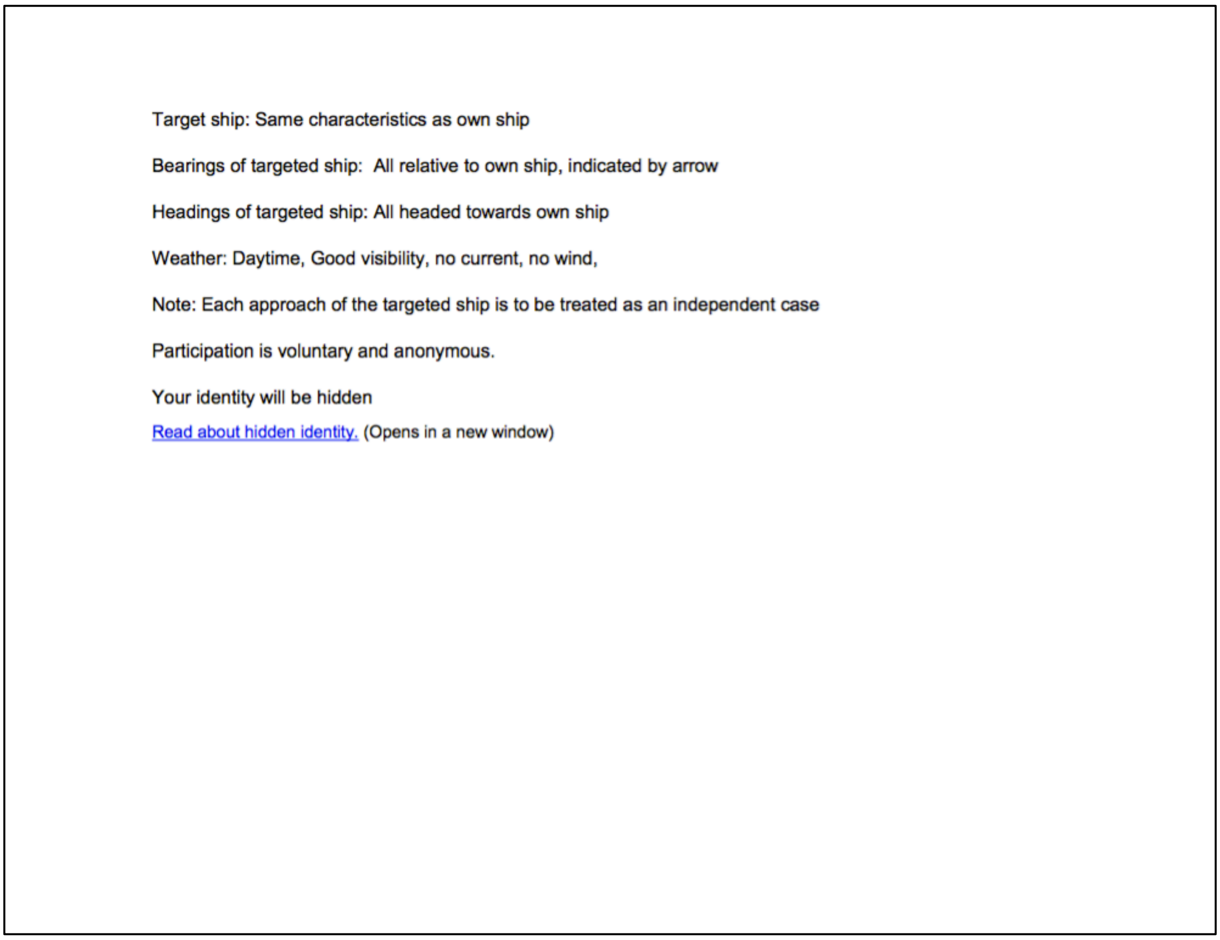
To investigate seafererer`s evaluation of the ship`s domain

- **Ship Domain definition:**

Ship domain is the effective area around a ship, which a navigator would like to keep free with respect to other ships and stationary obstacles. In other words, a free space around your own ship. You may think of it as equivalent to personal space.

- **Instructions:**

Own ship: One Becker rudder, one propeller, one bow- thruster, eco speed = 12 knots



Target ship: Same characteristics as own ship

Bearings of targeted ship: All relative to own ship, indicated by arrow

Headings of targeted ship: All headed towards own ship

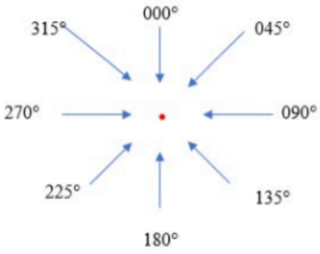
Weather: Daytime, Good visibility, no current, no wind,

Note: Each approach of the targeted ship is to be treated as an independent case

Participation is voluntary and anonymous.

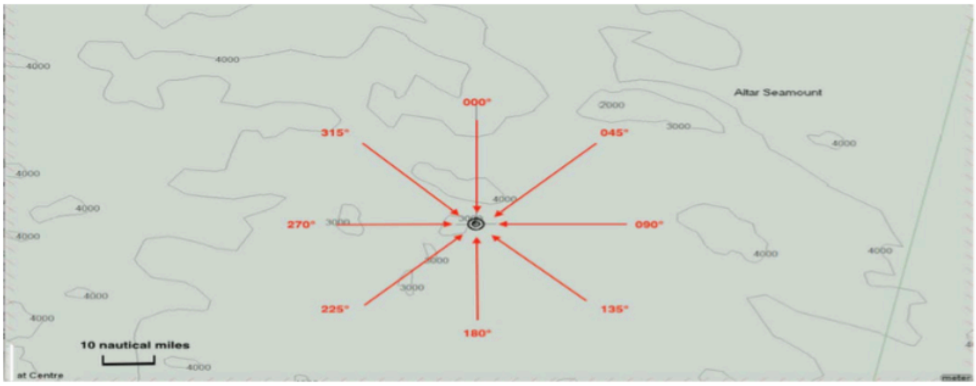
Your identity will be hidden
Read about hidden identity. (Opens in a new window)

Example



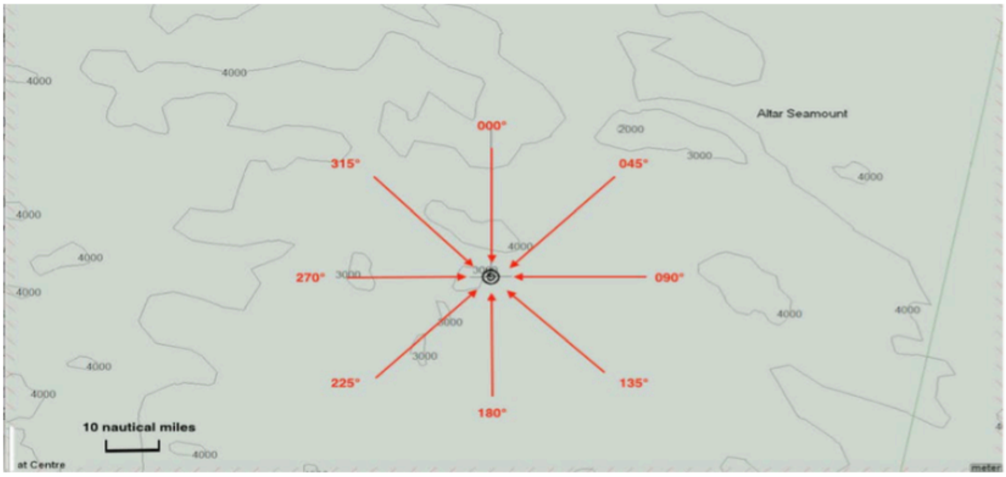
1) Collision avoidance takes place in the marked position and not at a later point in time.

☐ok



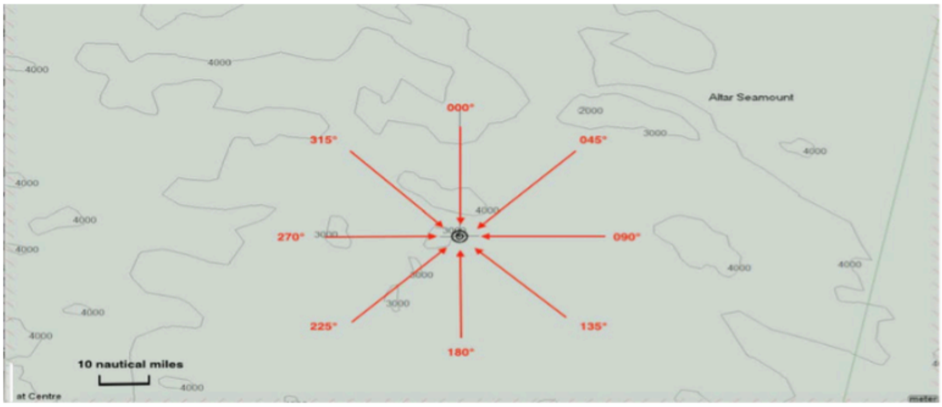
2) OPEN SEA, Own ship data: LENGTH= 50 m, Breadth =11 m, Draught = 3 m, Course = 000° , Speed = 12 knt, Current CPA = 0.0 NM Question: You are Officer of the Watch, what is the closest point of approach (CPA) you would be comfortable letting a targeted ship pass your own ship? Note: Collision avoidance takes place in the marked position and not at a later point in time. Answer with one decimal, in nm.

* 000° * 045° * 090° * 135° * 180° * 225° * 270° * 315°



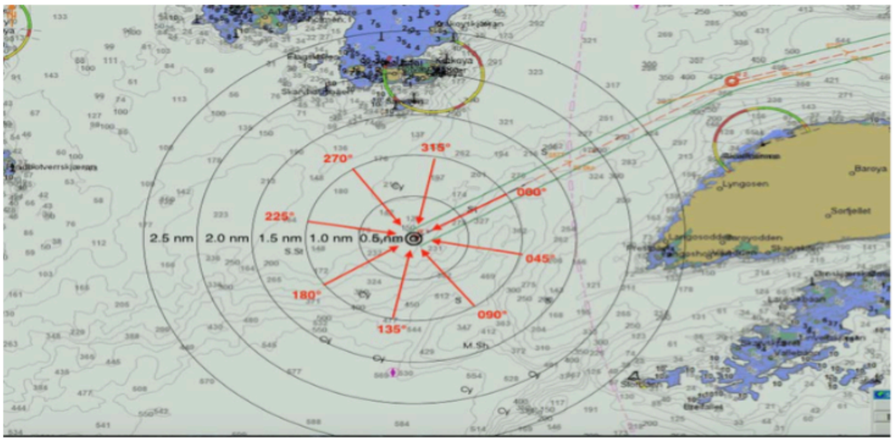
3) * OPEN SEA, Own ship data: LENGTH = 100 m, Breadth =20 m, Draught = 5 m, Course = 000° , Speed = 12 kt, Current CPA = 0.0 NM Question: You are Officer of the Watch, what is the closest point of approach (CPA) you would be comfortable letting a targeted ship pass your own ship? Note: Collision avoidance takes place in the marked position and not at a later point in time. Answer with one decimal, in nm.

* 000°	* 045°	* 090°	* 135°	* 180°	* 225°	* 270°	* 315°



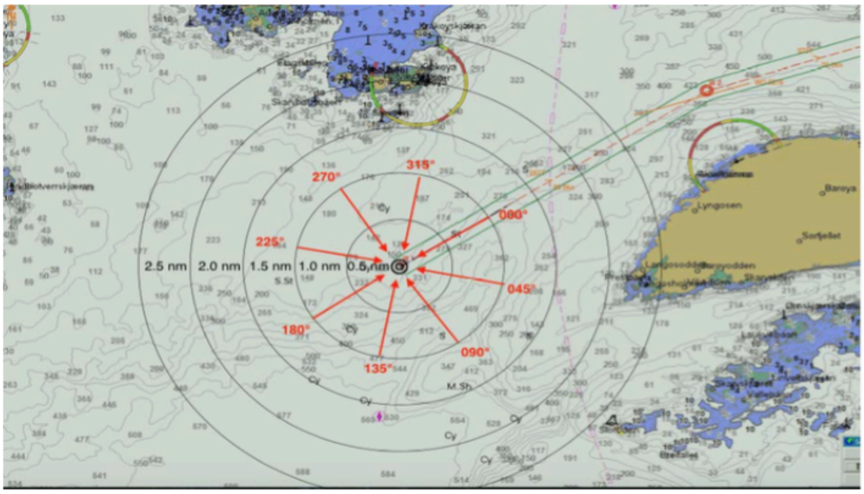
4) OPEN SEA, Own ship data: LENGTH = 200 m, Breadth =32 , Draught = 10 m, Course = 000°, Speed = 12 knt, Current CPA = 0.0 NM Question: You are Officer of the Watch, what is the closest point of approach (CPA) you would be comfortable letting a targeted ship pass your own ship? Note: Collision avoidance takes place in the marked position and not at a later point in time. Answer with one decimal, in nm.

* 000° * 045° * 090° * 135° * 180° * 225° * 270° * 315°



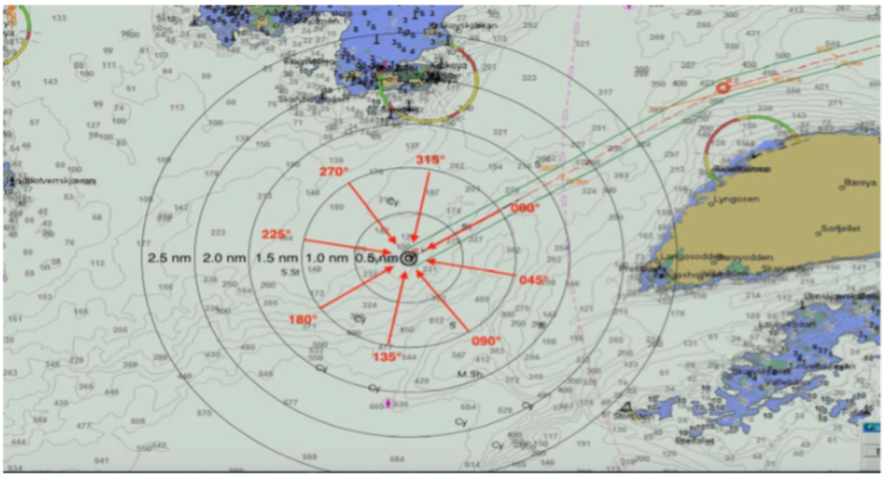
5) RESTRICTED WATERS, Own ship data: LENGTH= 50 m, Breadth =11 m, Draught = 3 m, Course = 057° , Speed = 12 knt, Current CPA = 0.0 NM Question: You are Officer of the Watch, what is the closest point of approach (CPA) you would be comfortable letting a targeted ship pass your own ship? Note: Collision avoidance takes place in the marked position and not at a later point in time. Answer with one decimal, in nm.

* 000° * 045° * 090° * 135° * 180° * 225° * 270° * 315°



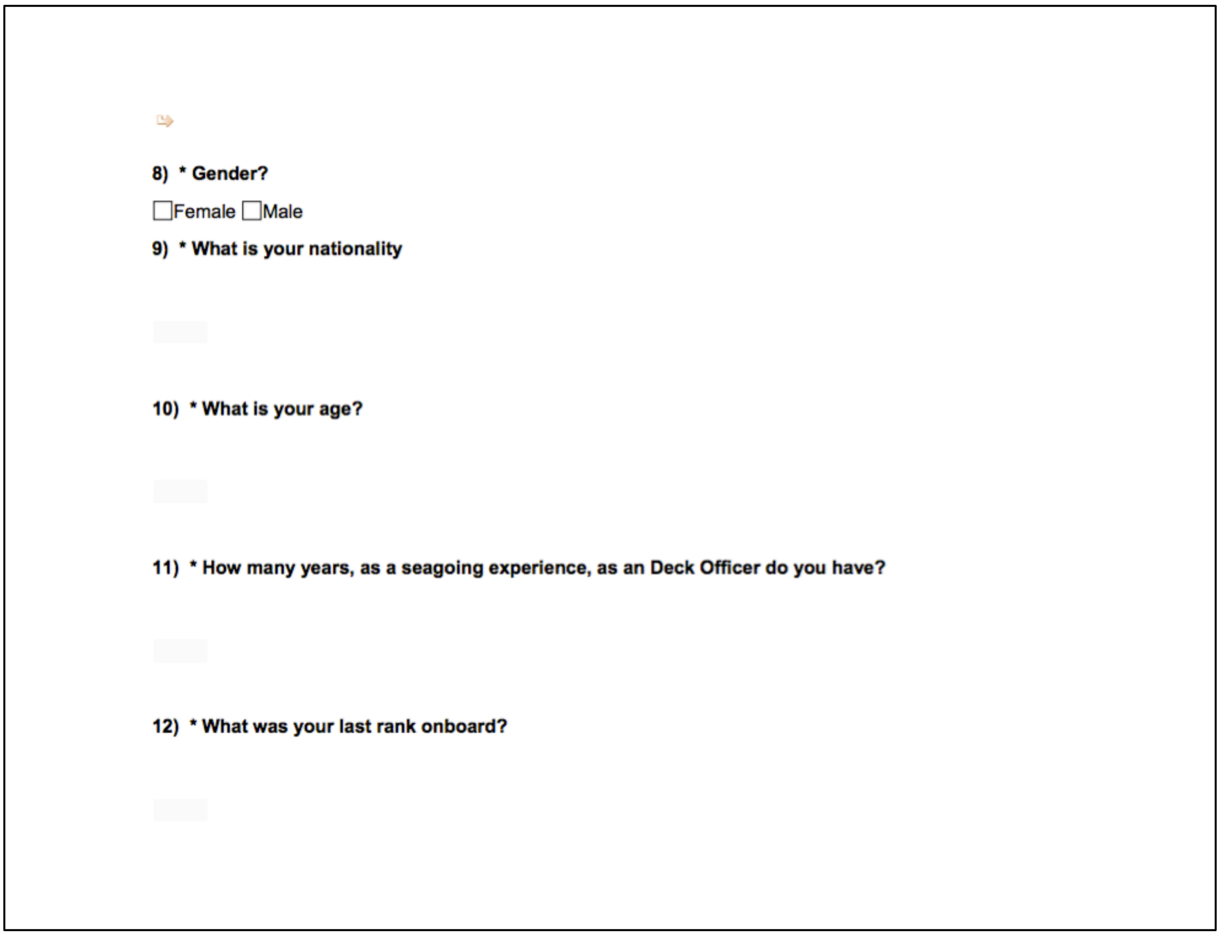
6) Own ship data: LENGTH = 100 m, Breadth =20 m, Draught = 5 m, Course = 057° , Speed = 12 kt, Current CPA = 0.0 NM Question: You are Officer of the Watch, what is the closest point of approach (CPA) you would be comfortable letting a targeted ship pass your own ship? Note: Collision avoidance takes place in the marked position and not at a later point in time. Answer with one decimal, in nm.

* 000°	* 045°	* 090°	* 135°	* 180°	* 225°	* 270°	* 315°



7) RESTRICTED WATERS, Own ship data: LENGTH = 200 m, Breadth =32 , Draught = 10 m, Course = 057°, Speed = 12 knt, Current CPA = 0.0 NM Question: You are Officer of the Watch, what is the closest point of approach (CPA) you would be comfortable letting a targeted ship pass your own ship? Note: Collision avoidance takes place in the marked position and not at a later point in time. Answer with one decimal, in nm.

* 000°	* 045°	* 090°	* 135°	* 180°	* 225°	* 270°	* 315°



8) * Gender?

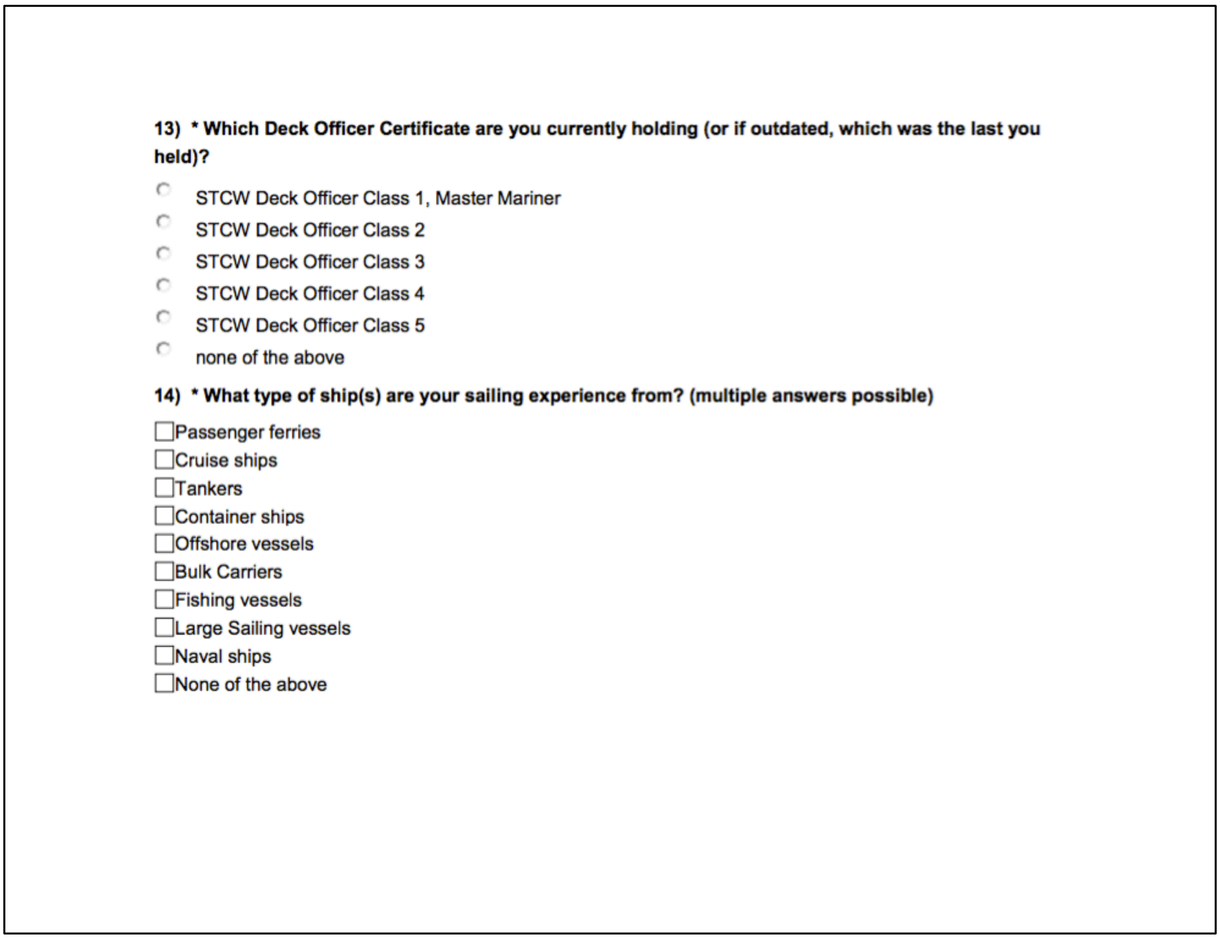
☐Female ☐Male

9) * What is your nationality

10) * What is your age?

11) * How many years, as a seagoing experience, as an Deck Officer do you have?

12) * What was your last rank onboard?



13) * Which Deck Officer Certificate are you currently holding (or if outdated, which was the last you held)?

○ STCW Deck Officer Class 1, Master Mariner
○ STCW Deck Officer Class 2
○ STCW Deck Officer Class 3
○ STCW Deck Officer Class 4
○ STCW Deck Officer Class 5
○ none of the above

14) * What type of ship(s) are your sailing experience from? (multiple answers possible)

☐ Passenger ferries
☐ Cruise ships
☐ Tankers
☐ Container ships
☐ Offshore vessels
☐ Bulk Carriers
☐ Fishing vessels
☐ Large Sailing vessels
☐ Naval ships
☐ None of the above