YRKESHÖGSKOLAN NOVIA

GPS Disturbance Onboard Ships

Recognizing and Mitigating GPS Faults Onboard Ships

Elias Eid

Degree Thesis

Thesis for Bachelor's degree

Degree Programme in Maritime Management, Captain

Turku, Finland 2025

DEGREE THESIS

Author: Elias Eid
Degree Programme and place of study: Bachelor of Maritime Management, Novia UAS
Specialisation: Maritime Management
Supervisor: Tony Karlsson

Title: GPS Disturbance Onboard Ships

Date: 30.5.2025 Number of pages: 45 Appendices: 2

Abstract

The maritime technology has been developing at a faster pace than ever, driven by equipment advancement inclined towards digitalization and autonomous shipping. The role of human intervention has been important yet debatable in the context of the autonomy of running the ships. It has been repeatedly proven that the human element cannot be replaced and thus, there is a significant need to invest in the development of human element.

Human intervention plays a crucial role in the prevention of catastrophic consequences such as running aground, collision and environmental damage. Different navigational tools are used on the ships to determine its safe voyage. These tools include, GPS, Gyro, speed log, echo sounder, radar and ECDIS. Global positioning system (GPS) helps in enhancing the navigational safety and provides precise positioning.

The aim of this thesis is to study the disturbance in GPS onboard ships. It was also substantial to examine the effects caused by this phenomenon on the maritime transport in the Gulf of Finland and what measures were taken.

Qualitative research method is carried out supported by relevant literature and scholarly articles targeting the reader to comprehend themselves with a safety related topic. Interviews were conducted with officers of the watch (OOW) and material were collected from trusted information sources such as the Finnish officials and maritime professionals. Multiple simulation pictures have been added to this research. The purpose of the simulation pictures is to show the GPS disturbance and its effects on navigation in real time.

This research encourages individuals to value the importance of the human element, the importance of knowledge behind how technology works and foster critical thinking rather than only relying on tools.

Language: English
Key Words: Safety, Situational Awareness, GPS Disturbance, Jamming, Spoofing, Human Element

Table of Contents

Appendices

Abbreviations and definitions

GPSS: Global Positioning Satellite System

GPS: Global Positioning System

GNSS: Global Navigation Satellite System

PNT: Position, Navigation and Timing information

Interference: To interfere / to disturb

Jamming: To disturb/to block the receiver from receiving

Spoofing: To spoof/to fool the receiver with fake signals

IMO: International Maritime Organization

ITU: International Telecommunication Union

SOLAS: International Convention for the Safety of Life at Sea

STCW: International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

INTERTANKO: International Association of Independent Tanker Owners

TRAFICOM: The Finnish Transport and Communications Agency

RADAR: Radio Detection and Ranging navigational equipment

Heading line: Line pointing out of ship’s bow connected to Gyro or Magnetic compass

Vector line: Graphical presentation of the vessel’s future position based on its course and speed

EBL: Electronic Bearing Line

VRM: Variable Range Marker

SOG: Speed Over Ground

COG: Course Over Ground

STW: Speed Through Water

CTW: Course Through Water

ARPA: Automatic Radar Plotting Aid

ECDIS: Electronic Chart Display and Information System

DR: Dead Reckoning

EP: Estimated Position

1 Introduction

Maritime transport is the backbone of the global economy as 90% of the world trade is transported by sea (Shipping, International Chamber of, n.d.). Originating from transporting civilizations' necessities such as grain and oil towards raw materials and manufactured goods, shipping form the basis for the global supply chain. Given this significancy, maritime transport technologies have been developing and advancing to enhance safety, security, efficiency and sustainability. This technological evolution brings also challenges that can lead to impact on the implementation.

Technologies and equipment that determines ship's heading and positioning are crucial for navigating and decision making. SOLAS Regulation V/19.2.1.6 states that *"All ships regardless of their size shall have a receiver for a global navigation satellite system or a terrestrial radionavigation system, or other means, suitable for use at all times throughout the intended voyage to establish and update the ship's position by automatic means"* (Islands, 2016). This has led to the integration of Global Positioning satellite System (GPSS) into ships. The Global Positioning System (GPS), the first fully operating GNSS system and its availability for civilian has allowed ships to use it as early on as 2000's and it was formally adopted by IMO in December 2000 (IMO, 2000).

Since it has been adopted, the GPS have been proven to be reliable and accurate in determining ships' position and has been integrated into other navigational equipment that are operating it. The phenomena of GPS disturbance and jamming have existed globally in high tensioned geopolitical and near war zones such as the Mediterranean Sea, Black Sea and the Baltic Sea.

Baltic Sea is considered to be one of the busiest seas in the world and it is estimated that there are over 2000 ships within the Baltic Sea at any given moment. A total of 15% of the world trade is transported via the Baltic Sea. (Helsinki Commission, 2009). The Baltic Sea consist of the Gulf of Finland, the Gulf of Bothnia, the Gulf of Gdańsk, Gulf of Riga and the Danish Straits and Kattegatt. It covers a total area of 415,266 square kilometre with an average depth of 50 meters.

There are 85 million people who benefit and live within the Baltic Sea drainage area. This area consists of the Baltic Sea coastal states Finland, Sweden, Denmark, Latvia, Lithuania, Estonia, Poland, Germany and Russia (HELCOM, 2023). Finland as an example is dependent on the sea transport as the country get 80% of its import and 90% of its export via the sea carriage (Government, Finnish, 2025). The importance of the Baltic Sea lies also within its biological diversity as well as to its ecological system as it has a total of 5000 living species. Due to this importance, sensitivity, vulnerability and the increasing of the sea transport, the Baltic Sea was designated as a sensitive sea area by the Internation Maritime Organization IMO in 2005 (IMO, 2005). A further illustration which has been aiming to protect the marine environment and ensure safe shipping in the Baltic Sea is the Helsinki convention which is dated back to 1974.

A continuous Global Navigation Satellite System (GNSS) disturbance and spoofing reports took place in the Baltic Sea as of 2023. This has raised up concerns regarding the safety of navigation and serious environmental damages. A given interview by the Finnish Coast Guard on October 2024, reveals the consequences of disturbance and spoofing as many vessels have strayed out of their intended routes bound towards shallow dangerous waters before they have been alerted (YLE, 2024). The Finnish Transport and Communication agency reported a total of 238 cases of GNSS disturbance in 2024 in comparison to almost none as before 2024 (TRAFICOM, 2025). The agency has also recommended the usage of radar, old seaman skills and to practice the usage of the available instruments onboard ships.

This thesis is to highlight the event of the GPS disturbance and spoofing. It also demonstrates how to mitigate the GPS disturbance and spoofing onboard ships empowering the seafarers of the ability to recognize, alarm and execute safe actions in ample time.

1.1 Objectives

The aim of this thesis is to assess and find out modern day navigator's ability to identify and mitigate GPS faults. This chapter also outlines the research questions designed to investigate this phenomenon, as well as it indicates the limitations on the study.

1.2 Research Questions

1) How to recognize and mitigate the GPS disturbances onboard ships to enhance safe navigation?

2) How aware are the Officers of the watch, and do they have the needed knowledge to recognize and mitigate the GPS disturbances?

1.3 Limitations on the study

This research mainly focuses on the seafarers who have been sailing onboard in the Baltic Sea in 2024 and 2025. The sample size is limited to seven officers of the watch (OOW) who have been working on different IMO ship types. This sample size does not represent all the OOW who sail in the Baltic Sea or the world.

This research doesn’t focus on the type of Global Navigation Satellite System (GNSS) affected in the Baltic Sea. This research mainly studies the OOW´s abilities to recognize and mitigate the GNSS disturbances onboard ships.

The scope of this thesis is limited to GPS disturbances; therefore, AIS spoofing was not included in the research questions, nor were participants questioned on this distinct subject in the interview.

2 Theoretical foundation

The rising reports of the GPS disturbance in Finland as of 2024 has led to a safety concern about this phenomenon. There were 238 incident reports documented by the Finnish Transport and Communications Agency (TRAFICOM) in the water ways of the Gulf of Finland in 2024 (TRAFICOM, 2025). In a situation comparison, the below picture Figure 1 illustrates the extinct of the GPS disturbance in 8.5.2023. A year later, Figure 2 represents the GPS disturbance in the eastern part of Gulf of Finland. Figure 3 displays the existence of the GPS disturbance as of March 2025.

The green coloured area shows that there is no GPS disturbance, while the yellow coloured area indicates a minimal GPS disturbance in range of 2 - 10 %. Red coloured area is presenting the GPS disturbance with a percentage higher than 10%.

Alarming reports have been taking place, as some of the passing merchant ships in the Gulf of Finland were deviated from their intended routes, got closer to islands and shallow water areas before being alerted by authorities. A second observed phenomena have been the spoofing of location, as some of passing vessels in the Gulf of Finland have intentionally misrepresented their location by turning the vessels Automatic Identification System (AIS) off and adding a new false location. (Kauranen, 2024).

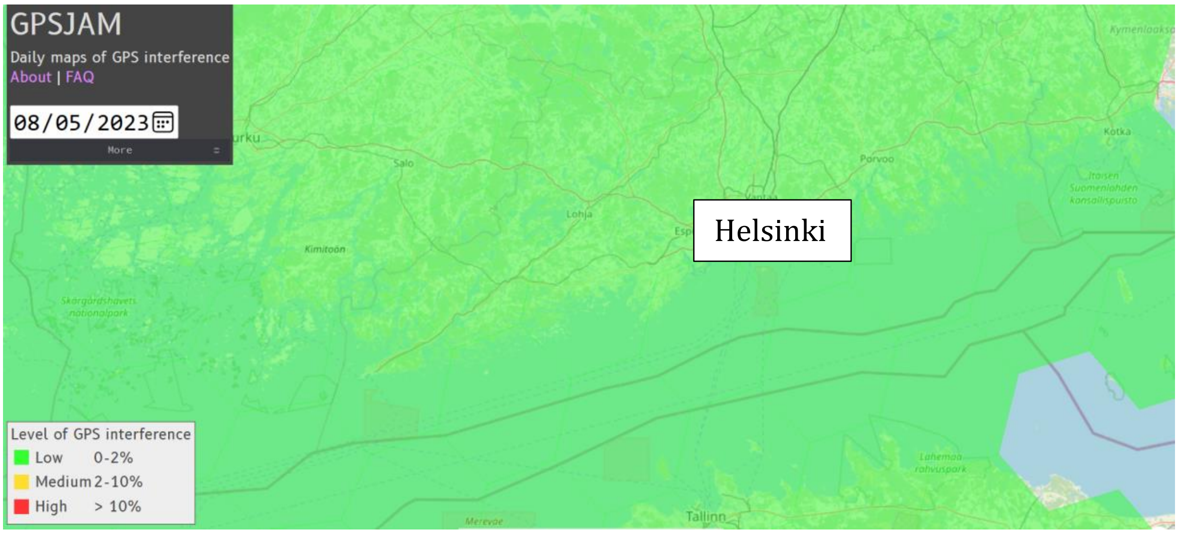


Figure 1. GPS disturbance map on the Gulf of Finland 8.05.2023. (Gpsjam, 2025).

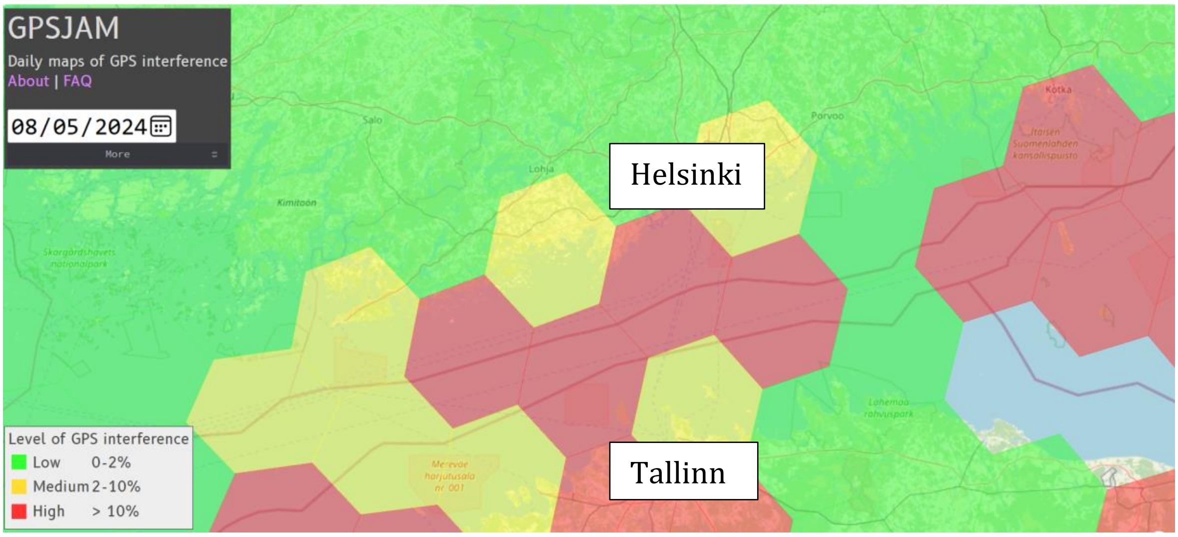


Figure 2. GPS disturbance map on the Gulf of Finland 8.05.2024. (Gpsjam, 2025).

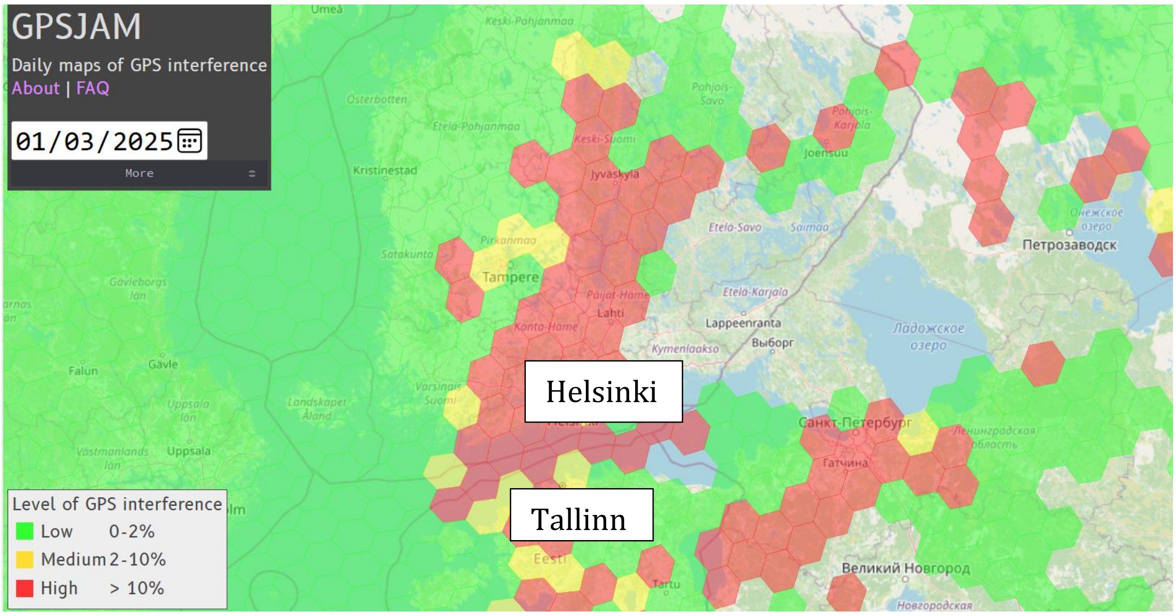


Figure 3. GPS disturbance map on the Gulf of Finland 1.03.2025. (Gpsjam, 2025).

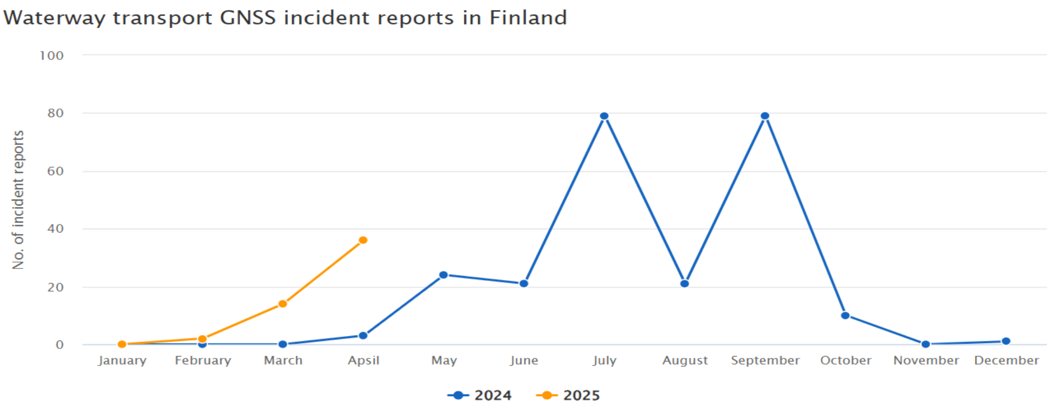


Figure 4. GPS disturbance for maritime in 2024. (TRAFICOM, 2025).

2.1 Literature Review

This chapter gives insights on how the GPS works in addition to giving the reader an understanding of the inputs, outputs that might affect the OOW ability in decision making and navigating the ship. These inputs are mainly heading, speed and position.

2.2 GPS History

Moving from the 1940s era where the Long-Range navigation was in use to determine the position based on land transmitters to new span of positioning based on a space segment. Hence, the Global Navigation system GPS which is based on transmitting a Satellite Radio signal was born in 1973. The GPS was initially developed by the United States's Department of Defence to serve the military needs. In 1978 the first GPS satellite NAVSTAR1 was launched to orbit, and it was 1993 when the GPS reached its full capacity that consist of 24 satellites in order to cover the globe and provide accurate timing and positioning. This perfect accuracy was limited to military purposes. The GPS system had a Selected Availability policy which reduced the quality of signals internationally. This gave the civilians the ability to use and benefit from the GPS, but with less accuracy. (History Timelines, n.d.). The selected availability was turned off in May 2000 and since then, civil and commercial services have been able to use the full accuracy of GPS (GPS Gov, 2021).

2.3 GPS Segment

GPS segment consists of space segment, control segment and user segment. The space segment consists of 6 different layers of slots that orbit the earth on a medium earth orbit which lies up to an altitude of 20200 km. Each layer consists of 4 slots given a total of 24 slots with the purpose of providing the users with coverage by 4 satellites at any given point on the earth. Out of the 24 slots, 3 slots were expanded resulting in a total of 27 slots to improve the coverage on the earth. There were a total of 31 operational satellites as of 2017. This constellation consists of old and new satellites. The newer generations of satellites are improved to offer better quality, signal strength and accuracy. (GPS Gov, 2022).

The control segment consists of land-based stations. There are a total of 29 operational control stations, 11 of which are ground antennas to control and command while 16 other stations are to monitor the satellites. The main and the alternative control stations are located in the United States of America.

The user segment refers to all receiver equipment that receives GPS signal from space on L-band frequencies. The first receiver equipment fitted onboard ships were only to receive a GPS signal. The IMO adopted the MSC.112(73) Resolution on December 2000 which regulates the shipborne Global Positioning System (GPS) receiver equipment (IMO, 2000).

Similar to the GPS, other space constellations such as Galileo, BeiDou and GLONASS have been operating and providing timing service, navigation and global positioning (EUSPA, 2025). SOLAS convention Chapter V, regulation 19 states that "*all ships, irrespective of size shall have a receiver for a global navigation satellite system or a terrestrial radionavigation system, or other means, suitable for use at all times throughout the intended voyage to establish and update the ship's position by automatic means*". This has led to the integration of other GNSS receiver equipment onboard ships.

2.4 The satellite compasses system

The satellite compass consists of antenna unit, processor unit and display unit (FURUNO, n.d.). The antenna unit consists of two or more receiver antennas separated by short known distance on the baseline. This baseline is fitted to be aligned with the vessel centreline. The GPS signal travels a certain distance with the speed of light from the satellite and reaches one of the antennas at a certain angle as shown in figure 5. Simultaneously, the same travelled signal reaches the other antenna. The GPS compass measures the difference of the arrival of signals (phase difference) to both antennas. (Khalique, 2009).

Knowing the exact positions of the satellites in their orbit in addition to knowing the exact fixed baseline allows for the relative bearing calculation to the true north. Thus, the ship's true heading is established. This (True heading) information provided by the satellite compass is connected to some of the most important navigational equipment such as Radar (The Vector Line and ARPA) in addition to ECDIS, AIS and AUTOPILOT. (FURUNO, n.d.).

The satellite compass can also provide the position of the ship (Longitude and Latitude) with a minimum of three satellites in its receiver's vicinity. A precise time is provided with the availability of fourth satellite in the receiver's vicinity (NOAA, n.d.). As the ship is moving forward all the time, the receiver estimates the course over ground COG based on the past positions. The speed over ground SOG is also obtained based on the previous past positions and how much distance travelled between them. (Wallin, 2016).

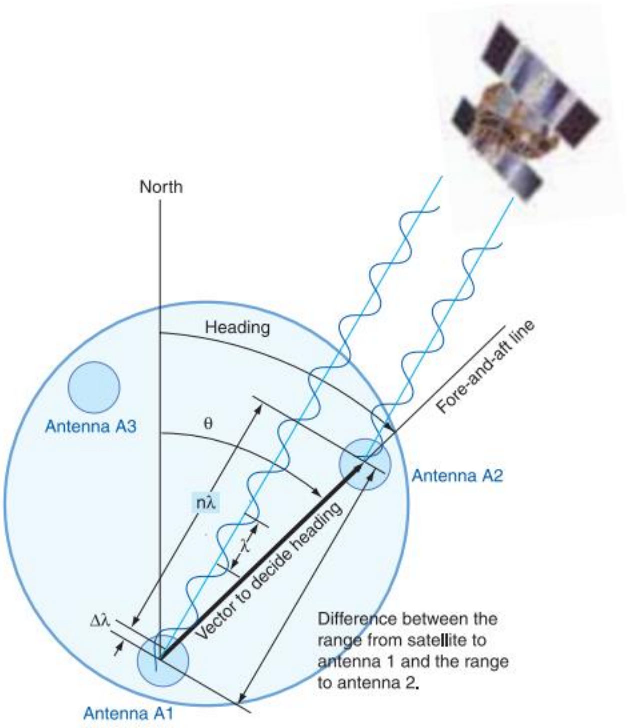


Figure 5. The principal of Satellite Compass (FURUNO, n.d.).

2.5 GNSS interference

The Global Positioning System (GPS) is a part of the Global Navigation Satellite System (GNSS) that transmits frequencies in L-band. The GNSS belong to the Radio Navigation Satellite Services (RNSS). Below figure shows the different frequencies for different GNSS systems. (GNSS Science Support Centre, 2011).

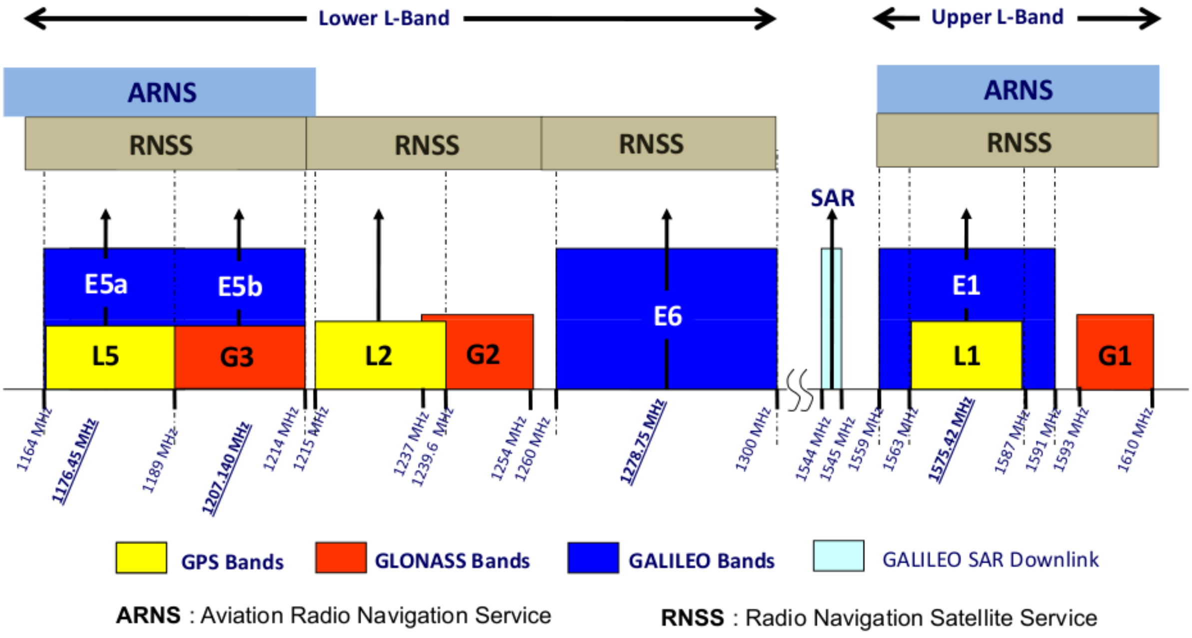


Figure 6. GNSS navigational frequency bands (GNSS Science Support Centre, 2011).

The International Telecommunication Unit (ITU) has divided the GNSS interferences into five types. These types are described below.

2.5.1 Atmospheric Interference

GPS malfunction can be attributed to several reasons. The atmospheric interference happens as the GPS signals pass through the ionosphere layers. The ionosphere layers consist of ionized particles. These ionized particles increase when there is more energy coming from the sun such as sun storms. The higher the density of particles, the more refractions can happen to the GPS travelled signals which results in delay of the signals arrival at the receiver. (Consortium, EarthScope, n.d.).

GPS satellites transmit signals on different frequencies which some are stronger than others. The stronger the frequency is, the less vulnerability it has to the ionospheric refractions. Atmospheric Interference effect is mitigated by some of the equipment's receiver itself as it compares different wave frequencies and corrects for it. Another correction method is the satellite-based augmentation systems (SBAS exist such as DGPS, EGNOS, MSAS and WAAS). These systems are land-based systems that receive the signal and apply the corrections before it is sent to the user's receiver. (Wallin, 2016).

2.5.2 Multipath Interference

The signal multipath is a result of signal bouncing between surfaces such as buildings or mountains. This bouncing causes a delay for the signal to reach the receiver causing errors in calculating the position accurately. (ITU, 2024).

2.5.3 Radio Frequency Interference

This interference is a result of the GNSS signal being interpreted by different sources such as radar systems and broadcast towers. This leads to the degradation of the signals or even to a complete blockage. (ITU, 2024).

2.5.4 Jamming Interference

Jamming interference can happen to a specific frequency range of the GNSS ranges or it can also happen to broad frequency ranges. It is a deliberate action to intentionally weaken the GPS signal or to cause a complete loss of the signal. This happens when a jammer sends radio frequency (RF) signals of high power on the same frequency that is used by the GNSS satellites. These RF signals overpower the GPS signals and overwhelm its receiver (everythingRF, 2022). Despite the illegality of operating a jammer in many countries, its cheap and widely available and could cause severe consequences for all the receivers in its vicinity.

Jammers can vary in strength and effect range and could cause severe damages. A study by Polish GNSS researchers has determined that the source of the GPS disturbance is originating from fitted GPS jammers onboard some vessels who cross the Baltic Sea (Maritime Executive, 2025).

Another study by the General Lighthouse Authorities of the United Kingdom and Ireland, Harwich, UK (GLA) on how the jamming can affect the ship has shown serious consequences. The study is undergone as one of the ships was exposed to 3 strength levels of gamming signal and how they affect the GPS-fed equipment. These observations were made:

1) The jamming signal is less than the GPS signal

   The operation of the vessel and navigation equipment continued to work normally without any triggered alarms or effect.

2) The jamming signal is the same strength as the GPS signal

   The GPS fed equipment provided inaccurate and misleading information such as high speed and wrong position.

3) The jamming signal is stronger than the GPS signal

   This has led to the GPS signal to fail in addition to failure in the receivers to provide any positioning, navigation or timing (PNT) outputs.

During this study, the vessel's position was showing wrong on ECDIS. AIS has also reported wrong information which resulted in a separation between the AIS target and its own echo in the radar screen. This study emphasizes the situational awareness and results in the GLA recommendations to mariners to use all the possible means in determining the position for safely navigation. (Dr. Alan Grant, 2009).

2.5.5 Simulation illustrations

The GPS disturbances can lead to following effect in the receiver: Incorrect position, erratic movement of the position (drifting), receiver's position loss, as it stops updating and keeps its last know un-updated position (freezes), shows inaccurate speed over ground or provide wrong timing.

A simulation was conducted for demonstration of GPS interference for the research purposes. The fist simulation was a GPS disturbance that resulted in the freezing of the GPS position which led to the GPS position coordinates to be unchangeable in the repeaters and in ECDIS. During this simulation, the autopilot steering mode was course mode, and the position input sensor was GPS. Below is the Radar picture with ENC overlay. A clear visible sign of the interference was the separation of the radar echo from the islands which indicates the GPS interference. Figure 7 shows the result of interference of the GPS signal and figure 8 illustrates ECDIS seems to be uninterrupted at the beginning of the interference.

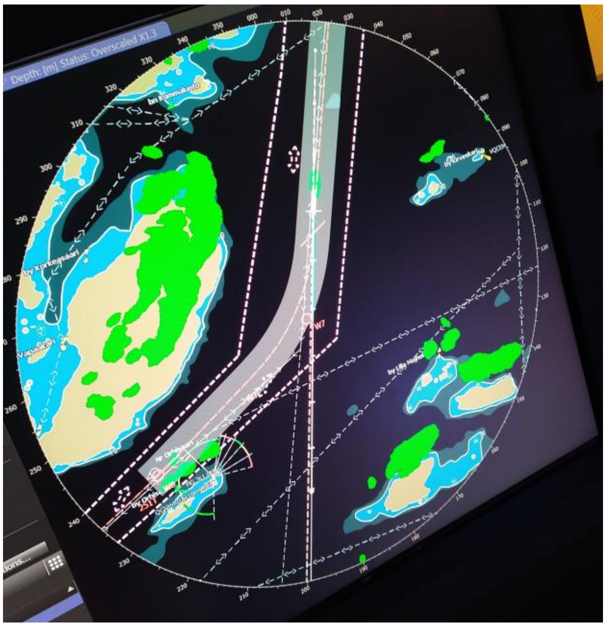


Figure 7. Picture of the RADAR

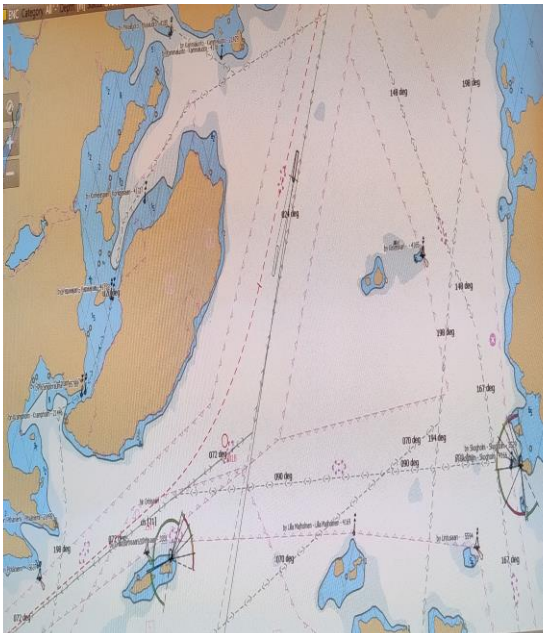
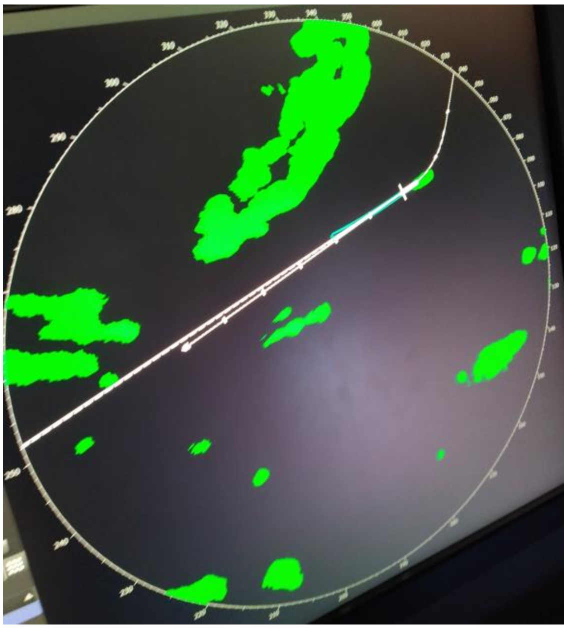


Figure 8. Picture of ECDIS

The input position sensor for ECDIS was the GPS, which resulted in a frozen location in ECDIS. Mitigating the fault was done using the following steps:

1) Switching the ENC off the radar screen and removing the route to have a clean radar picture.
2) Changing the reference of the vector line from Ground to Water, as the vector lines receives its input from the GPS.
3) Switching the autopilot mode from course mode to heading mode as the course mode receives its input from GPS.

It was possible to steer the vessel, execute the turn based on RADAR picture only and reach to the following course as in figure 9. As the ECDIS remained with its same position sensor settings (having GPS input), it appeared to be in the same position where the GPS position froze before the turn as displayed in figure 10.



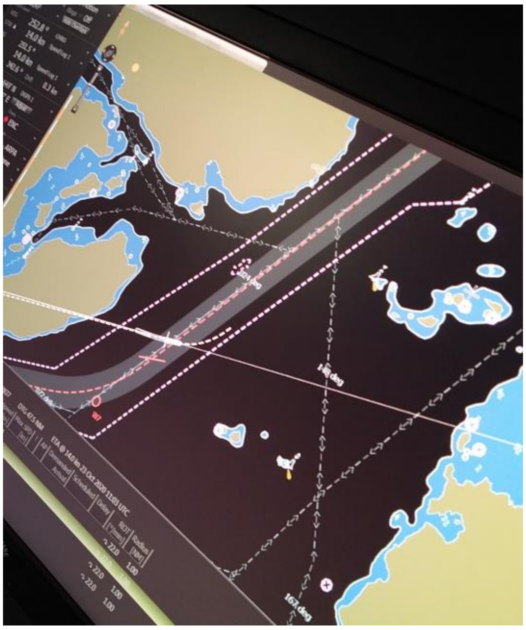


Figure 9. Picture of the RADAR

Figure 10. Picture of the ECDIS (Frozen position)

Another illustration in figure 11 demonstrates a result of GPS disturbance which resulted in a complete position shifting from sea to land (Incorrect position).

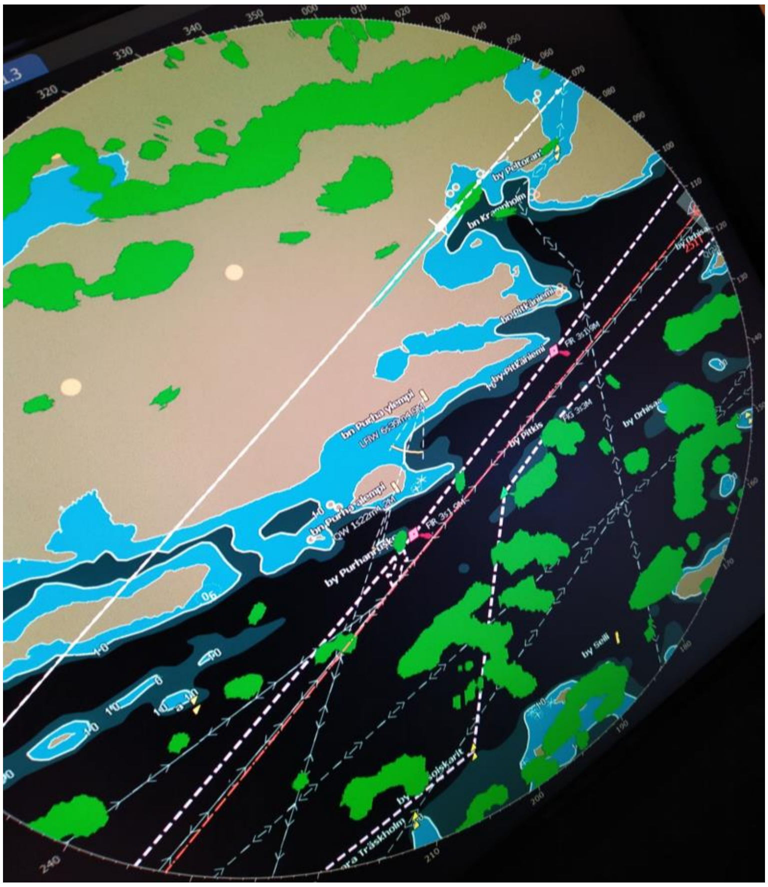


Figure 11. Position shifting from sea to land (Incorrect position)

2.5.6 Spoofing

GPS spoofing is a deliberately harmful attack that happens when stronger fake signals overtake the GPS weaker signal and manipulate it. This results in making the GPS-fed devices believe that they are somewhere else which they are not. The following figure shows the effect that can be caused by a spoofer.

Figure 12. Spoofing (INTERTANKO, 2019).

Spoofing can happen to a single vessel or more sophisticatedly can happen to multiple ships in a certain area. To demonstrate the severity and measure the difficulty of GPS spoofing, a research team from the Cockrell School of Engineering spoofed a yacht that costs $80 million dollars. The team produced a fake signal that took over the yacht's receivers gaining control of its navigational system. The team managed to deviate the yacht from its intended track and established a turn. The navigators onboard the yacht felt the turning of the yacht, but visibly on the chart display it was still on track. (The University of Texas at Austin, 2013) The dangerousness of GNSS spoofing is that; it can happen and effect the ship without any sounding alarms.

A spoofing of 20 vessels happened in the black sea in 2017. This resulted in the vessels GPS receiver's giving the false GPS position and the AIS to be presented in locations where they are not. (Goward, 2017). Figure 13 shows the difference between ship's actual position (on sea) and the wrong position (on land) presented by the GPS. The GPS receiver has also indicated that its location to be safe within 100-meter distance while being on land.

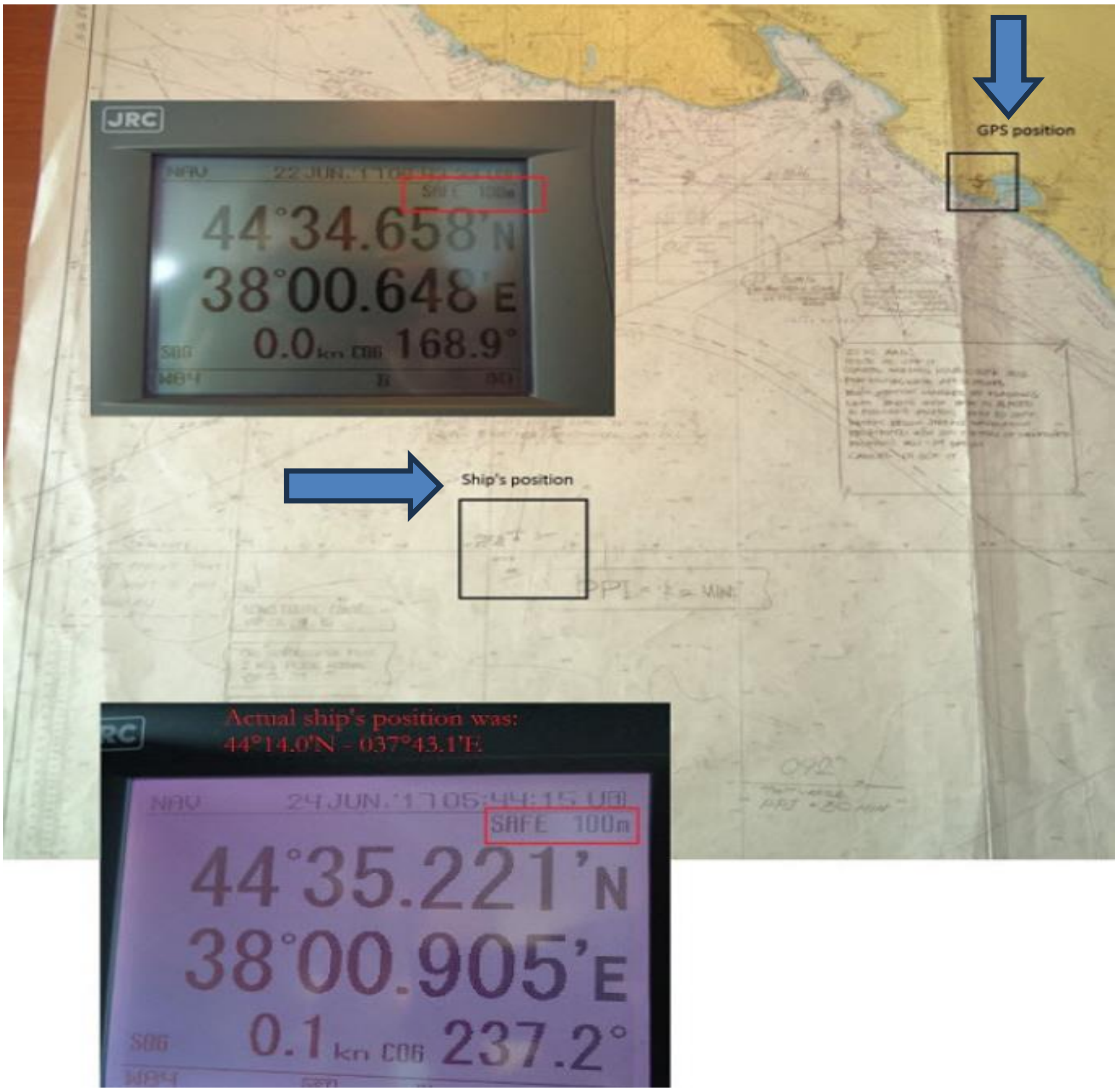


Figure 13. Picture shows the difference in ship's position as result of Spoofing. taken by the captain who reported the incident (Goward, 2017).

Below figure 14. is the RADAR's picture taken by the captain who reported the incident. It shows the difference between AIS targets and their echoes as result of Spoofing. Ships' AIS targets were presented to be in two areas close to each other (encircled in red).

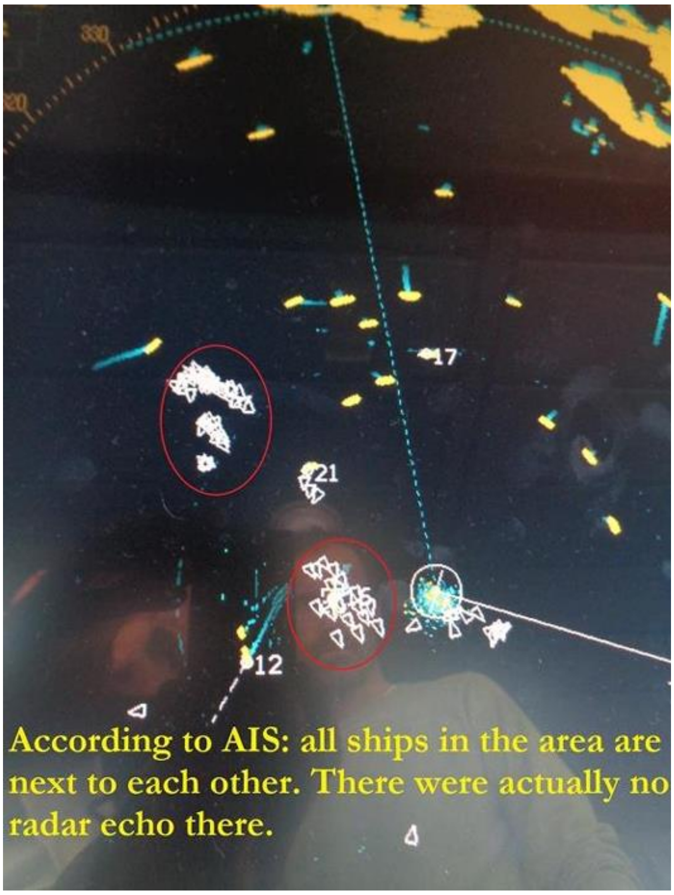
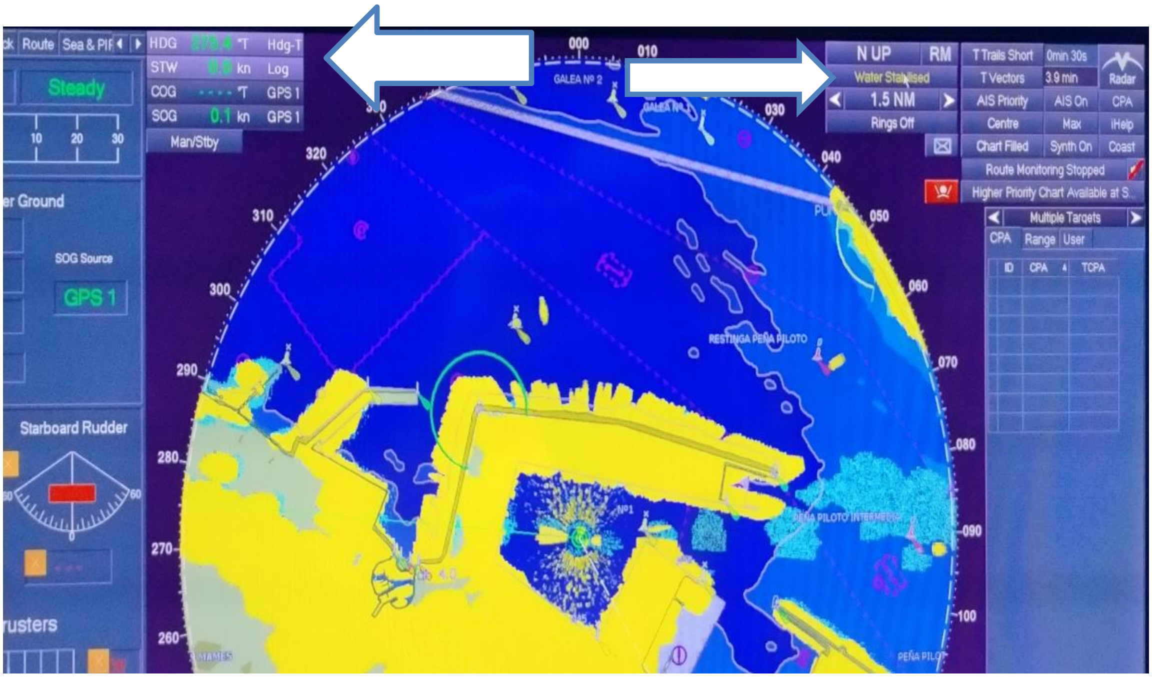


Figure 14: RADAR picture that show differences between vessels' location and their AIS (The Resilient Navigation and Timing Foundation, 2018).

2.6 The usage of Radar

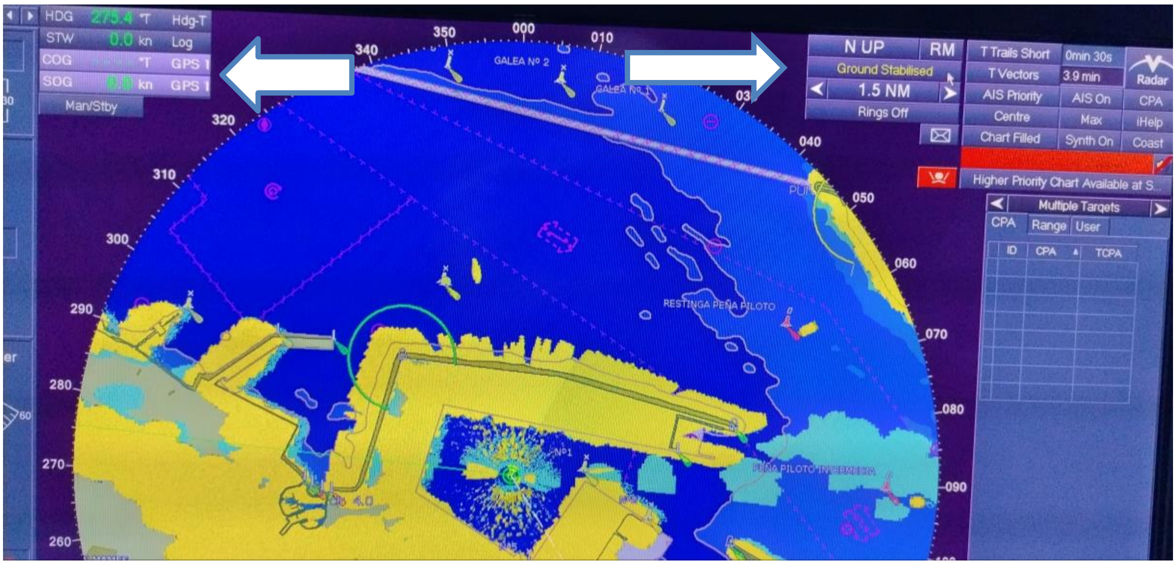
Radio, detection and ranging (radar) the main navigation equipment onboard vessels that assess in position fixing, traffic management and collision avoidance. The first version of marine radars was only available in relative motion, and it was called "Radar assisted collision". Then true motion was introduced and has been a preferable display among navigators. This is due to its presentation which matches the vessels' actual movement in accordance with each other and their surroundings. Having this compliance with the paper chart, the term "Anti-collision radar" was established. (Johansson, 2020).

There are two different modes for the radar, Water Stabilized and Ground Stabilized. Figures 15 and 16 Illustrate how to switch between these different modes on the RADAR screen. Each of the modes has its own sensor input sources as shown in figure 17 and 18. Figure 19 indicates the sensors that determine the position and whether the system is taking it from GPS1, GPS2, Dead reckoning, through Line of Position (LOP) or manually input.



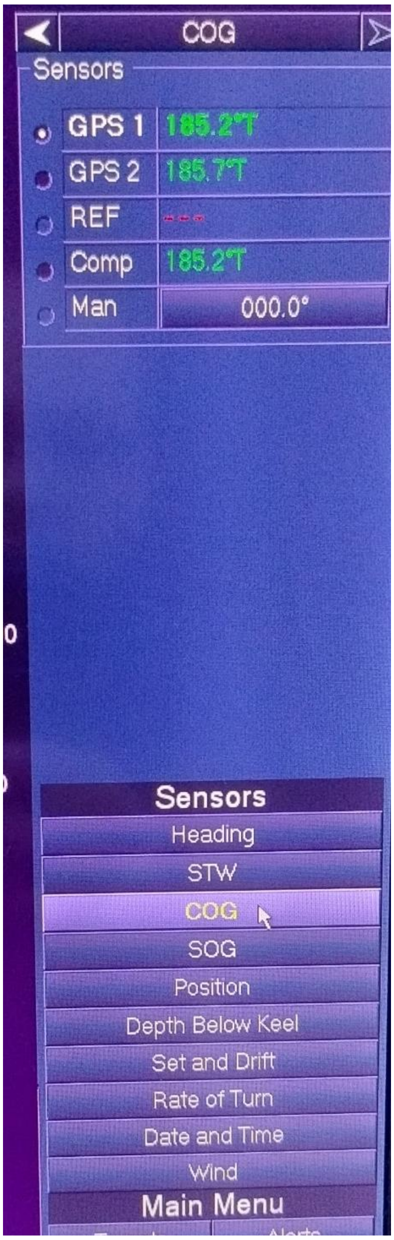
HDG 275.4 °T Hdg-T
STW 0.0 kn Log
COG - - - - °T GPS 1
SOG 0.1 kn GPS 1
N UP RM
Water Stabilised
1.5 NM
Rings Off
SOG Source GPS 1

Figure 15. RADAR picture that shows the Water Stabilized option and its sources HDG and STW.



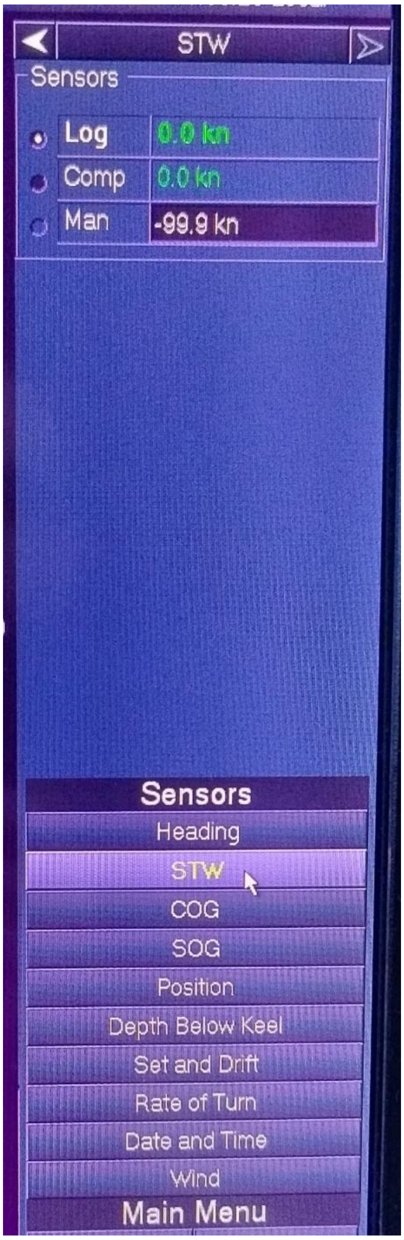
HDG 275.4 °T Hdg-T
STW 0.0 kn Log
COG - - - - °T GPS 1
SOG 0.0 kn GPS 1
N UP RM
Ground Stabilised
1.5 NM
Rings Off

Figure 16. RADAR picture that shows the Ground Stabilized option and its sources COG and SOG.



GPS 1 185.2°T
GPS 2 185.7°T
REF ---
Comp 185.2°T
Man 000.0°

Figure 17. COG sensor



Log 0.0 kn
Comp 0.0 kn
Man -99.9 kn

Figure 18. STW sensor

GPS 1 43°21.337' N 003°03.792' W Differential
GPS 2 43°21.337' N 003°03.792' W Differential
DR 43°21.337' N 003°03.792' W
LOP --- ---
Man 00°00.000' N 000°00.000' E

Position Offset
Sensor GPS 1
Range 0.0 m

Figure 19. Position sensor

2.7 Utilization of the heading information

Understanding the information sources for the heading line and vector line are crucial to assess navigation and for the OOW to take decisions. Heading line is connected to Gyro, and it shows where the ship's bow is pointing, while vector line is a graphical presentation of the vessel's future position based on its course and speed. Vector line can present either course over ground (COG) or course through water (CTW) depending on the speed source. CTW is the movement of the vessel relative to the water with speed input from the Log and is presented with one arrow vector as presented in figure 20. COG is the movement of the vessel relative to the seabed with speed input from the GPS and is presented with two arrows vector as presented in figure 21.

Figure 20: CTW vector

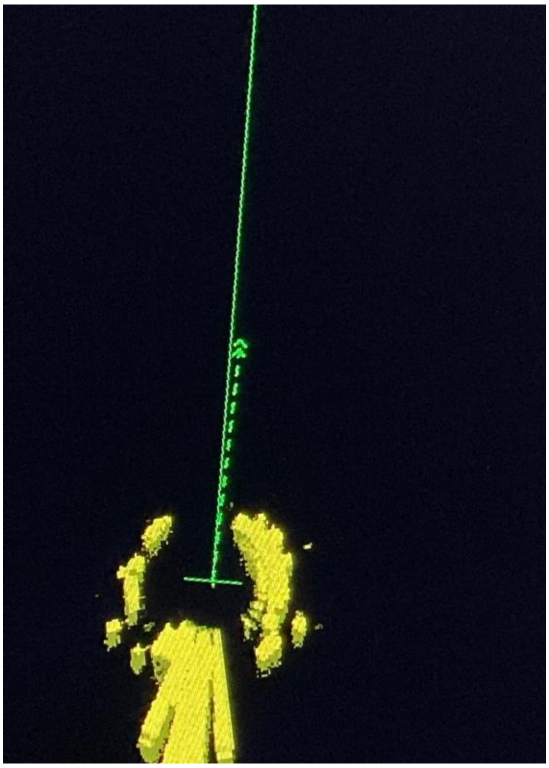
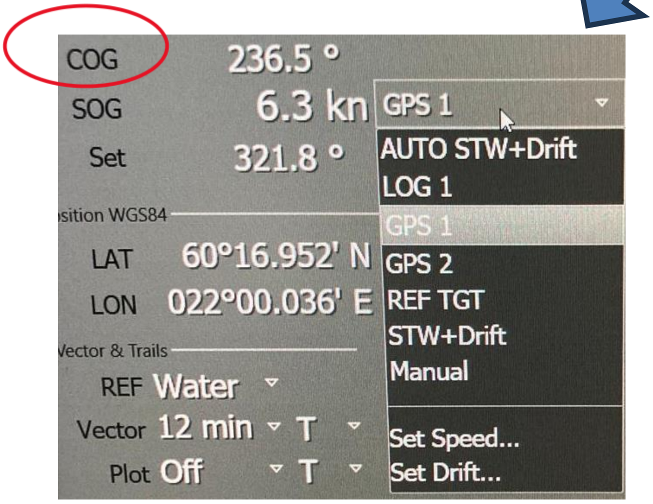


Figure 21: COG vector

On new modern integrated bridges as showed below (figure 22 and 23), it is also possible to have COG without the GPS input. This is achieved by having speed input from the Doppler log (ground track), calculation of STW+ drift or a reference target.



COG 236.5 °
SOG 6.3 kn GPS 1
Set 321.8 °
sition WGS84
LAT 60°16.952' N
LON 022°00.036' E
ector & Trails
REF Water
Vector 12 min T T
Plot Off T T

Figure 22. different SOG sources to get COG

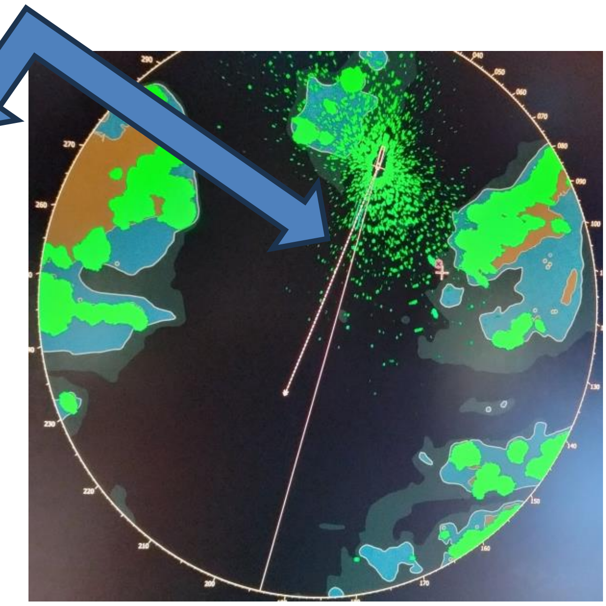


Figure 23. Heading line and vector line

In the case of GPS disturbances, the GPS signal is degraded, wrong or completely lost. Thus, the GPS input sensor cannot be used. It is necessary for the OOW to know the substitute input sensor, and whether it needs to be changed manually or does the integrated bridge change it automatically.

2.8 The usage of Autopilot

Autopilot is the most steering equipment relied on by the OOW as it assists in navigating and monitoring. It also increases the efficiency of executing. There are three steering modes for the autopilot, heading mode, course mode and track mode.

Heading mode is the most convenient option when it comes to the GPS disturbance. When using the Heading mode, there is no relying on GPS data but rather on the heading of the ship (where the bow is point) and that is dependent on the Gyro compass. The Course mode and Track mode do rely on GPS data input, and they are unreliable in case of GPS disturbances. On some integrated bridges, it is possible to use the course mode if the autopilot is fed with ground track information from the Log. Therefore, consulting the manufacturers manual is the safest way to determine the possibility of using course mode in case of GPS disturbances.

2.9 Automatic Identification System and AIS spoofing

AIS is a navigation aid system and a vessel tracking system that was introduced to the maritime sector from aviation (Helcom, n.d.). It assists navigators in having better situational awareness of their surroundings as well as the vessel traffic service (VTS) on keeping track of the vessels.

The AIS is classified into two types, type A and type B. Type A is for all vessels which are 300 GT and above as mandated by SOLAS V/19.2.4. Type B is for non-SOLAS vessels such as pleasure crafts. When fitted onboard ships, AIS transmits static data which reveals the identity of the ship, dynamic data that indicates ship's position and heading and voyage information such as ETA and vessel's draught. (Bhattacharjee, 2024).

Having these characteristics, AIS comes with limitations such as the possibility of turning it off and the overreliance on it by officers of the watch (OOW). This overreliance on AIS is dangerous and could lead to wrong decisions and misleading evaluation of the situational awareness. An example is the accident which took place in 2018 between a gas carrier and a container vessel. One of the main reasons which led to the accident was the complete relicense on AIS for course alteration done by the gas carries master (The Nautical Institute, 2023).

AIS gets position information from GPS and reports its location to the other navigational equipment such as ECDIS and RADAR. In case of GPS disturbance and the GPS signal is wrong or drifted, it will consequently affect the AIS symbols on the RADAR and ECDIS. This can lead to false target ships' position on ECDIS and a separate target from its echo on the RADAR screen.

Another challenge that is faced by the OOW is AIS spoofing. AIS spoofing means that vessels intentionally represent themselves falsely. This misrepresentation can be in the identity of the vessel, the location, the destination or the whole sailing route. Vessels that are involved in AIS spoofing are covering their activities such as illegal fishing, piracy, overstaying in anchorage areas and carriage of cargo which are under sanctions (Schuler, 2022). It is also used by the dirty vessels which are under legal restrictions to cover their activities under the names of clean vessels or even under the name of scrapped vessels.

The existing of this phenomenon misleads and may affect the OOW’s traffic situational awareness. This is due to the fake AIS symbol which can appear without the actual vessel (has radar echo) or an actual vessel (with radar echo) that may appear from nowhere with no identity or manipulated identity. Therefore, awareness of this matter and utilization of the RADAR is a must in enhancing safe navigation.

2.10 Dead reckoning

Maritime navigation has evolved throughout history, shifting from ancient methods towards electronic navigation. These earlier approaches involved celestial navigation, piloting and dead reckoning. Celestial navigation is based on the observation of the celestial bodies in the sky and the usage of instruments such as the sextant. Piloting is a navigation based on observations such as landmarks and seabed soundings. Dead reckoning is a position fixing technique that relies on the last known position (point of departure) of the ship, speed, its heading and time intervals. (Britannica Kids, n.d.).

Dead reckoning hasn’t been in appliance by navigators due to the presence of the GPS and advanced technologies which offer easier and faster ways in obtaining position. Due to the GPS disturbances or if the GPS signal is considered degraded or unreelable, then a dead reckoning navigation is established. When applying Dead Reckoning, it is important to select the (point of departure) by the most reliable fix available. An example, by RADAR and landmark if applicable.

Dead Reckoning doesn’t consider the effect of the wind and drift, and they would need to be applied separately. When using Dead Reckoning, the speed input comes from ship’s speed log, and it is speed through water (STW) as the officer of the watch (OOW) can’t rely on the Speed Over Ground (SOG) that comes from the GPS in case of GPS disturbances.

Here is an example on how to conduct a GPS drill and apply the dead reckoning onboard. A simulation of position sensor loss by Captain Tymur Rudov, published on YouTube on 18.01.2020 (Rudov, 2020).

This video demonstrates crucial actions for navigating when GPS signals are lost. This leads to a stressful situation for the OOW. Firstly, it shows how to switch between two onboard GPS receivers when one fails, emphasizing the importance of quick action and familiarizing the bridge team with this procedure to ensure safety, especially when approaching narrow water areas. Secondly, the video addresses a complete loss of GPS signal, potentially due to widespread outages, at which point the vessel must switch to dead reckoning (DR) mode on the ECDIS. This involves manually inputting the ship's last known position, course from the gyro compass, and speed from the speed log, while continuously verifying the estimated position with visual or celestial observations. The demonstration highlights the necessity for OOW to always be prepared to navigate without GPS. The simulation effectively prepares the OOW for real-life alarm situations across different equipment, fostering familiarity and improving their response in critical situations.

3 Research methodology

To address the research questions (see subchapter 1.2), the author has implemented a qualitative research methodology, supported by a comprehensive review of relevant literature and scholarly articles. This approach aims to help readers develop a deeper understanding of the safety-related aspects of the topic. Data collection involved conducting interviews with officers of the watch (OOW), alongside gathering material from credible sources, including Finnish maritime officials and industry professionals.

The data is collected from official websites such as Furuno manufacturer, educational material including pictures, official information sources such as TRAFICOM and the Finnish Coast Guards´ given interviews in Finland is consolidated in this research. Navigational Books like Ship Navigation (Wallin, 2016) and NAV Basics (Khalique, 2009) have been consulted for the understanding of the related topic.

By analysing the inputs and outputs that impact the GPS fed equipment, we can improve the capability of the officers of the watch OOW on how to recognize and mitigate the faults. Experimental simulations were conducted by the author in order to obtain informative illustrations on how the GPS disturbance scenario would look like on the Radar and ECDIS of the ship in a costal water area and what to be done to navigate safely out of the situation.

Furthermore, the research explores the current knowledge in the field and explaining how to mitigate the GPS disturbance, how to practice and apply dead reckoning with a simulation of position sensor loss. In the absence of paper charts, it is important to understand how to use the dead reckoning feature of ECDIS without GPS sensors.

OOW from different ranks in various ship types have been selected to interview. The research sample includes one senior officer, two mid-level experienced officers and four junior officers. The interviews involved 7 officers of the watch (OOW). The choice of officers is important to this study as this research questions the officer’s ability to recognize and mitigate the GPS faults. The purpose of these questions was to evaluate the officer's understanding of the necessary knowledge needed for mitigating GPS disturbances. Interview questions aimed at testing the officer’s awareness of the phenomena, their perceived seriousness of it and at identifying the different methods used in fixing ships position, their intervals and how positions were crosschecked during the watch. Research questions are available in Appendix 1.

Interviewed officers were working on different ship types in the Baltic Sea 2024, categorially, general cargo, bulk carrier and tankers. The sailing areas were the Gulf of Finland, the Gulf of Gdansk, the Gulf of Riga, the Danish Straits, the Kattegat and the North Sea. Interviews included the questions regarding OOW experiences of GPS jamming and their mitigation strategies. OOW were also asked if they are able to differentiate between jamming and spoofing. The interview included a spoofing scenario that is more complicated to recognize as it may happen without any sounding alarms.

As this research also aims to increase awareness of GPS disturbances, interviewees were told about officials’ warnings and the last joint statement by IMO, ICAO and ITU (See Appendix 1). In addition, they were given the following regulations to read and reflect on during the time of the interview:

1) Annex 24 RESOLUTION MEPC.136(53). Designation of the Baltic Sea area as a particularly sensitive sea area. (Appendix 1)

2) RESOLUTION MSC.138(76). Recommendation on navigation through the entrances to the Baltic Sea. (Appendix 1)

3) SOLAS Regulation 24-Use of heading and/or track control system. (Appendix 1)

At the end of the interviews, interviewees were asked what they think about the severity of GPS disturbances and if they wish for further studies, drills or guidelines that would increase their competence in handling GPS disturbances. It was also important to find out the measures taken onboard ships to cope with this challenge.

4 Analysis

Analysing the interviews is based on different themes: Recognition and mitigation, understanding of the information sources, the impact and awareness of GPS interference on navigation, jamming or spoofing in addition to the differentiation between a GPS error or Gyro error. The OOW are divided into three different groups based on their experiences.

1) Senior officers (Over 10 years of experience). **S1**
2) Mid-level officers (2-10 years of experience). **M1** and **M2**
3) Junior officers (Below 2 years of experience). **J1**, **J2**, **J3** and **J4**

4.1 Recognition and mitigation

This study included seven Officers of the Watch (OOW) who sailed the Baltic Sea in 2024, with working experience ranging from several months up to 22 years. The research sample consisted of one senior officer, two mid-level officers and four junior officers.

4.1.1 Officers who experienced the disturbance

The majority (four out of seven, **S1**, **M2**, **J3**, **J4**) had encountered GPS disturbances, which presented in various ways:

- Degradation of signal accuracy indicated by a colour change of the position's coordinates (green to red) and associated alarms.
- Sudden bridge-wide beeping from all the equipment that are having GPS input due to the complete loss of GPS data.
- Vessel's complete position shifting from sea to land.

When the officers of the watch (OOW) were questioned about their reactions to and mitigation of GPS disturbances, their sailing experience revealed an impact on their approaches. Demonstrating their actions, the two most experienced officers **S1** followed by **M2** have confidently and competently recognized and mitigated the GPS disturbance, continued their navigation dependent on the radar and other navigational aids. This high level of competence was not only due to the vast working experience, but also an outcome of hands-on practice with different navigational tools throughout sailing life including the usage of paper charts and different methods in obtaining the position of ship. Below is a quote from the senior officer's **S1** interview:

> Once I realized the GPS disturbance, I considered EDCIS to be unreliable. My first action was that I removed the electronic navigational chart (ENC) of the RADAR, to get a clear picture. Secondly, I compared Gyro 1 and Gyro 2 repeaters to be sure that they are the same and to eliminate the possibility of Gyro error. Thirdly, I disconnected GPS1 and GPS2 sensors and steered water stabilized mode with the Log sensor. Fourthly, I had ECDIS on DR and took more frequent fixes by Radar in interval of 10 minutes and I called the helmsman in addition to watchman to the bridge.

In contrast, officers with less sailing experience **J3** and **J4** who have started their career mainly using ECDIS and have a higher reliance on GPS found themselves confused and in a stressful situation which led to calling of the captain to the bridge. Afterwards the OOW **J3** have been wondering if he should have used the GPS device fault and self-test function to solve the problem. OOW **J4** expressed the situation by saying **"***All the equipment which are connected to the GPS were suddenly beeping and even my VHF-DSC was not working. The only way to get my VHF-DSC device to work was to enter my position manually***"**.

4.1.2 Officers who haven't experienced the disturbance

As the study examined all the interviewees' capabilities in recognizing and mitigating the GPS disturbances, officers **M1**, **J1**, **J2** have associated fault recognition primarily with GPS related alarm. According to **M1** and **J1** the mitigation would have been inadequate and wouldn't have solved the problems, as **M1** expressed **"**I will just shut down the GPS and all the problems and alarms would stop**"** and **J1** expressed **"**I will switch from GPS1 to GPS2**"**. On the other hand, **J2** has openly said that she doesn't know and would immediately call the captain to the bridge.

4.2 Understanding of the information sources

Furthermore, this study tested the OOW understanding on the following navigational equipment which is essential to establishing mitigation strategies.

4.2.1 The usage of Autopilot

As above mentioned in the theoretical foundation, heading mode is safest mode which is possible to use in case of the GPS disturbance. This study asked all OOW in which steering mode they normally navigate and which mode they would consider using in case of GPS disturbances.

The majority, five out of seven, are using course mode or track mode for normal steering. In case of GPS disturbances **S1** and **M2** were the only ones who said that they will use Heading mode while the rest said that they are unsure of the correct mode. **M1** and **J4** have said that "*Maybe I can use manual steering*".

On questioning the OOW about the speed source of their autopilot and if they know how to check it. Only **S1** knew the speed source of their ship's autopilot and how to check it. **M2** said that the source of their ship's autopilot is GPS but were unsure on how to check it or change it. **M1** has demonstrated the understanding of different sources of speed but was unsure about which one is in use and how to change it. The rest of the respondents have clearly said that they don't know, or they don't have information about this.

These results indicates that there is a significant lack of consensus regarding the source of information behind each steering mode and the speed sources.

4.2.2 The usage of RADAR

This research has revealed that **S1** and **M2** have the understanding and ability to change the information sources sensors that come to the RADAR, for example to switch from ground stabilization to water stabilization and its relevant sensors. In order to mitigate the GPS disturbance, they switched from GPS sensor to Log sensor.

4.2.3 The utilization of ship's heading information

While navigating and altering courses, navigators' eyes are connected to the heading line and Vector Line to control and predict the movement of the ship. The OOW were questioned on the information sources behind these two lines and what they should do in case of a GPS disturbance. **S1** and **M2** were the only participants who identified them correctly and showed the possibility of changing the information source of the vector line (from GPS to Log). **J2** and **J4** have identified the Gyro as the information source of the Heading Line while they were unsure about the Vector Line nor the possibility of changing its information source.

The rest of the participants, **M1**, **J1** and **J3**, express uncertainty about the sources of the heading line and vector line in their answers.

4.2.4 Connectivity and integration

Referring to chapter 2, the understanding of the integrated bridge and how the equipment is connected is very important for the OOW to determine the correct sensor for the specific situations in navigation. Modern navigational bridges come with automatic shifting between sensors. This research asked all its participants if they are aware of such connectivity and whether they have checked or know what the primary sensors and secondary sensors are in their ship's navigational equipment. The senior officer **S1** was the only one who was capable of and demonstrated his knowledge.

4.3 The Impact and Awareness of GPS Interference on Navigation

Interviewees were told that there have been vessels which deviated from their intended tracks in addition to one grounding accident that took place in the Baltic Sea in December 2024 (The Maritime Executive, 2025). Participants were asked to rate the perceived seriousness of the problem on a scale of 1 (not serious) to 10 (highest seriousness, potentially leading to an accident).

Most OOWs linked the seriousness to their ability to recognize and mitigate the issue. On average, the seriousness was rated 6 (moderate) when the OOWs had the adequate knowledge, rising to 9 (very high) if they lacked the necessary recognition and mitigation skills. Only one OOW said that it is not serious and challenged his answer based on his trust in the pilot's knowledge of the area and the expected call from vessel traffic services (VTS) in case the ship deviates off track.

OOW were aware of the Baltic Sea area as a sensitive area and six of them have Acknowledged the existence of risk to the environment in case of an accident that may be caused by GPS disturbances.

The GPS disturbance has caused confusion and uncertainty specifically among junior officers. It has also caused interruption for a whole vessel operation as one of the interviewees expressed. An important finding was that not all Officers of the Watch (OOWs) had received GPS-specific drills. Participants expressed a need for practical, onboard drills that could cover how to manage different equipment and respond during these incidents.

4.3.1 Equipment potential

The revised chapter V of SOLAS obligates shipping companies and masters to consider the full potential of the new and improved navigation equipment when navigating in specific water narrow areas. Four of the participants have navigated in the entrances to the Baltic Sea while the master present on the bridge. All the officers were given the following scenario:

"You are navigating in a narrow water area, and suddenly you lose the GPS. Would you be able to react independently? Do you exactly know what you are supposed to do with ECDIS, RADAR and the other navigational tools?"

Only **S1** answered with yes! I am fully aware and capable to do that, while the rest have said; they don't know. None of the interviewees have received a specific familiarization regarding how to deal with the navigational equipment such as ECDIS, due to the disturbances and loss of the GPS.

The OOW were asked on their position fixing techniques. According to the officers, the main method used to determine the position was GPS with intervals of two hours in the open sea. Position was also plotted before the course alteration and before entering the Traffic Separation Scheme (TSS). Near the coastal area, RADAR bearings were used when applicable. Only two of the interviewed officers were using paper charts in their job while the rest were using the electronic chart display and information system (ECDIS).

In assessing the OOW utilization of backup equipment, they were questioned regarding their use of the speed log and echo sounder. It was found that only two OOW have switched to the speed log when they couldn’t relay on the GPS signal. However, none of the OOW have used the echo sounder for navigation.

4.3.2 The navigational area

SOLAS regulation 24 as attached in appendix 12 does apply in areas of high traffic density, in conditions of restricted visibility and in all other hazardous navigational situations where heading and/or track control systems are in use.

Participants were asked if they would consider having the helmsman available on the bridge during their watch in areas in the Baltic Sea where GPS disturbance is assumed. OOW **S1**, **J2**, **M2**, **J3** and J4 have said yes, they would consider.

They were also asked if they switch between heading and/or track control system and manual steering during their watch. Only **S1** and **J2** said that they switch to manual steering at the beginning of their watch while the rest don’t switch between heading and/or track control system and manual steering.

OOW were asked also if they consider the Baltic Sea as hazardous navigational area and whether they think the SOLAS regulation 24 applies. All of the OOW except **M1** replied that they would consider the above-mentioned SOLAS regulation to be applied while navigating in Baltic Sea area.

4.4 Jamming or spoofing

All the OOW were aware of the jamming and the majority have experienced it as indicated in the above-mentioned subchapter 4.1. However, the spoofing was an unfamiliar term, and participants didn’t know what it meant. The interviewees were asked how they would react in the scenario mentioned in appendix 1. In this scenario, OOW said that they would confirm ship’s position by radar and compare to the GPS to clear the doubt of their position.

4.5 GPS error and Gyro error

There are some similarities between GPS and Gyro error when it comes to looking at the RADAR overlay information such as inaccuracies between the AIS targets and their echoes. Five OOW said that they can differentiate between the GPS error and Gyro error, while two junior officers said that they don’t know how to differentiate nor what actions need to be taken to solve the Gyro error.

Four OOW in this study have said that they would mitigate gyro error by changing to manual steering. While the rest could not explain if the autopilot should be used or manual steering in case of gyro error.

5 Discussion

Modern maritime operations are fundamentally dependant on technology’s crucial role, as it is the key factor for efficiency and the global chain flow. Despite this importance and reliance, these maritime operations periodically encounter challenges including pandemics and technological challenges such as GPS disturbances.

The importance of GPS in maritime extends far beyond fixing a ship's position. Its critical role is demonstrated by its deep integration with numerous onboard equipment, offering not only precise positioning, but also navigation and timing. This deep integration into various systems has made modern navigators highly reliant on GPS, driven by its high precision, proven reliability, and user-friendly interface.

As with all technologies, GPS is prone to vulnerabilities and problems. This research has studied the impact of GPS disturbances onboard ships. Its findings were not only that there is a gap in knowledge on how to deal with the equipment and the lack of understanding of the information sources behind them, but also a very high dependence that can lead to a whole operational interruption.

Given these facts, GPS which belongs to the modern electronical navigation is only one of the several navigational methods alongside to the celestial navigation, piloting and dead reckoning. Modern electronical navigation incorporates also the radar, which comes with enormous abilities forgotten or overshadowed by the modern technologies such as ECDIS and GPS.

A significant navigational technique in RADAR is the parallel indexing lines that have existed for decades. Parallel index lines assist navigator to monitor ship’s intended track, maintain safe distance to navigational hazardous objects, assess risk of collision (without the ARPA) and as a course deviation alert. This RADAR technique is distinguished by its complete independence of the GPS positioning system. RADAR can produce several index lines such as the zero index line, which can be used as a marking line for steering. (The Nautical Institute, 2021). Furthermore, RADAR provides additional capabilities, such as the VRM and EBL which they can assist in navigation and course alterations.

Out of this research sample there were a senior officer **S1** and mid-level experienced officer **M2** who demonstrated and emphasised the importance of RADAR navigation. The below figure 24 demonstrates a situation where the GPS signal is disturbed in a narrow water area, which can be observed by separation between the ENC and the echo that represent the islands on the RADAR. Figure 25 is an example of applying PIL in a combination with a fixed VRM and EBL to steer the ship and conduct the turn visually.

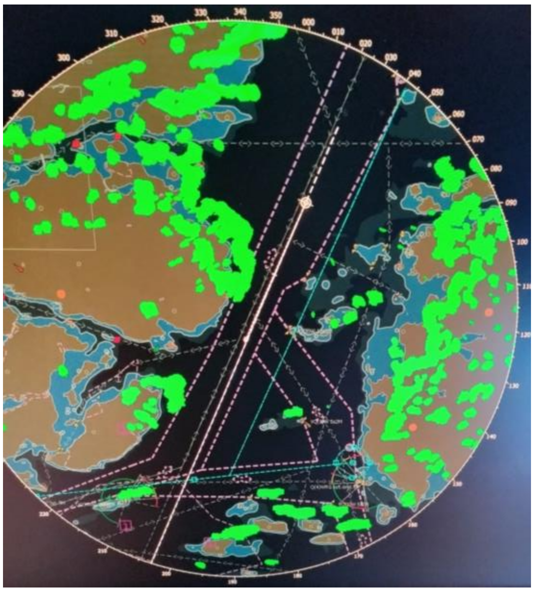


Figure 24: The GPS when observed

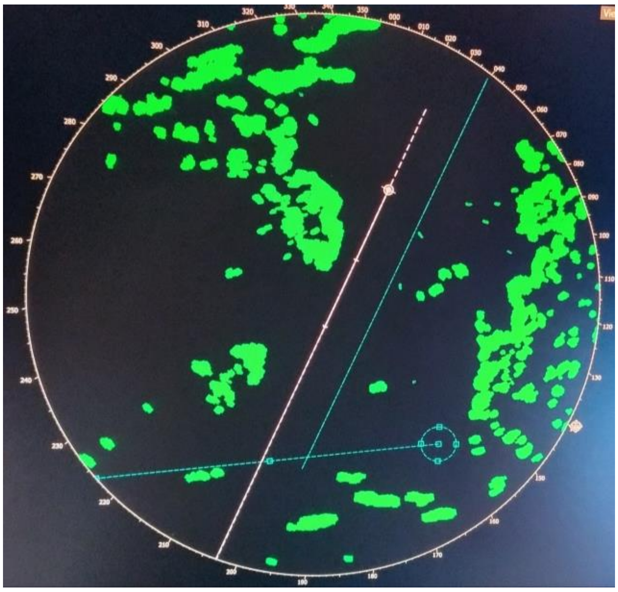


Figure 25: Applying the PIL and fixed VRM&EBL

This research has revealed an observable difference between officers' views and capability in applying ECDIS features with **S1** and **M2** demonstrating greater confidence, influenced by their prior working experience with paper charts

ECDIS offers a real time simulation which leads to the increase of the situational awareness. The unintended consequence, however, is that navigators have grown gradually dependent on it.

ECDIS is sensor-based equipment that is dependent on the speed, heading and position information sensors. Its main vulnerability is that if there is malfunction to any of its sensors, it will affect the whole presented picture, its orientation and could create a false situational awareness to the navigator. (The Nautical Institute, 2021).

Activating the DR mode on ECDIS means that ECDIS loses its GNSS sensor and calculate the position internally based on a valid last position in addition to the heading and speed information. With ECDIS, it is also possible to derivate the Lines of Position (LOPs), obtain bearings, and bearing transfers.

Applying these features electronically, seems like a challenge to navigators who are less familiar with the handling of the paper charts which requires a more practical use of the paper chart or an extra familiarization with ECDIS.

Below figure 26 is to illustrate an inbound situation where the GPS signal is disturbed (The echo and ENC are separated as well as the vessels and their AIS symbols are separated from each other). Figure 27 is after removing the ENC to have a clear picture and taking two bearing with the EBL to two different islands with RADAR. These two bearing were transferred from the RADAR to ECDIS (after the DR mode is applied) to fix the position of the ship and get the estimated position as in figure 28.

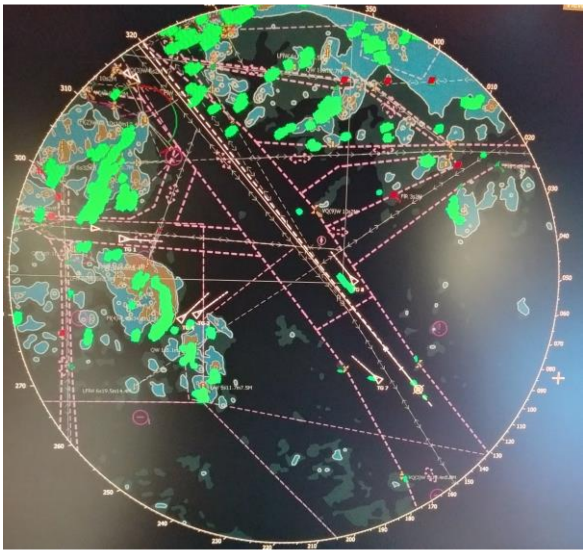


Figure 26. Inbound situation

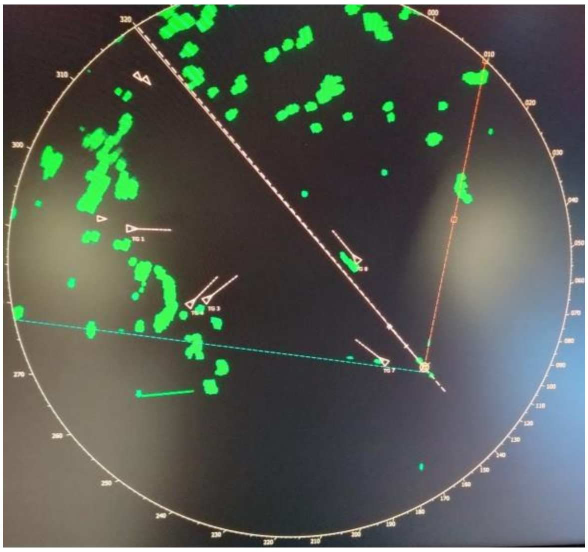


Figure 27. Applying the bearings to islands

Figure 28. Transferred bearings from RADAR to ECDIS and getting EP fix

In contrast, interviewee **J4**, who primarily used ECDIS as junior officers and encountered GPS disturbances on a vessel where both ECDIS and paper charts exist, expressed relief upon successfully fixing their ship's position using a paper chart. For **J4**, the paper chart offered a solid and trustworthy tool to locate ship’s position. This emphasizes the relevance of paper charts even in the availability of ECDIS.

Obtaining the fix (position) of the ship with other means than the GPS is vital especially during GPS interferences. The fix is a result of a minimum two terrestrial observation or measurement taken at the same time. There are four principles of observation that can be used for determining the fix. The range, direction given by compass (bearing), difference in bearings and difference in ranges. (Wallin, 2016).

This research results that the main navigation equipment to fix position is the GPS. All of the participant’s except **S1** and **M2** were using mainly a combination of a bearing EBL and range VRM. **S1** and **M2** have applied other methods such as difference in bearings.

In terms of equipment utilization, the research highlighted that the majority were unaware of neither the information sources behind different equipment modes such as the autopilot modes and radar’s different stabilizations or the speed sources behind them. It is recommended that to foster the critical thinking, question the reason for doing the things instead of only doing them.

Other equipment such as the speed log was utilized by the minority of the OOW. A speed log with single axis can offer speed through water (STW). Speed log with multi-axis can offer both speed through water (STW) and speed over ground (SOG). SOLAS, chapter V, regulation 19 2.2 that applies on vessels of 50 000 gross tonnage and above states that: "*a speed and distance measuring device, or other means, to indicate speed and distance over the ground in the forward and athwartships direction* ". Therefore, practicing and usage of this equipment efficiently can increase the dependency on the GPS.

Echo sounder should be used as a tool of navigation among other, its capabilities were not being used. STCW chap VIII, section A-VIII/I 36 clearly states that: "*Officers of the navigational watch shall be thoroughly familiar with the use of all electronic navigational aids carried, including the capabilities and limitations, and shall use each of these aids when appropriate and shall bear in mind that the echo-sounder is a valuable navigational aid*".

Learning the errors is a method to avoid errors. This study's focus was to ask about the observations and mitigations of GPS errors. Participants were also asked about the differentiation between the GPS and Gyro errors. Despite the majority's uncertainty regarding Gyro error mitigation, participants appeared more confident in identifying it. This is due two independent gyros on the ship which is possible to compare between them or due to the possibility of comparing Gyro to the magnetic compass. The officers would have likely preferred onboard training including a differentiation between the heading and the position information for different equipment.

What comes in common between the GPS error, Gyro error and with AIS spoofing incidents is that all of them include a separation between the echo of the vessel and it's AIS targets. This interrupt OOW's situational awareness with the surroundings and can lead to navigational hazardous situations. Therefore, understanding the different errors is vital to recognize which error is being dealt with and apply the correct mitigations.

Based on this research, it is recommended that officers continue to use paper charts, understand their ongoing relevance in navigation. It is also crucial to employ the full capabilities of radar and to familiarize OOW with handling ECDIS in the absence of GPS sensor. Furthermore, this study suggests for obtaining position fixes through different methods, based on various terrestrial observations. It is also necessary to utilize all navigational equipment and the information sources behind them in addition to utilizing the speed log and echo sounder. Ultimately, conducting GPS drills onboard ships which simulate real life situations in order to understand the potential errors across all navigational equipment is essential for successful mitigation and maintaining situational awareness.

There are several technological solutions in the field. The International Association of Independent Tanker Owner (INTERTANKO) explains the countermeasures solutions in case of jamming and spoofing. (INTERTANKO, 2019).

6 Conclusion

This study concludes that there is a significant gap in knowledge among OOWs concerning how to recognise and mitigate GPS interferences onboard. Participants understood jamming interferences, but spoofing remained an unfamiliar concept to them. It is revealed that the minority of the officers can recognize and mitigate the disturbances, while the majority don’t know how to recognize or mitigate them effectively. This minority's capabilities are associated with their work experience including the usage of paper charts in navigation.

The study emphasizes that handling the GPS interference and safe navigation depends on OOW understanding of the equipment and the information sources behind them. It is also dependent on the utilization of the alternative navigation tools in addition to the understanding of equipment connectivity. When comparing OOW knowledge of errors, participants appeared to be more familiar with gyro compass errors than the GPS error.

It was also remarkable how little the speed log as a source of information was utilized in case of the uncertainty about GPS signal integrity. Critically, the echo sounder was not used to assess the position fixing by any officers during GPS disturbances, highlighting an underutilized resource.

There are different methods to fix the position of the ship, yet GPS remains the primary and preferable method in fixing ship’s position, even in the presence of GPS disturbances in the Baltic Sea. In addition to the GPS, radar's variable rage marker (VRM) and the electronic bearing line (EBL) were the main method used for positioning near coastlines and islands.

Almost all interviewees were aware of the severity of GPS disturbances, and they linked this severity directly to the ability of the OOW to recognize and mitigate such an event. Given these findings, there is a clear and urgent need for better training and education for OOWs on dealing with GPS disturbances. The interviewees have expressed a high need of a clear set of instructions to identify and mitigate GPS disturbances among other errors. The author has created a concise guideline in form of a flowchart as presented in appendix 2. This can help OOW to successfully identify and mitigate the errors.

This research highly recommends for regular drills that simulate GPS sensor loss onboard ships. This will help officers build their skills and confidence, ensuring they are fully prepared to handle the navigational challenges and enhance safe navigation.

Based on this study and its findings, this research recommends for the further research on the effect of GPS loss on the Global Maritime Distress and Safety system (GMDSS) devices and Officers of the Watch (OOW) capabilities in conducting operations and executing GMDSS drills without GPS.

On the other hand, automation, while intended to decrease workload, at once increases alarms and warning systems that can overwhelm OOW information processing capabilities. This raises a crucial question: Can OOW effectively reintegrate traditional navigational skills, that are now out of practice, while coping with automated complexities? This research investigates the impact of workload on human performance, aiming to identify the optimal balance between automated complexities and the OOW ability to reintegrate traditional navigational skills as illustrated in figure 29 (The Nautical Institute, 2015).

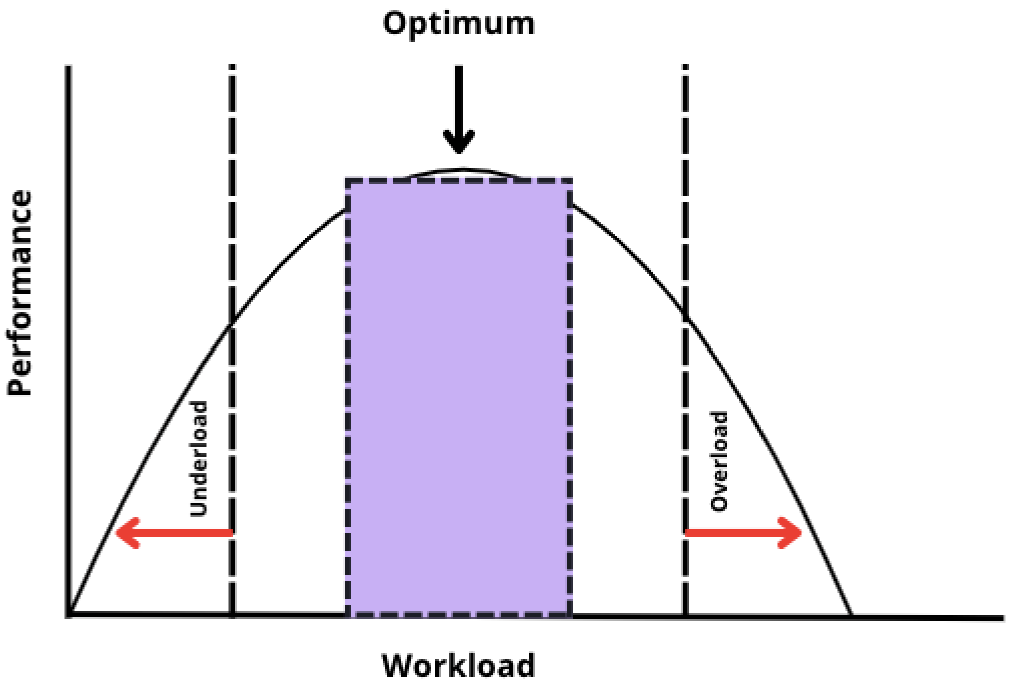


Figure 29. Workload: human performance curve (The Nautical Institute, 2015).

7 References

Bhattacharjee, S. (2024, 1 27). *Marine Insight*. Retrieved 5 10, 2025, from https://www.marineinsight.com: https://www.marineinsight.com/marine-navigation/automatic-identification-system-ais-integrating-and-identifying-marine-communication-channels/

Britannica Kids. (n.d.). *Britannica Kids*. Retrieved 5 20, 2025, from https://kids.britannica.com: https://kids.britannica.com/students/article/navigation/276043

Consortium, EarthScope. (n.d.). *Earth Scope*. Retrieved 3 17, 2025, from www.earthscope.org: https://www.earthscope.org/what-is/gps/gps-and-the-ionosphere/#:~:text=The%20ionosphere%E2%80%94a%20portion%20of,largest%20errors%20in%20GPS%20measurements.

Dr. Alan Grant, D. P. (2009). GPS Jamming and its impact on maritime safety. *porttechnology*, 39-41. Retrieved 3 26, 2025

EUSPA. (2025, 1 10). *EUSPA.* Retrieved 3 12, 2025, from www.euspa.europa.eu: https://www.euspa.europa.eu/eu-space-programme/galileo/what-gnss#:~:text=Global%20Navigation%20Satellite%20System%20(%20GNSS,GLONASS%20(Russia)

everythingRF. (2022, 7). *everythingRF*. Retrieved from www.everythingrf.com: https://www.everythingrf.com/community/what-is-rf-jamming

Executive, Maritime. (2025). *Maritime Executive*. Retrieved 4 3, 2025, from https://maritime-executive.com: https://maritime-executive.com/article/polish-researchers-detect-ship-based-gps-jammers-in-baltic-sea

FURUNO. (n.d.). *Furunousa*. Retrieved 3 4, 2025, from www.furunousa.com: https://www.furunousa.com/-/media/sites/furuno/document_library/documents/brochures/brochures/sc50_brochure.pdf

GNSS Science Support Centre. (2011). *GNSS Science Support Centre.* Retrieved 5 20, 2025, from gssc.esa.int: https://gssc.esa.int/navipedia/index.php/GNSS_signal

Government, Finnish. (2025). *Valtioneuvosto*. Retrieved 1 15, 2025, from valtioneuvosto.fi: https://valtioneuvosto.fi/en/maritime-policy#:~:text=Maritime%20transport%20is%20vital%20for,growth%20of%20the%20maritime%20cluster.

Goward, D. (2017, 7 11). *Maritime Executive*. Retrieved 4 5, 2025, from https://maritime-executive.com: https://maritime-executive.com/editorials/mass-gps-spoofing-attack-in-black-sea

GPS Gov. (2021, 5 24). *Official U.S. government information about the Global Positioning System (GPS) and related topics*. Retrieved 4 2, 2025, from gps.gov: https://www.gps.gov/systems/gps/modernization/sa/

GPS Gov. (2022, 6 28). *Official U.S. government information about the Global Positioning System (GPS) and related topics*. Retrieved 4 4, 2025, from gps.gov: https://www.gps.gov/systems/gps/space/

Gpsjam. (2025). *Gpsjam*. Retrieved 3 3, 2025, from https://gpsjam.org/: https://gpsjam.org/?lat=60.39226&lon=28.87456&z=3.4&date=2025-03-01

HELCOM. (2023). *State of the Baltic Sea-Third HELCOM holistic assessment 2016-2021.* Helsinki: Helsinki Commission – HELCOM. Retrieved 1 10, 2025

Helcom. (n.d.). *Helcom*. Retrieved 5 19, 2025, from https://helcom.fi: https://helcom.fi/action-areas/shipping/ais-and-e-navigation/

Helsinki Commission. (2009). *Helcom.* Retrieved 1 9, 2025, from helcom.fi: https://helcom.fi/wp-content/uploads/2019/10/Ensuring-safe-shipping-in-the-Baltic.pdf

History Timelines. (n.d.). *History Timelines*. Retrieved 3 15, 2025, from https://historytimelines.co: https://historytimelines.co/timeline/global-positioning-system-gps

IMO. (2000, 12 1). *IMO.* Retrieved 3 12, 2025, from imo.org: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.112(73).pdf

IMO. (2000, 12 1). *IMO.* Retrieved 1 2, 2025, from imo.org: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.112(73).pdf

IMO. (2002, FEB 5). *International Maritime Organization (IMO).* Retrieved 5 29, 2025, from https://wwwcdn.imo.org: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.138(76).pdf

IMO. (2005, 7 22). *ANNEX 24-RESOLUTION MEPC.136(53).* Retrieved 2 2, 2025, from imo.org: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.136(53).pdf

IMO. (2005, July 22). *International Maritime Organization (IMO).* Retrieved 5 28, 2025, from https://wwwcdn.imo.org: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.136(53).pdf

IMO. (2025, March 25). *IMO MediaCentre*. Retrieved 5 28, 2025, from https://www.imo.org: https://www.imo.org/en/MediaCentre/PressBriefings/pages/Joint-IMO-ICAO-ITU-statement-satellite-interference.aspx

INTERTANKO. (2019). *Jamming and Spoofing of Global Navigation Satellite Systems (GNSS).* INTERTANKO 2019. Retrieved 5 25, 2025

Islands, R. o. (2016, 4 29). *irclass*. Retrieved 1 2, 2025, from https://www.irclass.org: https://www.irclass.org/media/1211/technical_circular_no11-performance_standards_for_global_positioning.pdf

ITU. (2024, May 13). *International Telecommunication Unit*. Retrieved 5 22, 2025, from https://www.itu.int: https://www.itu.int/en/ITU-R/Documents/FAQs%20on%20GNSS%20Interference.pdf

Johansson, L. (2020, 2 22). *Maritime Executive*. Retrieved 5 3, 2025, from https://maritime-executive.com: https://maritime-executive.com/blog/how-radar-for-merchant-ships-developed

Kauranen, A. (2024, 10 31). *Reuters*. (A. Kauranen, Producer) Retrieved 2 25, 2025, from www.reuters.com: https://www.reuters.com/world/europe/finland-detects-satellite-navigation-jamming-spoofing-baltic-sea-2024-10-31/

Khalique, A. (2009). *NAV Basics.* Livingston: Witherby Publishing Group Ltd. Retrieved 2 16, 2025

NOAA. (n.d.). *National Ocean Service*. Retrieved 5 15, 2025, from https://oceanservice.noaa.gov: https://oceanservice.noaa.gov/education/tutorial_geodesy/geo09_gps.html#:~:text=It%20takes%20four%20GPS%20satellites,error%20in%20the%20receiver%27s%20clock.

Rudov, T. (2020, 1 18). *Youtube*. Retrieved 3 12, 2025, from https://www.youtube.com: https://www.youtube.com/watch?v=xaTFCJXVpBE

Schuler, M. (2022, November 10). *gcaptain*. Retrieved 5 11, 2025, from https://gcaptain.com: https://gcaptain.com/spire-global-launches-dark-shipping-and-spoofing-detection/

Shipping, International Chamber of. (n.d.). *International Chamber of Shipping*. Retrieved 1 1, 2025, from ics-shipping.org: https://www.ics-shipping.org/shipping-fact/shipping-and-world-trade-world-seaborne-trade/

The Maritime Executive. (2025, 3 6). *Report: GPS Jamming Sent Bangladeshi Bulker Aground in Baltic. The Maritime Executive*. Retrieved 5 16, 2025, from https://maritime-executive.com/article/union-bangladeshi-bulker-grounded-off-ust-luga-and-was-stuck-for-weeks

The Nautical Institute. (2015). *Human Performance and Limitation for Mariners.* London: The Nautical Institute. Retrieved 5 9, 2025

The Nautical Institute. (2021, 6 1). *The Nautical Institute*. Retrieved 5 16, 2025, from https://www.nautinst.org: https://www.nautinst.org/resources-page/parallel-indexing-and-lines-of-position-drawing-the-line.html

The Nautical Institute. (2023, Sep 23). *The Nautical Institute*. Retrieved 5 10, 2025, from https://www.nautinst.org: https://www.nautinst.org/resources-page/watchout-erroneous-ais-data-led-to-a-two-ship-collision-in-poor-visibility.html

The Resilient Navigation and Timing Foundation. (2018, 12). *US national PNT Advisory Board*. Retrieved 5 25, 2025, from https://www.gps.gov: https://www.gps.gov/governance/advisory/meetings/2018-12/goward.pdf

The University of Texas at Austin. (2013, JUL 30). *The University of Texas at Austin*. Retrieved 5 23, 2025, from https://news.utexas.edu: https://news.utexas.edu/2013/07/30/spoofing-a-superyacht-at-sea/

TRAFICOM. (2025). *Data.Traficom*. Retrieved 5 26, 2025, from https://tieto.traficom.fi/fi/tilastot: https://tieto.traficom.fi/fi/tilastot/satelliittinavigointipalveluiden-hairiot-suomessa

Wallin, B. (2016). *SHIP NAVIGATION.* The Netherlands: DOKMAR Maritime Publishers BV. Retrieved 2 16, 2025

YLE. (2024, 10 31). *Yle*. Retrieved 2 7, 2025, from yle.fi: https://yle.fi/a/74-20121555

List of figures

Interview Questions

Sailing Area-Experience

1) Have you been sailing in the Baltic Sea (2024-2025)? (Gulf of Finland, the Gulf of Bothnia, the Gulf of Gdańsk, Gulf of Riga and the Danish Straits and Kattegatt).
2) How many years of experience do you have as an officer of the watch (OOW)?
3) Have you been using a paper chart or ECDIS on your ship?

Experiencing the phenomena

1) Have you experienced a GPS disturbance during your watch?
    - If yes, how you were able to recognize it and how did you react/mitigate it?
    - If no, how would you recognize and react in case you face a GPS disturbance?
2) Do you know about GPS spoofing and what it is associated with?
3) Are you able to differentiate between the GPS disturbance and GYRO error?
4) Are you navigating with (ENS and RADAR top of each other) or do you use only a (clear RADAR picture, and you look separately on ECDIS)?

Technical part and mitigation

1) Which Autopilot mode do you usually use? (Heading, Course mode or Track mode). In case of a GPS disturbance, which mode will you consider using?
2) Which autopilot mode can use in case of Gyro failure, or can you use the autopilot?
3) What is the speed information source for your autopilot? And do you know how to check it? Or are there several sources of speed?
4) What is the heading information source for your heading line and vector line? And have you been checking if the vector line information source is changeable or is it unchangeable?
5) Have you used dead reckoning in navigation?
6) Have you obtained a position with terrestrial observations such as bearings and LOPs?
7) Have you obtained a line of sounding with Echo sounder, or did you utilize it to assist in fixing the position?
8) How often do you take a position of the ship? And by what means?
9) Have you obtained a position based on celestial observations?

Connectivity

1) Have you ever checked the level of your Bridge's Integration System? Or did you receive any familiarization about it?
2) Are you aware of the fall-back (primary and secondary sensors) system in your bridge?

Companies-Crew -Awareness

1) Have you gotten any guidelines or some form of education from your company on how to react in case of GPS disturbance?
2) Do you wish to receive courses or education on the matter (GPS disturbance)?
3) Have you recently noticed more leisure boats getting closer to your vessel? Or seem to be lost due to their possible GPS problem?
4) Do you have anything you recommend me to search, or you would like to read about in this research?
5) From 1-10, how serious do you think the GPS disturbance is? (*1=not serious at all,10=very serious and something needs to be done before an accident can happen*)

Scenario

You are in the middle of the watch during the night. Visually, you identify a lighthouse, yet you suspect the lighthouse closer than expected to be. However, the ECDIS shows that you are on track. What is your reaction?

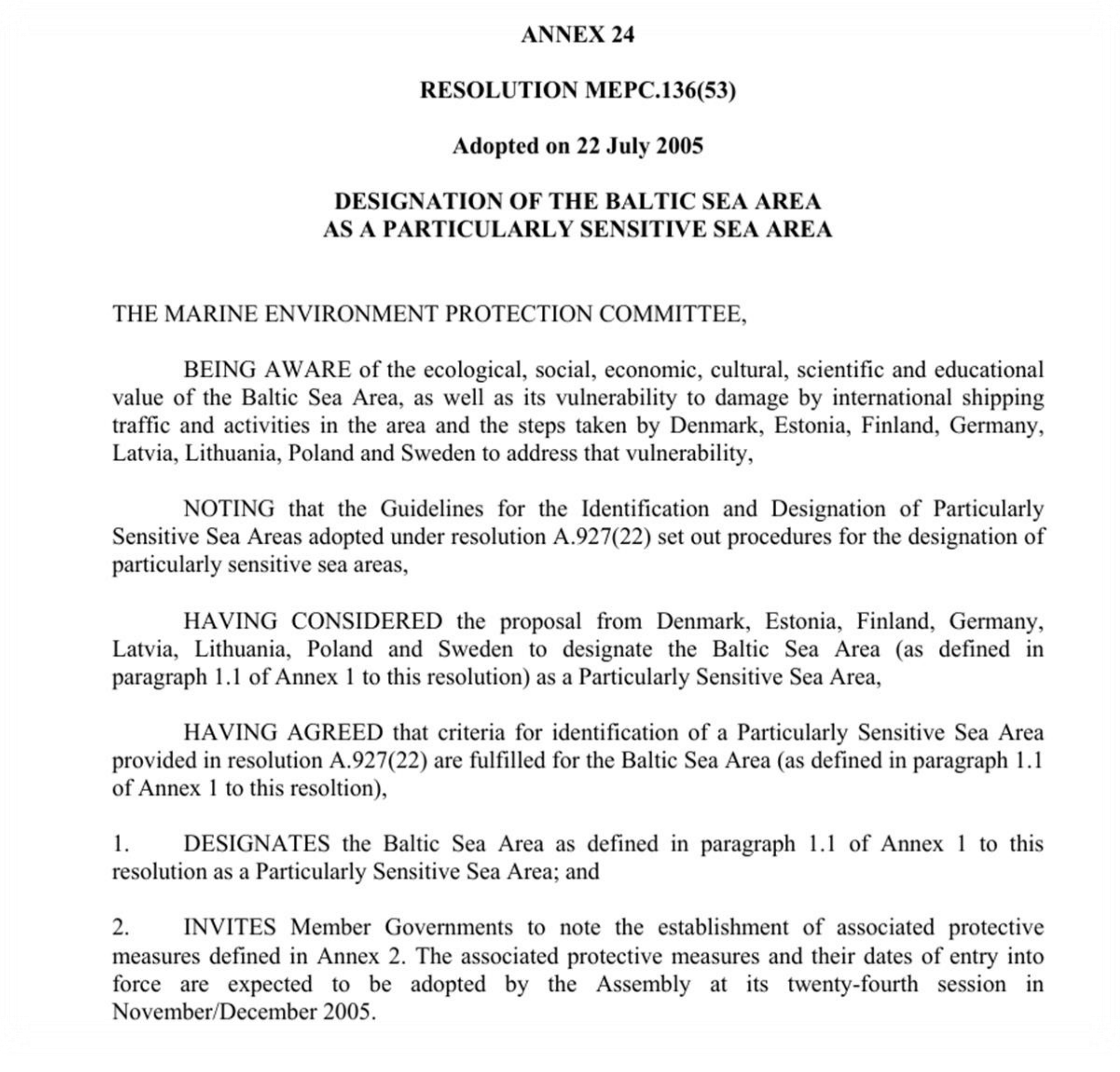
Appendix 1

Baltic Sea

The Baltic Sea area is a particularly sensitive area (Marine Environment) as illustrated in the IMO RESOLUTION MEPC.136(53) (IMO, 2005). Below are two facts:

- The Baltic Sea is a shallow Sea (average depth is 50 meters)

- Due to the GPS interference, a risk of collision/grounding exists and thus a risk for environmental damage.



ANNEX 24

RESOLUTION MEPC.136(53)

Adopted on 22 July 2005

DESIGNATION OF THE BALTIC SEA AREA
AS A PARTICULARLY SENSITIVE SEA AREA

THE MARINE ENVIRONMENT PROTECTION COMMITTEE,

BEING AWARE of the ecological, social, economic, cultural, scientific and educational value of the Baltic Sea Area, as well as its vulnerability to damage by international shipping traffic and activities in the area and the steps taken by Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden to address that vulnerability,

NOTING that the Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas adopted under resolution A.927(22) set out procedures for the designation of particularly sensitive sea areas,

HAVING CONSIDERED the proposal from Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden to designate the Baltic Sea Area (as defined in paragraph 1.1 of Annex 1 to this resolution) as a Particularly Sensitive Sea Area,

HAVING AGREED that criteria for identification of a Particularly Sensitive Sea Area provided in resolution A.927(22) are fulfilled for the Baltic Sea Area (as defined in paragraph 1.1 of Annex 1 to this resoltion),

1. DESIGNATES the Baltic Sea Area as defined in paragraph 1.1 of Annex 1 to this resolution as a Particularly Sensitive Sea Area; and

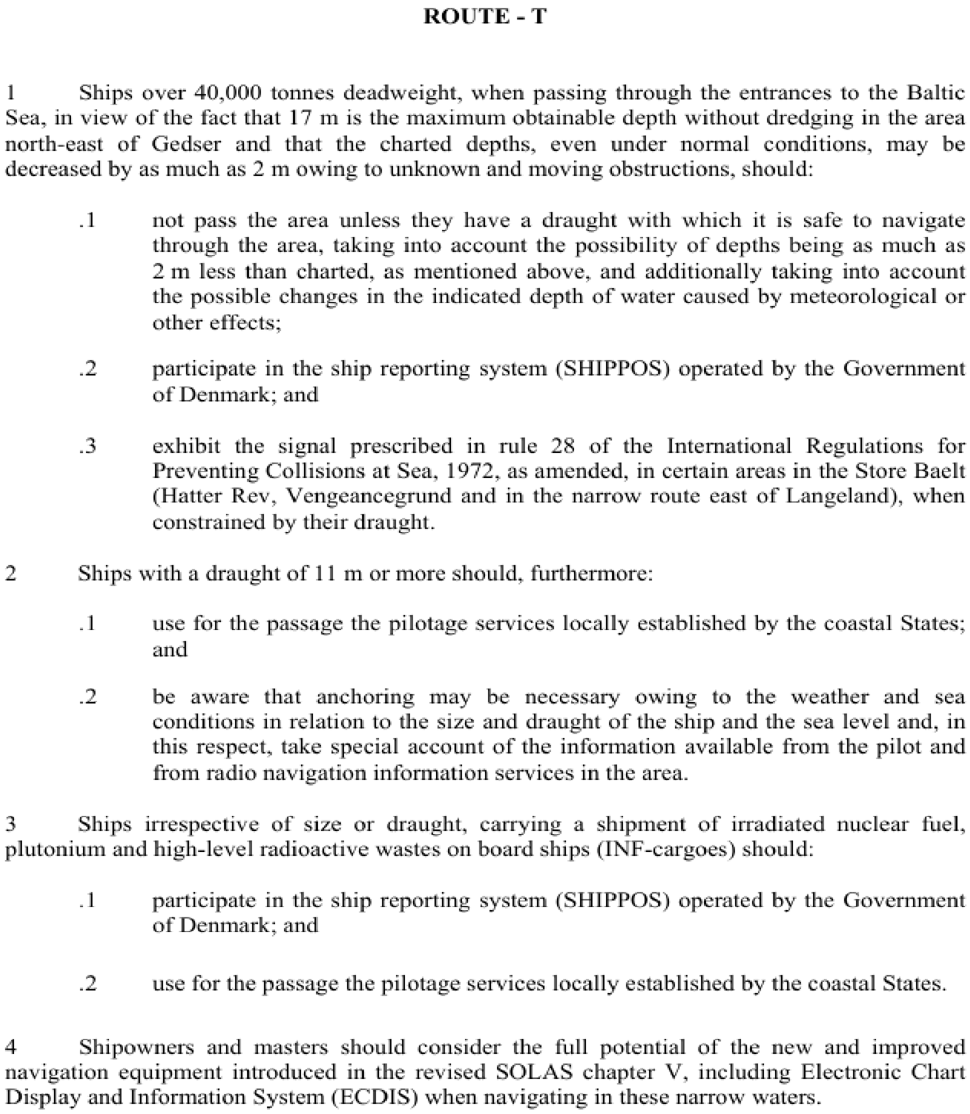
2. INVITES Member Governments to note the establishment of associated protective measures defined in Annex 2. The associated protective measures and their dates of entry into force are expected to be adopted by the Assembly at its twenty-fourth session in November/December 2005.

- Were you aware of this (Sensitive area)? Are you concerned about a marine damage due to accident or grounding which maybe a result GPS disturbance?

IMO recommendation

The IMO recommendation on navigation through the entrance to the Baltic Sea as illustrated in the RESOLUTION MSC.138(76) (IMO, 2002).

" Ship owners and masters should consider the full potential of the new and improved navigation equipment introduced in the revised SOLAS chapter V, including Electronic Chart Display and Information System (ECDIS) when navigating in these narrow waters"



ROUTE - T

1 Ships over 40,000 tonnes deadweight, when passing through the entrances to the Baltic Sea, in view of the fact that 17 m is the maximum obtainable depth without dredging in the area north-east of Gedser and that the charted depths, even under normal conditions, may be decreased by as much as 2 m owing to unknown and moving obstructions, should:

- .1 not pass the area unless they have a draught with which it is safe to navigate through the area, taking into account the possibility of depths being as much as 2 m less than charted, as mentioned above, and additionally taking into account the possible changes in the indicated depth of water caused by meteorological or other effects;
- .2 participate in the ship reporting system (SHIPPOS) operated by the Government of Denmark; and
- .3 exhibit the signal prescribed in rule 28 of the International Regulations for Preventing Collisions at Sea, 1972, as amended, in certain areas in the Store Baelt (Hatter Rev, Vengeancegrund and in the narrow route east of Langeland), when constrained by their draught.

2 Ships with a draught of 11 m or more should, furthermore:

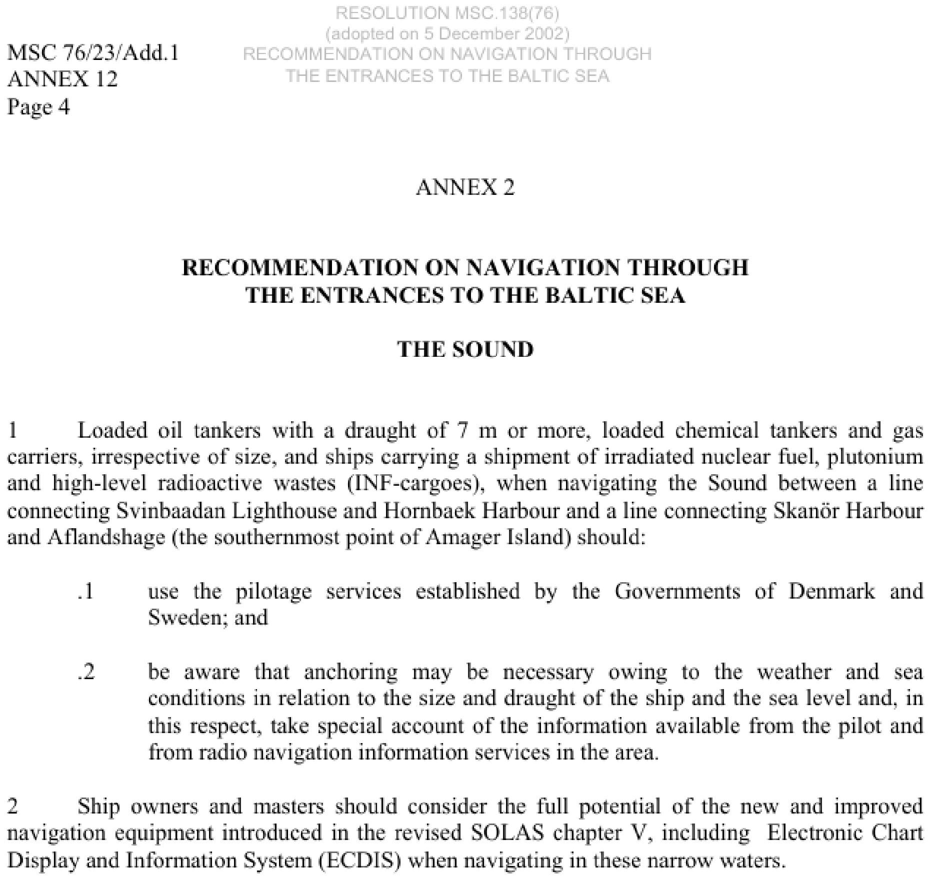
- .1 use for the passage the pilotage services locally established by the coastal States; and
- .2 be aware that anchoring may be necessary owing to the weather and sea conditions in relation to the size and draught of the ship and the sea level and, in this respect, take special account of the information available from the pilot and from radio navigation information services in the area.

3 Ships irrespective of size or draught, carrying a shipment of irradiated nuclear fuel, plutonium and high-level radioactive wastes on board ships (INF-cargoes) should:

- .1 participate in the ship reporting system (SHIPPOS) operated by the Government of Denmark; and
- .2 use for the passage the pilotage services locally established by the coastal States.

4 Shipowners and masters should consider the full potential of the new and improved navigation equipment introduced in the revised SOLAS chapter V, including Electronic Chart Display and Information System (ECDIS) when navigating in these narrow waters.

Appendix 1



MSC 76/23/Add.1
ANNEX 12
Page 4

RESOLUTION MSC.138(76)
(adopted on 5 December 2002)
RECOMMENDATION ON NAVIGATION THROUGH
THE ENTRANCES TO THE BALTIC SEA

ANNEX 2

RECOMMENDATION ON NAVIGATION THROUGH THE ENTRANCES TO THE BALTIC SEA

THE SOUND

1 Loaded oil tankers with a draught of 7 m or more, loaded chemical tankers and gas carriers, irrespective of size, and ships carrying a shipment of irradiated nuclear fuel, plutonium and high-level radioactive wastes (INF-cargoes), when navigating the Sound between a line connecting Svinbaadan Lighthouse and Hornbaek Harbour and a line connecting Skanör Harbour and Aflandshage (the southernmost point of Amager Island) should:

.1 use the pilotage services established by the Governments of Denmark and Sweden; and

.2 be aware that anchoring may be necessary owing to the weather and sea conditions in relation to the size and draught of the ship and the sea level and, in this respect, take special account of the information available from the pilot and from radio navigation information services in the area.

2 Ship owners and masters should consider the full potential of the new and improved navigation equipment introduced in the revised SOLAS chapter V, including Electronic Chart Display and Information System (ECDIS) when navigating in these narrow waters.

- As OOW, have you been navigating on the entrances to the Baltic Sea or was it always the master?

- If you were navigating, do you feel that you have the full potentials to use the equipment including ECDIS without GPS inputs?

- Have you received extra familiarization on using ECDIS during GPS disturbance?/Without GPS input

Joint statement

Joint statement by IMO, ICAO, ITU (18.3.2025) regarding the protection of Radio navigation satellite service from harmful interference. (IMO, 2025).

> “*NOTING with grave concern the increasing number of cases of harmful interference in the form of jamming and spoofing affecting the Radio Navigation Satellite Service (RNSS), which is critical for navigation of civil aircraft, maritime vessels, humanitarian assistance vehicles, as well as for time synchronization of telecommunication networks* “

SOLAS Regulation 24

Use of heading and/or track control system (Wallin, 2016).

1) In areas of high traffic density, in conditions of restricted visibility and in all other hazardous navigational situations where heading and/or track control systems are in use, it shall be possible to establish manual control of the ship's steering immediately.

2) In circumstances as above, the officer in charge of the navigational watch shall have available without delay the services of a qualified helmsperson who shall be ready at all times to take over steering control.

3) The change-over from automatic to manual steering and vice versa shall be made by or under the supervision of a responsible officer.

4) The manual steering shall be tested after prolonged use of heading and/or track control systems, and before entering areas where navigation demands special caution

- Regarding the above-mentioned (part 2), Have you considered having the helmsman ready at your bridge during your watch in the Baltic Sea?

- Regarding the above-mentioned (part 4), have you intentionally tested and switched to manual steering at the beginning of your watch, during the watch?

Appendix 2

Guideline

The content of this appendix guideline is based on the literature reviewed in this thesis and the author’s knowledge. It is subject to improvement and correction. Please consult your company's official procedures and your captain’s guidelines.