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GPS spoofing at sea

A potential threat to Swedish passenger ferries

Bachelor thesis in Maritime Sciences

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

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Cover:
A ship navigating in the vicinity of a buoy. Captioned by Nicklas Lindroth

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Abstract

The Global Positioning System (GPS) has been a central part of navigational equipment on ship bridges for decades. Navigational equipment is being integrated more in to a bridge system working in synergy, but the Officer Of the Watch (OOW) may not have the knowledge and training to deal with all the aspects of the rapid advance of technology.

To determine whether GPS spoofing is a potential risk, a structured interview was held with navigational officers on Swedish passenger ferries sailing in the Baltic Sea, Skagerrak and Kattegat. The interview was focused on key factors in the daily practice of the OOW to answer the questions of this study.

Tendencies towards over reliance on navigational equipment was found in the data presented. For example, if a Radio Detection and Ranging (RADAR) echo of a buoy and its position in the electronic chart would differ, the OOW would presume it most likely that the buoy is drifting. That the GPS has an offset or that any other navigational equipment is presenting false information was not regarded as likely by the interviewees.

Having land objects within RADAR range would be a solution to notice a difference between the electronic chart and RADAR echoes of land objects. Answers in the structured interview show that small RADAR scales often are used, especially in bad weather conditions. Therefore, noticing a spoofing attempt in certain scenarios seems slight.

Keywords: GPS, manipulation, spoofing, OOW, Swedish passenger ferries, RADAR scale, chart overlay, ECDIS.

Sammanfattning

GPS har varit en central del av navigationsutrustningen på fartygbryggor i decennier. Navigationsutrustningen integreras mer och mer till ett synkroniserat bryggsystem, men vakthavande styrmän kanske inte har den kunskap och träning som krävs för att hantera alla aspekter av en snabbt utvecklande teknologi.

För att avgöra om GPS-spoofing är en potential risk, hölls strukturerade intervjuer med svenska passagerarfartygs vakthavande styrmän som seglar i Östersjön, Skagerack och Kattegatt. Intervjun var fokuserad på nyckelfaktorer i det dagliga arbetsutförandet av den vakthavande styrmannen för att besvara studiens frågeställning.

Datan visar att det finns tendenser mot en övertro till navigationsutrustning. Till exempel, en bojs RADAR-eko och dess position i det elektroniska sjökortet överensstämmer inte, då skulle den vakthavande styrmannen anta att bojen är på drift. Det anses inte troligt av de intervjuade styrmännen att GPS eller någon annan navigationsutrustning visar felaktig information.

Landmärken inom RADAR-räckvidd skulle kunna vara en lösning för att upptäcka skillnader mellan det elektroniska sjökortet och RADAR-bilden. Svaren i den strukturerade intervjun visar på att små RADAR-skalor används ofta, speciellt om det är dåliga väderförhållanden. Därför verkar det osannolikt att en spoofing-attack upptäcks under vissa förhållanden.

Nyckelord: GPS, manipulation, spoofing, OOW, svenska passagerarfartyg, RADAR-skala, sjökortsöverlappning, ECDIS.

Acknowledgements

The authors would like to thank the interviewees who participated in this study. The authors would also like to thank supervisor Johan Hartler and examiner Jan Skoog at the Mechanics and Maritime Sciences at Chalmers University of Technology.

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Abbreviations

AIS: Automatic Identification System

BOW: Bad weather Open Waters. One of the scenarios in this study.

ECDIS: Electronic Chart Display and Information System

GNSS: Global Navigation Satellite System

GIA: Good weather Inshore Area. One of the scenarios in this study.

GOW: Good weather Open Waters. One of the scenarios in this study.

GPS: Global Positioning System

IMO: International Maritime Organization

INS: Integrated Navigation Systems

ISM: International Safety Management

ITF: International Transport workers Federation

OOW: Officer Of the Watch

RADAR: Radio Detection and Ranging

SPSS: Statistical Package for the Social Sciences

1 Introduction

During the last two centuries this world has seen an enormous increase in technical and scientific advancement. Humanity has taken to the sky, landed people on the moon and developed ways of communicating worldwide in the blink of an eye. The maritime world has also undergone major technical advancement, from millennia of sails and crude compasses to modern machinery and satellite positioning.

There are several Global Navigation Satellite Systems (GNSS), but the most commonly used to determine the latitudinal and longitudinal position is the GPS. Through the GPS we can determine position, course and speed over ground as well as time. This information is then used by several other equipment on the bridge such as radio communication equipment, RADAR and Electronic Chart Display and Information System (ECDIS).

ECDIS is a digital representation of chart data and a simple tool to get an overall picture of the navigation. Position, speed and course are provided to the chart from the GPS in order to establish a real-time view of the vessel movement across the map. False information regarding position and course over ground is an issue when it comes to safe navigation. If the navigator does not perceive and countermand false information, the result can be devastating.

Technology that disrupt or change information received by the GPS is called GPS manipulation and is generally divided in the two categories jamming and spoofing. While jamming simply disrupt and removes GPS signals, spoofing replaces the GPS signals and therefore leads to a calculated position by the GPS device which is false. Spoofing has been documented on a few occasions, both in testing and in action but it might not be well-known to navigational officers at sea.

This study will explore the relation between spoofing and the daily practice of the navigational officer to determine whether GPS spoofing is to be considered a threat to the shipping industry.

1.1 The purpose of this study

The purpose of this research is to determine whether GPS spoofing is a potential risk to merchant shipping and more specifically Swedish passenger ferries in the Baltic Sea area and waters around Skagerrak and Kattegat. Passenger ferries have a tendency to follow a regular route in and around the vicinity of shallow waters on a daily basis, therefore that specific vessel type is well suited for this study.

This study will examine what conclusions can be drawn from how the OOW utilizes the education, knowledge, training and experience when it comes to relying on certain navigational equipment. Depending on how the OOW uses the equipment at hand, this research will further analyse whether there is a risk for a spoofing attack.

1.2 Questions to be researched

- How does the daily practise of the OOW prevent him/her to notice a spoofing attempt?
- In which way can the working routines enable the OOW to notice that GPS spoofing has occurred?

1.3 Delimitations

Passenger ferries is well suited for this study because they tend to follow a regular route in and around the vicinity of shallow waters on a daily basis.

1.3.1 Non-technical point of view

Background information and theory regarding spoofing will be mentioned, but this study will not focus on the technical aspect of GPS spoofing, the various kinds of spoofing or the possible countermeasures on a technical level.

1.3.2 Interaction with navigational equipment by the OOW

How other crew members use the navigational equipment will be ignored and instead focus will be on the OOW. The possibility to notice a difference in GPS position and the actual position of the vessel with eyesight will not be included in this study.

1.3.3 Technical equipment on the bridge

The ECDIS screen is usually close to the navigational seat on the bridge which makes the GPS position presented in the ECDIS the most used and relevant for this study. GPS position shown in other navigational equipment than the ECDIS is ignored in this study

2 Background and theory

Position fixing is crucial when safely navigating at sea and according to International Maritime Organization (IMO) “Fixes shall be taken at frequent intervals, and shall be carried out by more than one method whenever circumstances allow” (IMO, 2010). This chapter contains the background and theory of positioning regarding technical aspects, spoofing, human interaction with navigational equipment and situational awareness. Traffic density in the focus area will be reviewed to demonstrate the extent of potential spoofing targets.

2.1 The technical aspect

Knowledge of the technical aspect is important for understanding how GPS manipulation can affect the navigation by the OOW. Subsequently a brief description of Integrated navigation systems (INS), GNSS, GPS, jamming and spoofing follows.

2.1.1 Integrated Navigation Systems

When integrating GNSS data with INS the potential false information will not be limited to the specific GNSS device. The integration will spread data between the various navigational equipment on the bridge and therefore affect all systems using INS. While much information is automatically cross-checked by the INS to find anomalies, the OOW is still required to do manual checks for position fixing (Försvarsmakten, 1999).

2.1.2 Short description GNSS and GPS

The major GNSS systems function in a very similar way, using the same principle when it comes to transmitting satellite signals (Hoffman-Wellenhof, Lichtenegger, & Wasle, 2008). GPS is the most commonly used GNSS system worldwide, it utilizes a number of satellites which constantly transmit signals from space. Since these satellites have known positions in space it is possible for a GPS receiver to measure the difference in time between transmitted and received signals, and therefore calculate the distance to each satellite. With three satellites it is possible to determine a general position on earth, but it requires a fourth satellite to establish the clock error of the receiver and subsequently establish a more precise longitude and latitude position on the globe (Humphreys, Ledvina, Psiasaki, O'Hanlon, & Kintner Jr, 2008).

2.1.3 Description of GPS jamming

There are two ways of intentionally manipulating satellite signals before they enter the GPS device. Disrupting the signals before they can be received is called jamming, and functions in such a way that radio frequency waveforms are produced to act like interference. This then heavily influence or completely inhibit the receiving capabilities of the GPS, resulting in a loss of position data (U.S D.H.S, 2017). Since the GPS device notice that the position data has been lost, alarms will be triggered and the OOW will become aware of the jamming attack. For this reason, jamming does not constitute the greatest threat when it comes to GPS manipulation (Humphreys, Ledvina, Psiasaki, O'Hanlon, & Kintner Jr, 2008).

2.1.4 Description of GPS spoofing

GPS spoofing in comparison to jamming, focuses on deceiving the receiver with fake signals sent from a source other than the satellite that is supposed to be the transmitter (DLR, 2016). There are two categories of spoofing mentioned by U.S Department of Homeland Security (2017), which are called measurement spoofing and data spoofing. Measurement spoofing is as described above a method of sending fake signals to manipulate the GPS receiver's calculation of distance and time, resulting in wrong position information. Data spoofing on the other hand focuses on altering or adding to the digital data of the device and therefore manipulates the calculations of the GPS receiver, resulting in incorrect positioning and timing. For example, the GPS receiver displays false information regarding position (Warner & Johnston, 2003) leading the OOW, or the autopilot, to believe that the vessel is off its intended track (Humphreys et al. 2008). Humphreys et. al. showed in their experimental testing onboard a yacht that this could lead the OOW to alter the course of the vessel in order to return to what was perceived as the designated route (UTA, 2013).

2.1.5 Comparison of jamming and spoofing

Military GPS signals are encrypted and secure, which does not apply to the civilian GPS signals who subsequently are at a greater risk for jamming and spoofing. While jamming disrupts satellite signals effectively, the GPS receiver is as mentioned in section 2.1.3 fully aware of the disruption. Spoofing however trick the GPS receiver with fake signals leading the receiver to display false position data unknowingly (Humphreys et al. 2008).

2.1.6 Awareness of the spoofing threat

In 2015 the International Transport Workers Federation (ITF) predicted that spoofing will become one of the main issues for the IMO to handle between 2018 and 2023. More advanced technology can increase the risk of cyberattacks such as spoofing, and raises concern whether the maritime industry is equipped to deal with technological threats of this character (ITF, 2015).

The first actual spoofing attack is suspected to have occurred in June 2017. Approximately twenty ships in the Black Sea found that their GPS positioned them all at the same position, on an air base approximately 32 kilometres inland (Hambling, 2017).

2.2 Situational awareness and human error

Connecting the aspects of situational awareness and human error with technology lead to an understanding of how the OOW can affect the outcome when a spoofing attack occurs. This part of the chapter explains this correlation with examples of case studies and contemporary research.

2.2.1 Statistics from the ISM-code regarding human error

In 1998 IMO implemented the International Safety Management (ISM) code with the purpose to "provide an international standard for the safe management and operation of ships and for pollution prevention" (IMO, 2018).

Kokotos & Linardatos (2011) established that the ISM code had an impact in decreasing Greek accidents caused by human error. Between 1995 and 1998, 57.1 % of accidents were labelled as human error. After the implementation of the ISM code between the years of 1998 and 2006, that percentage decreased to 29,0 %.

2.2.2 Human error and technology – the case of The Royal Majesty

In 1995 *The Royal Majesty* grounded because the GPS signal was lost and the ECDIS entered dead reckoning mode. The crew trusted the position shown in ECDIS and did not perceive the error in position, therefore the accident was written off as human error (NTSB, 1997). After the implementation of the ISM code Lützhöft and Dekker (2002) analysed the accident, and found that it could not be explained by single-point catastrophic failure. They argue that technology on the bridge to an extent mislead the navigators, and therefore should not be considered as purely a human error.

2.2.3 Situational awareness in regard to technology

Navigating with manual skills are still taught at nautical institutions today, but using those skills when working on a highly technological bridge can prove difficult. Grech, Horberry & Smith (2002) discuss situational awareness and how it decreases when the amount of technology increases. The lack of situational awareness can be devastating in critical situations and lead to accidents because of over reliance on system equipment.

The ship's position is determined by the navigational equipment, which then communicates that information through the interface to the OOW. (Nielsen, 2016). Subsequently the OOW gradually lose confidence in his or her ability to navigate manually and according to Grech et. al. (2002) this "obviously defeats the purpose of automation in itself".

2.2.4 Lack of situational awareness – the case of City of Rotterdam

In contrast to over reliance on system equipment, over reliance on manual skills can also cause accidents. In the case of *City of Rotterdam,* the pilot was under the impression that he was heading towards the southern part of the channel. The vessel was in fact heading towards the northern part, resulting in a collision with *Primula Seaways*. The pilot did not use any technological means to navigate, instead he relied heavily on visual navigation and personal experience. It should be stated that the unconventional rounded bridge on *City of Rotterdam* does not favour visual navigation, because of the "relative motion illusion" phenomena resulting in a lack of situational awareness (MAIB, 2017). A picture of *City of Rotterdam* (VesselFinder, 2016) can be found in appendix 3.

2.3 Traffic in the target area

The statistical Automatic Identification System (AIS) data in the area of interest for this study is presented below to highlight the extent of potential spoofing targets.

Many ships sail in the Baltic Sea area every year. In 2015 a total of 21 616 unique AIS targets were recorded, of these 577 were passenger ferries (HELCOM, 2016). Statistics show that 76 786 port calls were made in ports along the Swedish coast during 2016 (Trafikanalys, 2017). Ships passing Kattegat in 2015 was recorded to be 47 028, and 2 611 of these were passenger vessels. For Skagerrak the same year 61 286 ships passed and of those 2 562 were passenger vessels (Sjöfartsverket, 2017).

Most traffic follows designated routes and traffic separation schemes which leads to heavy traffic situations as shown in Figure 2-1, which cover the target area.

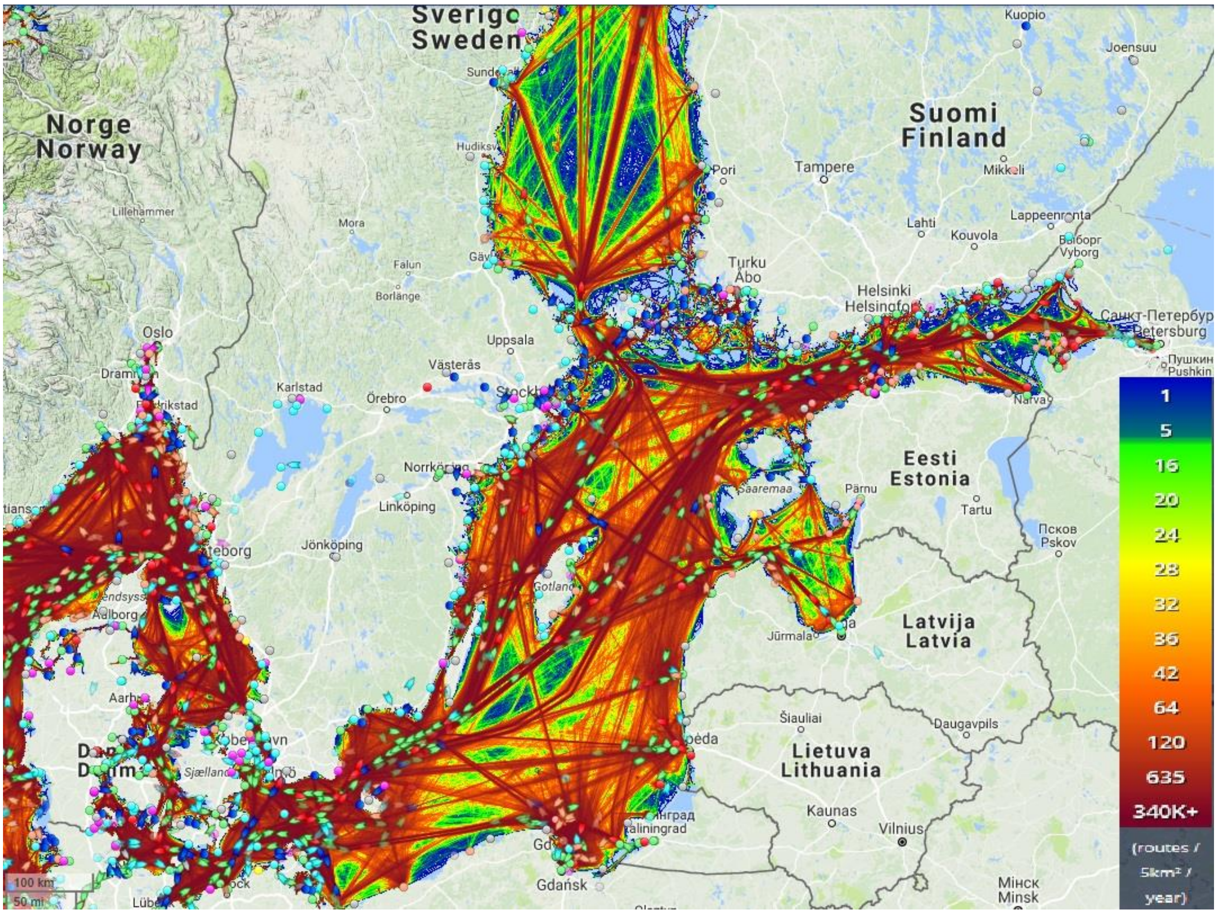

Figure 2-1. Traffic density

Figure 2-1 shows the traffic density based on AIS tracks for the year of 2017 (Marine Traffic, 2018).

3 Method

In this chapter the choice of method is explained and a detailed description of the interview questions are listed as well as the parameters of the interview itself.

3.1 Data collection through a structured interview

In order to collect valid data that could be used to answer the questions stated in this study, a structured interview (Denscombe, 2014) was conducted through telephone with OOW at Swedish passenger vessels sailing in proximity to Swedish coastal waters. The interviewees were chosen by having personally met the authors of this study during the authors maritime internships or the interviewees had been referred to the authors through various contacts within the maritime industry. None of the interviewees knew beforehand or during the structured interview that the questions were connected in any way to GPS spoofing. The interviewees were instead under the impression that this study was to simply analyse how Swedish officers were using their navigational equipment, how reliable they found each equipment and how reliable the information provided by this equipment were.

3.2 The questions asked during the structured interview

The answers during the structured interview were limited to a Likert scale with options from 1 to 7, where 1 symbolised very little or very low and where 7 symbolised very much or very high (Likert scale, 2018). The questions asked during the interview were:

3.2.1 RADAR scale

- How often do you use the 6 mile scale on your RADAR?
- How often do you use a smaller scale than 6 miles on your RADAR?
- How often do you use a larger scale than 6 miles on your RADAR?

3.2.2 Chart overlay

- How often do you use chart overlay in your RADAR?

3.2.3 Stabilization mode

- How often do you use sea-stabilization in your RADAR?
- How often do you use ground-stabilization in your RADAR?

3.2.4 Autopilot mode

- How often do you use heading mode on your autopilot?
- How often do you use track mode on your autopilot?
- How often do you use course mode on your autopilot?

3.2.5 Trust in navigational equipment

- How much do you trust the information given by the RADAR?
- How much do you trust the GPS position?
- How much do you trust the information given by the electronic chart?

3.2.6 Electronic chart and RADAR difference

- RADAR echo of a buoy and its position according to the chart differs, how likely is it that the buoy is drifting?
- RADAR echo of a buoy and its position according to the chart differs, how likely is it that the electronic chart is incorrect?
- RADAR echo of a buoy and its position according to the chart differs, how likely is it that the GPS position has an offset?
- RADAR echo of a buoy and its position according to the chart differs, how likely is it that a RADAR error has occurred?

3.3 Three different scenarios

The interview was divided in three parts where one scenario was described to the interviewees, then all questions above were asked. Once completed with the first scenario, the second scenario was described and all the questions were asked again and then moving on with explaining and asking questions for the third scenario. The scenarios were as follows:

- Scenario 1 was with good weather, good visibility, open waters, shallow areas in the vicinity and no landmarks nearby. Written in this paper as Good weather Open Waters (GOW).
- Scenario 2 was with heavy weather, no visibility, open waters, shallow areas in the vicinity and no landmarks nearby. Written in this paper as Bad weather Open Waters (BOW).
- Scenario 3 was in an inshore area with good weather, good visibility. Written in this paper as Good weather Inshore Area (GIA).

Once all questions had been asked one time for each scenario the interviewees were asked if they wanted to change their answers for any questions or if they were satisfied as it were. A few subjects wanted to overlook the answers with only one person noticing a mistake he made, leading to a small correction.

3.4 Data analysis

The answers were compiled and run through the statistical computer program Statistical Package for the Social Sciences (SPSS). Various tests were performed in SPSS to add statistical reliability and to analyse the high and low mean values of the data.

3.4.1 High and low mean values

When analysing the data and focusing on mean values a 95 % confidence interval was chosen. To determine answer differences, the mean upper limit value of one question was compared to the mean lower limit value of another question or the same question in a different scenario. If the mean upper limit value overlapped with the lower limit value, no noticeable difference in answers could be established.

3.4.2 Statistical reliability

Pearson’s chi square test was applied to the data to determine whether the answers given arose by chance or not (Plackett, 1983). Chi square distribution of less than 5 % is viable as statistically certain according to Diener-West (2008). To determine if there was any statistically significant difference in the data the Kruskal- Wallis H test was applied (Upton & Cook, 2014).

3.5 Ethics and use of personal information

Personal information concerning date of birth, year of graduation, years at sea, employer and current rank onboard were collected during the interviews. No discernible pattern could be established between the answers in the interview and the personal information, therefore the personal information was not included in this paper.

4 Result

In the first part of the chapter the results are listed in the form of column charts and in order of appearance in the interview. Only a selection based on interest of the results are listed here, the rest can be found in the appendix. In the later part of the chapter applicable data results are statistically compared in relation to relevance for the study.

4.1 Introduction and explanation of the result

The results are presented through column charts with the answer rates for the different scenarios of each question. On the vertical axis the number of answers is shown and the horizontal axis the Likert scale answer value, one through seven is shown. The scenarios will be presented as GOW, BOW and GIA as stated in chapter 3.3.

4.1.1 How often do you use the 6 mile scale on your RADAR?

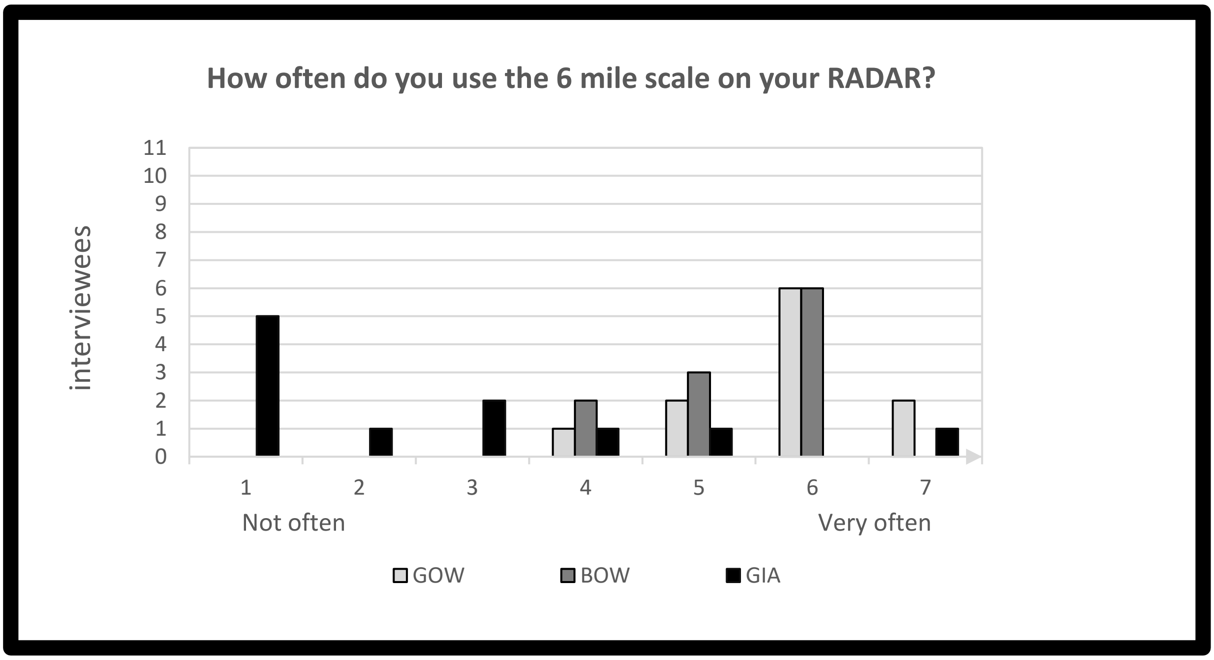

Figure 4-1. 6 mile scale on your RADAR

As seen in Figure 4-1, the 6 mile scale is often used in open waters, both in good and bad weather. In inshore areas the interviewees rarely use the 6 mile scale on their RADAR.

4.1.2 How often do you use a smaller scale than 6 miles on your RADAR?

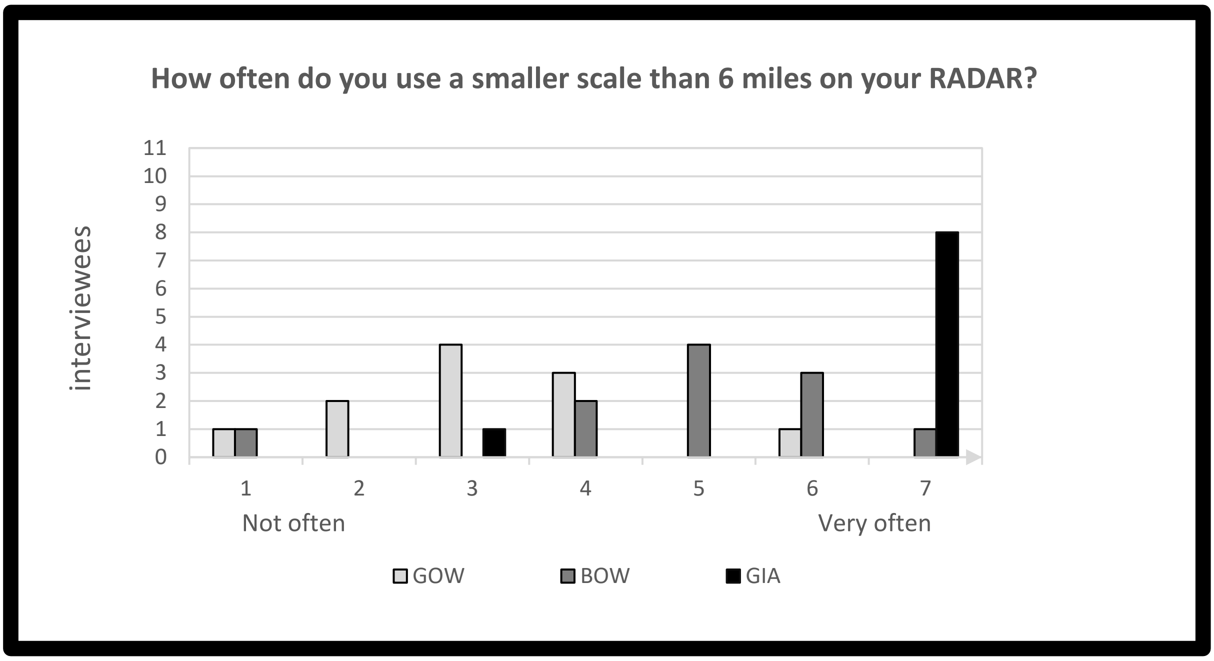

Figure 4-2. Smaller scale than 6 miles on your RADAR

As seen in Figure 4-2, in inshore areas a smaller scale than 6 miles is very often used on the RADAR. In open waters it is more often used in bad weather than it is in good weather.

4.1.3 How often do you use a larger scale than 6 miles on your RADAR?

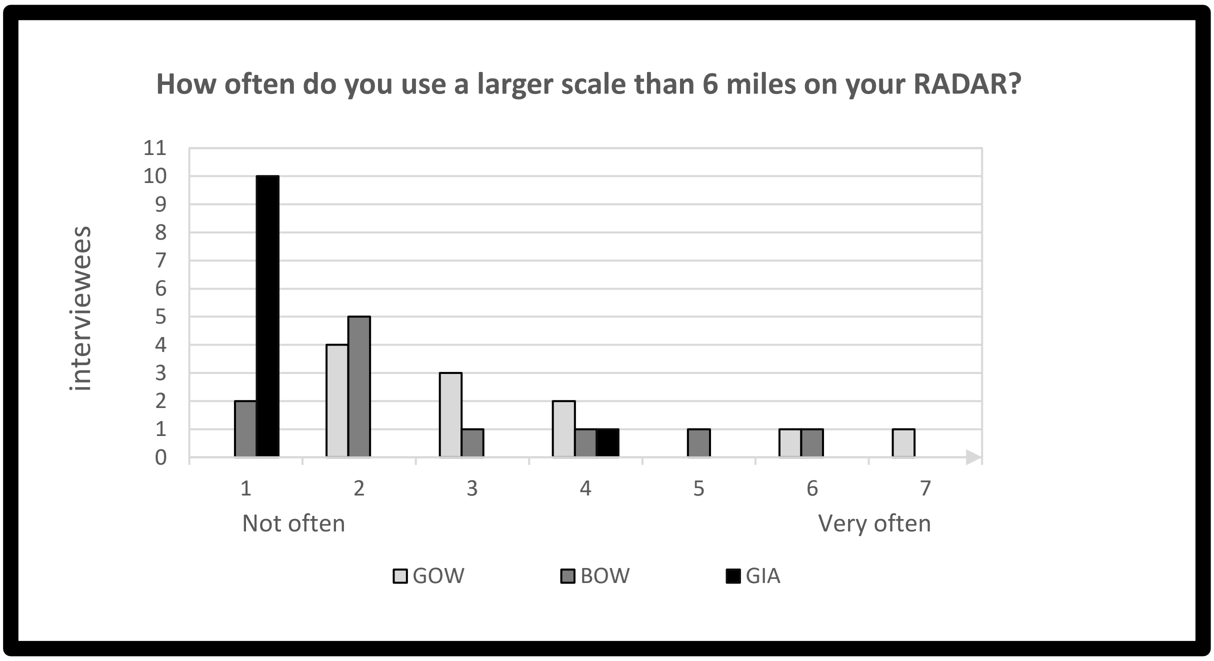

Figure 4-3. Larger scale than 6 miles on your RADAR

As seen in Figure 4-3, using a larger scale than 6 miles on the RADAR is hardly ever done in inshore areas. In open waters a larger scale is sometimes used, both in good and bad weather.

4.1.4 How often do you use chart overlay in your RADAR?

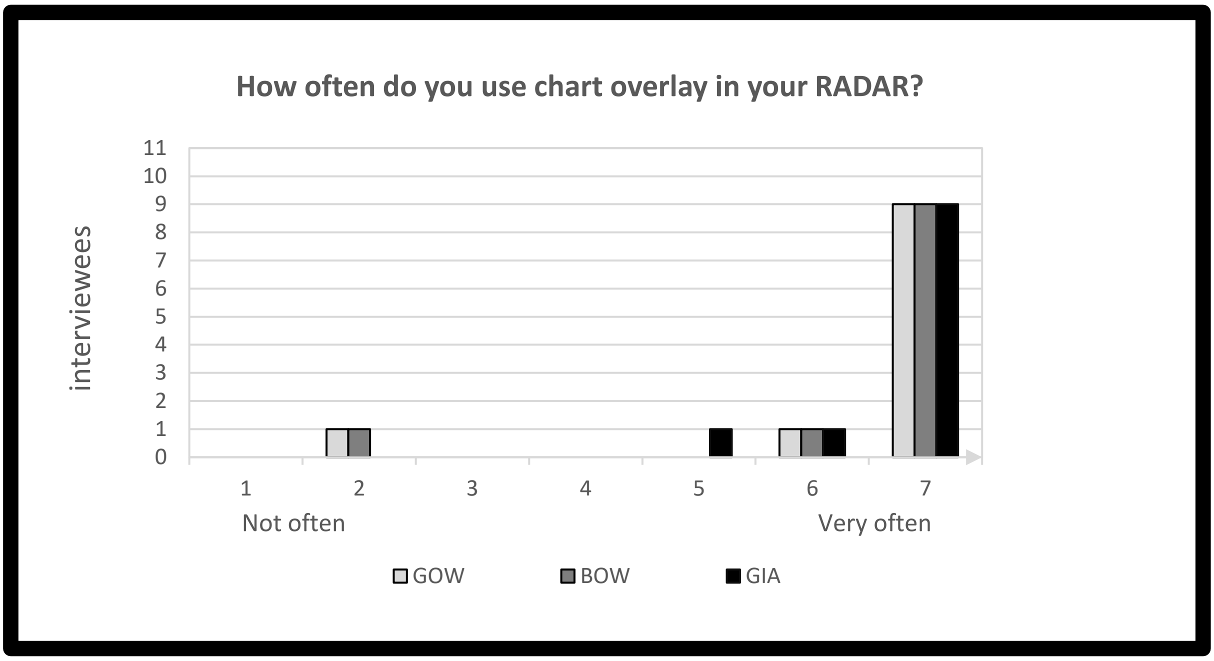

Figure 4-4. Chart overlay in your RADAR

As seen in Figure 4-4, chart overlay in the RADAR is very often used. There is barely any difference between area of navigation or weather conditions.

4.1.5 How often do you use sea-stabilization in your RADAR?

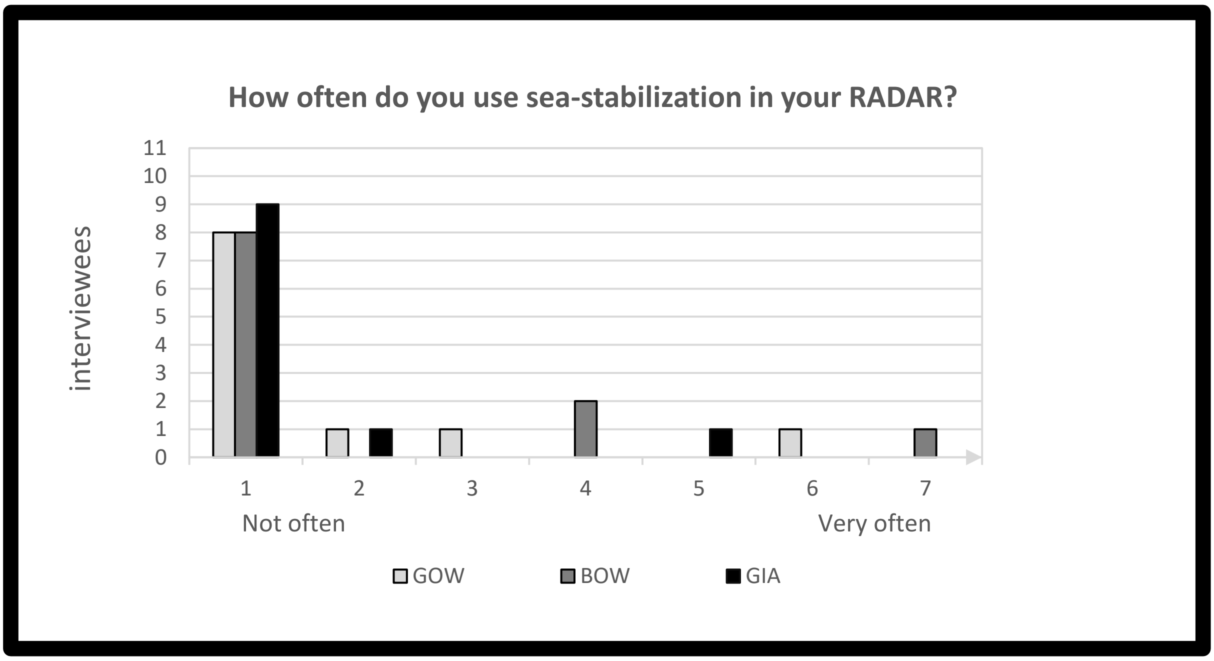

Figure 4-5. Sea-stabilization in your RADAR

As seen in Figure 4-5, sea-stabilization in the RADAR is rarely used. There is barely any difference between area of navigation or weather conditions.

4.1.6 How often do you use ground-stabilization in your RADAR?

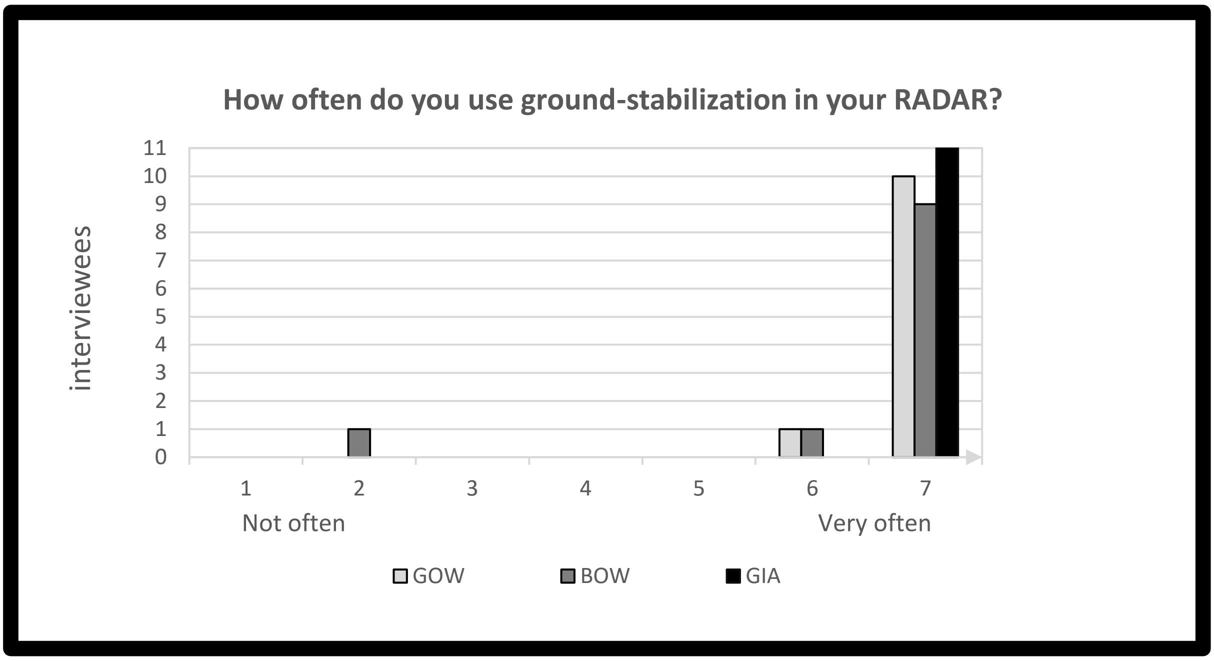

Figure 4-6. Ground-stabilization in your RADAR

As seen in Figure 4-6, ground-stabilization in the RADAR is very often used. There is no apparent difference between area of navigation or weather conditions.

4.1.7 How often do you use heading mode on your autopilot?

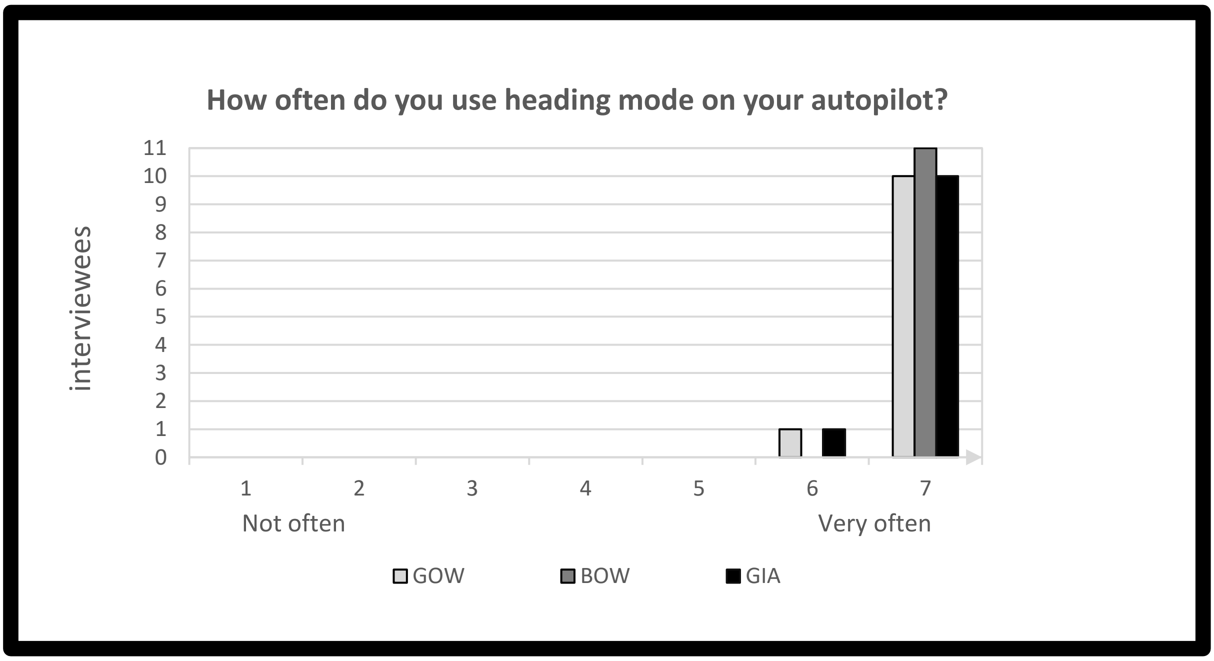

Figure 4-7. Heading mode on your autopilot

As seen in Figure 4-7, heading mode on the autopilot is very often used. There is no apparent difference between area of navigation or weather conditions.

4.1.8 How often do you use track mode on your autopilot?

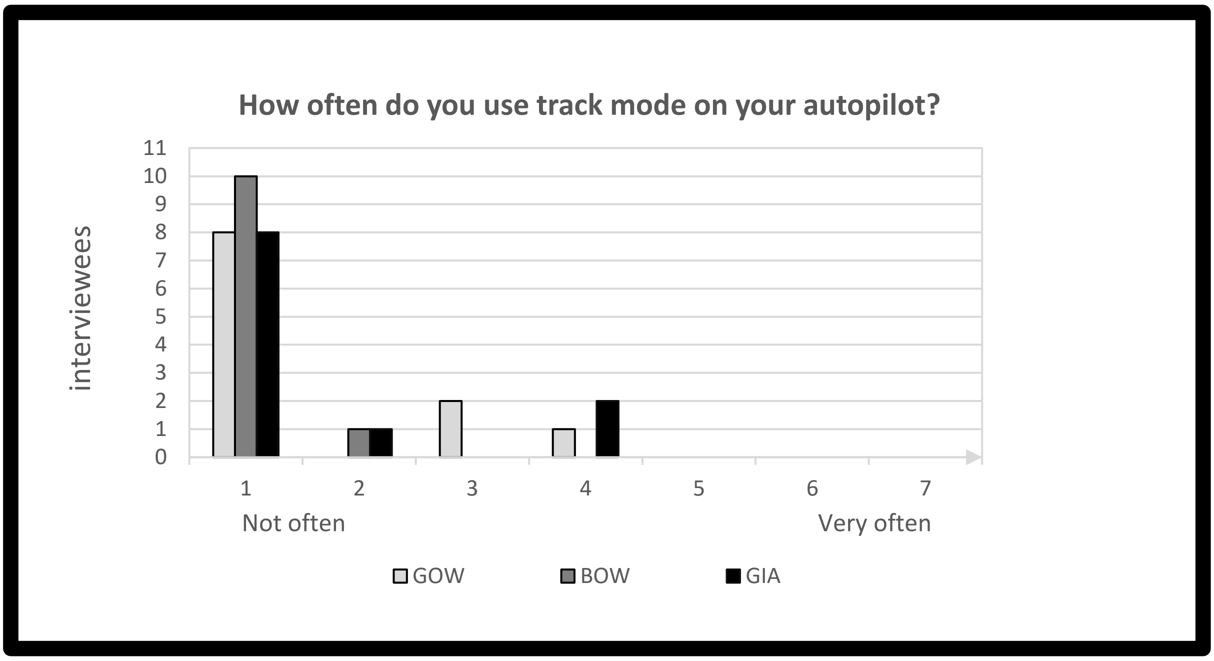

Figure 4-8. Track mode on your autopilot

As seen in Figure 4-8, track mode on the autopilot is rarely used. There is barely any difference between area of navigation or weather conditions.

4.1.9 How often do you use course mode on your autopilot?

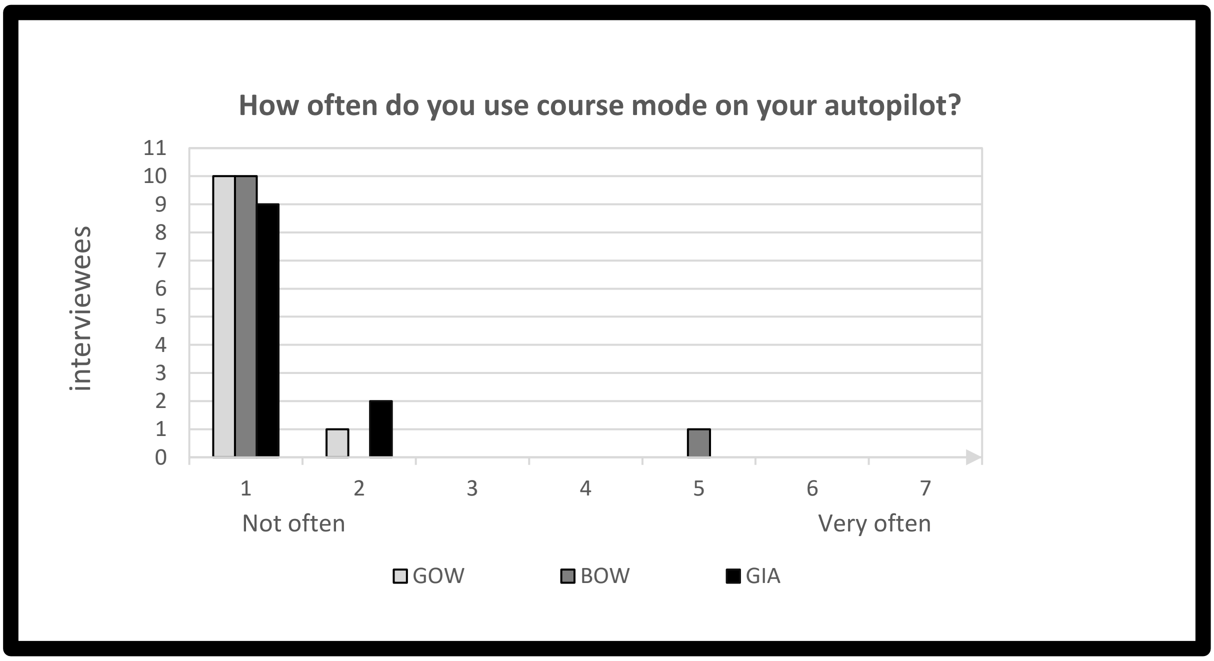

Figure 4-9. Course mode on your autopilot

As seen in Figure 4-9, course mode on the autopilot is not often used. There is barely any difference between area of navigation or weather conditions.

4.1.10 How much do you trust the information given by the RADAR?

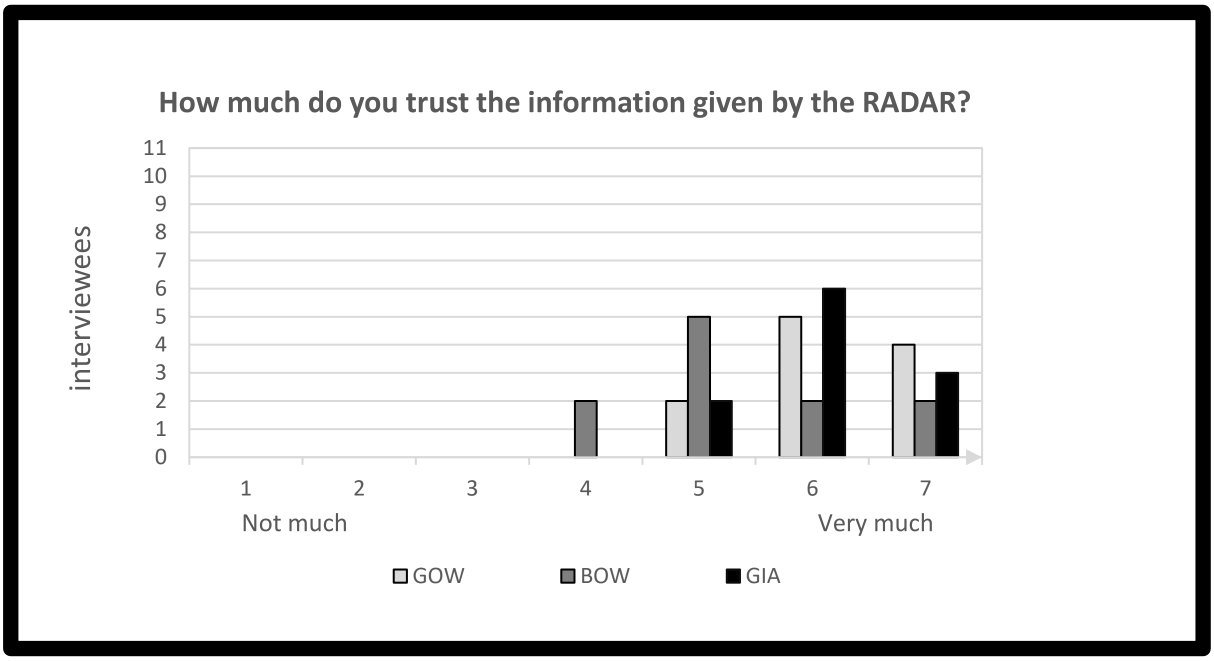

Figure 4-10. Trust the information given by the RADAR

As seen in Figure 4-10, the interviewees trust the RADAR information very much in good weather, but slightly less in bad weather. There is no apparent difference between open waters and inshore areas.

4.1.11 How much do you trust the GPS position?

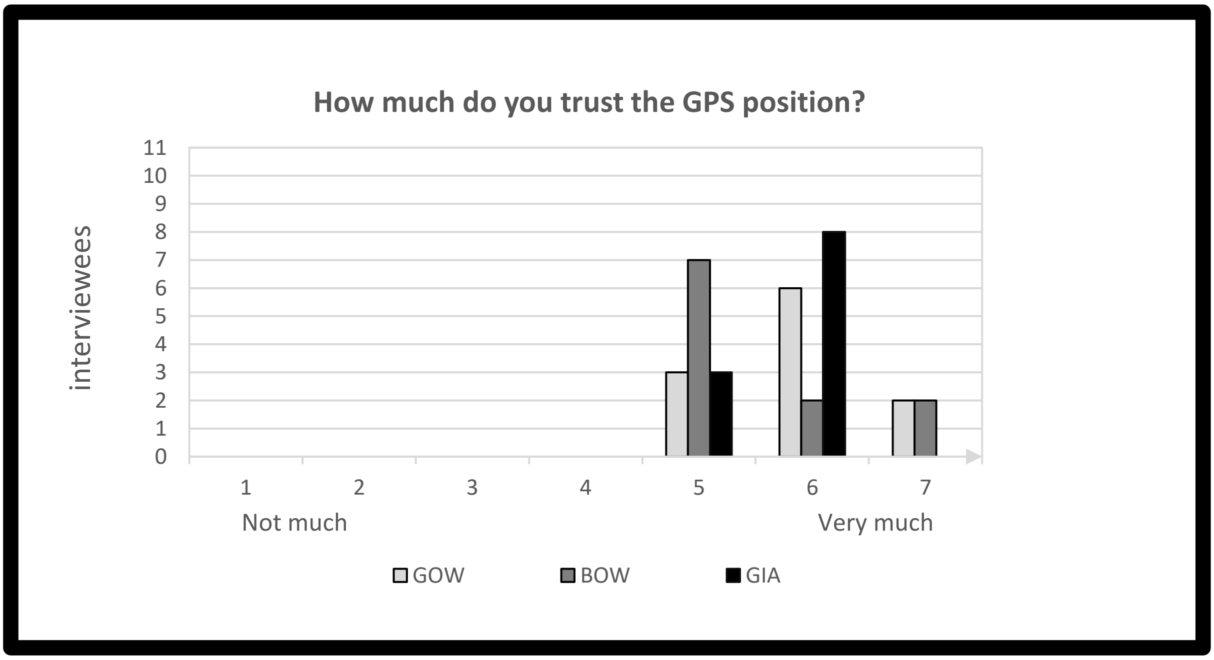

Figure 4-11. Trust the GPS position

As seen in Figure 4-11, the GPS position is trusted very much in good weather for both open waters and inshore areas. In bad weather the trust is slightly lower than in good weather, but still considered high.

4.1.12 How much do you trust the information given by the electronic chart?

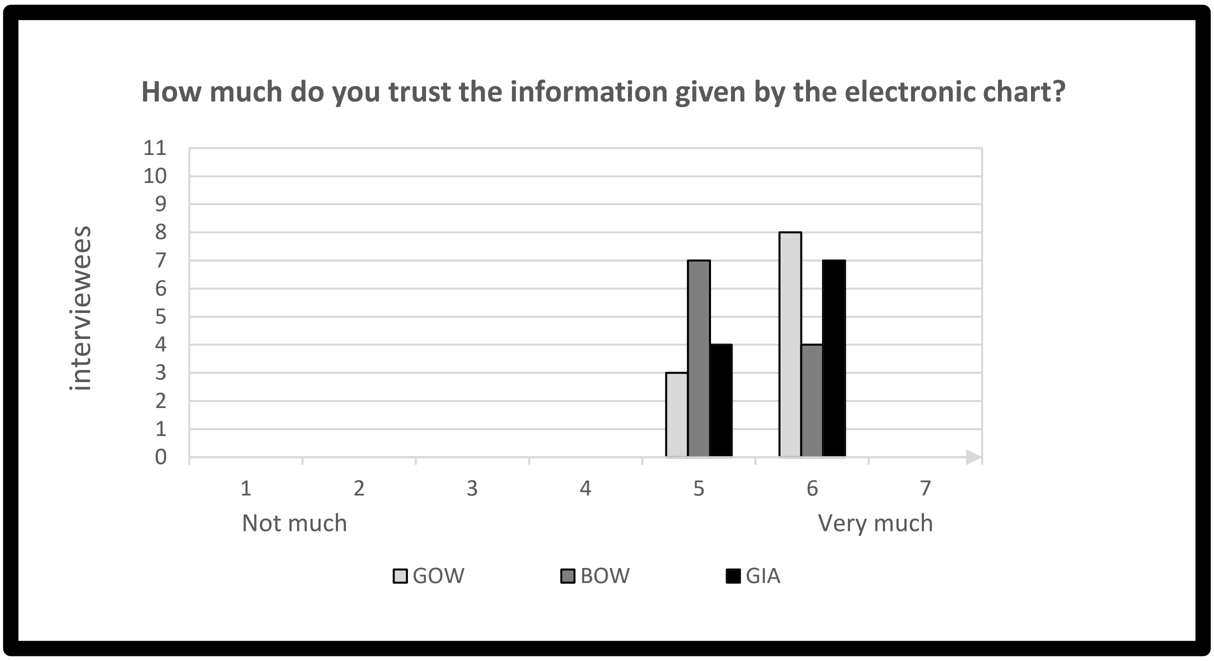

Figure 4-12. Trust the information given by the electronic chart

As seen in Figure 4-12, the information provided by the electronic chart is trusted in open waters and inshore areas. There is a slightly lower trust to the electronic chart in bad weather conditions, but still considered high.

4.1.13 RADAR echo of a buoy and its position according to the chart differs, how likely is it that the buoy is drifting?

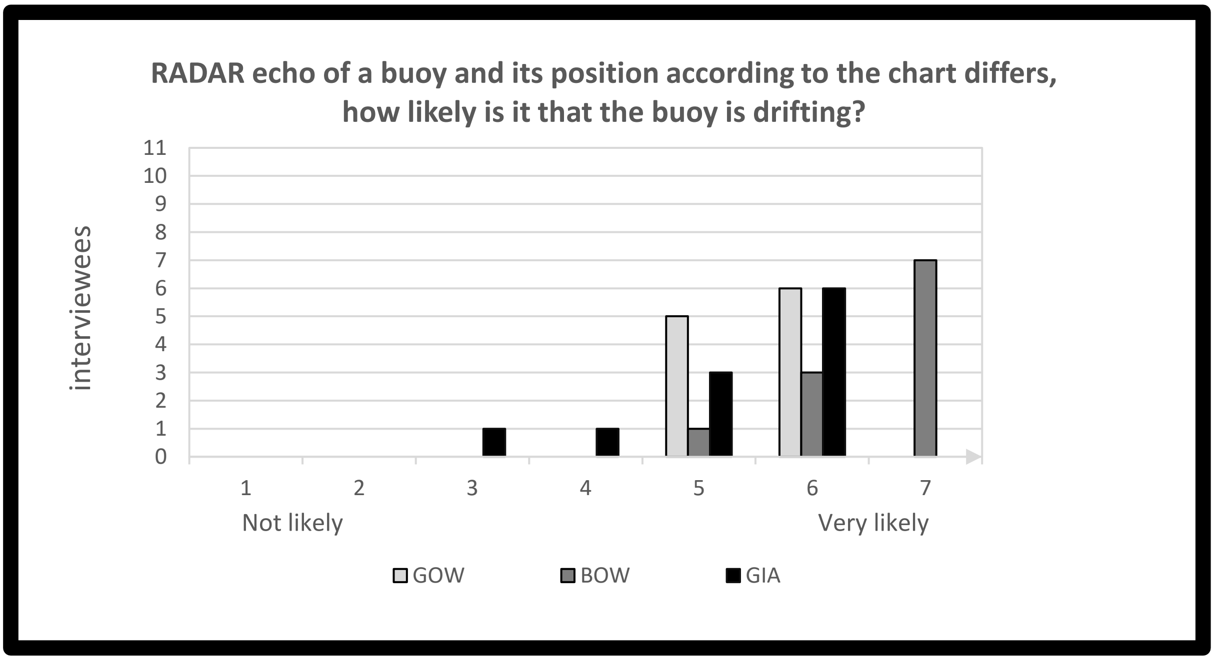

Figure 4-13. Likely that the buoy is drifting

As seen in Figure 4-13, it is considered likely that the buoy is drifting in good weather and very likely in bad weather. There is barely any difference between open waters and inshore areas.

4.1.14 RADAR echo of a buoy and its position according to the chart differs, how likely is it that the electronic chart is incorrect?

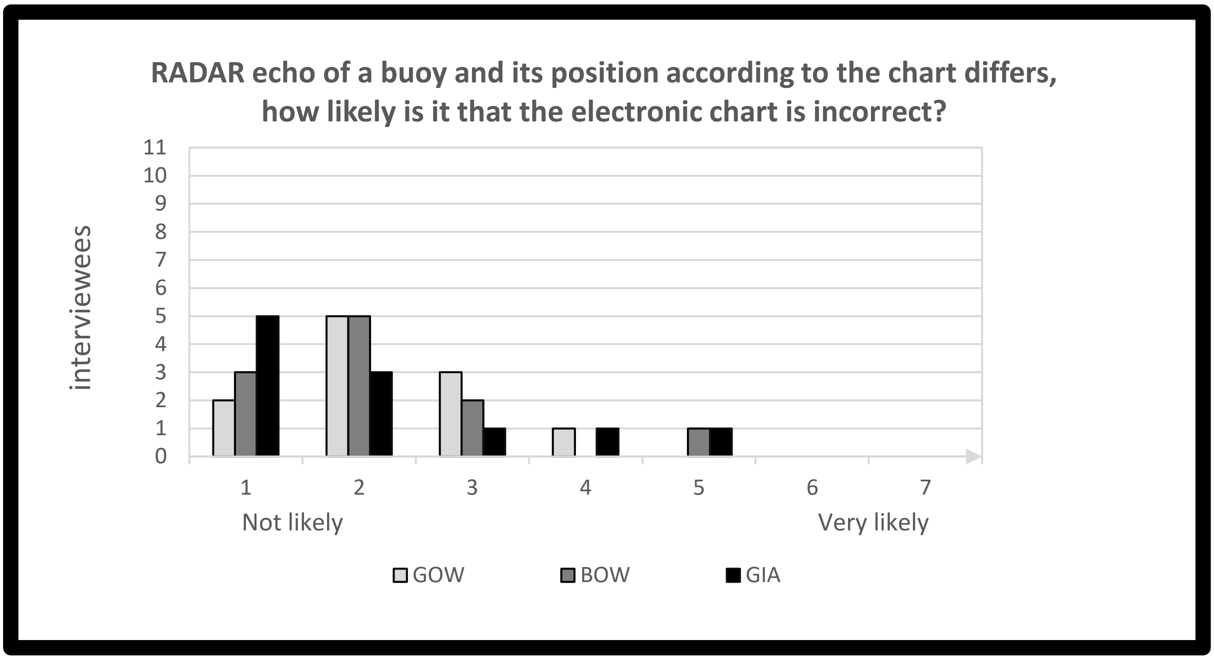

Figure 4-14. Likely that the electronic chart is incorrect

As seen in Figure 4-14, it is not likely that the electronic chart is incorrect. There is barely any difference between area of navigation or weather conditions.

4.1.15 RADAR echo of a buoy and its position according to the chart differs, how likely is it that the GPS position has an offset?

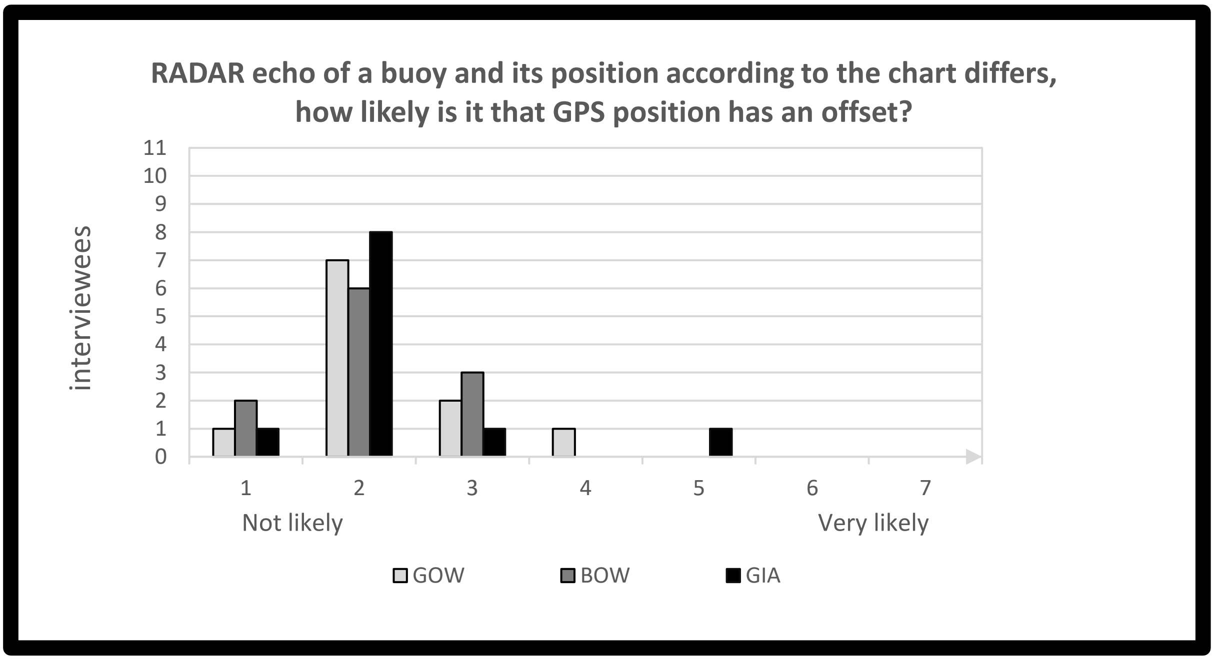

Figure 4-15. Likely that the GPS position has an offset

As seen in Figure 4-15, it is not likely that the GPS has an offset. There is barely any difference between area of navigation or weather conditions.

4.1.16 RADAR echo of a buoy and its position according to the chart differs, how likely is it that a RADAR error has occurred?

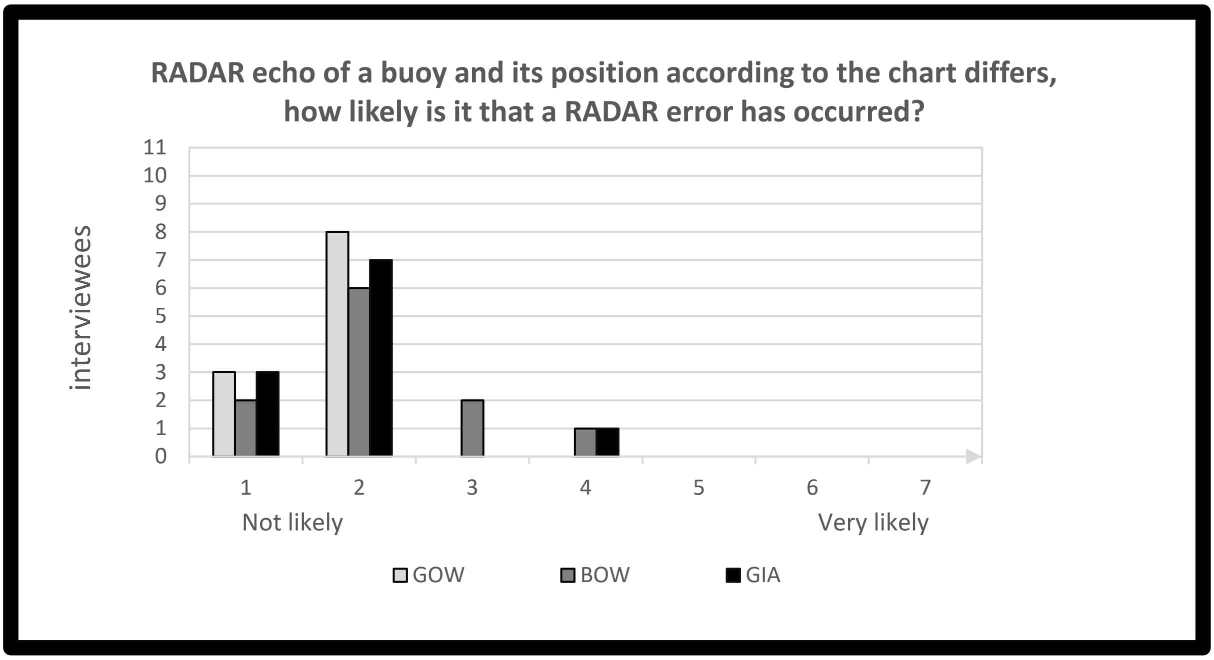

Figure 4-16. Likely that a RADAR error has occurred

As seen in Figure 4-16, it is not likely that the GPS has an offset. There is barely any difference between area of navigation or weather conditions.

4.2 Statistical comparison

For the statistical evaluation of the collected data, a comparison between upper and lower mean value was made with a confidence level set at 95 %. All numeric mean values can be found in appendix 1.

4.2.1 RADAR scale

In GOW the data show that there is not any difference between how often the interviewees use a scale of less than 6 miles and more than 6 miles on the RADAR. However, there is a difference when compared to the usage of the 6 mile scale, which is the RADAR scale most often used.

In BOW there is no difference in usage between scales smaller than 6 miles and the actual 6 mile scale. The RADAR scales larger than 6 miles is not used as often as in BOW.

Scales smaller than 6 miles is very often used in GIA while the scale of 6 miles or scales larger than 6 miles seldom are used.

4.2.2 Stabilization mode

In all three scenarios ground-stabilization is mainly used in comparison to sea-stabilization which is rarely used. There was not any difference between different areas of navigation or in different weather conditions.

4.2.3 Autopilot mode

The interviewees most often use the heading mode setting on their autopilot in all three scenarios, they rarely use the track mode or course mode. No difference could statistically be established regarding area of navigation or weather condition.

4.2.4 Trust in navigational equipment

According to the data there is no clear difference in how much the interviewees trust any singular navigational equipment. The mean values show that a high degree of trust is given to all mentioned equipment.

4.2.5 Electronic chart and RADAR difference

In all three scenarios the comparison show that it is not likely that the electronic chart, GPS position or the RADAR is displaying incorrect information. Most likely according to the interviewees is that the buoy is drifting. This can be statistically verified through the Chi square and Kruskal-Wallis test for all three scenarios. The 2 % score in the test makes the result conclusive for the target group as shown in appendix 2. Statistically this means that most OOW would think that a drifting buoy is a likely cause for the difference in RADAR echo and chart position.

5 Discussion

In this chapter an analysis of the data presented in the result chapter will be done and discussed in relation to relevant theory and previous scientific research. It will emphasize on how the data presented in the result can function as a key factor when answering the questions and purpose of this study. The answers of the interviewees composed the most likely settings they would use during three different scenarios, which is assembled as case examples.

The final part of this chapter will contain a discussion regarding the choice of method for this study. Reflections regarding the validity, reliability and accuracy of this method will also be discussed in that section.

5.1 Discussion of the data result

This part of the discussion will examine how the data presented in this study can be applied to real life navigational scenarios.

5.1.1 Chosen scale

Using a small scale in open waters can result in no visible land objects in the RADAR, which will force the OOW to rely more on buoys or the GPS position. The result chapter show that a larger scale than 6 miles rarely is used in open waters, especially in bad weather. This would imply that the chance the OOW would have of noticing spoofing by comparing RADAR echoes of land objects with the chart overlay is slight in open waters, since the chosen scale might be too small for that.

5.1.2 Chart overlay

The overlay function makes it easier to notice a difference between the RADAR echoes of land objects and the displayed chart. In theory that should increase the chance of noticing a spoofing attempt.

According to the data presented in this study, chart overlay is very frequently used in the RADAR no matter the area of navigation or weather conditions. By using the same logic as in 5.1.1 would suggest that in areas close to shore where there are plenty of land objects to navigate by, the chance is greater for the OOW to notice spoofing.

5.1.3 Stabilization mode

Since ground-stabilization base the vectors on GPS course rather than gyro heading which sea-stabilization is based on, there would be a difference in displayed vector in the RADAR when using ground-stabilized vectors if the vessel is under a spoofing attack.

In all three scenarios the ground-stabilization mode is preferred over the sea-stabilization mode. Theoretically this could lead to the OOW adjusting the course faster towards what he or she perceives as the correct course since the spoofed course is visibly presented directly on the RADAR screen.

5.1.4 Autopilot mode

Track mode is based on a system where the autopilot adjusts the course automatically according to GPS course over ground and GPS position to follow the set route. If the vessel is under a spoofing attack that could then lead to the autopilot changing course without the OOW ever noticing it.

Course mode follows a similar chain of events with the difference being that it is solely based on the GPS course rather than the course and position. This too could lead to the autopilot adjusting course without the knowledge of the OOW.

Heading mode on the other hand uses the gyro compass to determine course to follow, and is therefore not sensitive to a spoofing attempt in that aspect. On the other hand, if the OOW is brought in to the equation then the risk would be that the OOW manually changes the course to countermand for what he or she might perceive as an increase in drift off.

In all three scenarios the heading mode is most commonly used which mean that the risk of a spoofing attack steering the vessel automatically without the OOW awareness is very small. Instead the risk lies in the fact that the OOW might do course changes manually to counter the anomaly caused by the spoofing.

5.1.5 Trust in navigational equipment

As presented by Grech et. al. (2002) the over reliance on the system equipment can lead to a lack of situational awareness and in time gradually lose confidence in manually navigating the vessel. It could be argued that a certain level of trust in the equipment is needed to use the information given, but it is important to know what limitations each equipment have in order to make the best decision possible. Not knowing the limitations could be disastrous as mentioned in 2.2.4 with the case of *The Royal Majesty* where the ECDIS was in dead reckoning mode without the crew understanding that fact, which lead to the vessel grounding (NTSB, 1997).

The overall trust to navigational equipment is constantly high according to the result in this study. Over reliance in the navigational equipment could potentially cause the navigator to not notice or reflect over variations and anomalies the equipment is displaying.

5.1.6 Electronic chart and RADAR difference

As mentioned in the section above, too high trust in the navigational equipment have several risks involved. In the case asked in the interviews with the buoy RADAR echo which differs from the position in the electronic chart, too high trust in the equipment could lead to the OOW to disregard all viable reasons for the difference and instead choose to rely on that the buoy is drifting.

In all three scenarios the interviewees found probability of faulty equipment as low, and instead relied on the drifting buoy as the most likely cause for the difference in echo and displayed chart. That could be a risk when it comes to spoofing since the anomaly of a differing echo is disregarded as the buoy in the wrong position instead of the vessel being under a spoofing attack.

5.2 Method discussion

In this part of the discussion the validity and reliability of the method of choice is explained with relevant theory. Throughout this section the positive and negative aspects of the method is reflected upon.

5.2.1 Method of choice

Examining whether GPS spoofing constitutes a risk for Swedish passenger ferries in the Baltic Sea, Kattegat and Skagerrak can be done in different ways. Testing GPS spoofing practically on a specific vessel or testing it in a simulation environment faces the big problem that the test subjects will be on alert when there is a practical study taking place, which will increase the risk that the test subjects will notice the GPS spoof. Structured interviews are one method that could be suitable for the purpose and to answer the questions in this study.

Using structured interviews ensures that all the respondents are given the same questions, in the same way (Denscombe, 2014). Asking direct questions in the interview concerning GPS spoofing and if the navigating officers would notice a potential spoofing attack would most likely affect the answers, which would lead to unreliable data. Therefore, the structured interview focused on key factors and finally gave a result that could answer the purpose of this study. To receive the most accurate data possible for Swedish passenger ferries, the structured interview targeted navigating officers on ships trafficking various areas of the Baltic Sea, Kattegat and Skagerrak.

5.2.2 Method validity

11 interviewees took part in this study, which affects the validity of the data collected. Expanding the number of interviewees would strengthen the validity and add possibilities when statistically comparing the data since there would be more data to compare and perhaps eventuate in statistically certain data in accordance to the Chi-square test and the Kruskal-Wallis test.

5.2.3 Method reliability

With the interview being personal it meant that it was possible to make sure the interviewees really understood the questions and scenarios. The answers did not get compromised from another source which can happen with having interviews in groups, and this strengthens the reliability of the data collected (Denscombe, 2014).

Denscombe (2014) also states that during an interview the identity of the interviewer influences the answers. In this case the interviewer has the rank of Cadet and the interviewees the ranks of either Second officer or Chief officer. The fact that the interviewees has a higher rank than the interviewer eventuated in answers where there was no need to impress the interviewer and therefore the answers can be considered unbiased.

6 Conclusions

The purpose of this study was to determine whether GPS spoofing is a viable risk in concern to merchant shipping and more specifically Swedish passenger ferries in the Baltic Sea area and waters around Skagerrak and Kattegat. This chapter answers the purpose and research questions of this study. Recommendations for future research are stated in the end of this chapter.

6.1 Answering the research questions

Statistical certainty could not determine whether GPS spoofing is a viable risk in regard to the entire population of OOW onboard Swedish passenger ferries, though the data point towards the existence of such a risk.

The data collected regarding the working routines of the OOW show tendencies towards the risk that a spoofing attack could happen without the knowledge of the OOW. Aspects such as the scale of choice in the RADAR, especially in bad weather, point towards the fact that land objects are not always in range for position reference.

The high level of trust in the navigational equipment and perhaps foremost the GPS position raises concern in the case where the RADAR echo differs from the apparent position of the buoy in the electronic chart. This indicates a possible risk of a successful spoofing attack could occur and that the OOW might not recognise the key elements of a spoofing attack.

The result show that heading mode is used very frequently compared to the use of track mode and course mode. Heading mode may not be a factor that enable the OOW to specifically notice the spoofing attempt. It could however be an extra filter of noticing a spoofing attack since it enables the OOW to reflect over the reason for an additional change of course in comparison to course mode and track mode, where such a change is made automatically.

Chart overlay is often used according to the result. This means that a reference between the electronic chart and the RADAR echo is available when the set scale permits land objects to be within range. Subsequently this leads to a higher chance of discovering a GPS offset when it comes to spoofing. However as mentioned above, the use of small scales pose a concern since land objects might not be within the set RADAR range.

6.2 Future research

For future research it would be interesting with a practical study involving actual spoofing attacks either in a simulator or on a vessel at sea, to determine if the OOW notices the attack.

When analysing the data collected in this study it was found that ground-stabilization is used predominantly in all three scenarios, even in open waters where the sea-stabilization setting could be more suitable for anti-collision. It would therefore be interesting with a study regarding how the OOW uses the different RADAR settings for anti-collision and anti-grounding.

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Appendix

Appendix 1

Question	Scenario	Statistic	Answer
How often do you use the 6 mile scale on your RADAR?	GOW	Mean	5,82
		95 % confidence interval for mean - Lower bound	5,23
		95 % confidence interval for mean - Higher bound	6,41
		5 % trimmed mean	5,85
		Median	6,00
	BOW	Mean	5,36
		95 % confidence interval for mean - Lower bound	4,82
		95 % confidence interval for mean - Higher bound	5,91
		5 % trimmed mean	5,40
		Median	6,00
	GIA	Mean	2,64
		95 % confidence interval for mean - Lower bound	1,28
		95 % confidence interval for mean - Higher bound	3,99
		5 % trimmed mean	2,48
		Median	2,00

Question	Scenario	Statistic	Answer
How often do you use a smaller scale than 6 miles on your RADAR?	GOW	Mean	3,18
		95 % confidence interval for mean - Lower bound	2,29
		95 % confidence interval for mean - Higher bound	4,07
		5 % trimmed mean	3,15
		Median	3,00
	BOW	Mean	5,00
		95 % confidence interval for mean - Lower bound	4,10
		95 % confidence interval for mean - Higher bound	5,90
		5 % trimmed mean	5,06
		Median	5,00
	GIA	Mean	6,45
		95 % confidence interval for mean - Lower bound	5,64
		95 % confidence interval for mean - Higher bound	7,27
		5 % trimmed mean	6,62
		Median	7,00

Question	Scenario	Statistic	Answer
How often do you use a larger scale than 6 miles on your RADAR?	GOW	Mean	3,45
		95 % confidence interval for mean - Lower bound	2,32
		95 % confidence interval for mean - Higher bound	4,59
		5 % trimmed mean	3,34
		Median	3,00
	BOW	Mean	2,73
		95 % confidence interval for mean - Lower bound	1,64
		95 % confidence interval for mean - Higher bound	3,81
		5 % trimmed mean	2,64
		Median	2,00
	GIA	Mean	1,36
		95 % confidence interval for mean - Lower bound	0,55
		95 % confidence interval for mean - Higher bound	2,17
		5 % trimmed mean	1,18
		Median	1,00

Question	Scenario	Statistic	Answer
How often do you use chart overlay in your RADAR?	GOW	Mean	6,45
		95 % confidence interval for mean - Lower bound	5,44
		95 % confidence interval for mean - Higher bound	7,47
		5 % trimmed mean	6,67
		Median	7,00
	BOW	Mean	6,45
		95 % confidence interval for mean - Lower bound	5,44
		95 % confidence interval for mean - Higher bound	7,47
		5 % trimmed mean	6,67
		Median	7,00
	GIA	Mean	6,73
		95 % confidence interval for mean - Lower bound	6,29
		95 % confidence interval for mean - Higher bound	7,16
		5 % trimmed mean	6,81
		Median	7,00

Question	Scenario	Statistic	Answer
How often do you use sea-stabilization in your RADAR?	GOW	Mean	1,73
		95 % confidence interval for mean - Lower bound	0,68
		95 % confidence interval for mean - Higher bound	2,77
		5 % trimmed mean	1,53
		Median	1,00
	BOW	Mean	2,09
		95 % confidence interval for mean - Lower bound	0,73
		95 % confidence interval for mean - Higher bound	3,45
		5 % trimmed mean	1,88
		Median	1,00
	GIA	Mean	1,45
		95 % confidence interval for mean - Lower bound	0,64
		95 % confidence interval for mean - Higher bound	2,27
		5 % trimmed mean	1,28
		Median	1,00

Question	Scenario	Statistic	Answer
How often do you use ground-stabilization in your RADAR?	GOW	Mean	6,91
		95 % confidence interval for mean - Lower bound	6,71
		95 % confidence interval for mean - Higher bound	7,11
		5 % trimmed mean	6,95
		Median	7,00
	BOW	Mean	6,45
		95 % confidence interval for mean - Lower bound	5,44
		95 % confidence interval for mean - Higher bound	7,47
		5 % trimmed mean	6,67
		Median	7,00
	GIA	Mean	7,00
		95 % confidence interval for mean - Lower bound	7,00
		95 % confidence interval for mean - Higher bound	7,00
		5 % trimmed mean	7,00
		Median	7,00

Question	Scenario	Statistic	Answer
How often do you use heading mode on your autopilot?	GOW	Mean	6,91
		95 % confidence interval for mean - Lower bound	6,71
		95 % confidence interval for mean - Higher bound	7,11
		5 % trimmed mean	6,95
		Median	7,00
	BOW	Mean	7,00
		95 % confidence interval for mean - Lower bound	7,00
		95 % confidence interval for mean - Higher bound	7,00
		5 % trimmed mean	7,00
		Median	7,00
	GIA	Mean	6,91
		95 % confidence interval for mean - Lower bound	6,71
		95 % confidence interval for mean - Higher bound	7,11
		5 % trimmed mean	6,95
		Median	7,00

Question	Scenario	Statistic	Answer
How often do you use track mode on your autopilot?	GOW	Mean	1,64
		95 % confidence interval for mean - Lower bound	0,88
		95 % confidence interval for mean - Higher bound	2,39
		5 % trimmed mean	1,54
		Median	1,00
	BOW	Mean	1,09
		95 % confidence interval for mean - Lower bound	0,89
		95 % confidence interval for mean - Higher bound	1,29
		5 % trimmed mean	1,05
		Median	1,00
	GIA	Mean	1,64
		95 % confidence interval for mean - Lower bound	0,83
		95 % confidence interval for mean - Higher bound	2,45
		5 % trimmed mean	1,54
		Median	1,00

Question	Scenario	Statistic	Answer
How often do you use course mode on your autopilot?	GOW	Mean	1,09
		95 % confidence interval for mean - Lower bound	0,89
		95 % confidence interval for mean - Higher bound	1,29
		5 % trimmed mean	1,05
		Median	1,00
	BOW	Mean	1,36
		95 % confidence interval for mean - Lower bound	0,55
		95 % confidence interval for mean - Higher bound	2,17
		5 % trimmed mean	1,18
		Median	1,00
	GIA	Mean	1,18
		95 % confidence interval for mean - Lower bound	0,91
		95 % confidence interval for mean - Higher bound	1,45
		5 % trimmed mean	1,15
		Median	1,00

Question	Scenario	Statistic	Answer
How much do you trust the information given by the RADAR?	GOW	Mean	6,18
		95 % confidence interval for mean - Lower bound	5,68
		95 % confidence interval for mean - Higher bound	6,69
		5 % trimmed mean	6,20
		Median	6,00
	BOW	Mean	5,36
		95 % confidence interval for mean - Lower bound	4,67
		95 % confidence interval for mean - Higher bound	6,05
		5 % trimmed mean	5,35
		Median	5,00
	GIA	Mean	6,09
		95 % confidence interval for mean - Lower bound	5,62
		95 % confidence interval for mean - Higher bound	6,56
		5 % trimmed mean	6,10
		Median	6,00

Question	Scenario	Statistic	Answer
How much do you trust the GPS position?	GOW	Mean	5,91
		95 % confidence interval for mean - Lower bound	5,44
		95 % confidence interval for mean - Higher bound	6,38
		5 % trimmed mean	5,90
		Median	6,00
	BOW	Mean	5,55
		95 % confidence interval for mean - Lower bound	4,99
		95 % confidence interval for mean - Higher bound	6,10
		5 % trimmed mean	5,49
		Median	5,00
	GIA	Mean	5,73
		95 % confidence interval for mean - Lower bound	5,41
		95 % confidence interval for mean - Higher bound	6,94
		5 % trimmed mean	5,75
		Median	6,00

Question	Scenario	Statistic	Answer
How much do you trust the information given by the electronic chart?	GOW	Mean	5,73
		95 % confidence interval for mean - Lower bound	5,41
		95 % confidence interval for mean - Higher bound	6,04
		5 % trimmed mean	5,75
		Median	6,00
	BOW	Mean	5,36
		95 % confidence interval for mean - Lower bound	5,02
		95 % confidence interval for mean - Higher bound	5,70
		5 % trimmed mean	5,35
		Median	5,00
	GIA	Mean	5,64
		95 % confidence interval for mean - Lower bound	5,30
		95 % confidence interval for mean - Higher bound	5,98
		5 % trimmed mean	5,65
		Median	6,00

Question	Scenario	Statistic	Answer
RADAR echo of a buoy and its position according to the chart differs, how likely is it that the buoy is drifting?	GOW	Mean	5,55
		95 % confidence interval for mean - Lower bound	5,19
		95 % confidence interval for mean - Higher bound	5,90
		5 % trimmed mean	5,55
		Median	6,00
	BOW	Mean	6,55
		95 % confidence interval for mean - Lower bound	6,08
		95 % confidence interval for mean - Higher bound	7,01
		5 % trimmed mean	6,61
		Median	7,00
	GIA	Mean	5,27
		95 % confidence interval for mean - Lower bound	4,59
		95 % confidence interval for mean - Higher bound	5,95
		5 % trimmed mean	5,36
		Median	6,00

Question	Scenario	Statistic	Answer
RADAR echo of a buoy and its position according to the chart differs, how likely is it that the electronic chart is incorrect?	GOW	Mean	2,27
		95 % confidence interval for mean - Lower bound	1,67
		95 % confidence interval for mean - Higher bound	2,88
		5 % trimmed mean	2,25
		Median	2,00
	BOW	Mean	2,18
		95 % confidence interval for mean - Lower bound	1,40
		95 % confidence interval for mean - Higher bound	2,97
		5 % trimmed mean	2,09
		Median	2,00
	GIA	Mean	2,09
		95 % confidence interval for mean - Lower bound	1,77
		95 % confidence interval for mean - Higher bound	3,01
		5 % trimmed mean	1,99
		Median	2,00

Question	Scenario	Statistic	Answer
RADAR echo of a buoy and its position according to the chart differs, how likely is it that the GPS position has an offset?	GOW	Mean	2,27
		95 % confidence interval for mean - Lower bound	1,74
		95 % confidence interval for mean - Higher bound	2,80
		5 % trimmed mean	2,25
		Median	2,00
	BOW	Mean	2,09
		95 % confidence interval for mean - Lower bound	1,62
		95 % confidence interval for mean - Higher bound	2,56
		5 % trimmed mean	2,10
		Median	2,00
	GIA	Mean	2,27
		95 % confidence interval for mean - Lower bound	1,59
		95 % confidence interval for mean - Higher bound	2,95
		5 % trimmed mean	2,19
		Median	2,00

Question	Scenario	Statistic	Answer
RADAR echo of a buoy and its position according to the chart differs, how likely is it that a RADAR error has occurred?	GOW	Mean	1,73
		95 % confidence interval for mean - Lower bound	1,41
		95 % confidence interval for mean - Higher bound	2,05
		5 % trimmed mean	1,75
		Median	2,00
	BOW	Mean	2,18
		95 % confidence interval for mean - Lower bound	1,59
		95 % confidence interval for mean - Higher bound	2,77
		5 % trimmed mean	2,15
		Median	2,00
	GIA	Mean	1,91
		95 % confidence interval for mean - Lower bound	1,35
		95 % confidence interval for mean - Higher bound	2,47
		5 % trimmed mean	1,84
		Median	2,00

Appendix 2

RADAR echo of a buoy and its position according to the chart differs, how likely is it that the buoy is drifting?		All three scenarios
	Chi-square	12,654
	df	2
	Kruskal Wallis	0,002

Appendix 3

Picture retrieved from VesselFinder (2016).