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BSc. NAVIGATION AND MARITIME TRANSPORT

DISSERTATION

MARINE RADAR – A STUDY OF ITS INFLUENCE IN COLLISIONS AT SEA

Student: Ane Miren Aizpurua Labaca

Director: Itsaso Ibáñez Fernández

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Today, after a few months, I write this section to finalize my dissertation.

It has been an intense period, in which I have received the unconditional support of my family and friends, that no matter how far away some of them are, I have felt their backing as if they were by my side. For this and much more, thank you.

And thanks especially to the director of this project, Itsaso Ibáñez, because without her willingness, exigence, supervision and dedication, I would not feel as proud of it as I feel now.

ABSTRACT

The marine radar is considered by the officers of the Merchant Navy one of the most important navigation equipment on the bridge due to the valuable support it provides both to ensure safe navigation and in the decision-making process before an evasion manoeuvre is taken. Nonetheless, although it is a relevant equipment in terms of maritime safety, since it is an anti-collision device, many accidents happened in the past, and occur still today, as a result of a wrong use of the radar. Therefore, in this project, it is intended to determine the degree of influence of this system in the collisions at sea, as well as to ascertain the main reasons why they keep happening.

Keywords: marine radar, ARPA, collision avoidance, COLREG, human factor

LABURPENA

Itsas radarra nabigazio tresnen artean garrantzitsuenetarikotzat hartuta dago merkataritza-nabigazioko ofizialen iritziz itsasketa segurua bermatzeko edota maniobra posible baten aurrean erabaki-hartze prozesuan zuzkitzen duen laguntza baliotsuaren ondorioz. Aitzitik, nahiz eta itsas segurtasunarekiko gailu nabarmena izan talka-aurkako ekipo bat baita, bai iraganean eta bai oraingo garaietan ere itsas-istripu anitz jazo dira radarraren erabilera okerra dela medio. Hori dela eta, lan honen bidez, nabigazio sistema honek itsasontzien arteko talketan duen eragina zehaztu nahi da eta, halaber, hauen gertaeren arrazoi nagusiak.

Hitz gakoak: itsas radarra, ARPA, talka prebentzioa, COLREG, giza faktorea

RESUMEN

El radar marino está considerado uno de los equipos más importantes a bordo por los oficiales de la marina mercante debido a la valiosa ayuda que proporciona tanto para garantizar una navegación segura, como a la hora de tomar decisiones ante una posible maniobra. No obstante, aunque sea un dispositivo relevante en cuanto a la seguridad marítima debido a que se trata de un equipo anticolisión, muchos accidentes en el pasado y, todavía, en el presente suceden a causa del mal uso del radar. Por ello, a través de este proyecto se pretende determinar el grado de interferencia de este sistema en las colisiones y las razones principales por las cuales éstas siguen ocurriendo.

Palabras clave: radar marino, ARPA, prevención de colisión, COLREG, factor humano

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AIS	Automatic Identification System
ARBs	Area Rejection Boundaries
ATA	Automatic Tracking Aid
ARPA	Automatic Radar Plotting Aids
BA	British Admiralty
BNWAS	Bridge Navigational Watch Alarm System
CBDR	Constant Bearing Decreasing Range
COLREG(s)	Collision Regulation Convention on the International Regulations for Preventing Collisions at Sea, 1972
CPA	Closest Point of Approach
CRT	Cathode Ray Tube
DMAIB	Danish Maritime Accident Investigation Board
ECDIS	Electronic Chart Display and Information System
EPA	Electronic Plotting Aids
GPS	Global Positioning System
GT	Gross Tonnage
HFACS	Human Factors Analysis and Classification System
HMSO	Her Majesty's Stationery Office
IMO	International Maritime Organization
MAIB	Maritime Accident Investigation Branch of the United Kingdom Department for Transport
MCA	Maritime and Coastguard Agency
MPA	Maritime and Port Authority of Singapore

MSC	Maritime Safety Committee of IMO
MT	Motor Tanker
nm	Nautical Mile
OOW	Officer of the Watch
PAD	Predicted Area of Danger
PPC	Predicted Point of Collision
PPI	Plan Position Indicator
Radar	RAdio Detecting And Ranging
SOLAS	International Convention for the Safety of Life at Sea, 1974
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978
TCPA	Time to Closest Point of Approach
TSS	Traffic Separation Scheme
UKHO	United Kingdom Hydrographic Office
UTC	Universal Time Coordinated
VDR	Voyage Data Recorder
VHF	Very High Frequency

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INTRODUCTION

INTRODUCTION

In the same way that merchant ships have evolved over time, thanks to the incessant development of technology, the navigation equipment of the bridge has also experienced a huge progress. The marine radar, in its more than 70 years of history since its first use at sea, has also improved, while its main objectives remain the same: navigational support and collision prevention. However, despite all these facilities that are available to back officers of the watch (OOW) in order to ensure safe navigation, it is a fact that accidents still occur. Why? In which way does the radar influence on them? How can collisions be stemmed by a proper radar use?

OBJECTIVES

This work aims to approach the proposed questions as well as to expand the awareness about the adequate use of one of the most relevant navigational equipment on board.

The main objective of this work is, thus, to study the influence of the marine radar use (or misuse) in maritime accidents. Since it is intended to learn about the way in which this equipment affects collisions at sea, the anti-collision facet of the system is examined both in real crash cases and in Collision Regulations (COLREG). This, in turn, will allow screening for the reasons why collisions still occur.

Furthermore, this work also expects to call attention to the significance of the effective training of Officers of the Watch in radar operation, in order to guarantee a safe, free of accidents, navigation. It is a commonplace that the human element is the main source of error when accidents occur, so that, in our case, to minimize this effect, the practical skilful operation of marine radars becomes critical. This can be of some use to future sailors, who can raise awareness on this subject from the lessons learned from the human errors leading to collisions, which are highlighted in the final chapter.

STRUCTURE

In order to achieve the goals above, this dissertation is structured in five chapters.

First, a brief approach on the marine radar is provided, where its history, framework, operation principles, and ARPA facilities are explained. This first chapter is planned to show the most relevant information regarding this equipment so that the reader will be prepared to understand the thesis as a whole.

In the second part, the role of the radar in collision avoidance is dealt with. In addition, the potential human errors when operating this equipment are described. An overview on the impact of the marine radar misuse in maritime collisions concludes this chapter.

As it will be explained, the use of the marine radar in collision avoidance is closely linked to the Convention on the International Regulations for Preventing Collisions at Sea (1972, thereafter COLREG), so in the third part some of its main rules are examined in detail.

The fourth part takes charge of the analysis of four real maritime accident cases in which the radar operation had a clear, definite influence. This chapter concludes with some lessons learned from the previous analysis.

Finally, this work ends up with some conclusions, highlighting the objectives already met and emphasizing the pending issues to improve the safe and effective marine radar operation.

METHODOLOGY

For the elaboration of this dissertation, a combination of quantitative and qualitative research has been carried out.

On the one hand, taking into account that it is relevant to our study to establish a relationship between the use of the radar and the accidents at sea, a quantitative methodology has been used to statistically analyse the available data in this regard.

On the other hand, the qualitative method has been applied to study the characteristics of accidents, seafarers' behaviours, as well as the decision-making process when choosing a course of action.

Within the qualitative research, the case study method has been selected in order to analyse real collision episodes: first, the background is exposed, then the failures committed by both parties are presented, and, finally, a brief conclusion is made. A sort of lessons based on the information presented during the accidents analysis completes the study.

Regarding data sources, secondary sources (books and articles from nautical publications) have been mostly used. Primary sources have also been accessed for this purpose, such as different official specialized investigation institutions (e.g. MAIB), and conventions and resolutions of IMO (International Maritime Organization), specialized body of the United Nations responsible for the safety and security of navigation and the prevention of sea pollution by ships.

STATE OF THE ART

There are many and diverse works dealing with the marine radar, mainly books and papers. Most of the former are textbooks or manuals (Bole, Dineley & Wall, 2005; Skolnik, 1990); others relate to technical aspects (Briggs, 2004), or to historical issues (Brown, 1999).

In relation to collisions, there are also many sources of information as the investigation has become institutionalized and the released reports provide open access. This is for instance the case of MAIB (United Kingdom), DMAIB (Denmark), CIAIM (Spain), among others. In their reports, the facts and the possible causes that produced the accident are related. The involved consequences are also detailed and appropriate conclusions and recommendations to each case are provided. But not only national and international organizations investigate about maritime accidents: there are authors like Cahill (2002) and Dewar (1989) who have also studied a large number of incidents.

The maritime collisions have also been the subject of many studies or reviews on safety at sea, in which the evolution of these accidents is analysed; the works by Batalden & Sydnes (2014) and Eleftheria, Apostolos & Markos (2016) are two examples. Moreover, the issue of the human factor, in particular, is a fundamental part of these works (Chauvin, Lardjane, Morel, Clostermann & Langard, 2013; Chauvin, 2001); as such, they have proved to be essential to address the current situation in our research.

In the same way, there are numerous works that discuss the 1972 Convention on the International Regulations for Preventing Collisions at Sea. Besides the official IMO publication, there exist books with instructive purpose in which COLREG's rules are analysed and interpreted (De Simón, 1989; Salinas, 2004), as well as articles remarking the aspects that still need to be improved (Mohovic, Mohovic & Baric, 2013; Zeki, Mohovic & Mohovic, 2015). Plus, there are books that examine maritime accidents in relation with the COLREG (Marí, 1994).

Nonetheless, as far as we know, there are no works in which all these issues are addressed together, linked with the use of the marine radar as an anti-collision device. Once the originality of our study was guaranteed, based on these related previous works, we tackled this project, the final touch to graduate in Navigation and Maritime Transport.

CHAPTER 1

THE MARINE RADAR

1. THE MARINE RADAR[1]

Radar, whose acronym comes from RAdio Detection And Ranging, is the device which detects surrounding objects (normally referred to as targets) by transmitting radio signals in known directions from an antenna that scans the horizon; then, timing the instants of reception of returned echoes from these targets. In other words, it is the technique whereby the position of objects, i.e. range and bearing from the own ship, is determined by illuminating it with radio waves and observing the reflections, and then shown in de Plan Position Indicator (PPI) of the display unit.

The radar cannot be attributed to a single inventor. Indeed, it was developed along a process that counted on numerous scientists' contribution. The beginning can be set in the 1860s, when Maxwell (1831-1879) formulated the electromagnetic radiation theory, which brings together electricity, magnetism and light for the first time. Heinrich Hertz (1857-1894), inspired by Maxwell's equations, was the first to demonstrate that metallic objects could reflect radio waves. Later on, in 1903, the German engineer Christian Hülsmeyer (1881-1957) patented in numerous countries a device that was able to detect reflected radio waves by ships. However, it was not until the turn of century, in the 1920s, when the idea of the marine radar was first suggested by Guglielmo Marconi (1874-1937), based on Hertz's achievement.

In 1935, it was possible, for the first time, to detect and locate a vessel at distances longer than 10 nautical miles (nm hereinafter). Still in the 1930s, developments and researches about radar were carried out in different countries such as France, Germany, United States and Great Britain due to the bloom experienced in the electronic industry, which was enhanced with the emerging threatens of a World War. As a result, crucial elements that compose radar such as the cathode ray tube[2] were developed.

Keeping with technological progress, at that time, antennas were too big so that ships could not be fitted with them and for smaller antennas to be used, higher frequency equipment was required. Accordingly, at the beginning of the 1940s, the cavity magnetron was developed, one of the biggest progresses of the radar history. It consists of a device which generates microwaves using the interaction of a stream of electrons with a magnetic field while moving past a series of open metal cavities.

[1] The elaboration of this chapter has been based on the works by Bole, Dineley & Wall (2005), Briggs (2004), Brown (1999) and Hull (1921).
[2] See section 1.2.4.

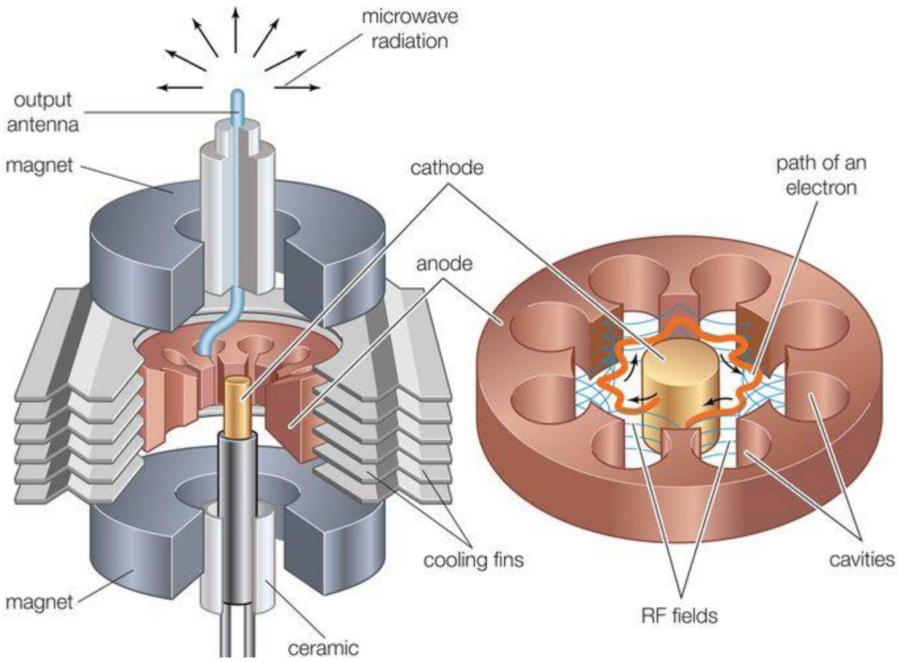


Figure 1.1. Schematic design of cavity magnetron (2004).

In 1944 the marine radar started to be installed onboard merchant ships and, after the war, its use became mandatory and widespread aiming to perform both as a help in navigation and an anti-collision aid.

1.1 BASIC RADAR PRINCIPLES

An object is detected by the transmission of a pulse of radio energy and the subsequent reception of a fraction of such energy (the echo) which is reflected by the target in the direction of the transmitter. Thus, if the total time that energy takes displacing to and from the object is measured, as well as the direction of the trajectory, the object can be localized at a certain bearing and distance from the ship. In a marine radar system, both the transmission and the reception are made by the antenna. This antenna spins in azimuth at a constant velocity. Since the energy emission and reception cannot be blended, the signal is not continuedly emitted by the aerial. Plus, the returning echo must be received before the new pulse is transmitted; that is why the system alternates short periods of emission with longer silence spans.

Even if the velocity of radio waves depends on the nature where they are emitted, for marine radar it is considered a constant value of 300 000 000 m/s. As a result, a simple relation between time (from emission to reception) and range (at which the object is located) can be deduced:

Be it: t = time between emission and reception of the pulse

d = distance travelled by the pulse

r = range at which the object is located

c = speed of the pulse

$$d = 2r = c \cdot t \longrightarrow r = \frac{c \cdot t}{2} \longrightarrow r\,(m) = \frac{300\,(m/\mu s) \cdot t\,(\mu s)}{2} \longrightarrow r\,(m) = 150 \cdot t\,(\mu s)$$

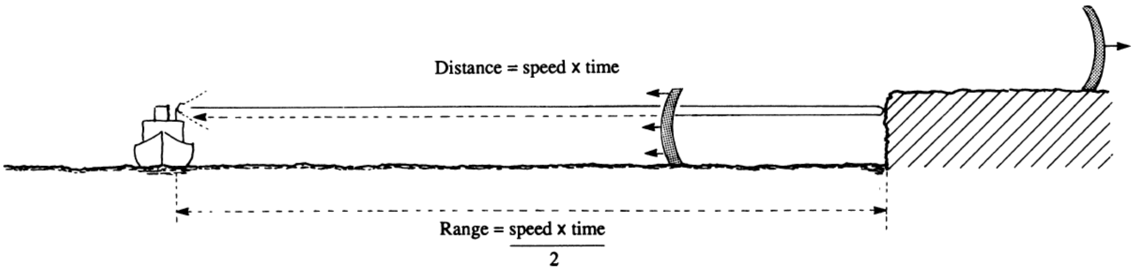


Figure 1.2. The echo principle (Bole, Dineley & Wall, 2005, p. 2).

The application of this relationship can be illustrated by the following examples.

Example 1. Calculate the elapsed time for a pulse to travel to and return from a radar target whose range is 40 metres.

r = 40 m

t = 40/150 = 0,27 µs

This value is of particular interest because 40 metres represents the minimum detection range that must be achieved to ensure compliance with the IMO Performance Standards for Navigational Radar Equipment (see 5.4.1 in Annex 2).

Example 2. Calculate the elapsed time for a pulse to travel to and return from a radar target whose range is 5 nm.

Example 2. r = 5 nm ⟶ d = 5 · 1852 m = 9260 m

t = 9260/150 = 61,73 µs

1.2 OPERATIONAL PRINCIPLES OF RADAR SYSTEM

Radar is composed by the following units (see Figure 1.3):

- The transmitter
- The antenna
- The receiver

- The presentation unit or display

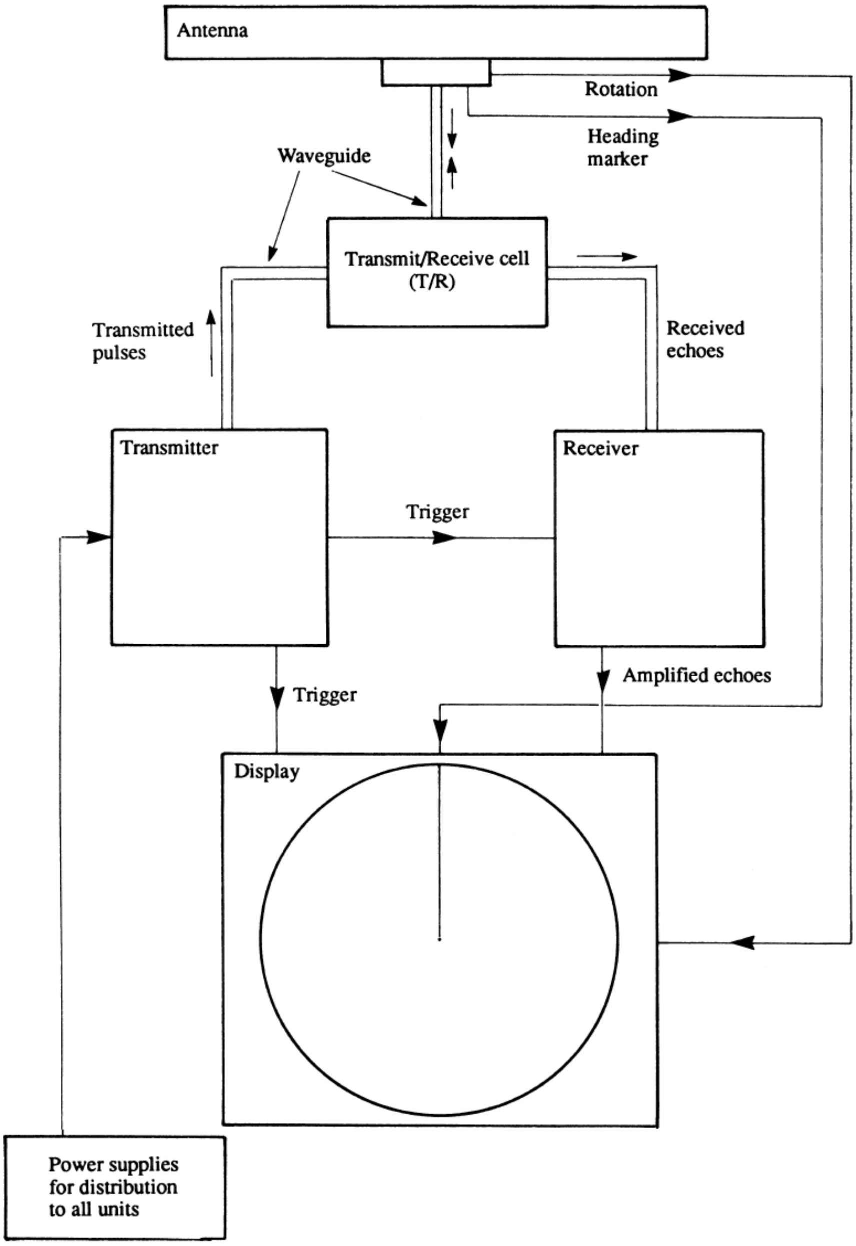


Figure 1.3. Block diagram of a marine radar (Bole, Dineley & Wall, 2005, p. 28).

1.2.1 The transmitter

The electromagnetic energy pulses that radar antenna emits are generated by the transmitter. Its function is to provide correct repetition frequency, length, shape, power and radiofrequency to the pulses. In order to achieve those energy characteristics, the following elements are needed:

– the trigger, which controls the frequency of pulse repetition;

- the modulator and the associated pulse formation network, which stablish the length, shape and power of the transmitted pulses; and
- the magnetron, which determines the radiofrequency of the pulse that travels through the waveguide[3] to the antenna. The waveguide is common for both the transmission and the reception of waves. It would thus appear that the powerful pulses generated by the transmitter might be able to pass directly into the receiver. In order to protect it, a device known as a transmit/receive switch (or T/R cell) is installed in the waveguide immediately before the input to the receiver. The T/R cell blocks the input to the receiver during transmission in order to avoid the powerful transmitted energy pass to the receiver and damage it.

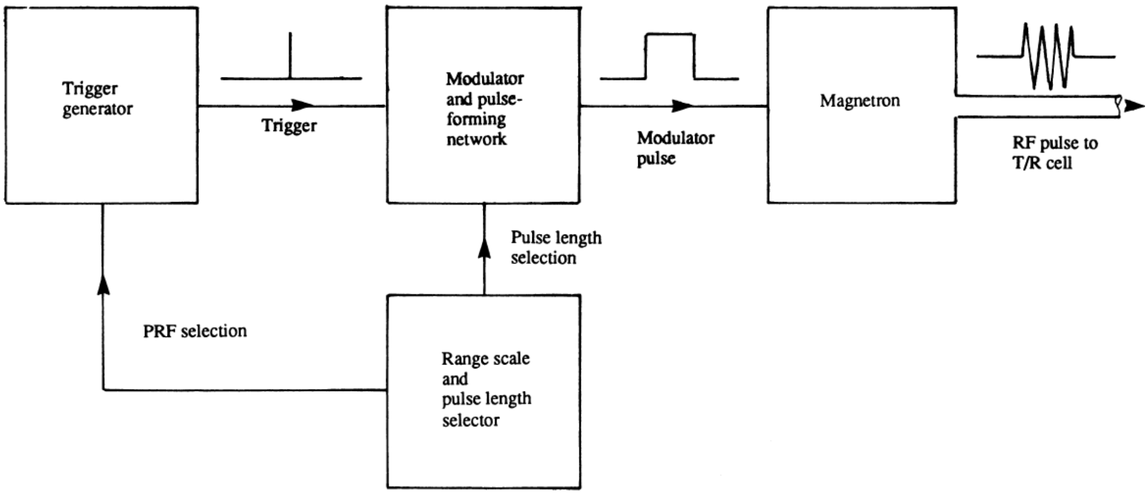


Figure 1.4. Transmitter's block diagram (Bole, Dineley & Wall, 2005, p. 32).

1.2.2 The antenna

It is the device that radiates the electromagnetic waves into space and receives the returning echoes. By its construction, waves are spread both in the horizontal and vertical planes.

Regarding the horizontal plane, to obtain the bearing at which the object is located with respect to the ship, the antenna focuses the energy pulses within two defined angular limits that constitute the beamwidth, covering the entire horizon rotating 360° continuously.

[3] A waveguide is the structure that guides the electromagnetic waves with minimal loss of energy by restricting expansion.

To achieve the directional transmission necessary for the accurate measurement of bearings the horizontal beamwidth must be narrow. This also has the effect of producing very high aerial gain by concentrating all the available power in one direction at a time. The smaller the value of the beamwidth is (therefore, the narrower it is), the better the bearing discrimination will be, that is, the ability of the equipment to represent two echoes of two targets that are at the same distance and close to each other. In fact, this pulse opening angle is stablished by IMO in its IMO Performance Standards for Navigational Radar Equipment (see 5.5.2 in Annex 2) as 2.5° maximum.

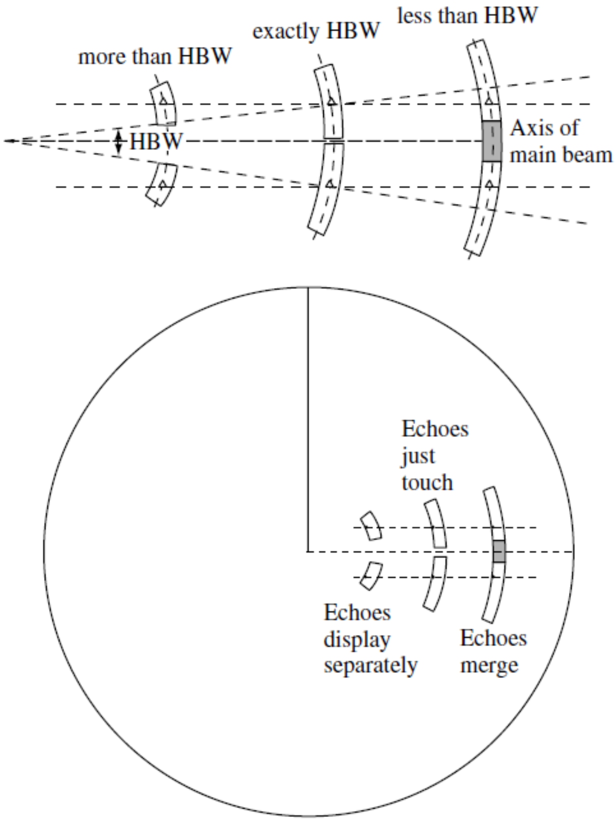


Figure 1.5. Bearing discrimination (Bole, Dineley & Wall, 2005, p. 94)

On the contrary, the pulse in the vertical axis must be wider in order to get a proper performance of the equipment when the ship is rolling or pitching when navigating. Commercially available aerials normally offer values which lie in the approximate range 20° to 25°.

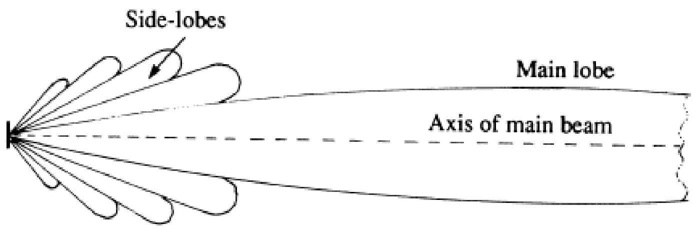
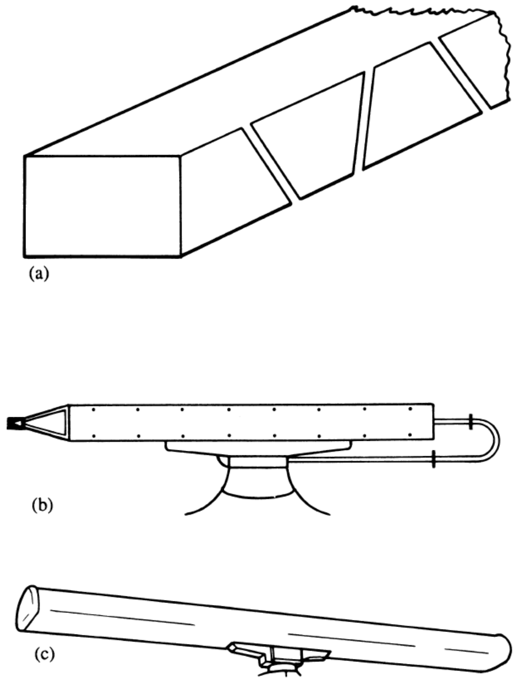


Figure 1.6. Antenna horizontal radiation pattern (Bole, Dineley & Wall, 2005, p. 45)

About the type of antenna, in marine radar the most common one is the slotted wave guide: a waveguide tube through which one of its sides, slots of approximately half of the wave length are cut, distanced so as to excite all the slots in equi-phase. IMO Performance Standards stated that the minimum rotation speed of the antenna must be 12 rpm. However, the new IMO standards (see Annex 2) for installations on new vessels built on or after 2008 no longer specify the minimum rotation speed for both conventional and high speed craft. The reason for this is so that new technologies can be introduced.



(a) Detail of waveguide slots

(b) Slotted waveguide antenna

(c) Enclosed slotted waveguide antenna

Figure 1.7. Slotted waveguide antenna (Bole, Dineley & Wall, 2005, p. 49).

1.2.3. The receiver

This element's function is to select the signal of interest from the jumble of wavelengths picked up by the antenna by amplifying the weakened echoes to a useful level. So that these echoes are visible in the presentation unit, the receiver treats them, creating pulses with appropriate form and power.

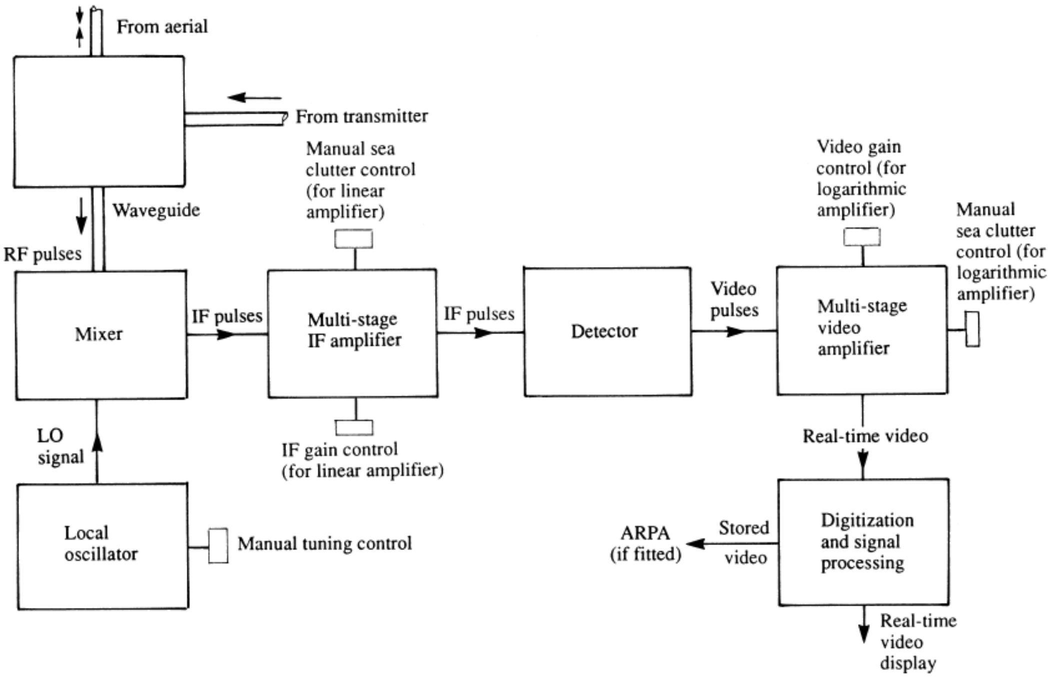


Figure 1.8. Receiver's block diagram (Bole, Dineley & Wall, 2005, p. 60).

1.2.4 The presentation unit or display

As it can be deduced from its name, this unit aims to create a radar image: a screen that shows the objects around the ship, localizable by means of bearing and distance. Since this image must be as optimal as possible, this unit is fitted with measures, adjustments, presentation and other controls.

Traditionally, radar image has been presented on a cathode ray tube screen. This screen is the so-called PPI (Plan Position Indicator).

The cathode ray tube is a vacuum tube containing and electron gun and a fluorescence screen with means to accelerate and deflect the electron beam, used to create images in the form of light emitted from the fluorescent screen.

The electron gun is subdued by the vacuum and it consists of a heater, the cathode (the electron transmitter), the control grid (which gathers the produced electrons), anodes (electron accelerators) and a focusing system (which concentrates the electron in a certain point).

About the deflectors, they have two main functions: one, move the electron beam from the origin to the edge of screen (trace creation); and two, make the trace spin synchronized with the antenna's turn.

Finally, the screen of the CRT, or the so-called PPI, is a circular plain with the function of representing the echoes intercepted by the radar antenna as well as the information that the operator may require from them. Its surface is covered by a phosphorescent layer which warranties the persistence of the targets on the screen, persistence that needs to last, at least, one-revolution period of the antenna.

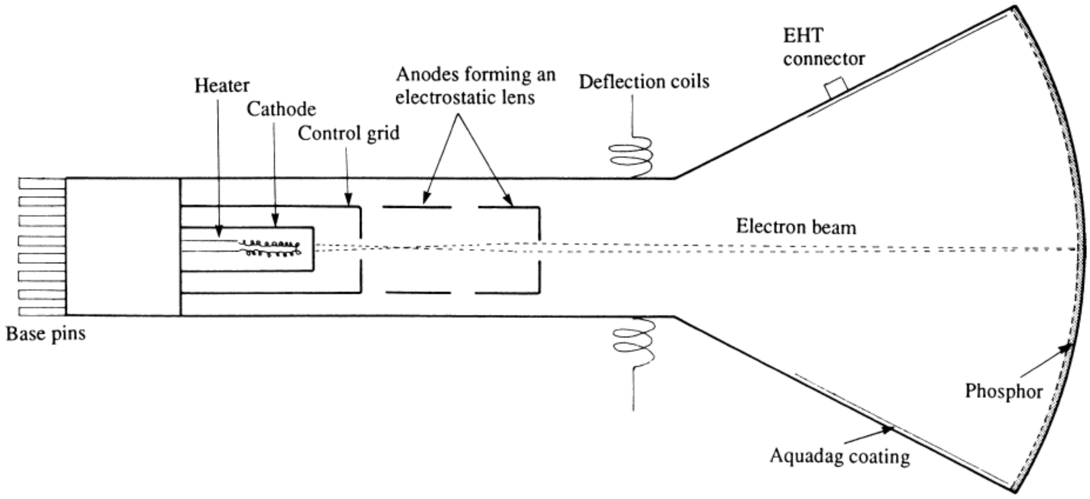


Figure 1.9. Cathode ray tube (Bole, Dineley & Wall, 2005, p. 73).

The display unit also receives a rotation signal from the antenna. Thus, the trace rotates at the same angular rate as the antenna. Consequently, all targets will appear in the correct angular relation to other objects on the PPI.

In the same way, this unite is provided with a heading marker signal. The forward direction of the ship is highlighted by a radial indicator. Therefore, there is a reference from which relative bearings can be measured.

Nowadays, other display devices are available. CRTs are bulky and are rapidly being replaced in television and PC monitors by various kinds of flat screen low voltage semiconductor arrays, including liquid crystal displays (LCD), which are produced by the million. LCDs consume very little power. Long widespread in laptop computers, they were first taken up by the radar industry in small craft radars. Problems of available brilliance range, adequate area and wide angle of view are being overcome and price is falling. As a result, high resolution LCDs are replacing CRTs in new big-ship marine radars. Advantages include low bulk, screen flatness, low power consumption and avoidance of high voltage.

For example, the raster scan display, beside brightness, important features include their ability to display in different colours, and quickly to amend:

- the radar picture (plots and tracks);
- text, enabling targets to be tagged with identification symbols (also operator's menus for controls);
- radar graphics such as predicted tracks (from ARPA, etc.), range and bearing markers for position measurement, target alpha-numeric identification tags;
- non-radar graphics such as charts (from ECDIS, etc.).

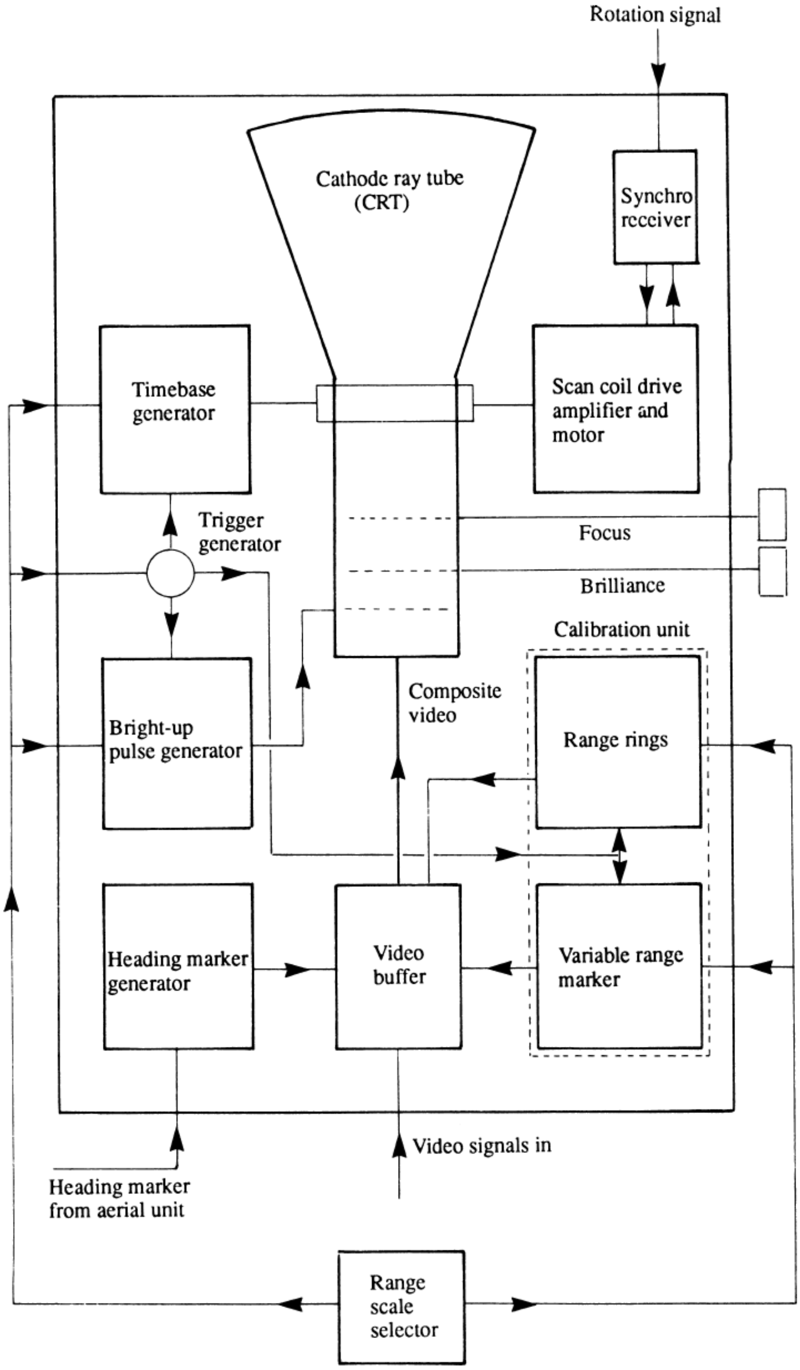


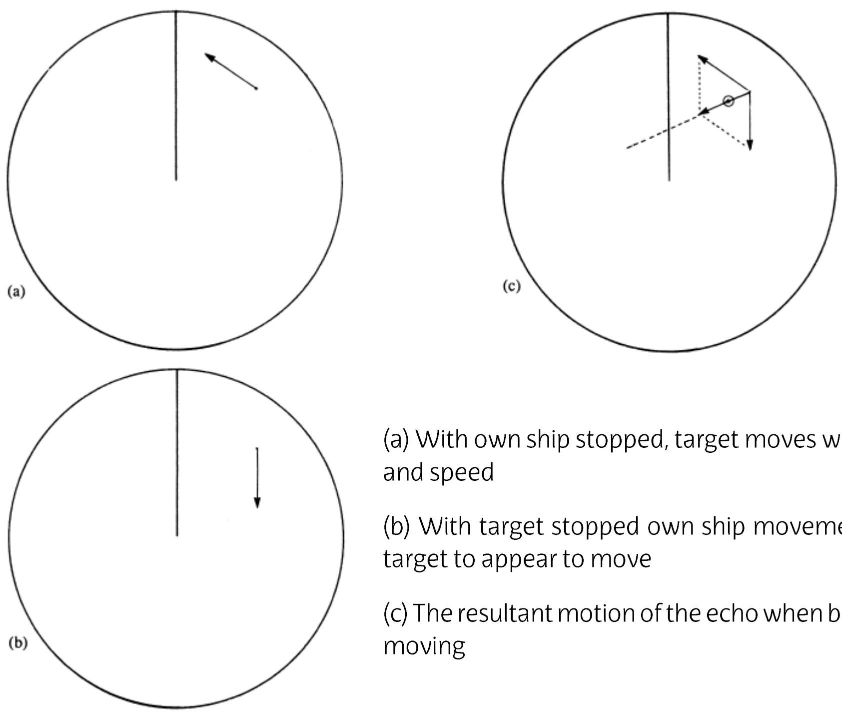
Figure 1.10. Block diagram of the display unit (Bole, Dineley & Wall, 2005, p. 81).

1.3 RADAR PLOTTING

Radar plotting covers the whole process of target detection, tracking, calculation of parameters and display of information.

The method by which this information has been displayed to the navigator has seen a steady progression from paper plotting sheets and manoeuvring boards to the present day ARPAs (Automatic Radar Plotting Aids). In order to understand the more complex operations performed by ARPA (feature that will be developed in the next section), it is still necessary to have a fair degree of skill and dexterity in practical plotting.

The manoeuvring board is a polar-coordinate plotting sheet devised to solve relative motion problems (see figure 1.11). The relative motion is the motion of targets with respect to own ship regarded as fixed (see section 2.1.1.3); therefore, other ships will relatively move according to own ship.



(a) With own ship stopped, target moves with true course and speed

(b) With target stopped own ship movement causes the target to appear to move

(c) The resultant motion of the echo when both vessels are moving

Figure 1.11. Relative motion scheme (Bole, Dineley & Wall, 2005, p. 302)

The manoeuvring board or paper plotting sheet contains equally spaced circles and thirty-six radial bearing lines, one originating at the centre. At the bottom is a nomogram, which is used to compute speed, distance, and time. On each side of the sheet are two vertical scales, known as *speed/distance scales*.

Prior to widespread availability of computers, manoeuvring boards were used aboard ships and aircraft to provide rapid solutions to commonly encountered relative motion problems.

The specific function of radar plotting (whether carried out on a paper plotting sheet or a manoeuvring board, with the aid of an ARPA or with any of the intermediate facilities or techniques) is to provide the data on which a collision avoidance strategy can be based.

Since the radar is carried along by the vessel as it proceeds, the direct measurements obtainable are always relative to the observing vessel. Thus, in order to determine the true courses and speeds of other vessels, it is necessary to resolve this observed relative or apparent motion into its components by using a knowledge of own ship's true course and speed. The means by which this may be achieved ranges from pencil-on-paper plotting sheets via reflection plotters to computer-based collision avoidance systems. If systematic observations are made of the bearing and range of a displayed echo and the positions are plotted on a traditional plotting sheet or reflection plotter, the line joining the plotted positions will depict the target's apparent motion OA, which if extended will enable a measure of the target's closest point of approach, CPA, to be obtained. The time to closest point of approach, TCPA, can be obtained by stepping off the rate from O to A along OA extended to CPA. (assuming that both vessels maintain their present courses and speeds). CPA and TCPA are important when it comes to assess if risk of collision exists because evasion manoeuvre priorities will be establish considering these two criteria. Nonetheless, this question will be discussed extensively in the next chapter (see section 2.2).

1.3.1 The plotting triangle and the relative plot

By plotting the apparent motion of a target and with a knowledge of own ship's true course and speed, it is possible to determine the true course and speed of the target. With the plotting triangle, these data can be reckoned. The following example describes the process of hand-plotting, including an evasion manoeuvre:

While steering 000° at 20 knots, the echo of a vessel is observed as follows:

1000 echo bearing 050° at 5.0 nm

1006 echo bearing 047.5° at 4.0 nm

1012 echo bearing 045° at 3.0 nm

At 1012, determine the target's true course (R_A) and speed (V_A), CPA and TCPA as well as the new steered course so that the target passes by two miles off. Assume that the action is taken instantly and that there is no speed change.

The steps to be followed are shown below:

1) Draw in own ship's heading line on the plotting sheet.

2) Construct a track of the target to establish the relative movement, naming O to the first plot and A to the last ($\overrightarrow{OA}$ vector) and longer it across the manoeuvring board. Determine the relative speed.

V_R=OA/t= 2/0,1=20 knots

3) In order to find the side of the plotting triangle referred to own ship, lay off a line to represent the motion of her, from O, opposite to the direction of the heading line and with the value of the speed of own ship; name that point W.

At this point, the plotting triangle is constructed, letting us know the target's course and speed by its representative vector formed from W to A.

R_A=$\overrightarrow{WA}$=298°

V_A=WA/t=2/0,1=**20 knots**

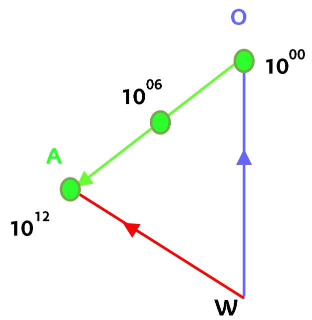


Figure 1.12. Plotting triangle (compiled by author).

4) Obtain the CPA (CP in the figure 1.11) and the TCPA by dividing the AP distance by the relative speed value.

CPA=0,7 nm=7 cables

TCPA=AP/V_R=3/20= **9 minutes**

5) As it is intended to pass 2 miles away from the vessel, a tangent line equivalent to the new relative vector of the target from A (moment when the action is taken) to the 2 miles circle is laid off in both directions. As we are asked to alter course, the speed keeps still; from W, with the length referred to the speed (WO) an arc is traced, cutting the new relative vector. This point is named O'. In this way, the vector $\overrightarrow{WO'}$ determined the new course steered by own ship.

$\overrightarrow{WO'}$=058º

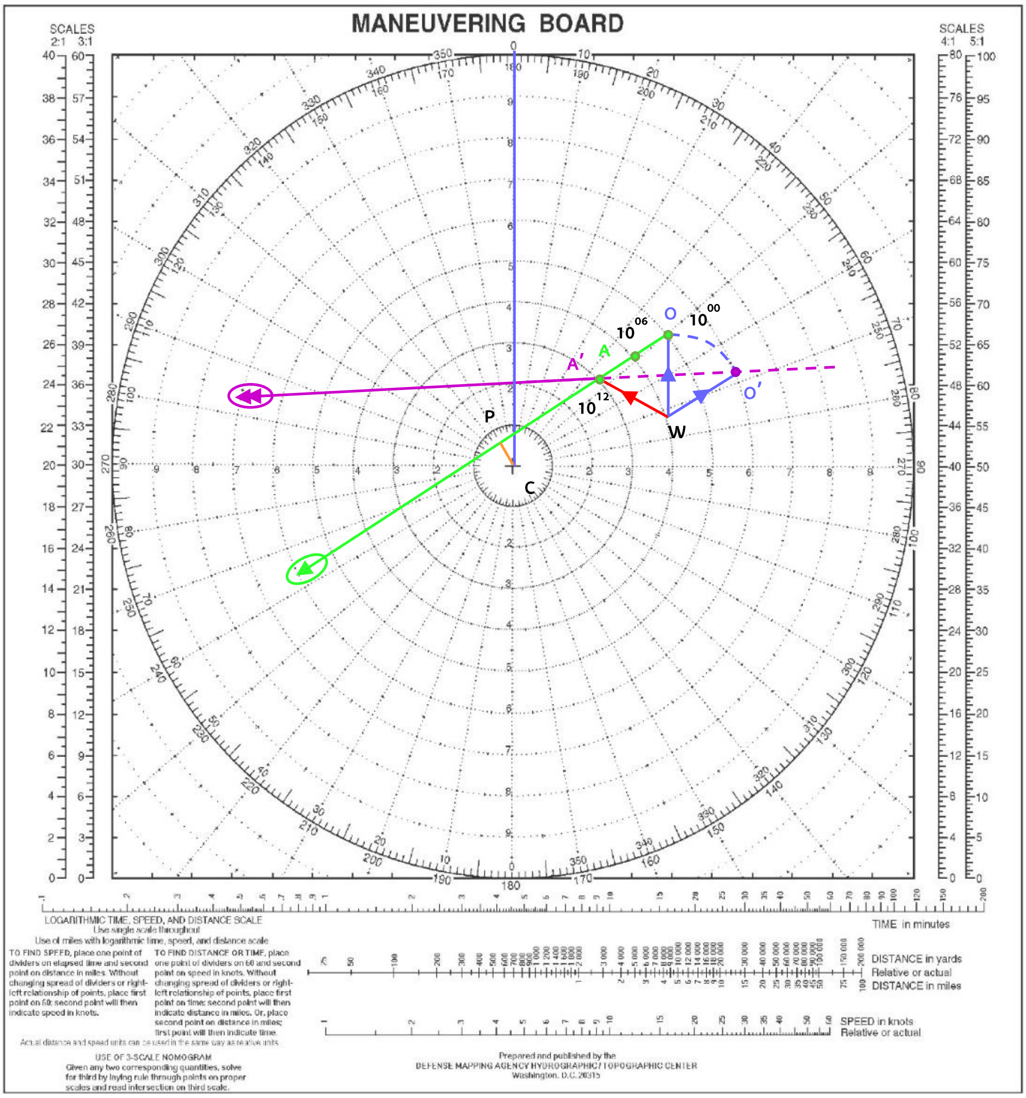


Figure 1.13. The relative motion plot on a paper plotting sheet (compiled by author)

After explaining the former, which is the simplest situation one can encounter at sea, it can be easily deduced that this task requires quite a long time to fulfil, besides the fact that a close quarters or risk of collision situation might be developing while carrying out this work. Therefore, if it is executed in a computerized way (i.e. using ARPA), more time and less burden will be made available to the deck officer when keeping a watch and, certainly, in the decision-making process.

1.4 AUTOMATIC RADAR PLOTTING AID (ARPA)

It is undeniable how technology has been developed throughout the years. In particular, equipment such as the marine radar has also experienced an upgrade in order to improve this system. In part, thanks to the needs stated by mariners, fabricators have been able to ameliorate this device.

The most important implemented feature on radar has been the ARPA, which stands for Automatic Radar Plotting Aid. By acquiring and tracking determined targets, the ARPA provides the watchkeepers with predictive vectors of ships and information about them. Therefore, the officer of the watch does not need to carry out the plotting in a paper plotting sheet because, in effect, the system makes it itself.

Development of ARPA started after the accident when the Italian liner SS *Andrea Doria* collided with the MS *Stockholm* in 1956 in dense fog and sank off the east coast of the United States. ARPA radars started to emerge in the 1960s and, with the development of microelectronics. The first computerised radar was installed onboard the cargo liner MV *Taimyr* in 1969.

About target acquisition, the process may be done manually or automatically. Afterwards, the automatic track is carried out by the system, giving fuller and quicker information on selected targets, so the workload of the officers decreases severally. ARPA enables the navigator to cope with traffic under the most taxing of conditions (Cahill, 2002).

About automatic acquisition, every echo is tested against different criteria: some manufacturers restrict the detection to a watch zone set by the operator; others sieve the acquisition under parameters such as the closest point of approach (CPA), time to closest point of approach (TCPA), range and bearing, among others. As a result, the first 20 are tracked in priority order.

Regarding the tracking of targets, when objects are first acquired, the ARPA receives data within a certain time in order to show the most precise movement vector of it. This is, the system gathers successive positions so as to determine the predicted direction and speed of the target (see figure 1.13).

In the same way the ARPA predicts the track that target will follow, the system provides important and decisive data such as CPA and TCPA. They are obtained by the tracked, smoothed and stored bearings and ranges of the targets; they derived from stored relative data (see figure 1.14).

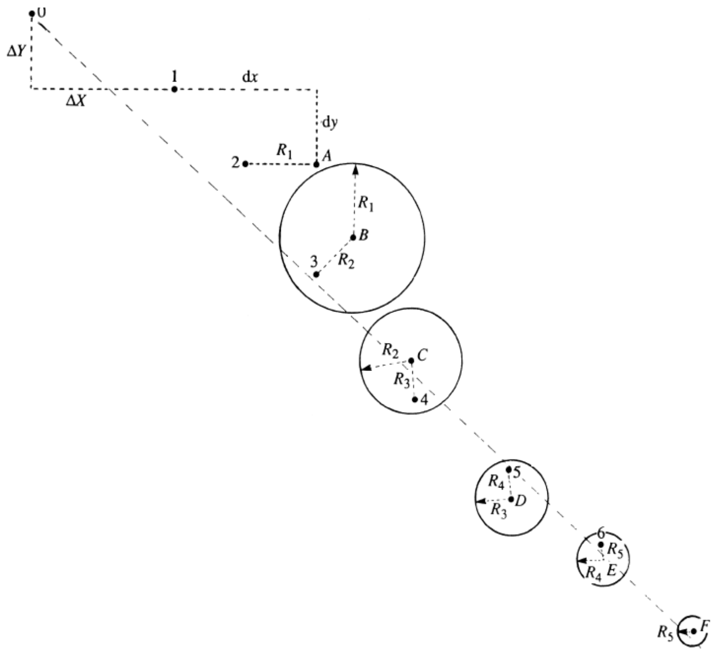


Figure 1.14. Predicted direction of a target by a rate of successive positions of it (Bole, Dineley & Wall, 2005, p. 223).

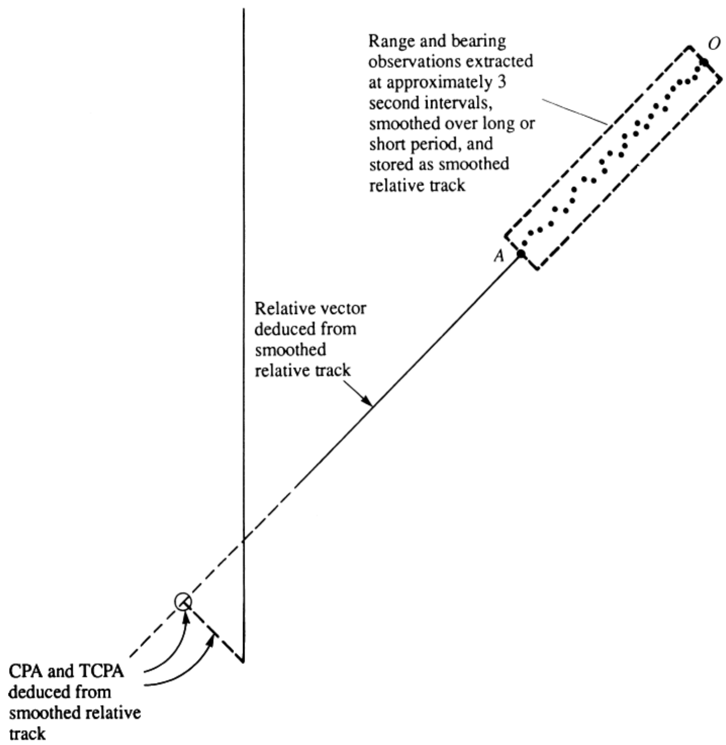


Figure 1.15. CPA and TCPA from storage of relative data (Bole, Dineley & Wall, 2005, p. 229).

CPA and TCPA are decisive before an evasion manoeuvre is performed. But, when risk actually is considered, and an action must be taken, the ARPA gives the chance of trying a simulation in order to visualize what would happen if a course and/or speed alteration was carried out. After the trial, the situation with regard to other vessels in the vicinity is also shown; therefore, it may help in order to avoid subsequent collisions.

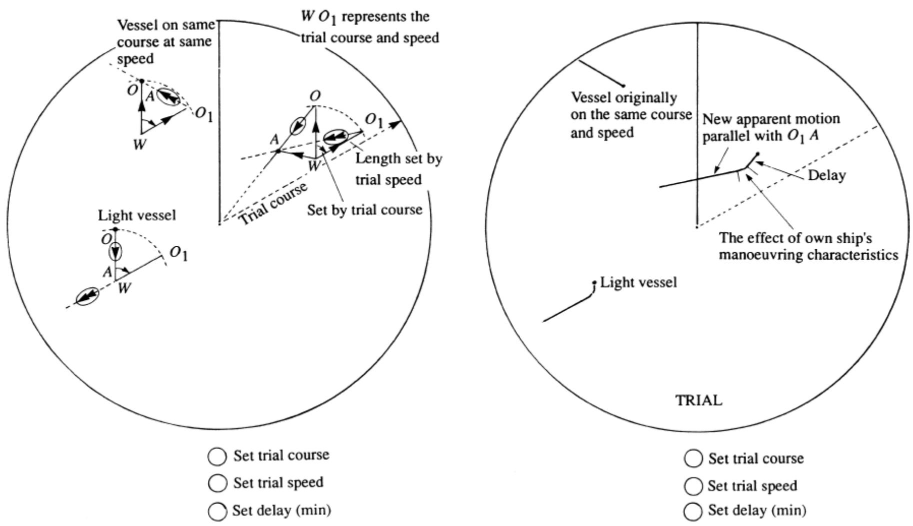
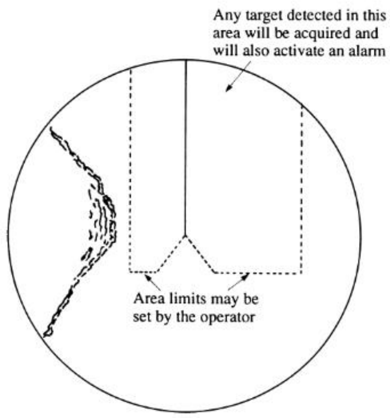
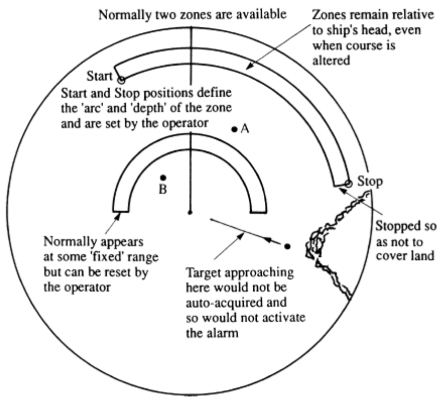


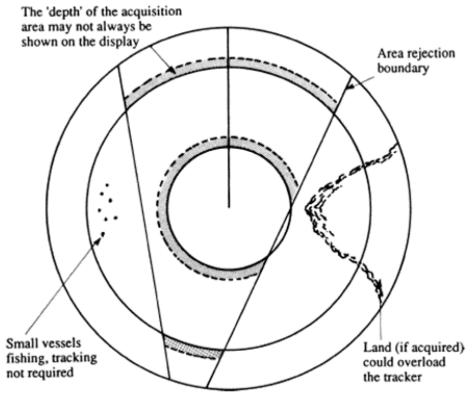
Figure 1.16. Left: relative vectors construction; right: trial manoeuvre display (Bole, Dineley & Wall, 2005, p. 236).

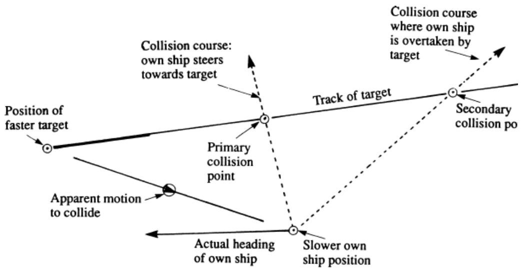
In Table 1.1 a brief summary on the main ARPA facilities regarding target acquisition is shown.

Table 1.1. ARPA's main facilities (Bole, Dineley & Wall, 2005, pp. 220, 221, 248)

Facility	Description	Figure
Area acquisition	Automatic acquisition can also be adjusted so that the ARPA detects and tracks targets within a restricted area set by the operator.	

<table>
<tr>
<td>Guard zones</td>
<td>Guard zones are specified by arc and depths, so targets which meet the established criteria will be acquired and tracked.</td>
<td>


</td>
</tr>
<tr>
<td>Guard rings and area rejection boundaries (ARB)</td>
<td>Any detectable object within the set area will be recognized and tracked by the system, and land, ships or any objects comprised in the ARBs will be automatically rejected.</td>
<td>


</td>
</tr>
<tr>
<td>Predicted Point of Collision (PPC)</td>
<td>It is the point towards which the observing ship should steer at her present speed in order for a collision to occur.</td>
<td>


</td>
</tr>
</table>

1.5 REGULATION

1.5.1 Carriage requirements. International Convention for the Safety of Life at Sea (SOLAS), 1974

This International Convention on Safety of Life at Sea is binding on all Contracting States after ratification by a pre-set number of them. It has a number of chapters and is revised from time to time. Chapters V includes the Carriage Requirements for radar and other on-board navigation equipment for ships in its 19th Regulation. These define what must be carried on each size and class of ship, including the navigational radar. SOLAS also states if and when exceptions may be permitted by national authorities and defines specifications and type-testing procedures applicable to the equipment. Excerpts from this convention regarding radar are shown in the Annex 1.

1.5.2 IMO Performance Standards for Radar and Automatic Radar Plotting Aids

The minimum operating standards of the marine radar and ARPA equipment installed onboard on or after 1 July 2008 have been established by IMO, through the resolution MSC 192(79), which is attached in the Annex 2.

For radars installed in different time periods in the past, the following resolutions regulate the operation of this equipment: A.222(VII), A.278(VIII), A.477(XII), MSC.64(67), A.820(19) and A.823(19).

1.5.3 Training requirements. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978 and STCW Code

The main purpose of the Convention is to promote safety of life and property at sea and the protection of the marine environment by establishing in common agreement international standards of training, certification and watchkeeping for seafarers.

Regarding radar and ARPA, the STCW Code stablishes the mandatory minimum requirements for knowledge, understanding and proficiency in Table A-II/1 and in Section B-I/12. These requirements are extended in the Annex 3.

CHAPTER 2

THE USE OF MARINE RADAR IN COLLISION AVOIDANCE

2. THE USE OF THE MARINE RADAR IN COLLISION AVOIDANCE

Once the main framework and operation principles of the marine radar have been explained, it is time to study this system from the operator point of view, that is, its use in navigation.

The marine radar is a versatile tool, which, generally speaking, can be utilized in two ways: as an aid to navigation, or as an anti-collision unit. On the one hand, the marine radar gives support to the officer to fix the own ship's position by means of measuring bearings and/or distances from radar echoes of fixed objects (land, fixed aids to navigation), provided they are recognizable on the nautical chart.

On the other hand, it can be used for collision avoidance. As Briggs (2004, p. 4) summarized the marine radar helps:

- To assess the traffic situation,
- To monitor movements of other shipping for collision avoidance,
- To monitor own ship's progress relative to sea-marks or coastal features,
- To detect ice, uncharted wrecks or other obstructions,
- To maintain anchor watch,
- etc.

Given that the main goal of this dissertation is to evaluate the impact of the radar misuse in maritime accidents, particularly in collisions between ships, this chapter will only focus on the marine radar as anti-collision unit.

2.1 THE MARINE RADAR AS AN ANTI-COLLISION UNIT

2.1.1 Radar configuration[4]

In this part, some radar settings are analysed due to their relevancy in collision avoidance. After each one, a table summarizing their features is included.

2.1.1.1 Frequency: radar bands

By international agreement two groups of radio frequencies are allocated for their use by civil marine radar systems.

[4] Excerpts from Bole, Dineley & Wall (2005).

One group lies in the X-band and includes those frequencies that lie between 9320 and 9500 MHz. These frequencies correspond with a wavelength of approximately 3 cm. The second group lies in the S-band, and includes the frequencies lying between 2900 and 3100MHz that corresponds with a wavelength of approximately 10 cm.

The characteristics of X-band and S-band transmissions are complementary and a thorough knowledge of them leads to a more effective use of the equipment.

A comparison between the performance of both bands in relation to some features is provided in Table 2.1.

Table 2.1. X-band and S-band comparison (Bole, Dineley & Wall, 2005, p. 39).

Feature	Comparison
Target response	For a target of a given size, the response at X-band is greater than at S-band
Bearing discrimination	For a given aerial width the horizontal beamwidth effect in an S-band system will be approximately 3.3 times that of an X-band system
Vertical beam structure	The vertical lobe pattern produced by an S-band aerial is about 3.3 times as coarse as that from an X-band aerial located at the same height
Radar horizon	The radar horizon with S-band is slightly more distant than with X-band
Sea clutter response	The unwanted response from sea waves is less at S-band than at X-band, thus the probability of targets being masked due to saturation is less
Precipitation response	The probability of detection of targets which lie within an area of precipitation is higher with S-band transmission than with X-band transmission
Attenuation in precipitation	In any given set of precipitation conditions, S-band transmissions will suffer less attenuation than those at X-band

2.1.1.2 Picture orientation

Orientation is defined as the choice of directional reference to be represented by the 000° graduation on the fixed bearing scale around the PPI.

In practice, one of three preferred directions will be chosen, namely:

- *Head-up* (unstabilized). This orientation is so called, because the observer views the picture with the heading marker (and thus the ship's head) at the top of the screen. The single attractive feature of the ship's-head-up orientation is that it corresponds directly with the scene as viewed through the wheelhouse window. However, with every moment or the natural yaw of the ship, the image will smudge most of the time. Therefore, it is not advisable to use it normally; it will only be helpful when the stabilized orientations cannot be used due to a technical failure.
- *True north* (stabilized). In true-north-up orientation, the heading marker is aligned with that graduation on the fixed bearing scale which corresponds with the instantaneous value of the ship's heading. As a result, the 000° graduation represents true north. The addition of compass stabilization overcomes the serious, inherent limitation of the ship's-head-up (unstabilized) orientation by removing the smear which is associated with any change in heading. Not only does this eliminate the masking of targets by the afterglow generated during an alteration of course, but it allows true bearings to be read off directly and quickly from the fixed bearing scale without the need to check the direction of the ship's head at the same instant. These features are of particular importance in both collision avoidance and navigation applications.
- *Course-up* (stabilized). In a course-up orientation the heading marker is aligned to the 000° graduation on the fixed bearing scale at an instant at which the vessel is right on the chosen course. Provided that the observing vessel does not stray very far from her chosen course, this orientation effectively combines the attractive features of both of the orientations previously described. It eliminates the angular wander of the picture due to yaw, while maintaining the heading marker in a substantially (though not exactly) ship's-head-up position. Inevitably a major alteration of course will become necessary either due to the requirements of collision avoidance or to those of general navigation and the 'head-up' property will not be possible until the image is stabilized.

Table 2.2. Picture orientations comparison (Bole, Dineley & Wall, 2005, p. 17).

Feature	**Orientation**		
	Ship's-head-up, unstabilized	*True-north-up, stabilized*	*Course-up, stabilized*
Blurring when observing vessel yaws or alters course	Yes: can produce very serious masking	None	None

Measurement of bearings	Awkward and slow	Straightforward	Straightforward
Angular disruption of target trails when observing vessel yaws or alters course	Yes: can be dangerously misleading	None	None
Correspondence with wheel-house window view	Perfect	Not obvious	Virtually perfect except after large course change
Correspondence with chart	Not obvious	Perfect	Not obvious

In Table 2.2. the main characteristics of these orientations are summarized. The fundamental function of any civil marine radar is to provide a means of measuring the ranges and bearings of echoes and hence to make possible the tracking of target movements for collision avoidance and the determination of the observing vessel's position in order to ensure safe navigation. The ease with which these objectives can be attained is affected by the choice of orientation. Thus, the modes north-up and course-up are preferably used, while head-up orientation would be reserved for cases in which the previous two were not available due to technical failures.

2.1.1.3 Presentation

Picture presentation is used to indicate if the movement of displayed echoes is shown with respect to the observing vessel (relative motion), the water (true motion), or the ground (true motion corrected by the drift due to the existing current). There are two choices of presentation:

- *Relative-motion* (RM). In the relative-motion presentation the origin of the display is stationary, and, as a consequence, the movement of all targets is shown with respect to the observing vessel. Commonly the origin is located at the centre of the circular screen, but this need not be the case as off-centred relative-motion presentations are available in many display systems. This presentation mode provides the officer with essential data when it comes to consider whether a risk of collision or close quarters situation is developing: the CPA and TCPA.

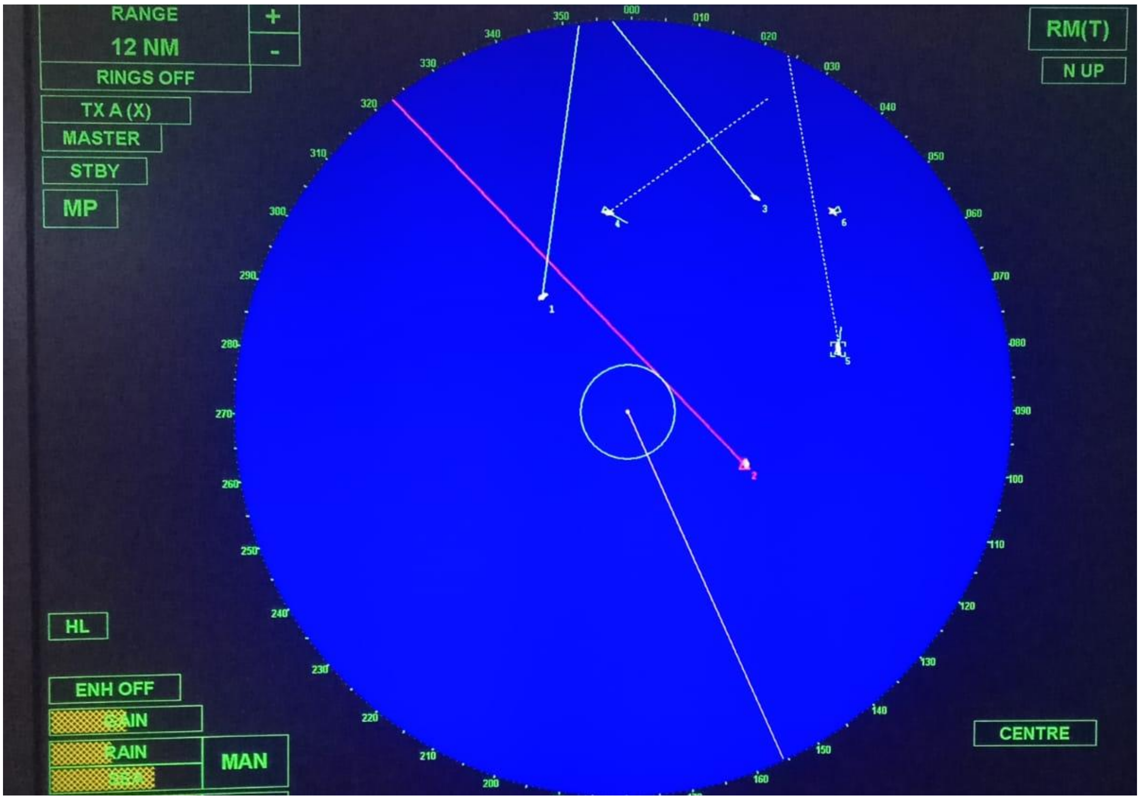


Figure 2.1. Relative-motion display (NAVI TRAINER 5000 v.5.25 TRANSAS Simulator from the Nautical College of the University of the Basque Country).

- *True-motion* (TM). It has been shown that in a relative-motion presentation the movement of all echoes across the screen is affected by the course and speed of the observing vessel. In a correctly adjusted true-motion presentation, the echo movement of all targets is rendered independent of the motion of the observing vessel. This is achieved by causing the origin of the picture to track across the screen in a direction and at a rate which correspond with the motion of the own ship over ground or over sea.

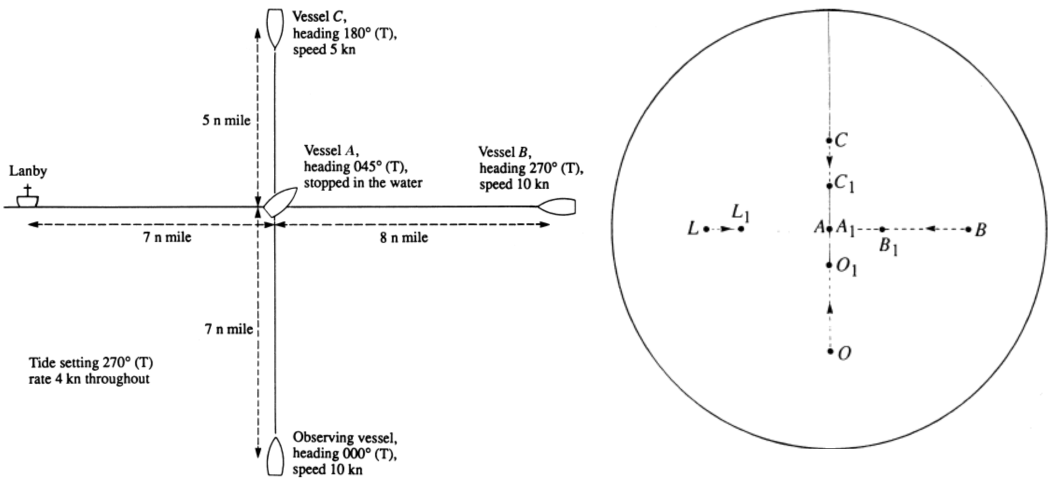


Figure 2.2. True-motion representation (Bole, Dineley & Wall, 2005, pp. 21-22)

The choice of presentation made in any given circumstances will be influenced by a number of factors. Material to the decision will be the question of whether the radar is being used primarily for collision avoidance or for position fixing and progress monitoring. In Table 2.3 a comparison between the main features of relative and true presentations is provided.

On the one hand, in the relative-motion presentation, systematic observation of ship's movement readily offers both the CPA and the TCPA. As it has been pointed out before, this information is an effective measure of the risk of a close-quarters situation developing. However, the presentation gives no direct indication of the heading or speed of target vessels. Such information is essential to the choice of avoiding action in encounters with other vessels and has to be obtained by the resolution of a vector triangle (this may be done graphically or automatically by using the trial manoeuvre). Thus, the relative-motion presentation gives direct indication of some of the information required for collision avoidance, but the remainder must be found by deduction.

On the other hand, the true-motion presentation makes the headings and speeds of targets available directly, but the observer is required to deduce the CPA and TCPA. In respect of the use of radar for collision avoidance it can be seen that the relative motion and the true-motion sea-stabilized presentations are complementary. The true-motion does have the added advantage that it makes it very much easier to identify target manoeuvres.

Table 2.3. Presentations comparison (Bole, Dineley & Wall, 2005, adapted)

Feature	**Presentation**	
	Relative motion	*True motion*
Ease of assessing target's CPA/TCPA	Directly available	Resolution required
Ease of assessing target's course, speed and aspect	Resolution required	Directly available
Need for additional sensor inputs: course and speed	No	Yes
Displayed information relative to:	Observer	The water or the ground
Particular application for collision avoidance/navigation	Partial contribution to collision avoidance data. Ideal for parallel indexing	Partial contribution to collision avoidance data

Limitations for collision avoidance	Target heading not directly available	CPA and TCPA not directly available
Limitation for navigation	Movements of land echoes may hinder target identification	Limited movements of land echoes

However, it must be highlighted that the ARPA can display relative motion information in real time, as well as data referred to true movement (course and speed), regardless of the utilized presentation mode.

2.1.2 Procedure to determine if there is a risk of collision or close quarters situation and take corrective action, if necessary

In order to assess if a navigation situation can lead to a risk of collision or close quarters situation, the officer of the watch needs to follow a certain process:

1. Keep a constant and exhaustive look-out. Track all the relevant targets by all available means besides sight and hearing.
2. Gather and interpret CPA and TCPA data. If certain vessels are considered to be a difficulty for own ship's headway, these criteria are used to stablish a priority of actuation.
3. Weather and navigation conditions must be borne in mind. It is not the same to manoeuvre with daylight or at night, or to act in a foggy area rather than in cloudless circumstances.
4. According to the previous point, the most suitable action to avoid collision is determined following the COLREGs (see Chapter 3). Therefore, radar, when it is used as an anti-collision unit, is directly connected to IMO Collision Regulations (1972). Furthermore, some of these rules refer to the use of this system, as it will be explained in the next chapter.
5. Leverage the trial manoeuvre facility provided by the ARPA in order to decide which manoeuvre would be the most applicable and safe as it allows to know beforehand the final situation (new CPAs).

Figure 2.3. Risk of collision situation before using the trial manoeuvre facility (NAVI TRAINER 5000 v.5.25 TRANSAS Simulator from the Nautical College of the University of the Basque Country).

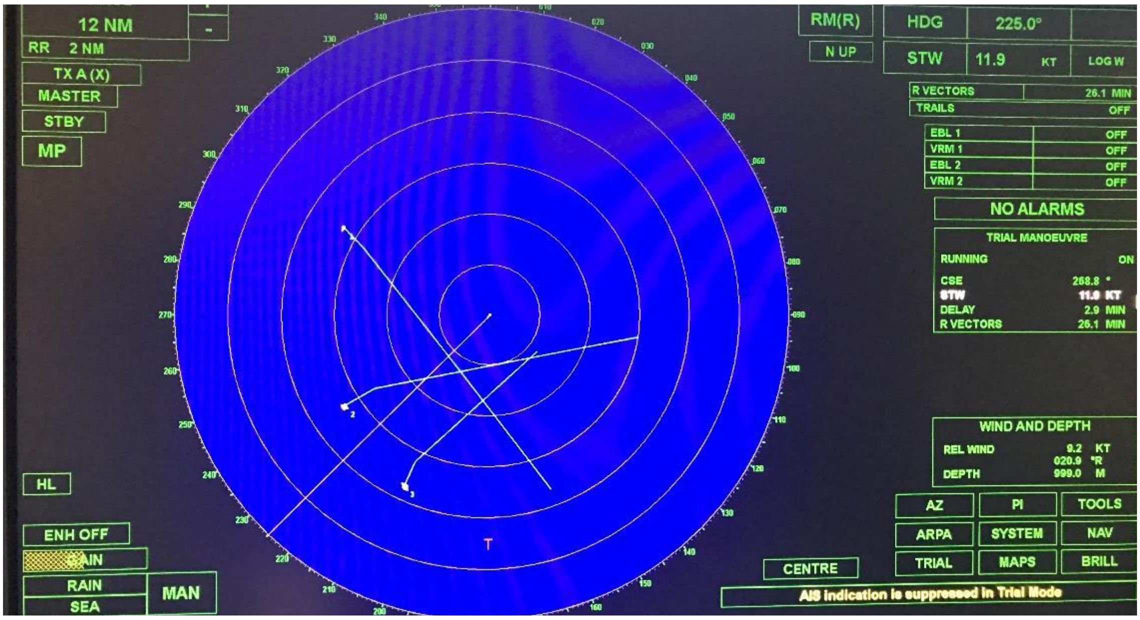


Figure 2.4. Results of a course change by own ship provided by the trial manoeuvre facility (NAVI TRAINER 5000 v.5.25 TRANSAS Simulator from the Nautical College of the University of the Basque Country).

Figures 2.3 and 2.4 show, respectively, the actual, risky navigation situation and the predicted safe situation should the own ship's true course be altered 44° to starboard. It can be observed noticeable changes in the targets' relative vectors, meaning that all the targets would pass at least 2 nm from own ship.

2.2 ERROR SOURCES[5]

It is evident that errors presented in the data displayed on the radar and ARPA screen or by alphanumeric read-out will affect decision making. It is also a potential source of mistake the wrong interpretation of the information on the PPI: for example, if true vectors are shown and the operator understands them as relative ones, she or he could take actions that may lead to hazard. Therefore, errors can be stemmed from both the radar and the operator.

Among those that proceed from the equipment, there are some that cannot be properly considered errors, but refer to the limitations of the system itself. In this sense, the OOW must know the accuracy of the information provided by default by the marine radars, which is regulated for the IMO-approved radar-ARPA equipments by IMO Performance Standards for Radar Equipment (see Annex 2).

In this way, the main factors that may affect the accuracy of the data can be arranged in the following groups:

- Errors which are generated in the radar installation itself, the behaviour of the signals at the chosen frequency and the limitations of peripheral equipment such as log, gyro compasses and dedicated trackers.
- Operator's errors:
  - which may be due to inaccuracies during processing of the radar data, inadequacies of the algorithms chosen, and the limits of accuracy accepted; or
  - errors in interpretation of the displayed data.

2.2.1 Errors that are generated in the radar installation

Errors in the radar, gyro compass and log which feed data to the ARPA system will result in errors in the output data. Range and bearing errors which remain constant or nearly so during the encounter, e.g. a steady gyro compass error of a few degrees, will introduce an error into the predicted vectors of other ships, but are unlikely to cause danger since all data will be similarly affected, including own ship. The effect of errors on the predicted data depends on the kind of error, the situation and the duration of the plot for which the data is stored for processing and prediction. These are some examples:

[5] This part is based Bole, Dineley & Wall (2005).

- glint;
- errors in bearing measurement that can lead to errors in the observed relative track and therefore the predicted CPA due to backlash in gearing, unstable platform or antenna tilt, asymmetrical antenna beam, or azimuth quantization error;
- errors in range measurement because of roll of own ship or pulse amplitude variation;
- the effect of random gyrocompass errors; or
- the effect of random log errors.

2.2.2 Operator's errors

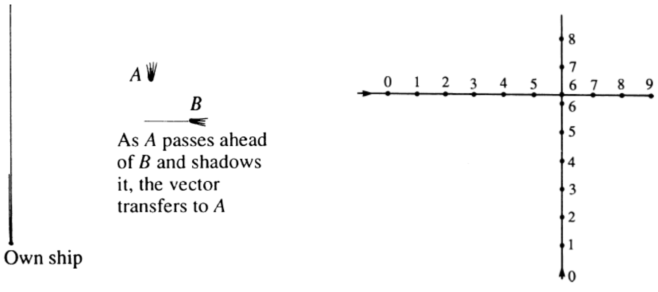
2.2.2.1 Errors in displayed data

2.2.2.1.1 Target swap

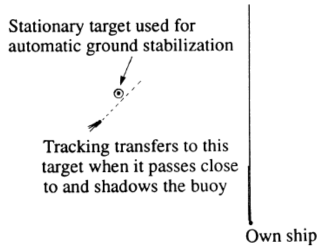
When two targets are close to each other, it is possible for the association of past and present echoes to be confused so that the ARPA processor is loaded with erroneous data.

The result is that the historical data on one target may be transferred to another target and the indicated relative (and true) track of that ship will be composed of part of the tracks of two different target motions. The human factor intervenes when one of those targets is considered a threat and, even if it is automatically tracked, it must be controlled so as to avoid its loss after swapping.

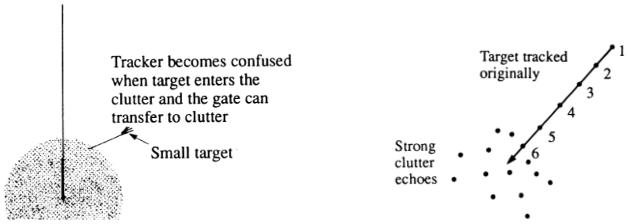
Table 2.4. Target swap examples (Bole, Dineley & Wall, 2005, pp. 224 and 403)

Target swap example cases	
Two different predictive tracks of different targets coincide at the same point and time	

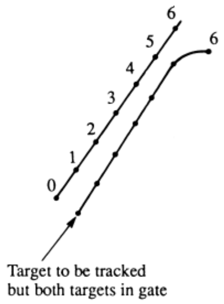
When a ship's track passes next to a stationary target such as a buoy, the moving object may transfer its track to the stationary target



When target enters a clutter area it may be confused with the clutter itself



Targets travel close together for a period, then separate. The tracker may not follow the diverging target ship



2.2.2.1.2 Track errors

The motion of a target is rarely completely steady and even steady motion will return positions which are randomly scattered about the actual track, due to basic radar limitations. The effect of these errors should of course fall within the limits set out in IMO Performance Standards, and the operator needs to keep them in mind.

Accuracy is most difficult to achieve with targets whose track movement is slow. In the case of relative track storage this will affect a target whose course and speed are close to those of the observing vessel. The length of the relative track will be small and thus the system errors are a much more significant proportion of track length than would be the case with a target having a rapid relative motion. Thus, the inherent accuracy of CPA data will be low.

In general, the tracker is likely to offer the best indication of both the relative motion and the true motion when both the target and the observing vessel maintain their course and speed for a full smoothing period. A clear example is when both observing vessel and target manoeuvre at the same time, it is unlikely that any system will commence to provide a reliable indication of any target data until either the observing vessel or the target ceases to manoeuvre.

Regarding stationary targets, it must be remembered that, even in steady-state conditions, a land-stationary target may display some component of motion due to the effect of tidal currents, and water-stationary targets may have small non-zero vectors due to system errors.

On the contrary, when moving targets are tracked down to very close ranges, the relative motion will give rise to very rapid bearing changes and this may make it impossible for the tracker to follow the target; thus the 'target lost' condition may arise, not because the echo is weak, but because the gate cannot be moved fast enough or opened up sufficiently to find it.

In summary, it must be remembered that whenever the steady-state conditions are disrupted there will be a period in which the data will be particularly liable to the track errors described above, in the same way as is the case when a target is first acquired. When the steady state is regained, accuracy and stability will improve, first over the short smoothing period and then over the long period. Any track data extracted during periods of non-steady-state conditions must be observed with suspicion. Therefore, this (regulated) errors are generated by the system but they need to be borne in mind by the operator in order to optimize the performance of the marine radar.

2.2.2.1.3 The effect on vectors of incorrect course and speed input

Whatever approach the tracker uses, it is essential for the observer to ensure that the correct course and speed inputs are fed in when setting up and that regular and frequent checks are made to ensure that the values remain correct. Failure to do this will in general result in the erroneous display of true data which may seriously mislead the navigator when choosing a suitable evasion manoeuvre strategy.

It is true that the relative vectors and the associated CPA/TCPA data should be unaffected if the observer allows a fixed erroneous input of course and speed data to be applied. On the contrary, the true vectors will be displayed incorrectly if the observer allows the errors. This may give the observer a seriously misleading impression of the other vessel's heading and speed and may prompt an unsafe manoeuvre.

2.2.2.2 Errors of interpretation

These errors are not within the system but are those likely to be made by the operator through misunderstanding, inexperience or casual observation.

In general, the human factor is responsible for a great part of the collisions at sea. In this group we can find: decision errors, skill-based errors, perceptual errors, and violations which are behaviours that show wilful disregard for the rules and regulations. They have been analysed in multiple researches and their results always match, as it will be seen in the section 2.3.

Different conflictive situations in which mistakes committed by radar operators take part, are addressed next.

2.2.2.2.1 Impure presentations

In the case of vector systems, the most common mistakes arise because the observer, either from lack of concentration due to stress of the moment or through lack of knowledge, confuses relative and true vectors (see figure 2.5).

Because the vector mode (i.e. relative or true) is not necessarily the same as the radar presentation which has been selected, vectors and afterglow trails may not match. When true vectors are selected on a relative motion presentation, the vectors and the afterglow will not correlate in the same way when relative vectors are selected while using a true-motion presentation, the true afterglow will not match the relative vector.

Definitively, it must be understood what relative motion and true motion are, what kind of information the operation can gather from both of them and which type of vectors are the most suitable for each occasion.

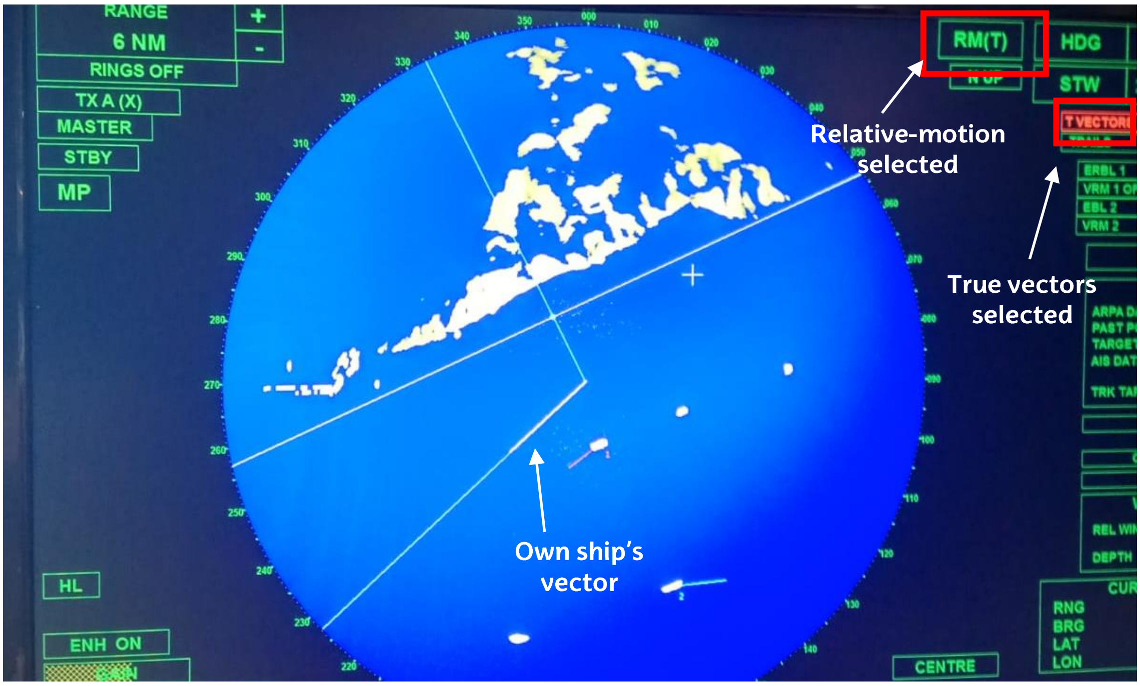


Figure 2.5. Impure presentation (NAVI TRAINER 5000 v.5.25 TRANSAS Simulator from the Nautical College of the University of the Basque Country).

2.2.2.2.2 Overreliance on accuracy of the presented data

It is an issue always highlighted when operating every navigational equipment. However, radar data can be one of the most useful and essential when it comes to assess a risk of collision situation and act consequently.

Overreliance on, and failure to appreciate inaccuracies in presented data which has been derived from imperfect inputs should be avoided at all costs. It must always be borne in mind that a vector/PAD/alphanumeric read-out is not absolutely accurate, just because it has been produced by a computer.

2.2.2.2.3 Missed targets

The simple fact that the ARPA can acquire and track targets automatically does not mean that the system follows all the valuable and interesting objects for the operator. Plus, the target may subsequently be re-acquired and present a course and speed which may indicate that the target has manoeuvred when, in fact, the track is new and has not yet established its long-term accuracy. Again, it is a question of overreliance.

2.3 IMPACT OF THE RADAR MISUSE IN COLLISIONS

Butler (1973) showed, through his research about the development of an anti-collision system for merchant ships, that the marine radar was not as effective as expected. In fact, collisions increased considerably in the beginning of the implantation of this unit onboard vessels:

“Even though only a small number of collisions belong to ships fitted with radar, the percentage raised from 4.3% in 1963 to 15% in 1971, according to recent statistics” (Mayo, 1989, p. 53). In this same study, results evidenced that from 100 investigated collisions, only in 8 a bad or deficient radar functioning was reported.

The rising of general maritime accidents is attributable to three main reasons: radar limitations and officer’s adaptation to new technology, greater maritime traffic and ship’s speed increase (linked to an inadequate velocity to the situation). As for the radar-assisted collisions, the reasons differ; in this case, the wrong use of the system thrives, in addition to the incompetence when interpreting the information display and the lack of understanding of the relative and true motions.

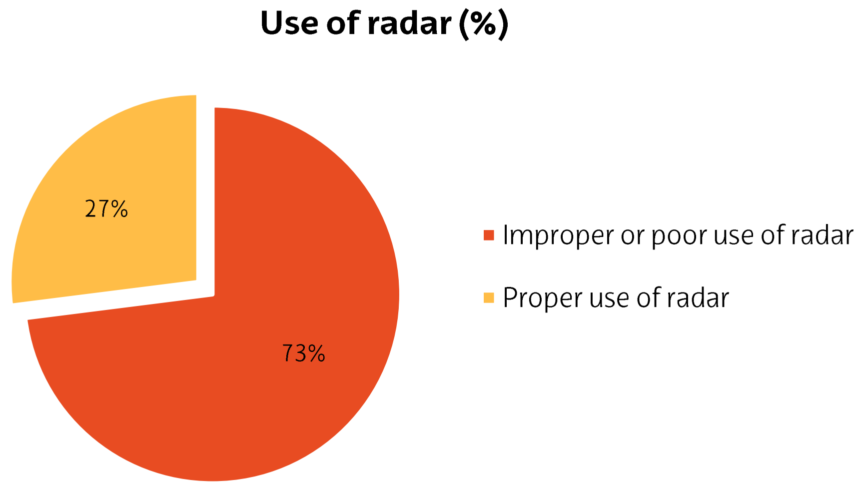
However, from that time up to now, maritime accidents have been reduced significantly. Large shipping losses have declined by 50% over the past decade, driven by improved regulation and the development of a more robust safety culture (AGCS, 2017).

Nevertheless, radar remains a major concern. According to the Bridge Watchkeeping Safety Study by MAIB[6], "as technology has advanced with regard to radar and ARPA, and the [...] crew [...] has decreased in parallel with increased automation, [...] bridge watchkeeping practices have changed in recent years. OOWs place more reliance on radar and ARPA to maintain a lookout, and to assess the risk of collision" (MAIB, 2004, p. 21). The study also revealed that "the most common contributory factors in all of the collisions were poor lookout and poor use of radar" (MAIB, 2004, p. 15).

Indeed, many newer vessels nowadays are not even provided with a gyro pelorus, for example, with which visual bearings can be taken. Therefore, visual lookout is losing its sovereignty because of the contravention of the indications given by the COLREGs (see section 3.2) by vessels involved in collision (see graphic 2.1).

It is therefore disturbing that the OOWs on 73% of the vessels involved in collision contravene the indications given by the COLREGs (see section 3.2).

By contrast, Chauvin et al (2013) in their article about Human Factors Analysis and Classification System (HFACS)[7] stated that in only a 5% of the analysed cases, which corresponded to two collided vessels, the crew reported radar operative failures.

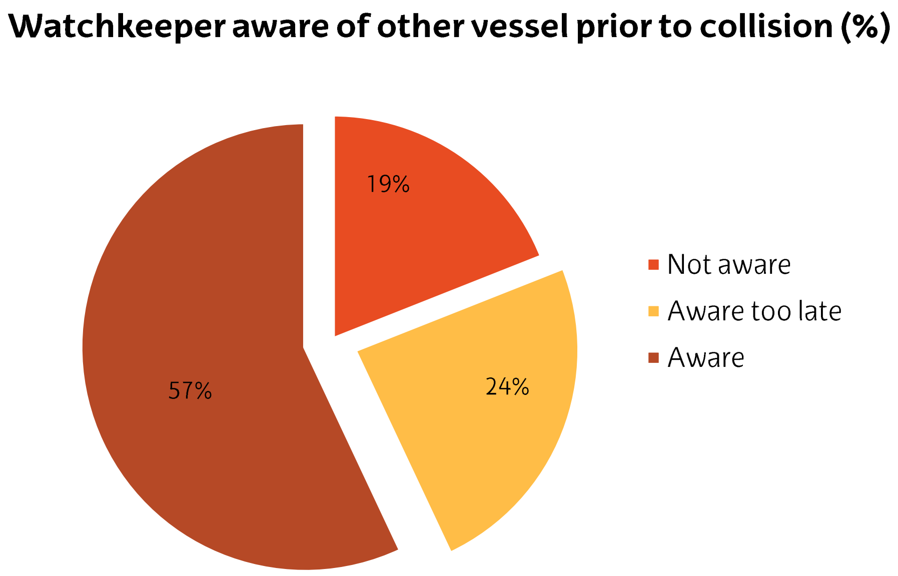


Graphic 2.1. Use of radar in maritime accidents (MAIB, 2004).

[6] Results are based upon 33 collisions happened between 1994 and 2003 in which 41 ships over 500 GT were involved. Different navigation, light and meteorological situations were considered.
[7] Human Factors Analysis and Classification System. Study carried out basing on 39 vessels involved in 27collisions that occurred between 1998 and 2012.

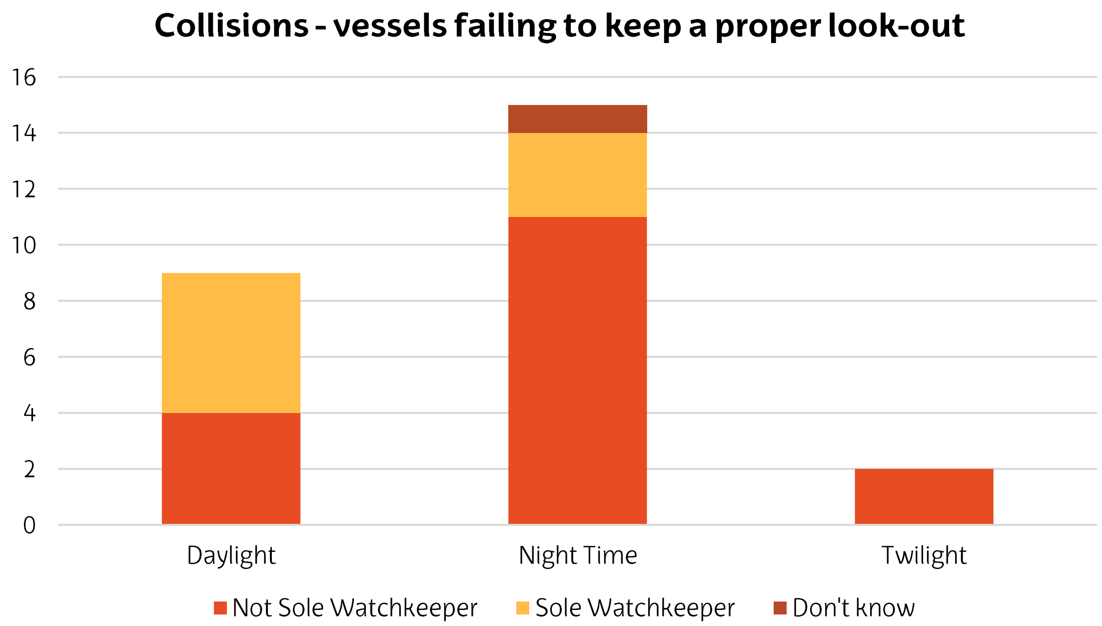
Furthermore, look-out is closely linked with this anti-collision unit. As it will be shown in the analysis of the chapter 3, the OOW needs to keep a mandatory visual and auditive lookout as stated in the Collision Regulations, but also take advantage of all the navigational equipment available on the bridge (radar among them) so as to fulfil correctly the watchkeeping task. Therefore, in this section, the impact of the type of look-out in collision is also assayed. The previously mentioned MAIB study also analyses this question (see graphic 2.2), confirming that "19% of the vessels involved in collisions, OOWs were completely unaware of the other vessel until the collision, or in some cases even after the collision" (MAIB, 2004).

Chauvin et al. (2013) also affirmed that, as far as conditions of operators are concerned, situation awareness and deficit of attention appear to be major elements. As a result, inappropriate situation awareness is the precursor of a poor decision.



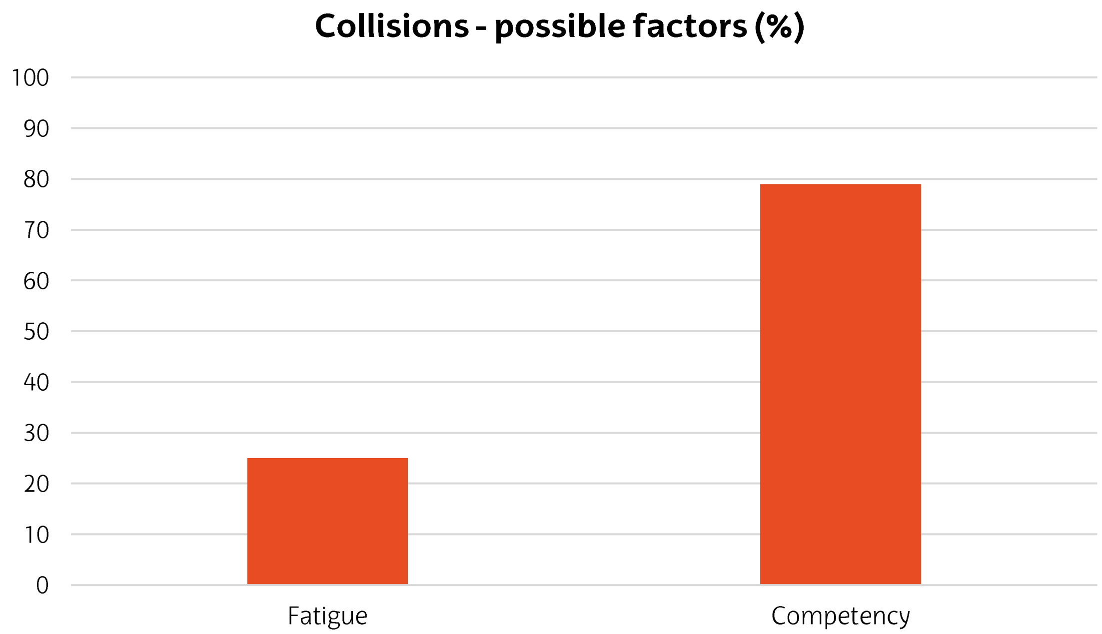
Graphic 2.2. Watchkeeper aware of other vessel prior to collision (MAIB, 2004).

In keeping with look-out, but in this instance in relation to the number of watchkeepers, the report shows that at least three of the fifteen vessels which failed to keep a proper look-out at night had lone watchkeeper on the bridge. Of the nine vessels not maintaining a proper lookout by day, five had sole watchkeeper; three of these were in an area of high traffic density, and one was in poor visibility. It follows that seven of the eight vessels with a unique watchkeeper ended up in collision, in which poor look-out was deemed to be a contributing factor, representing nearly one third of the vessels in this category (see graphic 2.3).



Graphic 2.3. Collisions – vessels failing to keep a proper look-out (MAIB, 2004).

It is also evident, however, that the bridges of 19 vessels were manned in accordance with the provisions for lookout, yet still failed to maintain a proper lookout. There are several possible reasons for this, and graphic 2.4 illustrates that competency may be more contributory in this respect than fatigue. MAIB's experience, however, concluded that "poor visual lookout can also be linked to the poor employment of ratings on the bridge. On many ships, although ratings are usually available to provide an additional lookout [such as radar], they are rarely used for this purpose during daylight".



Graphic 2.4. Collisions – possible factors (MAIB, 2004).

According to MAIB, officers seem to interpret the concept of watch wrongly. Performance tests have shown that the alertness and concentration of lookouts diminishes after about 30 minutes, which shows the futility of employing them in this way. A proper look-out consists of gathering navigational information and not only visually; radar, AIS, radio, and telephones all need to be monitored. Therefore, the OOWs ought to be adequately trained so that they know how to manage in such circumstances.

To corroborate these issues, the cited study carried out by Chauvin et al. (2013) showed that the main factor that affect to the deck officers are inappropriate situation awareness (33.33%), attention deficit (30.77%), and knowledge limitations (20.51%), concluding that "unsafe acts are mainly related to decision-making (85%) while non-perception of the other vessel concerns 15% of the vessels involved in the [analysed] 27 collisions" (Chauvin et al., 2013, p. 34). The analysis also brought out poor visibility and the misuse of instruments as the main environmental factors.

CHAPTER 3
COLREG ANALYSIS

3. COLREG ANALYSIS

3.1 CONVENTION ON THE INTERNATIONAL REGULATIONS FOR PREVENTING COLLISIONS AT SEA, 1972 (COLREG)

The IMO's Collision Regulations (COLREGs) which were adopted in 1972 entered in force in 1977 and have been amended in five occasions (1983, 1989, 1991, 1995 and 2003). They replaced the previous Collision Regulations of 1960, which had been adopted at the same time as the 1960 SOLAS Convention.

The International Regulations for Preventing Collisions at Sea, at their name says, consist of a collection of navigational standards that have been formulated to prevent troubled situations involving risk during navigation. For that aim, these regulations help seafarers to detect and avoid these cases in advance. However, the text does not always give precise commands indicating how to proceed in each unsettled situation, but some sort of guidance which can be interpreted in one way or another depending on different factors (OOW, weather conditions, etc.).

The structure of COLREGs, also called *Rules of the Road*, are shown in Table 3.1.

Table 3.1. Structure of the COLREG (Mayo, 1989, p. 26. Adapted)

Parts	Rules	Explanation
A. General	1 – 3	
B. Steering and Sailing	4 – 10	Section I – *Conduct of vessels in any condition of visibility*
	11 – 18	Section II – *Conduct of vessels in sight of one another*
	19	Section III – *Conduct of vessels in restricted visibility*
C. Lights and Shapes	20 – 31	
D. Sounds and Light Signals	32 – 37	

E. Exemptions	38	Ships which comply with the 1960 Collision Regulations and were built (or building) before the 1972 COLREG Convention
Annexes	Annex I	Positioning and technical details of lights and shapes
	Annex II	Additional signals for fishing vessels fishing in close proximity
	Annex III	Technical details of sounds signal appliances
	Annex IV	Distress signals, which lists the signals indicating distress and need of assistance

COLREG only defines basic principles, and the accuracy of its rules is very scanty, particularly that of B part rules. Experts –mostly captains of the Merchant Navy- have many times highlighted this problem. In the decision-making process, officers may doubt and/or fail to interpret them adequately. According to Salinas (2004) "we would have a more exact perception of the Regulation if we observed it under the only prism for which it has been conceived: the prevention" (p. 29).

As seen in Chapter 2, this Regulation is closely linked with the use of radar as an anti-collision unit, and, for this reason, it is considered necessary to elaborate an analysis of the COLREG from the radar and ARPA point of view.

3.2. ANALYSIS OF COLREGS IN WHICH RADAR AND ARPA ARE INVOLVED

The rules comprising the *Part B: Steering and Sailing* are the most influenced by the marine radar use so this assay will focus only on some of those COLREGs.

3.2.1. Section I – *Conduct of vessels in any condition of visibility*

Rule 5. *Look-out*

Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.

Comments. First, from the sentence "every vessel shall at all times maintain a proper look-out [...] by all available means" it can be deduced that every navigational equipment may be helpful in order to keep a proper watch, radar among them. In addition, if radar and ARPA are used, it is essential to make all the indispensable arrangements regarding range, anti-clutter adjustments and other controls and to consider all the small and weak targets that might trigger a perilous situation. Nevertheless, the type of look-out depends on each situation; thus, visual and auditory watch remains indispensable in any case and radar is used as a supporting system with the exception of restricted visibility (see section 3.2.3).

Rule 6. *Safe Speed*

Every vessel shall at all times proceed at a safe speed so that she can take proper and effective action to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions.

In determining a safe speed, the following factors shall be among those taken into account:

[...]

(b) Additionally, by vessels with operational radar:

- *i) the characteristics, efficiency and limitations of the radar equipment;*
- *ii) any constraints imposed by the radar range scale in use;*
- *iii) the effect on radar detection of the sea state, weather and other sources of interference;*
- *iv) the possibility that small vessels, ice and other floating objects may not be detected by radar at an adequate range;*
- *v) the number, location and movement of vessels detected by radar;*
- *vi) the more exact assessment of the visibility that may be possible when radar is used to determine the range of vessels or other objects in the vicinity.*

Comments. This rule has a specific section related to ships operating radar, besides the general factors that an officer needs to keep in mind. Therefore, the comments on this regulation will be based specially on the section b).

So, regarding radar technical aspects, the operator must meet all the controls, characteristics, functions and, above all, the failures or restrictions it can generate (see section 2.2). In addition, sea and weather conditions may affect the information gathered from the radar in case anti-clutters are adjusted or not to the specific meteorological situation.

Range is also a question to discuss about. It must always be adequate to current circumstances; however, it may happen that targets outside the radar watch region involve risk, be it because of their speed, course or any other reason. That is why the officer operating the radar ought to change periodically the range so that further or closer (and weaker) targets are noticed.

Nevertheless, as it was mentioned above, watch cannot be based only on radar. Visual vigilance is indispensable (also in foggy situations there must be a lookout so that small targets nearby are detected be it by sight or audible signals). These small targets may interfere in the manoeuvre that the officer thought to carry out previously; therefore, both course and speed can be reconsidered.

With regard to the meaning of safe speed, *safe* usually relates to slow speed. However, safe speed signifies that the vessel has to be able to manoeuvre in order to avoid the collision, not exceeding velocity limits and not losing her command, because there is always a minimum speed for ships to con.

In the particular case of navigation with restricted visibility[8], it has to be taken into account that, when there is fog in the vicinity, although the own ship is not within the boundaries of the foggy area, she cannot proceed with her habitual speed. When entering, leaving behind or sailing near fog banks, velocity needs to be moderate because it may not be possible to detect all the ships or objects nearby due to lack of visual information.

Finally, it is obvious that a crash with lower speed will be less harmful than sailing at high velocity. Furthermore, besides losses, damages and costs, high speed involves less risk-detection time and, therefore, a lack of enough reaction time.

Rule 7. *Risk of Collision*

a) *Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is any doubt such risk shall be deemed to exist.*
b) *Proper use shall be made of radar equipment if fitted and operational, including long-range scanning to obtain early warning of risk of collision and radar plotting or equivalent systematic observation of detected objects.*

[8] Information about sailing through fog (or other meteorological phenomena reducing the range of vision) will be extended in the rule 19 regarding restricted visibility.

c) *Assumptions shall not be made on the basis of scanty information, especially scanty radar information.*

d) *In determining if risk of collision exists the following considerations shall be among those taken into account:*

   i) *such risk shall be deemed to exist if the compass bearing of an approaching vessel does not appreciably change;*

   ii) *such risk may sometimes exist even when an appreciable bearing change is evident, particularly when approaching a very large vessel or a tow or when approaching a vessel at close range.*

Comments. This rule talks about the means to detect a situation of risk, and again, it is said that all means will be used in order to determine whether danger is involved or not. Therefore, radar is included in this list. Still, as Mayo (1989) pointed out "all the circumstances and conditions of any moment are appropriate for such determination, however, undoubtedly the circumstance of poor visibility occupies a principal place" (p. 51). So, radar should be mostly used as main navigational information source when fog or any vision range-decreasing condition hampers visual look-out.

About when and how to act when there is risk involved in navigation, there have always been doubts among deck officers. As it was mentioned at the beginning of this section, COLREGs are written with the aim of preventing collisions at sea; that is why there are not specific orders to follow but general indications which can lead to different interpretations.

One of the methods to clarify if a vessel steers a collision course and, therefore, if it supposes crash risk, is the so-called *constant bearing, decreasing range* (CBDR) navigation technique. If the rule is fulfilled, the vessels may collide. With good weather it can be checked visually; however, radar provides this information much quicker. But in case of worse climate or rush, the usage of this rule by sight is not worth it due to the time it takes. Radar is always an acceptable option to gather data in advance provided that it is well adjusted.

To finish the study of this rule, a list of advices about radar use by De Simón (1989) are given:

- proper functioning checking before its use shall be done;
- controls will be adjusted for each situation in order to get the best performance;
- a certified operator will handle the radar;

- shadow sectors will be taken into account for the procedure in case of collision risk;
- too much time controlling radar's screen is counter-productive; so,
- periodical radar look-outs will be made;
- stable radar presentation improves the display because the image does not smudge;
- range will be always controlled but not constantly changed, especially when targets are nearby; and
- slowing down will be considered in fog cases, even if radar is working properly.

Rule 8. *Action to Avoid Collision*

a) Any action taken to avoid collision shall be taken in accordance with the Rules of this Part and shall, if the circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship.
b) Any alteration of course and/or speed to avoid collision shall, if the circumstances of the case admit, be large enough to be readily apparent to another vessel observing visually or by radar; a succession of small alterations of course and/or speed should be avoided.
c) [...]
d) Action taken to avoid collision with another vessel shall be such as to result in passing at a safe distance. The effectiveness of the action shall be carefully checked until the other vessel is finally past and clear.
e) [...]
f) [...]

Comments. As we can observe in the first paragraph, there is lack of accuracy, again, since concepts such as "ample time" are not specified. This leads to confusion and doubts when it comes to perform a collision avoidance manoeuvre. The action taken can be a simple course alteration, speed change or a mix of both; it depends on the surroundings, ship's features and meteorological factors: the performance carried out in the open sea surely will not be the same as in vessel-gathered areas such as the English Channel or the Strait of Gibraltar; therefore the manoeuvre will always be adapted to the current situation.

> When navigating across the open sea, with enough water to each side, the most effective manoeuvre would be a course alteration. In narrow channels, paths and rivers, the most appropriate one could be a speed decrease, as

> long as it is noticeable enough so that the other vessel may detect it. (Salinas, 2004, p. 55)

To clarify this issue, Mayo (1989) stated that "we believe that permissive circumstances [to make a course change] include: sufficient time, enough space and safe passage distance between both ships. If these requirements are not met, or more time is needed to study the situation, we will be in the case of [...] speed reduction [...]".

But, for the record, it cannot be forgotten that sometimes, the most suitable answer to a risk of collision situation is to keep course and speed.

The most relevant about this rule is that the manoeuvre must be as noticeable as possible so that ships nearby can assess the situation. This statement involves radar, because course alteration (and/or speed change) should be ample and easily detected by the system, besides by sight if visibility circumstances permit it.

> To shed light, we must look up at judgments handed down by the courts, which are the product of numerous consultations, analysis of tests and *ad hoc* studies. Summing up [...] course changes of less than 10° are usually qualified as invalid [...] They are considered suitable turns from 20° onwards. In the case of navigating with reduced visibility, these must be greater, in the order of 30° to 60°. (Salinas, 2004, p. 55)

Two examples are given in order to understand the importance of wide and noticeable course and/or speed alterations (both are supposed to happen in good visibility situation):

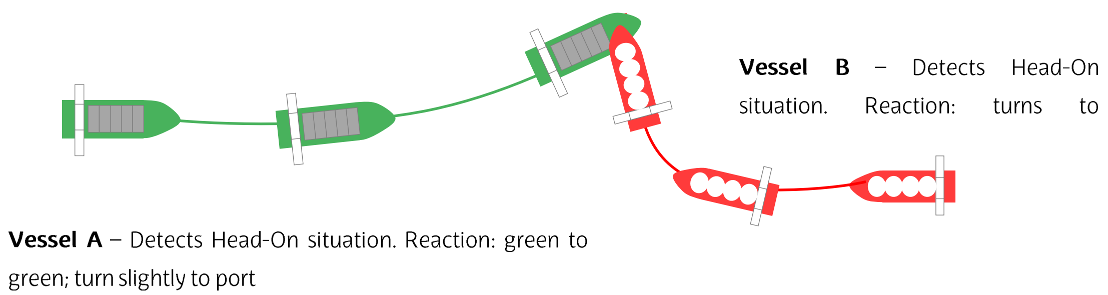


Figure 3.1. Example 1: Side collision scheme (compiled by author)

In Example 1 (Figure 3.1), ship A wants to proceed green to green with vessel B, so she alters course gently to port. However, ship B does not guess A's intention so, as B considers that it is a head-on situation, she alters course to starboard for the evasion of the collision. This misunderstanding leads to an imminent crash between them.

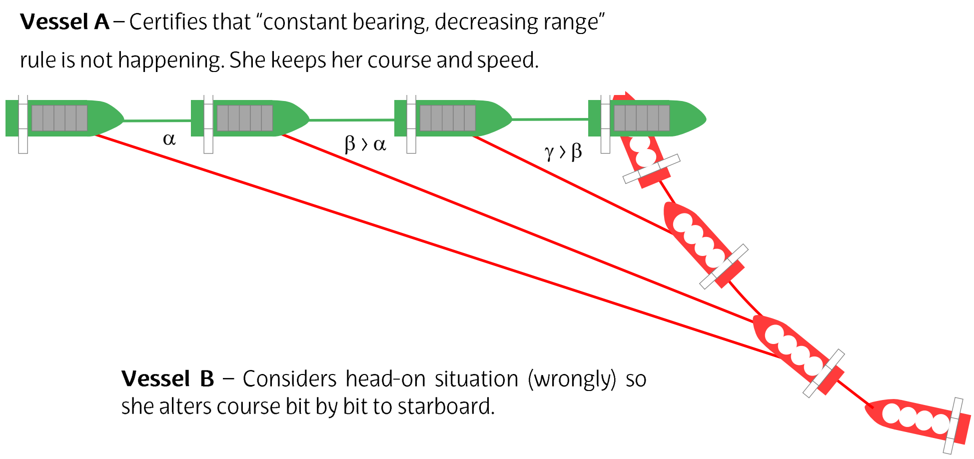


Figure 3.2. Example 2: Collision caused by incorrect detection of situation (compiled by author)

In the second example (Figure 3.2), vessel B considers head on situation (wrongly, as it will be explained in the following *Steering and Sailing* COLREGs) so she starts to turn to starboard carrying out small alterations. On the other hand, vessel A observes that relative bearing regarding B increases so she guesses that she will leave B on her starboard side. Collision will happen. It could be avoided by altering course thoroughly to starboard in the case of the ship B.

3.2.2. Section II – *Conduct of vessels in sight of one another*

Rule 11. *Application*

Rules in this section apply to vessels in sight of one another.

Comments. It is important to highlight the condition "in sight of one another" in the following COLREGs. Therefore, the vision is the fundamental way to detect and track ships. It is true that radar use is not forbidden, but in this section, it is not part of the principal means for the monitoring. The rules in this Section II are meant to be used according visual information; the situations coming up in the following pages will be defined according to the aspect. However, the radar equipment can be operated to visualise nearby vessels' manoeuvres, observe the general situation in case of having multiple neighbouring vessels, measure distances, etc.

3.2.2.1 The anti-collision rules

The following COLREGs (Rules 13, 14 and 15) are the so-called anti-collision rules. Since the relation that each of them has with the radar equipment (and ARPA) is very similar, the three are shown below, including a general comment.

Rule 13. *Overtaking*

a) *Notwithstanding anything contained in the Rules of Part B, Sections I and II, any vessel overtaking any other shall keep out of the way of the vessel being overtaken.*
b) *A vessel shall be deemed to be overtaking when coming up with another vessel from a direction more than 22.5 degrees abaft her beam, that is, in such a position with reference to the vessel she is overtaking, that at night she would be able to see only the sternlight of that vessel but neither of her sidelights.*
c) *[...]*
d) *[...]*

Rule 14. *Head-on Situation*

a) *When two power-driven vessels are meeting on reciprocal or nearly reciprocal courses so as to involve risk of collision each shall alter her course to starboard so that each shall pass on the port side of the other.*
b) *Such a situation shall be deemed to exist when a vessel sees the other ahead or nearly ahead and by night she could see the masthead lights of the other in a line or nearly in a line and/or both sidelights and by day she observes the corresponding aspect of the other vessel.*
c) *When a vessel is in any doubt as to whether such a situation exists, she shall assume that it does exist and act accordingly.*

Rule 15. *Crossing Situation*

When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel.

Comments. Perhaps, at first sight, it is possible not to see the relation between the texts of these rules and radar and ARPA. However, it is important to highlight that the radar is an auxiliary way for obtaining navigational information so visually-gathered data must be employed to evaluate the situation. As Salinas (2004) comments about the rule 14, "what determines that a vessel is in head-on situation is the aspect with which she sees the other vessel, not the cut of their radar vectors" (p. 73).

3.2.3. Section III – *Conduct of Vessels in Restricted Visibility*

In this last part of the analysis, rule regarding poor visibility conditions are be assayed. As radar-based watch is essential in these circumstances, the 19th COLREG will be deeply studied. Plus, in the next chapter, within the four analyses of real maritime collisions, two which happened under limited range of vision are studied.

Rule 19. *Conduct of Vessels in Restricted Visibility*

a) *This Rule applies to vessels not in sight of one another when navigating in or near an area of restricted visibility.*
b) *Every vessel shall proceed at a safe speed adapted to the prevailing circumstances and conditions of restricted visibility. A power-driven vessel shall have her engines ready for immediate manoeuvre.*
c) *Every vessel shall have due regard to the prevailing circumstances and conditions of restricted visibility when complying with the Rules of Section I of this Part.*
d) *A vessel which detects by radar alone the presence of another vessel shall determine if a close-quarters situation is developing and/or risk of collision exists. If so, she shall take avoiding action in ample time, provided that when such action consists of an alteration of course, so far as possible the following shall be avoided:*
    i) *an alteration of course to port for a vessel forward of the beam, other than for a vessel being overtaken;*
    ii) *an alteration of course towards a vessel abeam or abaft the beam.*
e) *Except where it has been determined that a risk of collision does not exist, every vessel which hears apparently forward of her beam the fog signal of another vessel, or which cannot avoid a close-quarters situation with another vessel forward of her beam, shall reduce her speed to the minimum at which she can be kept on her course. She shall if necessary take all her way off and in any event, navigate with extreme caution until danger of collision is over.*

Comments. First, besides fog, reduced visibility can be caused by heavy rain, hail or snow, among others. However, the text does not determine these circumstances. Furthermore, this rule must be applied during restricted visibility situations, but also near these areas, i.e. before getting in a fog bank or leaving it behind. This is a noteworthy question because officers might use the Section II of the COLREGs instead of the Section III, which indicate different ways to manoeuvre when vessels are not in sight of each other. As Salinas (2002) said, "there is a generalized tendency to continue assimilating the crossing, overtaking and head-on situations, when, in reality, these do not exist in reduced visibility. Rule 19 establishes very different manoeuvring behaviours" (p. 29).

Keeping with the issue above, Craig stated that studies have demonstrated that Rule 19 is in general poorly understood by many watchkeeping officers; according to a study from 1990 concluded that 80% of the encounter between radar-equipped vessels in restricted visibility "will be conducted by personnel with a totally erroneous view of the requirements of the Rules" (as cited in Mohovic, D., Mohovic, R., & Baric, 2016, p. 768).

Nevertheless, in addition to those procedures, speed reduction must be taken into account. Even if radar is running (among other electronic systems like VHF or AIS), in bad visibility machine regime ought to be considered. Then Rule 6, *Safe Speed,* has to be kept in mind. In fact, in addition to the results of the study carried out by Butler (see section 2.3), it was stated that one of the main reasons for the accidents to happen is the non-moderation of speed, especially in restricted visibility conditions.

Regarding navigational watch, although visual watch cannot be normally performed, it is wise to establish auditory and even visual look-out on the bow of the ship, in order to gather additional information. However, it is true that this system is almost the only and best way to get data.

About how to manoeuvre, the text is clearer and has a more instructive and accurate character comparing to precedent suggestive rules. In fact, this 19th rule's part d) regarding collision avoiding actions orders not to perform determined actions by vessels in these reduced visibility circumstances.

To conclude, Mohovic, D., Mohovic, R. & Baric (2016) in their article affirmed that "Rule 6 and Rule 19 are breached in 60% of the analysed cases [...]. These rules are very important in cases of poor visibility. They were broken in 14 analysed collision cases. 50% of the examined collisions occurred in poor visibility. Also, in the questionnaire, licensed seafarers marked these two Rules as hard to understand".

CHAPTER 4

STUDY OF RADAR ASSISTED COLLISION CASES

4. STUDY OF RADAR ASSISTED COLLISION CASES

In this part, four particular cases are shown aiming to prove the indisputable role of radar in numerous marine accidents in any meteorological condition. Indeed, they can be called 'radar assisted collisions' because of the degree of influence of this navigational device on them. Cahill (2002) said that "[the marine radar] came to be recognized as a two-edged sword that sliced through fog on the one hand, but could also take a "healthy cut out of profits if its misuse brought about collision". This concept was unknown before the collision between the *Andrea Doria* and the *Stockholm* in 1956, the considered first radar-caused accident.

Still, although nowadays marine radars are amazingly developed, collisions keep happening. "[These accidents are] the incontestable proof of the necessity of using radar constantly while at sea [...]; the fact that their use of radar led them into collision is another matter" (Cahill, 2002), matter that is assayed in this chapter. For that aim, both past and current cases in different weather and navigation situations are analysed:

- MT *Bonifaz* and MT *Fabiola*, 1964. Night, light breeze, slight sea and restricted visibility (no ARPA).
- *Eglantine* and *Credo*, 1984. Daylight, dense fog (ARPA).
- *Spring Glory* and *Josephine Maersk*, 2012. Night, light breeze, moderate sea and good visibility (ARPA).
- *Paula C* and *Darya Gayatri*, 2013. Clear night, good visibility (ARPA).

First, the account of the events is explained; second, an overview of the committed mistakes is given; and finally, the conclusions are shown. The study concludes with a summary of the lessons learned.

4.1. MT *BONIFAZ* AND MT *FABIOLA*[9]

4.1.1. Facts

On 3 July 1964, MT *Bonifaz*, a Spanish tanker of 12,942 tons sailed from Corunna Bay to Carthagena. She was making 13 knots of speed and a 196° course. However, this course was stated by the court; the *Bonifaz* declared that the course she steered was 180° (this

[9] The explanation of this case has been excerpted from Dewar (1989, pp. 643-654).

issue will be developed later). She was in ballast, but her tanks were not yet gas-free. The first and third officers were on watch.

Figure 4.1. MT *Bonifaz* (Fernández, n.d.)

The other ship, MT *Fabiola*, was a French super-tanker of 32,124 tons. She was on passage from Tunisia to Havre, deep-laden with a cargo of crude oil at a speed of 16.2 knots and a North course. About the watchkeeping, the chief officer was on watch. He also kept radar watch. The master was also on the bridge.

Figure 4.2. MT *Fabiola* (n.d.)

The collision and the previous moments happened at night. Moreover, visibility was bad: in the *Fabiola,* the range of vision worsened rapidly in the last twenty minutes before the collision, from 3 nm to just 1 nm; the *Bonifaz* met restricted visibility (1 nm) when off Cape Villano, two hours before the incident. Regarding weather, it was good, light breeze and slight sea.

As far as the carriage of radar equipment is concerned, both vessels carried sophisticated units, with true and relative motion sets. However, at that time, 1964, the ARPA technology had not yet been developed. As mentioned above, onboard the *Fabiola,* the chief officer was keeping the radar watch; on the bridge of the Spanish tanker, *Bonifaz*, the master was operating the radar after passing Cape Villano.

In this case it is important to consider the courses of the vessels, specially, that of the Spanish tanker. In Figure 4.3, the Court's collision plot for this case is shown. As the *Bonifaz* declared, they were following a South course; nevertheless, the Court concluded that her approach course was 196° and that it was maintained for some two hours whilst rounding Capes Villano and Toriana with an offing of 5 to 10 nm. The Court did allow that she might have proceeded further westwards to complete the washing of her tanks. A conclusion of the plot is that she did proceed further westwards before turning south to sail the coasts of Spain and Portugal. But, besides the unreliable version of the *Bonifaz,* the bearings of *Fabiola* were also incorrect. The Spanish vessel stated that her radar bearings were to port; *Fabiola*'s bearings, however, were to starboard.

Radar contacts were stablished at the same time (21:54) when the ships were about 8 nm apart: 191° from the *Bonifaz*, and 004° from the *Fabiola.* These bearings are not reciprocal but, if plotting was made to starboard from the *Bonifaz* with a ship's head of 180° (Spanish tanker version), there is only one-degree difference between both plottings.

The only other recorded bearing from the *Bonifaz* is 178°, which showed up as a bad bearing. In case of using this bearing with the course they stated (180°), it does not make sense either.

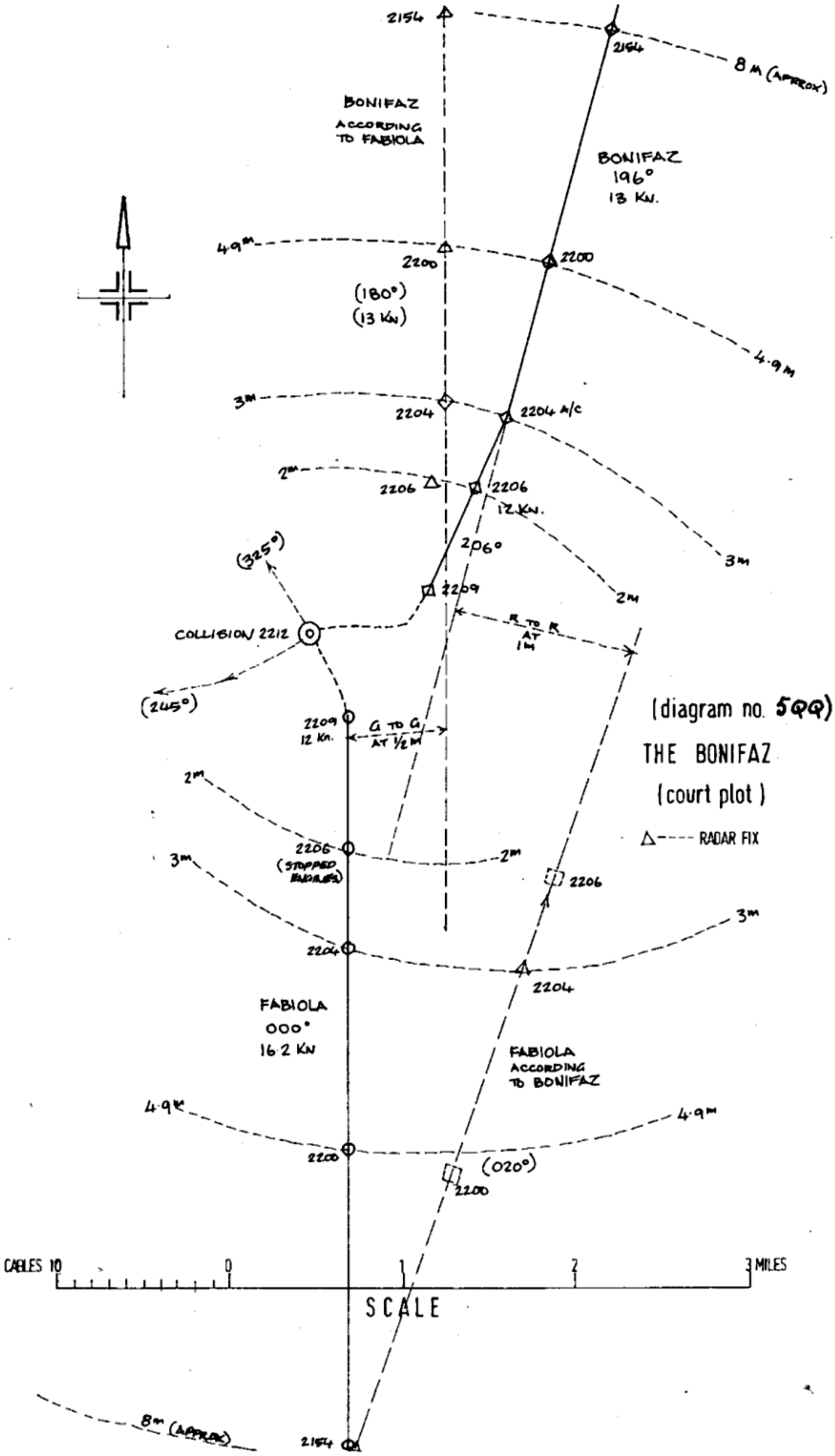


Figure 4.3. Court's collision plot for *Bonifaz – Fabiola* case (Dewar, 1989, p. 648).

MT *Fabiola*'s series of three radar fixes gives a course of 180° for the *Bonifaz* and speed 13 knots (see figure 4.4).

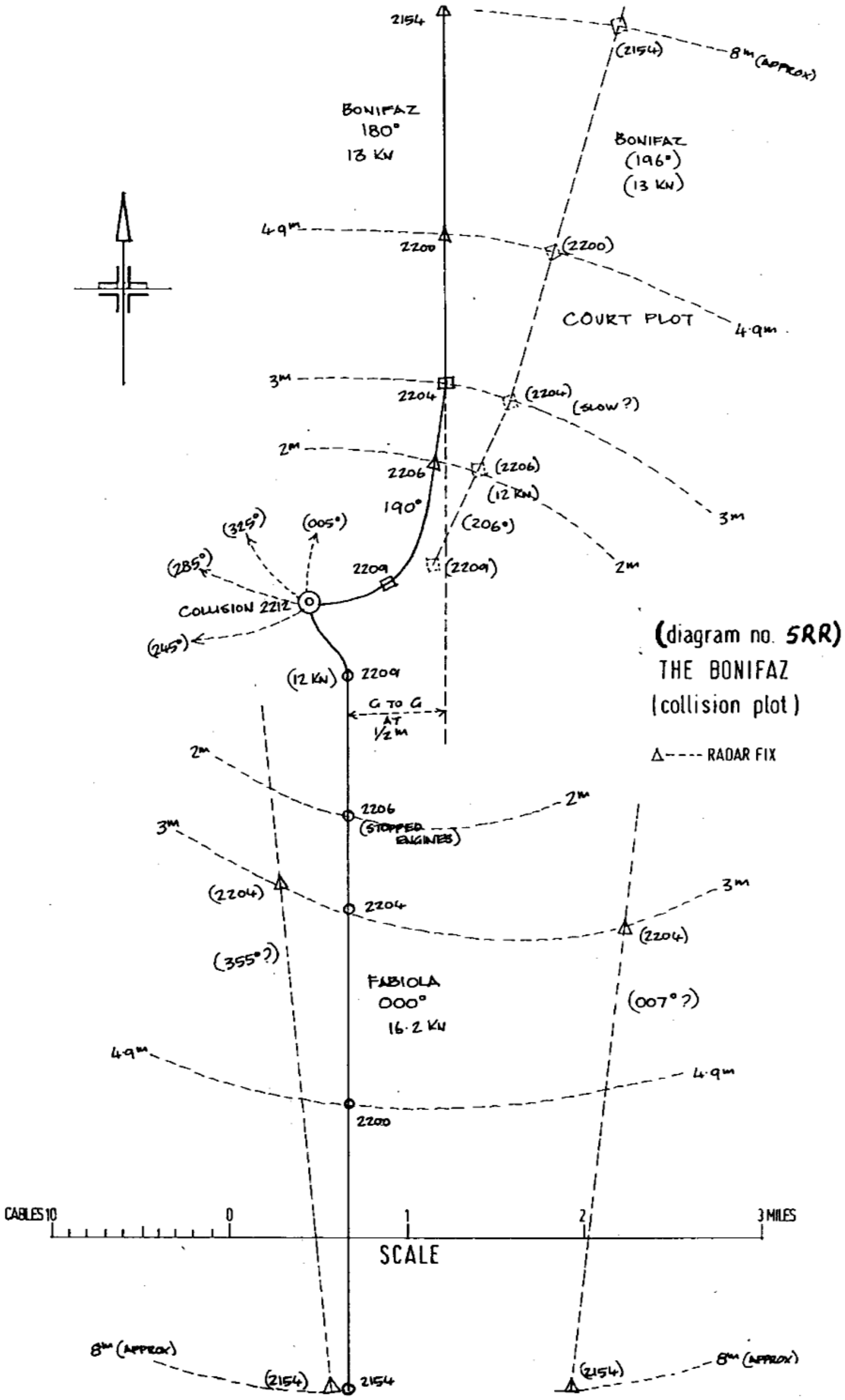


Figure 4.4. The *Bonifaz* collision plot (Dewar, 1989, p. 649).

Back to the collision, the *Bonifaz* changed her steering from automatic to hand when the French ship appeared on her radar screen. She altered course 10 degrees to starboard (22:04) as a result of her radar interpretation. The *Fabiola* stated that her engines were stopped when the ships were 2 nm apart (22:06).

Just before sighting the French vessel, the *Bonifaz* turned to starboard. As for the *Fabiola*, she saw the Spanish tanker at a distance of 8 cables. Her decision was to turn to port considering a close-quarters situation. The Court stated that both ships were at a speed of around 12 knots at this time, although the declarations by the vessels differed.

In order to avoid the imminent collision both ships made decisions. The *Fabiola* ordered 'hard-a-starboard' and 'full ahead'. The *Bonifaz* ordered 'hard-a-starboard', 'stop engines' and 'full speed astern'. But they were already fated to crash. At 22:12 the stem and port bow of the *Bonifaz* struck the *Fabiola* on her starboard side.

As a result of the collision, with oil starting to leak from the *Fabiola*, plus the not yet gas-free tanks of the *Bonifaz,* and the sparks due to the crash between the ships, explosions happened. The *Fabiola,* even if she was on fire and big damage on her leaking haul, proceed to the next port. As for the Spanish tanker, she finally sank. 25 souls in total were lost.

4.1.2. Errors

In this case, it is evident that the main mistakes which caused the accident were the wrong interpretation (therefore wrong use) of the radar equipment onboard and the unfulfilment of the COLREG regarding navigation in restricted visibility. At that time, the COLREG into force was not exactly the same as currently; ships were governed by the Collision Regulations of 1948 in which radar was not taken into account yet. Analysis regarding regulations will be based on today's COLREGs, as they keep the *Steering and Sailing* instructions given in the 1948 regulations.

About regulation, both ships made mistakes:

- MT *Bonifaz*
  - Rule 5. Lookout. It is unjustifiable the lack of vigilance by MT *Fabiola.* First, even if the echo of the French tanker appeared on the radar screen, they did not track it. In fact, only two bearings were taken which, furthermore, were wrong. Plus, in spite of the reduced visibility, there was not any lookout posted on the bow of the ship nor were any whistle signals sounded.

- Rule 6. Safe Speed. Although this ship claimed that 'slow ahead' had been ordered five minutes beforehand (and afterwards it was concluded that her collision speed was quite higher than 3 knots), this reaction should have been considered before, when tracking the *Fabiola* by radar. Plus, the circumstance of fog had to be taken into account when making decisions.
- Rule 7. Risk of Collision. In the same way of the previous rule, if anti-collision procedure regarding radar had been followed and a proper lookout had been carried out, they would have detected the risk beforehand, and thus, acted consequently.
- Rule 8. Action to Avoid Collision. The *Bonifaz* made a gentle turn of 10° to starboard. As it is mentioned in the previous part of COLREGs analysis, turns have to be seen both visually and by radar. For that aim, turns over 20° degrees are suitable in good visibility situations and course changes within 30° and 60° when fog or other meteorological phenomena restrict the vision range; so 10° change in this incident case is imperceptible so that the other ship can realize the action.
- Rule 19. Conduct of Vessels in Restricted Visibility. As she considered a risk of collision situation, she did not reduce her speed until the minimum at which she can be kept on her course and did not made an appreciable course alteration.

- MT *Fabiola*
    - Rule 5. Lookout. As on the *Bonifaz,* no lookout was standing watch in the bow of the ship in order to have an auditive and/or visual information beforehand.
    - Rule 6. Safe Speed. Even if she reduced her speed stopping engines when there were 2 nm of distance between them, the speed she was making (almost full ahead) was excessive and unjustified taking into account the circumstances of poor visibility.
    - Rule 7. Risk of Collision. It is undeniable that the ship considered that there was a risky situation when they were 2 nm from the *Bonifaz*. But the target appeared when she was at a distance of 8 nm. Therefore, the *Fabiola* could consider that they could encounter a collision situation with enough time.
    - Rule 8. Action to Avoid Collision. It is true that the ship stopped engines when she detected the ship on the radar screen. However, it could not be the best solution to save the situation; in fact, as it is mentioned in the facts, the *Fabiola* altered course to port; there were 8 cables of distance though. This reaction, if taken beforehand, could be helpful and the incident would have been avoided.

- Rule 19. The *Fabiola* does not follow the rule which clearly says "a vessel which detects by radar alone the presence of another vessel [...] [in] close-quarters situation [...] she shall take avoiding action in ample time, provided that when such action consists of an alteration of course, so far as possible the following shall be avoided: i) an alteration of course to port for a vessel forward of the beam, other than for a vessel being overtaken". It still is not clear if the French tanker saw the *Bonifaz* and then turn to port or if it happened the other way round. However, the 19th rule must be applied in restricted zone areas or nearby, so the *Fabiola* did not follow the COLREG. Plus, instead of stopping engines, the rule is clear saying that the speed must be reduce to the minimum at which the course can be kept.

About mistakes regarding radar, as mentioned above, the lookout was scanty. The bearings for both ships (mostly the ones taken on the *Bonifaz*) were wrong or imprecise. This reveals a poor knowledge of the radar tools by the officers. Nevertheless, even if both ships had taken good bearings, the *Bonifaz* only gathered two bearings, not enough when tracking a vessel in the vicinity with dense fog.

4.1.3. Conclusions

This case evidences a poor seamanship of both vessels. The collision could have been perfectly avoided if the radar had been used correctly and the COLREG followed. Actually, if both vessels had not altered their course, they could have passed green to green at a small but sufficient distance from each other. Specially, even if the COLREG is not as clear as seamen wish, the 19th rule's instructions are specific enough for this case.

In case of doubt and considering a risk of collision situation, a clear turn to starboard of the two ships in ample time could be the solution for the case. In addition, although the course change to port by the *Fabiola* was made, if she had turned in advance, the collision could have been avoided as well.

This case both nowadays and at that time is inconceivable taking into account all the regulations regarding navigation. Damage and life losses were absolutely preventable. In case of proceeding with their routes making use of good seamanship and, principally, a proper use of radar equipment, the situation would have been solved.

As far as radar is concerned, this case analysis demonstrates how deeply radar can affect in COLREGs, and therefore, in collisions. If 1948 Regulation had been chosen for the study, it would have been way more difficult to establish a relation between the radar and this collision as well as to determine the actual causes of the accident. As a result, it has been evidenced the development and the improvement of the Rules of the Road so far, even though there are still gaps to be filled.

4.2. *EGLANTINE* AND *CREDO*[10]

4.2.1. Facts

On 17 August 1984, the French flag, diesel propelled, bulk carrier *Eglantine* was proceeding up the Dover Strait in dense fog. She had loaded a cargo of grain in Rouen and was bound for Ventspils, Latvia. She was on a course of 020° making about 13.5 knots when she passed cape Griz Nez at a distance of about 4 nm not long after 1100. The Norwegian motor vessel *Credo*, a bulk carrier out of Lisbon to Mongstad, Norway was about 2.5 nm astern at the time, overtaking the *Eglantine* on a course of 039° at a speed of at least 16 knots. The *Credo* passed Cape Griz Nez about 10 minutes after the French vessel and was on her starboard quarter. The tide at the time was running in a south-westerly direction at about two knots.

Figure 4.5. The *Eglantine* (n.d.).

In this case, a third ship took part in the collision: the *Inez*. She was a twin screw, diesel powered, motorized tank barge flying the Belgian flag and was bound from Antwerp to Calais with a cargo of fuel oil. Her master had retired in 1981 at the age of 65, but

[10] The explanation of this case has been excerpted from Cahill (2002, pp.36-38).

subsequently took up part time employment as relief master. However, masters usually do not take part (ordinarily) in the navigation of their vessels as officers do during their watches.
According to a written statement and presented to the court, he did not know the ship's position when fog set in. She was bound for Calais on a south-westerly course but had unintentionally passed her destination and strayed into the northbound lane of the Dover Strait TSS. In his deposition the master maintained that he first noticed the *Eglantine* when she was little more than half-a-mile distant dead ahead, but the court rejected that contention as she began to alter course to starboard when the *Eglantine* was still about 3 nm off, slightly on the starboard bow.

The third mate of the *Eglantine* discovered the *Inez* ahead when she was something over 5 nm off. It soon became apparent that she was a southbound vessel and it appeared she would pass down the starboard side if she held her course. He immediately called the master who was in his cabin below. After assessing the situation, the master estimated that the southbound ship would pass about two-thirds of a mile off down the starboard side. He also became aware at this time of the presence of the *Credo* overhauling on the starboard quarter. He was sufficiently concerned at this discovery to switch on an auxiliary whistle on the after mast. About this time, the *Inez* altered course to starboard and it appeared to the master of the French ship that this put her on a collision course. He accordingly made a bold alteration to starboard. This was about six minutes before the collision (see figure 4.6).

Aboard the *Credo*, the master was at the conn, assisted by the second mate. The master maintained that he was at the ARPA on the port side of the wheelhouse while the second mate was stationed at the two radar sets on the starboard side, one of which was on the six-mile scale and the other on 12-nm scale. There was a lookout on the starboard wing of the bridge and the vessel was being steered by autopilot. The visibility at this time was about one cable. ARPA, if properly programmed, would automatically acquire targets that might pose a threat and sound a warning alarm if any target would approach within a mile within the next ten minutes. But, no alarm sounded.

At about 1130, *Credo*'s course was altered from 039° to 045° and she remained on that heading for less than one minute when her wheel was put hard to starboard. Both the master and the second mate claimed that at the time of the collision the *Credo* had swung to a heading of between 070° and 080°. The court rejected that testimony, however, concluding instead that the ship was on a heading of no more than 050° at the time the ship collided and that the order of 'hard-a-starboard' was given at the time the *Eglantine* came into sight less than a minute before the collision.

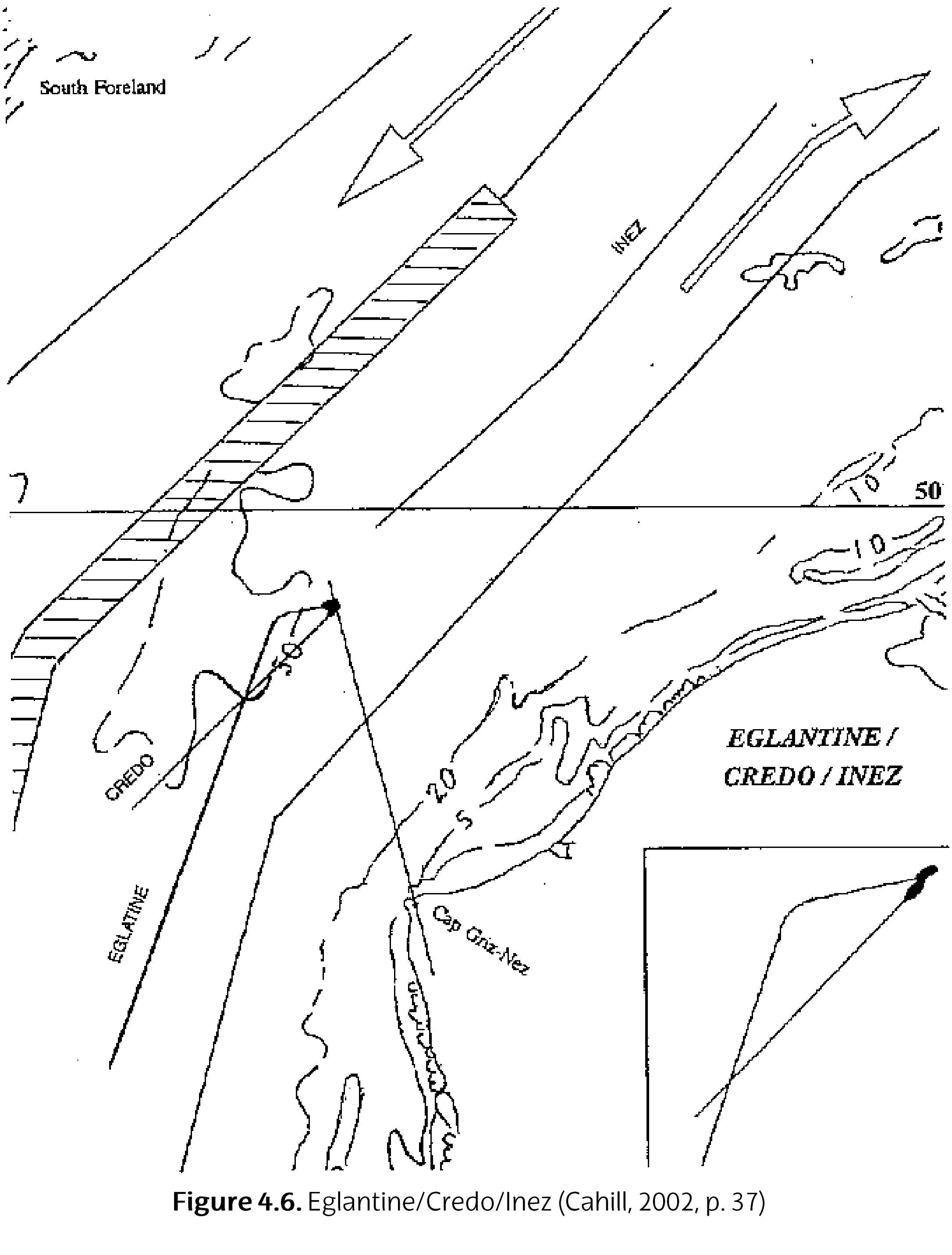


Figure 4.6. Eglantine/Credo/Inez (Cahill, 2002, p. 37)

Aboard the *Eglantine*, the master had ordered 'hard-a-starboard' at about 11:35. The ship was on a heading of about 020° at that time and by 11:38 she had reached a heading of 070°. About a minute later she was steadied on a course of 080°. There was an entry in the ship's log that at 11:34 speed was reduced to 'slow ahead.' The scrap log, in which note was made of the actual manoeuvres of the vessel, shows an entry of 'half ahead' at 11:41. Conflicting evidence was given by the master at the trial and the court concluded that the entry in the scrap log was the true entry in the scrap log was the true indication of the vessel's movements.

The court also rejected the testimony of both masters as to their manoeuvres prior to the collision and decided instead that the order, 'hard-a-port' on the *Eglantine*, and 'hard-a-starboard' on the *Credo* were given no more than a minute before the collision at 11:42. The bow of the *Credo* struck the *Eglantine* on her starboard side and while inflicting substantial damage did not penetrate the hull. Following this initial collision, the port quarter of the Credo came into contact with the starboard side of the Eglantine between number 4 and number 5 holds.

4.2.2. Errors

Regarding COLREG, the three vessels made mistakes:

- The *Eglantine*
  - Rule 5. Lookout. The absence of the master in this complicated situation affected the decision-making process on the bridge. If he had been there, they could have kept a better lookout and, probably, have made a better decision to avoid the accident. As Cahill (2002) said, "it is undeniable responsibility [...] of every master to see that special attention be given to the navigation of his vessel when it approaches and enters waters where encounters with other vessels are likely to be increased".
  - Rule 6. Safe Speed. At the beginning of the event, the *Eglantine* was making a speed of 13 knots. She maintained it until the last minute, even if in the logbook is written that ten minutes before the collision 'slow ahead' was ordered, there was 'half ahead' noted in the scrap log. Therefore, the action of reducing speed was inefficient taking into account that the decision was made a minute before the crash.
  - Rule 19. Restricted Visibility. *Eglantine*'s manoeuvre to avoid collision with the *Inez* was a hard turn to starboard, which is totally against to the text of the COLREG 19: "A vessel which detects by radar alone the presence of another vessel [and determines that] close-quarters situation is developing and/or risk of collision exists [...] shall take avoiding action in ample time [and] the following shall be avoided: [...]; an alteration of course towards a vessel abeam or abaft the beam". Plus, the speed was not adjusted to the fog circumstances.

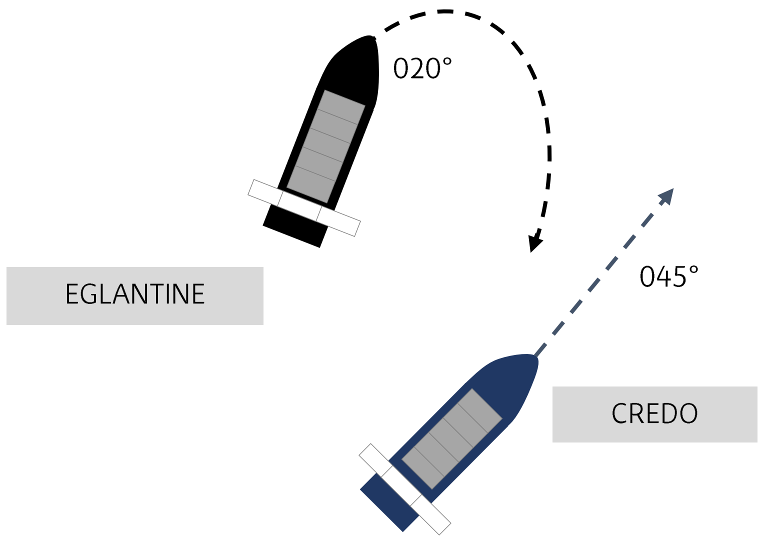


Figure 4.7. *Eglantine*'s action opposing to 19th COLREG's d) ii) part (compiled by author)

- The *Credo*
  - Rule 5. Look-out. As the fog was very dense and the visibility extremely reduced, lookout had to be based on radar. In addition, there was also a lookout on the starboard wing for auditive and visual watch. However, it seemed to the court that either the second mate or the master were not keeping a proper radar lookout. Plus, the ship was steered by autopilot in a zone where manual control should be taken.
  - Rule 6. Safe Speed. The *Credo* was making a speed of at least 16 knots. It is true that she was overtaking another vessel, the *Eglantine*, but since the visibility was less than a cable and she was navigating in the TSS of the Dover Strait where there usually are ship congestions, the Norwegian bulk carrier should have reduced her speed, although she aimed to overtake.
  - Rule 7. Risk of Collision. It is evident that this ship did not realized the risk of the situation until the last minutes. If ARPA function had been used or a proper radar lookout carried out, the OOW could have notice the risk of collision much earlier.
  - Rule 8. Action to Avoid Collision. Following what it is mention in the rule above, time is key in these cases. The reaction the ship had to the prevention of the crash was to turn to starboard (from 39° to 50°) and less than a minute before the collision 'hard-a-starboard' order was given. Obviously, the accident was unavoidable. Besides course changes, it is important to mention that the crew did not try the option of avoiding overtaking the *Eglantine* dropping speed.
  - Rule 19. Restricted Visibility. As it said in the rule 6, speed should have been adapted to the current meteorological circumstances.

- The *Inez*
  - Rule 5. Look-out. The simple fact of navigation in the northbound lane of the TSS when the vessel was southbound evidences the lack of lookout (both radar and non-radar look-outs), onboard the *Inez*. Plus, it is unusual to stand a watch alone as a master (who was a 65-year-old relief master), as it happened in this case. Because of this, it is comprehensible the loss of capacity or the atrophy of navigational skills. However, this does not justify the unknowledge of the current position and situation of navigation. In addition, It was known that the ship unintentionally passed her port of destination. It is possible that there was not crew enough on the bridge or the people there did not have enough skills and knowledge of navigation.
  - Rule 8. Action to Avoid Collision. The master declared that he noticed the Eglantine when she was about half a mile distant; however, the Inez turned to starboard when the Eglantine was still 3 nm off. This means that risk of collision was considered. Nevertheless, the action of turning to starboard was not enough. The ship should have tried to enter the southbound lane or just have given way to ships to which the *Inez* was an obstacle.
  - Rule 10. Traffic Separation Scheme. It is clear that the vessel was sailing southbound when she was actually in the lane of north direction. As it is known that they skipped the port of destination by mistake, they should have decided to anchor and wait until visibility improved.
  - Rule 19. Restricted Visibility. Having detected the *Eglantine* by radar, the master should have considered if risk of collision existed and, consequently, have taken determining actions to avoid a potential collision.

About radar, as in the COLREGs analysis above it is said, the radar lookout in the three ships was scarce. Information from this device might have been misunderstood, wrong used or ignored. Onboard the *Credo,* ARPA function was not in use even if it was available.

It is necessary to highlight the role of the master of the *Inez*. Besides the fact that he was alone on the bridge, he appeared to be not skilled enough to keep a watch at that point of his career.

But it seemed that, as on the *Inez* bridge, onboard the *Credo,* the crew on watch was scanty. A better lookout would have been carried out if there had been a person keeping visual and auditive watch, another one at the helm for manual steering (not by autopilot in fog and in a TSS of the Dover Strait) and a last one keeping the radar watch.

4.2.3. Conclusions

All of them were equally guilty for the court: the *Inez* because of the navigation in the wrong TSS lane and for not making a bigger and clearer course alteration to starboard when the master on the bridge detected the *Eglantine*; the *Eglantine* because of the speed she carried and the precipitate action in the last moment; the *Credo* because of the lack of awareness and the fact that she did not stop the overtaking manoeuvre.

Probably, the best action to avoid collision or, at least, to have more time in order to make a proper decision would be the speed dropping to the slowest at which the vessel could manoeuvre. Plus, a lookout on the bow of the *Credo* would have probably detected the *Eglantine* and her intentions before by sight and by hearing the signals. in this event the scanty crew during the watch affected directly in the lookout and the decision-making process.

Regarding the *Credo,* the officer on the bridge did not consider the narrow navigable area between the limit of the TSS and the overtaken vessel, the *Eglantine.* In addition, in this occasion, besides the restricted room for manoeuvre, there was bad visibility; therefore, the chances of hazard and collision increase considerably. As Cahill (2002) commented on this case, "in such a situation as we are examining here, passing should only be undertaken with great caution, having due regard to the width of the navigable area at that point and other vessels in the vicinity" (p. 38).

Finally, this case shows the failure of seamen to avail themselves of radar equipment (including ARPA) even if it was developed aiming to decrease collisions at sea.

4.3. *SPRING GLORY* AND *JOSEPHINE MAERSK*[11]

4.3.1. Facts

On 5 June 2012, the Chinese bulk carrier *Spring Glory* was bound for Quingdao (China), leaving the port of Singapore. At 2154 hours, she was abeam Horsburgh Lighthouse navigating on the course 046° at a speed of 10.4 knots in the TSS of Singapore Strait.

[11] The explanation of this case has been excerpted from DMAIB (2013).

Figure 4.8. The *Spring Glory* (Maat, 2018).

As for the *Josephine Maersk,* the containership departed from New Zealand to Malaysia, via the Torres Strait. In the evening of the same day, she was approaching the TSS in the eastern approaches of the Strait of Singapore at a speed of 21 knots.

Figure 4.9. The *Josephine Maersk* (Brown, n.d.).

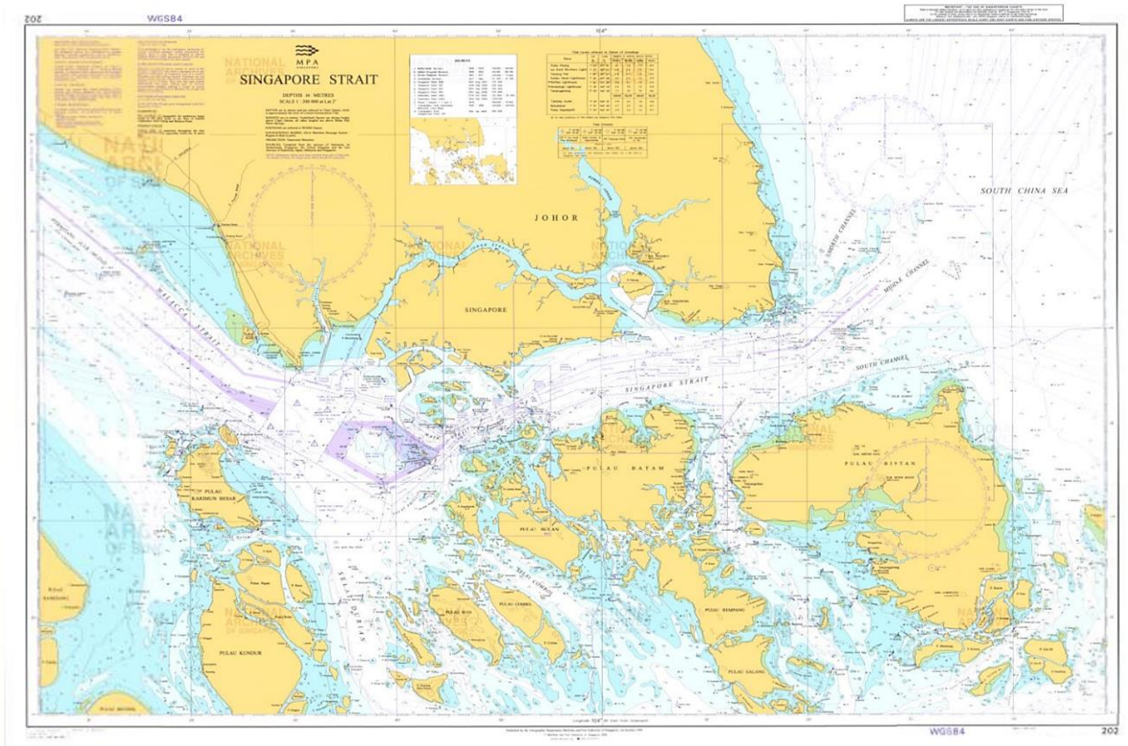


Figure 4.10. Singapore Strait 202 Chart (MPA, 2009)

At approx. 2200 hours, the master of the *Spring Glory* left the bridge. The officer of the watch was the 3rd officer. The radar (ARPA implemented) setting was 6 nm range head up, off centre and relative motion. The ARPA plot functions were not used, but trails were used. The radar had AIS overlay. At 2216 hours, the radar range was 12 nm. The *Josephine Maersk* was then visible with a clear trail at a distance of approx. 10 nm on the starboard bow and crossing the course of the *Spring Glory*. Thereafter and until the collision, the *Josephine Maersk* remained visible on the radar at a setting of 6 nm (see figure 4.10).

On the bridge of the *Josephine Maersk*, the 3rd officer took over the watch at 2000 hours and an able seaman was on duty as a lookout as was normal practice. The master left the bridge and he asked to be called upon in case of doubt and when entering the TSS. The radar (also with automatic plotting aids) range was set on 12 nm, north up, relative motion, off centre and trails. At approx. 2145 hours, the officer of the watch did not notice any ships approaching on the port side, nor did the lookout who was standing at the centre of the bridge. The officer was focusing on the traffic on his starboard side and concentrated on a hard turn to port which he was about to make when entering the TSS.

As the *Spring Glory* was approaching the eastern exit of the TSS, there was dense traffic transiting in both directions of the TSS, traffic from the east to be expected entering the

TSS, several ships at anchor in the vicinity of the TSS, fishing vessels some of which sailing and some not, and good visibility. However, the view was disturbed by the lights from the many ships at anchor on the starboard side.

At 22:24:04 hours, at a distance of approx. 5 nm, the *Josephine Maersk* was selected as a target on the radar and identified with expanded data on the AIS (see figure 4.10). The bearing on the *Josephine Maersk* had not changed. Both on the port and starboard bows the *Spring Glory* had several oncoming ships, besides the *Josephine Maersk*.

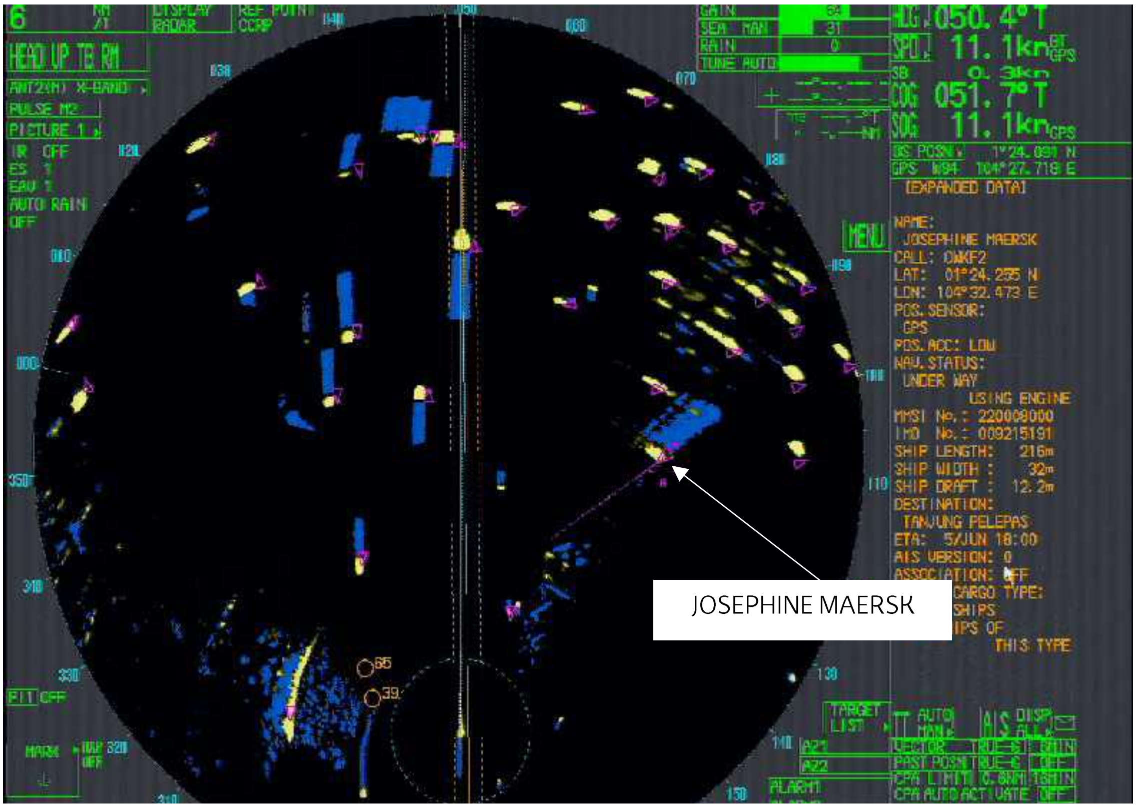


Figure 4.11. Recording of radar from the *Spring Glory* at 22:24:36 (DMAIB, 2013, p. 11).

Regarding the *Josephine Maersk*, at 22:14:00 hours, while the radar was on 6 nm range, the *Spring Glory* became visible on the radar and ten minutes later she could be identified on AIS, at a distance of approx. 5 nm. However, the officer of the watch had not observed the other ship on the radar prior to his visual observation of the ship nor had the able seaman who was on duty as a lookout. The officer placed the curser of the radar on the ship in question and found that the distance between the ships was approx. 2 nm.

Then, at 22:30:54 hours, the ship on the port bow that was the *Spring Glory* called the *Josephine Maersk* on the VHF channel.

The communication on VHF was not effective. At 22:32:47, the officer of the watch understood that he was advised to increase the speed of the *Josephine Maersk* and to pass the *Spring Glory* in a way that he did not understand clearly. However, he immediately knew it would be quite impossible to increase the speed in due time, so he did not reply because he saw the other ship coming close very fast and therefore he called the master asking for help and altered the course giving full starboard helm by manual steering at 22:33:10. He did not notify the master anyways.

When the master arrived on the bridge at 22:34:30 hours, after detecting course changes and supposing that they were entering the Singapore Strait TSS, the *Josephine Maersk* was still in a hard turn to starboard and the *Spring Glory* was very close to the port side (see figures 4.11 and 4.12). A few moments later, at 22:34:40 hours, the starboard side of the *Spring Glory* hit into the *Josephine Maersk*'s port side and a few seconds later into the port side quarter.

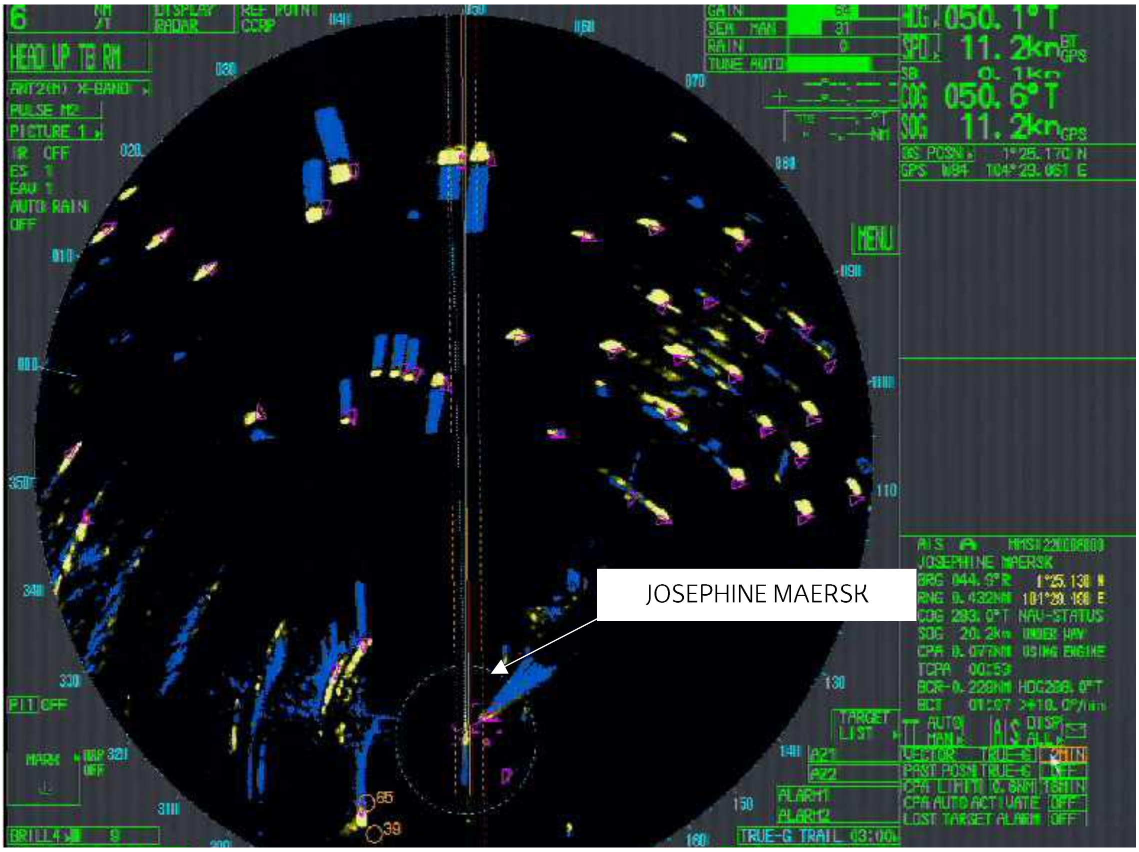


Figure 4.12. Recording of radar from the *Spring Glory* at 22:34:00 (DMAIB, 2013, p. 13).

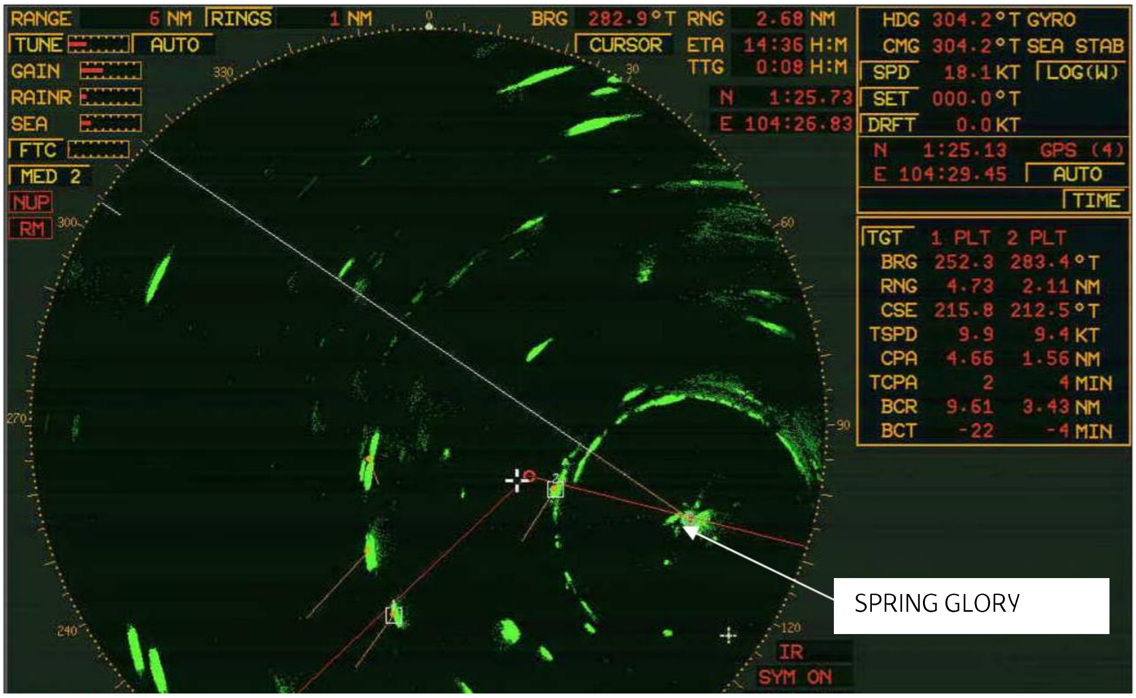


Figure 4.13. Recording of radar from the *Josephine Maersk* at 22:34:00 (DMAIB, 2013, p. 19).

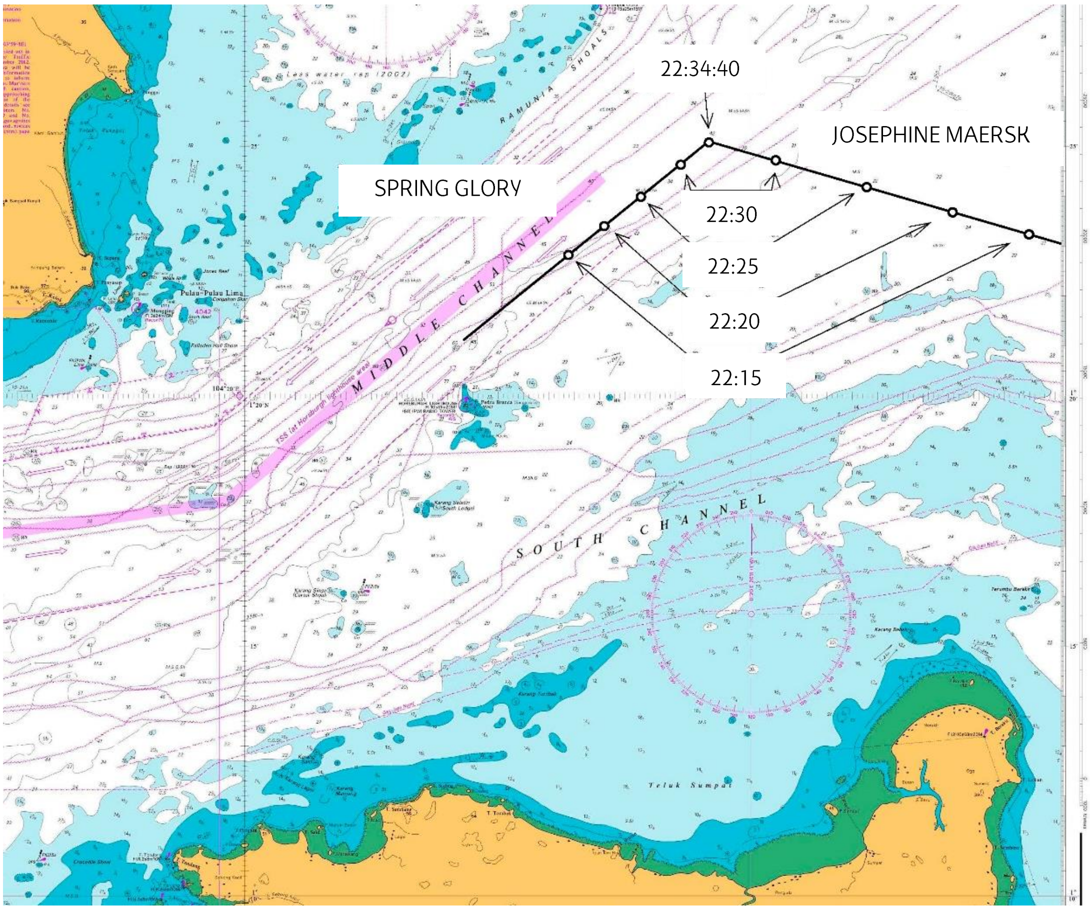


Figure 4.14. Site of the incident and *Josephine Maersk*'s and *Spring Glory*'s positions prior to the collision. Singapore Strait Eastern Part, BA 3831 chart (UKHO edited by DMAIB, 2013, p. 9).

4.3.2. Errors

To get started, both ships did not fulfil some COLREGs:

- The *Spring Glory*
  - Rule 5. Lookout. Although the *Josephine Maersk* was visible following the same course well before, the officer did not track the echo until ten minutes before the accident, when the containership was at 5 nm of distance. MAIB (2014) declared that "AIS-information on the *Josephine Maersk* remained visible on the radar while the echo of the *Josephine Maersk* also remained visible, still approaching at an unchanged bearing". In addition, the officer did not call upon the master.
  - Rule 7. Risk of Collision. The officer did not acknowledge the actual risk of the situation until the last moment. Even if the bearing did not change and the distance between the ship was shorter, he considered the navigation was proceeding normally.
  - Rule 8. Action to Avoid Collision. As the OOW realized the danger at the last moment, the actions taken in order to prevent the collision were scanty and inefficient. It is true that because of the congested traffic in the TSS the ship could not manoeuvre easily; but if he had followed the containership before, he would have had more options (i.e. reduction of speed) so that the crash could be avoided. Since the ship had a restricted manoeuvrability due to the traffic, his decision was to stablish a VHF conversation with the other ship in order to set a mutual manoeuvre to avoid the collision. Withal, it was not effective.
  - Rule 15. Crossing Situation. According to these rule, "When two power-driven vessels are crossing so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way and shall, if the circumstances of the case admit, avoid crossing ahead of the other vessel". Therefore, even if the *Spring Glory* was navigating in a TSS, she should have given way to the *Josephine Maersk*. However, it is true that there were ships in the vicinity hampering her movements but, still, if she had detected the containership before, there would probably have been more possibilities to manoeuvre safely with due time.
  - Rule 16. Action by Give-Way Vessel. As in the previous rule is said, the bulk carrier was the ship to give way in this case. For that aim, the OOW should have carried out a proper lookout in order to detect risk of collision or ships that could endanger the navigation and, consequently, act not crossing the other vessel.

- The *Josephine Maersk*
  - Rule 5. Lookout. Onboard the Josephine Maersk, the *Spring Glory* appeared very early on the radar screen; however, the OOW did not observed the ship prior to the visual detection of the bulk carrier. The able seaman who also kept the lookout, did not notice her. Plus, during the process of approach to the TSS, both the seaman and the officer were focusing just on the starboard side traffic, leaving the port side without a lookout. In addition, the officer did not call upon the master, although the captain asked to do so in any case and when entering the TSS. However, the master should have been supporting the OOW during his watch as it is his responsibility to pay special attention to troublesome and congested navigation.
  - Rule 6. Safe Speed. It is evident that the ship from Maersk Line did not proceed safely in this occasion. She was entering a TSS, in a very congested navigation zone, so she should have navigated with special caution. The 21 knots she ran were not appropriate to the situation. When the vessels collided, she was sailing at a speed of 18 knots.
  - Rule 7. Risk of Collision. As the two on the bridge were focusing on just one side of the vessel, the OOW did not notice the *Spring Glory* until they were at a small distance on 2 nm, when he detected a green light from the *Josephine Maersk* port side, which was ignored.
  - Rule 8. Action to Avoid Collision. As he did not have time to manoeuvre correctly and safely, his decision after the failed VHF call was a hard turn to starboard. It could be a possible option but if the action had taken beforehand.

About radar use, the *Spring Glory* did not track the echo of the *Josephine Maersk* even if ARPA function was available; when the ships were at a distance of 5 nm, the bulk carrier selected the containership on AIS and identified with expanded data. Therefore, it seems that radar watch was not carried out until that moment, when risk of collision was considered.

It is true that the vessel was sailing in a congested traffic area (Singapore Strait TSS), so visual lookout was not easy due to the amount of navigation lights nearby. However, this is a reason to increase the employment of radar which they did not take into account.

The *Spring Glory* was the ship to give way, but, because of the traffic situation with fishing vessels and other oncoming ships, the opportunities of manoeuvring were limited. That is why the officer was hindered by the difficult navigation and he did not manoeuvre, believing that the situation could improve if the *Josephine Maersk* had altered course.

As for the *Josephine Maersk*, it was stated that:

> The radar range was set on 6 nm and sometimes briefly on 12 and 3 nm, north up, relative motion and off centre. It showed an extensive side lope and though the trail setting was 'medium', the echoes showed only weak trails. In hindsight, the setting and usage of the radar was not optimal because it made it difficult to interpret a picture or a visual representation of other ships. When setting the radar at different ranges, other settings are to be adjusted to achieve an optimal picture and representation of other ships. However, this is not always done, and it may have been the situation in this case. (MAIB, 2004, p. 26)

4.3.3. Conclusions

Maritime traffic congested areas are always crucial points for navigation. In this case, it seems that there was a lack of people on both bridges in order to keep a good watch, or, perhaps, more experienced watchkeepers.

Still, there are unjustifiable errors such us the speed of the *Josephine Maersk*, or the scanty use of radar during the *Spring Glory*'s lookout. This accident could have been avoided in case of being aware of the ships beforehand and taking into account the characteristics of the current navigation situation (night, TSS, great amount of ships nearby, etc.).

4.4. *PAULA C* AND *DARYA GAYATRI*[12]

4.4.1. Facts

On 10 December 2013 at 2245 UTC[13], the general cargo vessel *Paula C* was on passage in the south-west traffic lane of the Dover Strait TSS. The vessel was following a heading of 221° at a speed of 11.9 knots. The *Paula C* was in ballast and its destination was Poole, England. It was a dark, clear night and the visibility was good.

[12] The explanation of this case has been excerpted from MAIB (2014).

[13] The time zone kept on board the Paula C and the Darya Gayatri was UTC+1.

Figure 4.15. The bulk carrier *Paula C* (Thun, 2015).

Paula C's master was keeping the navigational watch. The second officer took over the watch on *Paula C*'s bridge. In preparation for the watch handover, he checked the settings on the port 'X-band' radar display. As he did so, he noticed several radar targets following the south-west traffic lane. In particular, the second officer saw a target on *Paula C*'s starboard quarter at a range of 1.9 nm.

From the AIS data shown on the radar display, the second officer identified the radar target as *Darya Gayatri*, a bulk carrier in ballast on passage to Baltimore, USA.

Figure 4.16. The tanker *Darya Gayatri* (n.d.).

She was making a regular course of 216° at a speed of 12.4 knots and was overtaking the *Paula C*. The CPA between the vessels was 0.5nm in 88 minutes time.

The navigational and communications equipment fitted on the bridge included two X-band radars with ARPA, an AIS and a GPS receiver. The AIS was interfaced with both radar displays, which enabled AIS information to be shown.

During the second officer's bridge watch on 11 December, the port radar display was set to north-up, in relative motion, and was showing target vectors and trails. The second officer set the range scale to 6nm and off-centred the display. The starboard radar display was also switched on but was not used by the second officer; this display tended to be for the master's sole use.

As for the *Darya Gayatri*, she was fitted with an integrated navigation and control system which included X and S band radar displays fitted with ARPA, an AIS and a BNWAS. The AIS was interfaced with both radar displays.

On 11 December 2013, the X-band and the S-band radar displays were set on the 6nm and 12nm range scales respectively. Both displays were north-up and off-centred to increase the area of the radar coverage displayed ahead of the vessel.

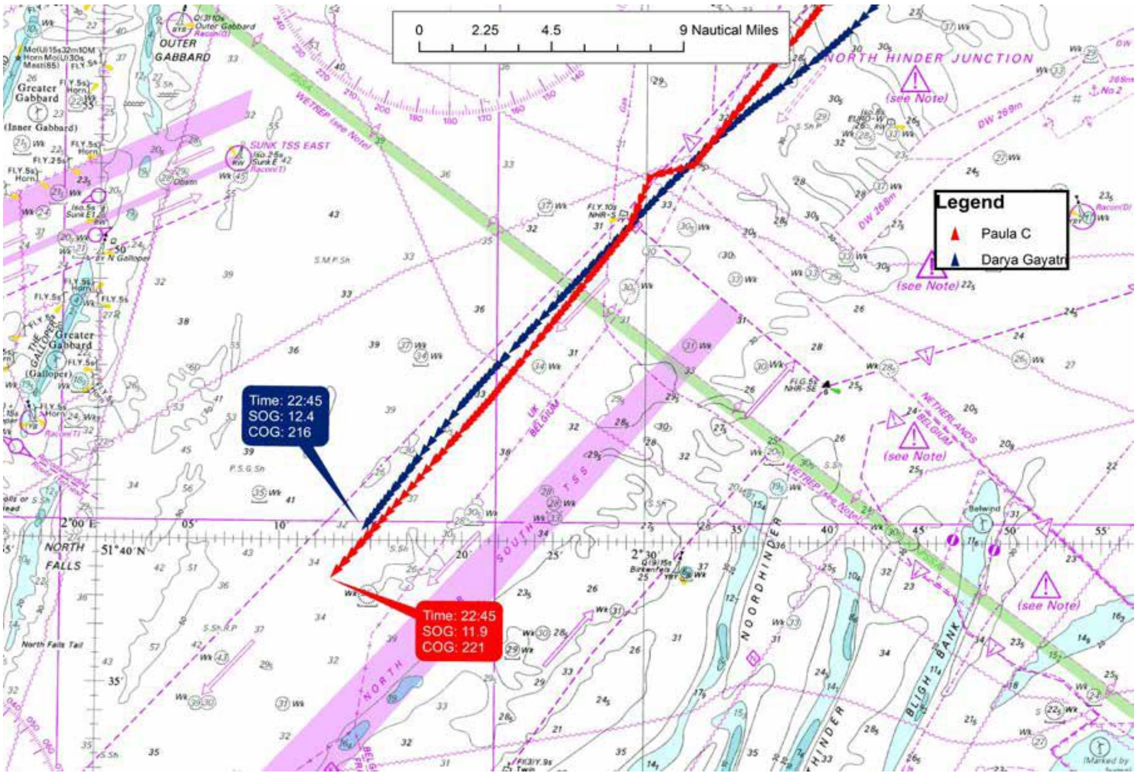


Figure 4.17. *Darya Gayatri*'s and *Paula C*'s positions at 2245 (MAIB, 2014, p. 5).

At approximately 2300, *Paula C*'s master finished his night orders and advised the second officer to keep to the passage plan and to call him if in any doubt. About the bulk carrier, she was 79° abaft *Paula C*'s starboard beam at a distance of 1.7 nm. The vessel remained on track.

At 2345, the *Paula C* arrived at a navigational waypoint indicating a planned course alteration. Accordingly, the OOW altered the vessel's heading to follow a track of 212°. The other vessel was plotted, and she remained on the planned track. At 0011, he saw a vessel 20° off the starboard bow. He was able to see the vessel's lights. He also correlated the unidentified vessel with a radar target which at a range of 3.9 nm and had a CPA of 0.1 nm. The unknown vessel was assessed as a crossing vessel which was supposed to pass *Paula C*'s bow from starboard to port. He also assessed that the *Paula C* was the give way vessel.

The vessel ahead of the *Paula C* was the Belgium registered beam trawler *Raquel*, which was towing its nets on a course of 153° at a speed of 4.8 knots.

From the *Raquel*, both the *Paula C* and the *Darya Gayatri* were identified following the traffic lane and the skipper was aware of the need to act in order to keep out of their way. Accordingly, at approximately 0013, with the *Paula C* 3.4 nm off the trawler's port bow, *Raquel* began the first of several alterations to port. A single, broad alteration was not possible because *Raquel*'s manoeuvrability was limited by its fishing gear.

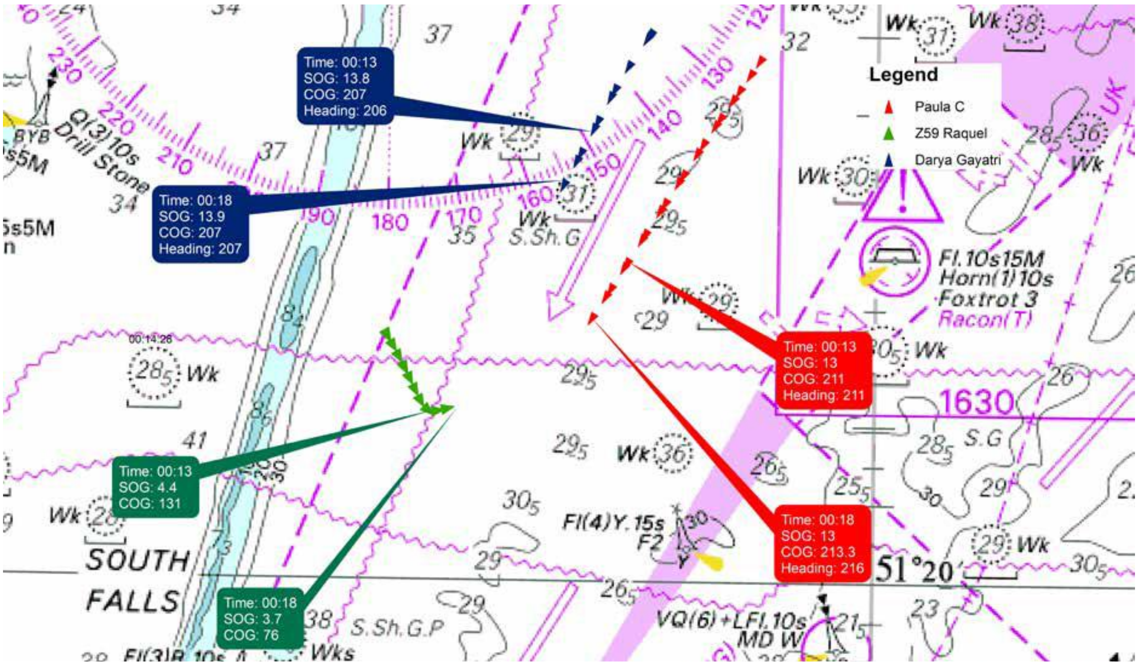


Figure 4.18. *Raquel*'s, *Darya Gayatri*'s and *Paula C*'s positions at 0018 (MAIB, 2014, p. 8).

Raquel's changes in heading were not seen by *Paula C*. At approximately 0018, when the *Raquel* and the *Paula C* were 1.82 nm apart, the OOW adjusted the heading set on the autopilot to 230°. No sound signal was made, and the second officer did not look over the starboard quarter to make sure that there was no vessel in close proximity. The OOW also did not use the ARPA's trial manoeuvre facility either.

As the *Paula C* steadied onto her new heading, the second officer noticed that the heading of the *Raquel*, which was now almost directly ahead, had changed to the north-east. In response, the OOW adjusted *Paula C*'s heading further to starboard. By 0022 *Paula C*'s heading was 266° and the fishing vessel was about 30° off Paula C's port bow at a distance of 1.1 nm; the *Darya Gayatri* was on the cargo ship's starboard beam at a distance of 0.98 nm.

Over the next 2 minutes, Paula C's OOW adjusted the autopilot to alter the vessel's heading to port and then to starboard. The vessel's changes in heading between 0022:06 and 0023:35 are detailed at table 4.1.

Table 4.1. Paula C's heading between 0022:06 and 0023:35 (MAIB, 2014).

Time	Heading (°)
0022:06	266
0022:23	263
0022:54	255
0023:04	253
0023:15	259
0023:24	273
0023:30	282
0023:35	287

Paula C's manoeuvring was seen by *Darya Gayatri*'s OOW, who determined that the cargo ship would now pass about 2 cables ahead of his vessel. *Darya Gayatri*'s OOW was also aware that the *Raquel* was ahead of him and was engaged in fishing. He was closely monitoring both vessels.

Later on, *Paula C*'s OOW adjusted the cargo ship's heading from 287° to 253° and, immediately after, he selected hand-steering and applied 35° of starboard helm. The *Paula C* started to turn quickly to starboard. The OOW did not check visually or by radar that the intended manoeuvre was safe. He was unaware that *Darya Gayatri* was 511m off *Paula C*'s starboard beam. About the *Darya Gayatri*, she apparently did not alter course and kept her course and speed.

Paula C's headings varied from 253° to 000° within a minute. Regarding the *Darya Gayatri*, after a VHF conversation with Dover Strait Coastguard, the OOW changed to hand-steering and instructed his lookout to take the helm. He then ordered the helm hard to port. By now, the *Paula C* was turning through a heading of 297° at an increasing rate. *Darya Gayatri*'s OOW was not aware that the cargo ship was under helm to starboard. He assumed that the *Paula C* would pass ahead of the bulk carrier before starting to manoeuvre to the north; he expected the vessels to pass starboard to starboard.

At 0026, 18 seconds after port helm was applied, the *Darya Gayatri* started to turn to port. At the same time, the second officer noticed that the *Paula C* was turning towards the bulk carrier. He immediately ordered the lookout to put the helm hard to starboard and then telephoned the master in his cabin to inform him that there was another ship "*very close*". The OOW also put the engine telegraph astern for several seconds. He soon returned the telegraph to full ahead after he assessed that there was no time for an astern movement to take effect. *Darya Gayatri*'s master arrived on the bridge just as *Paula C*'s port bridge wing collided with *Darya Gayatri*'s port anchor. At the point of contact, which was at 0026:52, the *Darya Gayatri* was heading 198° at 12.9 knots; the *Paula C* was heading 070° at 6.2 knots.

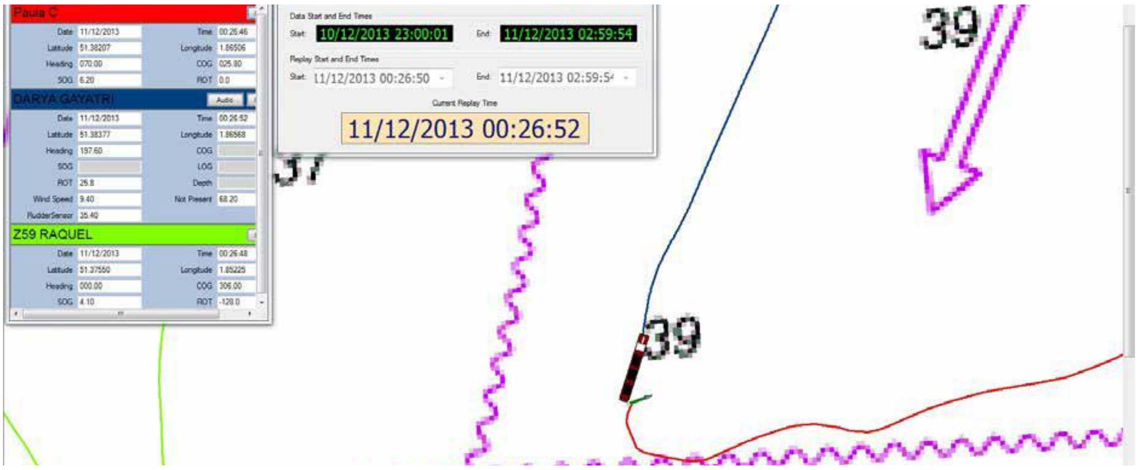


Figure 4.19. The collision between the *Paula C* and the *Darya Gayatri* (MAIB, 2014, p. 14).

4.4.2. Errors

Regarding COLREG, there were the following unfulfillments:

- The *Paula C*
  - Rule 5. Lookout. At first sight, it looks like there was a proper lookout carried out. However, when from *Paula C*'s bridge the *Raquel* was detected, the bulk carrier turned to starboard, not checking if other vessels came from that side. Actually, the *Darya Gayatri* was at 0.98 nm on the cargo ship's starboard beam at that time. Plus, before her action to avoid the collision with the beam trawler, she was unaware of the course change of the *Raquel,* but that change was too gentle because of her restricted manoeuvrability so that the *Paula C* could notice it. Summing up, she focused on the ship ahead of her, forgetting about the beforehand detected tanker which was overtaking her from her starboard side.
  - Rule 7. Risk of Collision. She did detect the risk of collision with the *Raquel*, however, the OOW did not care about the other ship who was sailing too close. In addition to this, the OOW was steering with autopilot. In case of risk of collision, he should have steered manually.
  - Rule 8. Action to Avoid Collision. If the we considered that there was just one ship nearby (the *Raquel*) it would probably be a good decision. However, knowing that another ship was coming from the starboard side, side to which she manoeuvred, she did not do an ARPA trial or look for another solution to avoid the collision with the trawler but also not endanger the navigation with the *Darya Gayatri.* After skipping the *Raquel,* she had to prevent a crash with the second vessel, but the decisions that the OOW made were not precise but dubitative and changeable (he did a numerous alterations). Thus, the intentions were not clear and finally, it led to an imminent collision.
  - Rule 15 and Rule 16. Crossing Situation and Action by Give-Way Vessel. The Paula C should have started to manoeuvre quite before knowing that the vessel ahead was a vessel engaged in fishing (therefore with restricted manoeuvrability). If that ship had detected the bulk carrier's action giving her way, she would not probably have turned towards the Paula C.
- The *Darya Gayatri*
  - Rule 5. Lookout. It is true that from this ship the *Paula C* was followed. However, both by radar or sight, the ship had to notice that there was another ship engaged in fishing impeding a normal navigation in the traffic lane.

- Rule 7. Risk of Collision. The *Darya Gayatri* tracked the bulk carrier but with the evident course changes of her, she did not react until the last moment; therefore, the OOW did not consider risk of collision situation, even if she was too close to the *Paula C* as she was overtaking her.
- Rule 8. Action to Avoid Collision. Not aware of the movement of the bulk carrier towards his ship, the OOW decided to turn to port to keep clear from the other ship. However, when detected that the *Paula C* would not pass as he thought, he made a sequence of immediate decisions with the hope of avoiding the collision: 'hard to starboard', 'astern', 'full ahead'. With no time to react as the risk was not considered beforehand, the actions were not effective.
- Rule 13. Overtaking. As a overtaking vessel, the *Darya Gayatri* should have been aware of any movement of the overtaken vessel. However, it seems that in the end, when they were too close, the OOW did not realized the other ship's actions. As they were navigating in a TSS, they did not have an ample area to keep clear from each other, but as an overtaking vessel, the tanker should have kept clear when realizing they were approaching too much.

- The *Raquel*

This ship did not fulfil the Rule 10 part (i), which says: "a vessel engaged in fishing shall not impede the passage of any vessel following a traffic lane". However, she was in a crossing situation with the *Paula C*, and the second vessel was the one to give way according to the 15^{th} COLREG. It seems that there is an incongruity due to these two situations.

About radar, both ship carried developed and ARPA-integrated radar equipment. However, they did not benefit from them. It is true that they were in sight of each other and, consequently, they had to keep a visual lookout. Nevertheless, ARPA can be useful when there is a need to take action when risk of collision is assumed but there are other vessels nearby to keep clear from.

4.4.3. Conclusions

Although in this accident radar does not have a big impact on the collision as in the others, this case has been selected in order to highlight the scanty use of aids and tools that radar has in order to make the navigation easier and to avoid collisions. It is evident that onboard the *Paula C* there could have been a collision avoidance trial so that the OOW could see that the ship passed clear from both the trawler and the tanker.

Therefore, even if nowadays the bridge crew is provided with multiple navigation equipment, it seems that they do not take advantage of such a help or they are not taught enough to operate the marine radar.

4.5. LESSONS LEARNED

Having set forth the previous four collision cases and analysing the factors that intervene in them, certain lessons arise.

While it is true that there are more collision cases in the past, radar is still an unfinished business for the officers of the Merchant Navy. As it has been shown both in the analysis and in the study about the impact of the marine radar (see section 2.3), there are still numerous incidents in this equipment has been wrongly used or its information wrongly interpreted. Therefore, since navigators fail utilizing radar and ARPA, there is an undeniable need to provide the bridge crew with a proper and complete formation on this navigational equipment and its implemented aids.

It has been verified that the reason is not the lack of adaptation period but the scanty formation on radar usage; perhaps, in the beginnings of this marine tool, it could be a justifiable answer. As Briggs (2004) stated, "Initially [radars] were not very reliable and it took time for deck officers to accustom themselves to [...] this radically new aid to navigation. Nevertheless, the basic concept was sound, early problems were gradually beaten and radar became mandatory for all ships".

However, as it has been seen in some of the analysed cases, officers are not completely trained when it comes to use the marine radar as an anti-collision unit. That is why it is important to highlight the demand of instructing diligent radar operators.

In keeping with training, it is also established that officers do not understand the COLREG or they do not follow it when they are actually in need of fulfilling the rules. In the analysis of the 'Rules of the Road' it is showed that the paucity of accuracy does not let the OOW make decision because, in fact, she or he cannot interpret the rules correctly.

However, even though sometimes these regulations are not totally comprehensible, the collision reports prove that the problem is not the lack of understanding but the ignorance and incompetence by the officers towards this set of norms. Furthermore, it should be understood that the text cannot be as accurate as desired because it is impossible to stablish clear and precise instructions for each situation that sailors may encounter at sea or an actuation pattern cannot be set. Thus, poor seamanship is demonstrated; the seafarers must be engaged and comply with all the regulations which aim to make navigation as safe as possible.

In a study on deficiencies in learning COLREGs, Mohovic et al. (2016) concluded that "by acknowledging these deficiencies it is possible to identify knowledge gaps and to improve the learning process". Therefore, to solve this issue, as it has been demonstrated a need to improve officers instruction, the most feasible option is the change of teaching methodology.

About watches on the bridge, they cannot be based only on radar. It is true that depending on the visibility circumstances, radar use differs (taking more or less importance), but lookouts in different parts of the ship or even another officer (or the master) on the bridge may help so that a better visual, auditive and radar watch are carried out.

Nevertheless, radar should always be available. It may not be the main tool which determines the potential risk of collision, but, for example, if there are ships in the vicinity and actions must be taken, priorities can be stablish or a trial manoeuvre might be helpful.

Regarding actions to avoid collisions, once again, it is confirmed that gentle course changes (although they happen consecutively) are not useful because visual and radar detection is not guaranteed. Hence, alterations must be broad. About velocity, if data gathered both visually and by radar are not well interpreted, the speed adjustment will not be considered; there is a step back on bridge crew formation anew. To conclude, when crossing situation happen, the 'right of way' should not be totally assumed because rules might be breached by the other vessel.

What's more, although the main topic of this dissertation is the marine radar, the difficulties generated by the reduction of personnel during navigation look-outs cannot be ignored. As far as the radar is concerned, an officer in charge of all the equipment on the bridge is not productive, since she or he must also focus on the visual and auditory watch. If more lookouts or officers were available (at least in complicated situations), the tasks would be distributed, so the OOW would operate in a more adequate and reliable way. However, this dilemma cannot be solved by improving officers' instruction; it is a question to be considered only by shipowners.

From all these particular lessons, a final conclusion can be deduced: it shows up that the accidents follow a similar pattern. The cases start with a bad look-out, followed by a non-detected or late-considered risk of collision; finally, they end up by taking too precipitate actions which lead to a direct and imminent collision. As a result, it comes of easy to evince the committed errors.

Summing up, the four case studies demonstrate that the collisions could have been avoided as long as the following had been fulfilled:

- a proper interpretation of the information provided by radar and ARPA;
- understanding of the relative motion of the target's vectors on the radar display;
- taking advantage of the trial manoeuvre using ARPA;
- obeying COLREGs; and
- consideration of the need for more crew during the watch in risky navigation circumstances.

CHAPTER 5
CONCLUSIONS

5. CONCLUSIONS

As it has been mentioned along this dissertation, despite radar was designed to be an anti-collision navigational equipment in order to make navigation easier and safer, collisions at sea still occur.

When this project was outlined, two main objectives were set out: 1) The analysis of the impact of the misuse of radar and ARPA in maritime collisions, and 2) The ascertainment of the reasons why those accidents happen. In this regard, it has been established that watchkeepers not only fail when operating with radar (in 73% of the cases the use was improper) and during the decision-making process (85%), but also when keeping a look-out (43% of the officers were not aware or aware enough). It has also been determined that collisions occurred as a result of the different causes that have been listed at the end of the Chapter 4, among which those that are related to human errors stand out.

The statistics and numerical data about collisions at sea are scarce. There is also a lack of studies assessing the actual impact of the marine radar/ARPA misuse in collisions at sea. However, it was finally possible to elaborate a short summary on the evolution of accidents over time considering this anti-collision equipment.

Furthermore, by using a deductive methodology, a series of lessons or weaknesses regarding radar operators and the way in which they use this equipment has been worked out, namely:

- the look-out is essential and cannot be pushed into the background;
- deck officers are not adequately instructed as radar operators;
- radar cannot replace navigators nor relieve them from their watchkeeping task;
- COLREGs are not accurate and are still misunderstood by mariners;
- there is a need of changing teaching methodology both in relation to COLREGs and to radar/ARPA operation;
- weather conditions must be considered;
- there is lack of awareness or ignorance about the collision avoidance process when fulfilling COLREGs; and
- manning reduction hinders navigational watches.

The four collision cases that have been chosen and exhaustively examined, were carefully selected among more than twenty that also follow a certain pattern. All of them have been taken into consideration in order to draw conclusions in section 4.5: lessons learned.

Human factor has turned out to be the most influencing issue in maritime collisions, in relation to both radar/ARPA and COLREGs. In most cases it was due to inexperience, ignorance, lack of comprehension and confidence, or mere misunderstanding. As Mohovic et al. (2016, p. 775) pointed out, "by acknowledging these deficiencies it is possible to identify knowledge gaps and to improve the learning process [of the deck officers]".

Radar is widely considered as one of most important tools for navigation onboard the bridge and because of that, it is essential to emphasize how favourably would this device influence in the navigation if it was correctly employed for the collision prevention at sea. Still, Briggs draws attention to the fact that "even the finest radar is merely a tool which can be ignored, misused or misunderstood. It is always up to the operator to decide whether and how to use the radar and its information" (Briggs, 2004, p. 2).

Summarizing, even though the marine radar is highly important in navigation, it is not but a tool to rely on, and it cannot substitute any other method nor, indubitably, the seafaring practices of an officer. Depending on the situation, it will have a certain degree of relevance, but the radar is not the one that governs the ship, but just a help to the decision-making process of the officer in charge of a navigational watch.

CHAPTER 6

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6. SOURCES AND BIBLIOGRAPHY

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ANNEX 1

INTERNATIONAL CONVENTION FOR THE SAFETY OF LIFE AT SEA (SOLAS), 1974

INTERNATIONAL CONVENTION FOR THE SAFETY OF LIFE AT SEA (SOLAS), 1974

CHAPTER V

Regulation 19 - Carriage requirements for shipborne navigational systems and equipment

1 Application and requirements

Subject to the provisions of regulation 1.4:

1.1 Ships constructed on or after 1 July 2002 shall be fitted with navigational systems and equipment which will fulfil the requirements prescribed in paragraphs 2.1 to 2.9

1.2 Ships constructed before 1 July 2002 shall:

.1 subject to the provisions of paragraphs 1.2.2 and 1.2.3, unless they comply fully with this regulation, continue to be fitted with equipment which fulfils the requirements prescribed in regulations V/11, V/12 and V/20 of the International Convention for the Safety of Life at Sea, 1974 in force prior to 1 July 2002;

.2 be fitted with the equipment or systems required in paragraph 2.1.6 not later than the first survey after 1 July 2002 at which time the radio direction-finding apparatus referred to in V/12 (p) of the International Convention for the Safety of Life at Sea, 1974 in force prior to 1 July 2002 shall no longer be required; and

.3 be fitted with the system required in paragraph 2.4 not later than the dates specified in paragraphs 2.4.2 and 2.4.3.

2 Shipborne navigational equipment and systems

2.1 All ships irrespective of size shall have:

.1 a properly adjusted standard magnetic compass, or other means, independent of any power supply, to determine the ship's heading and display the reading at the main steering position;

.2 a pelorus or compass bearing device, or other means, independent of any power supply, to take bearings over an arc of the horizon of 360°;

.3 means of correcting heading and bearings to true at all times;

.4 nautical charts and nautical publications to plan and display the ship's route for the intended voyage and to plot and monitor positions throughout the voyage; an electronic chart display and information system (ECDIS) may be accepted as meeting the chart carriage requirements of this subparagraph;

.5 back-up arrangements to meet the functional requirements of subparagraph .4, if this function is partly or fully fulfilled by electronic means;

.6 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;

.7 if less than 150 gross tonnage and if practicable, a radar reflector, or other means, to enable detection by ships navigating by radar at both 9 and 3 GHz;

.8 when the ship's bridge is totally enclosed and unless the Administration determines otherwise, a sound reception system, or other means, to enable the officer in charge of the navigational watch to hear sound signals and determine their direction;

.9 a telephone, or other means, to communicate heading information to the emergency steering position, if provided.

2.2 All ships of 150 gross tonnage and upwards and passenger ships irrespective of size shall, in addition to the requirements of paragraph 2.1, be fitted with:

.1 a spare magnetic compass interchangeable with the magnetic compass, as referred to in paragraph 2.1.1, or other means to perform the function referred to in paragraph 2.1.1 by means of replacement or duplicate equipment;

.2 a daylight signalling lamp, or other means, to communicate by light during day and night using an energy source of electrical power not solely dependent upon the ship's power supply.

2.3 All ships of 300 gross tonnage and upwards and passenger ships irrespective of size shall, in addition to meeting the requirements of paragraph 2.2, be fitted with:

.1 an echo sounding device, or other electronic means, to measure and display the available depth of water;

.2 a 9 GHz radar, or other means, to determine and display the range and bearing of radar transponders and of other surface craft, obstructions, buoys, shorelines and navigational marks to assist in navigation and in collision avoidance;

.3 an electronic plotting aid, or other means, to plot electronically the range and bearing of targets to determine collision risk;

.4 speed and distance measuring device, or other means, to indicate speed and distance through the water;

.5 a properly adjusted transmitting heading device, or other means to transmit heading information for input to the equipment referred to in paragraphs 2.3.2, 2.3.3 and 2.4.

2.4 All ships of 300 gross tonnage and upwards engaged on international voyages and cargo ships of 500 gross tonnage and upwards not engaged on international voyages and passenger ships irrespective of size shall be fitted with an automatic identification system (AIS), as follows:

.1 ships constructed on or after 1 July 2002;

.2 ships engaged on international voyages constructed before 1 July 2002:

.2.1 in the case of passenger ships, not later than 1 July 2003;

.2.2 in the case of tankers, not later than the first survey for safety equipment on or after 1 July 2003;

.2.3 in the case of ships, other than passenger ships and tankers, of 50,000 gross tonnage and upwards, not later than 1 July 2004;

.2.4 in the case of ships, other than passenger ships and tankers, of 300 gross tonnage and upwards but less than 50,000 gross tonnage, not later than the first safety equipment survey see footnote after 1 July 2004 or by 31 December 2004, whichever occurs earlier; and

.3 ships not engaged on international voyages constructed before 1 July 2002, not later than 1 July 2008;

.4 the Administration may exempt ships from the application of the requirements of this paragraph when such ships will be taken permanently out of service within two years after the implementation date specified in subparagraphs 2 and 3;

.5 AIS shall:

.1 provide automatically to appropriately equipped shore stations, other ships and aircraft information, including the ship's identity, type, position, course, speed, navigational status and other safety-related information;

.2 receive automatically such information from similarly fitted ships;

.3 monitor and track ships; and

.4 exchange data with shore-based facilities;

.5 the requirements of paragraph 2.4.5 shall not be applied to cases where international agreements, rules or standards provide for the protection of navigational information; and

.6 AIS shall be operated taking into account the guidelines adopted by the Organization. see footnote Ships fitted with AIS shall maintain AIS in operation at all times except where international agreements, rules or standards provide for the protection of navigational information.

2.5 All ships of 500 gross tonnage and upwards shall, in addition to meeting the requirements of paragraph 2.3 with the exception of paragraphs 2.3.3 and 2.3.5, and the requirements of paragraph 2.4, have:

.1 a gyro-compass, or other means, to determine and display their heading by shipborne non-magnetic means and to transmit heading information for input to the equipment referred in paragraphs 2.3.2, 2.4 and 2.5.5;

.2 a gyro-compass heading repeater, or other means, to supply heading information visually at the emergency steering position if provided;

.3 a gyro-compass bearing repeater, or other means, to take bearings, over an arc of the horizon of 360°, using the gyro-compass or other means referred to in subparagraph .1. However, ships of less than 1,600 gross tonnage shall be fitted with such means as far as possible;

.4 rudder, propeller, thrust, pitch and operational mode indicators, or other means, to determine and display rudder angle, propeller revolutions, the force and direction of thrust and, if applicable, the force and direction of lateral thrust and the pitch and operational mode, all to be readable from the conning position; and

.5 an automatic tracking aid, or other means, to plot automatically the range and bearing of other targets to determine collision risk.

2.6 On all ships of 500 gross tonnage and upwards, failure of one piece of equipment should not reduce the ship's ability to meet the requirements of paragraphs 2.1.1, 2.1.2 and 2.1.4.

2.7 All ships of 3000 gross tonnage and upwards shall, in addition to meeting the requirements of paragraph 2.5, have:

.1 a 3 GHz radar or where considered appropriate by the Administration a second 9 GHz radar, or other means, to determine and display the range and bearing of other surface craft, obstructions, buoys, shorelines and navigational marks to assist in navigation and in collision avoidance, which are functionally independent of those referred to in paragraph 2.3.2; and

.2 a second automatic tracking aid, or other means, to plot automatically the range and bearing of other targets to determine collision risk which are functionally independent of those referred to in paragraph 2.5.5.

2.8 All ships of 10,000 gross tonnage and upwards shall, in addition to meeting the requirements of paragraph 2.7 with the exception of paragraph 2.7.2, have:

.1 an automatic radar plotting aid, or other means, to plot automatically the range and bearing of at least 20 other targets, connected to a device to indicate speed and distance through the water, to determine collision risks and simulate a trial manoeuvre; and

.2 a heading or track control system, or other means, to automatically control and keep to a heading and/or straight track.

2.9 All ships of 50,000 gross tonnage and upwards shall, in addition to meeting the requirements of paragraph 2.8, have:

.1 a rate-of-turn indicator, or other means, to determine and display the rate of turn; and

.2 a speed and distance measuring device, or other means, to indicate speed and distance over the ground in the forward and athwartships direction.

.3 When "other means" are permitted under this regulation, such means must be approved by the Administration in accordance with regulation 18.

.4 The navigational equipment and systems referred to in this regulation shall be so installed, tested and maintained as to minimize malfunction.

.5 Navigational equipment and systems offering alternative modes of operation shall indicate the actual mode of use.

.6 Integrated bridge systems see footnote shall be so arranged that failure of one sub-system is brought to the immediate attention of the officer in charge of the navigational watch by audible and visual alarms, and does not cause failure to any other sub-system. In case of failure in one part of an integrated navigational system, see footnote it shall be possible to operate each other individual item of equipment or part of the system separately.

ANNEX 2

IMO PERFORMANCE STANDARDS FOR RADAR EQUIPMENT

MSC 192 (79)

ANNEX 34

RESOLUTION MSC.192(79)

(adopted on 6 December 2004)

ADOPTION OF THE REVISED PERFORMANCE STANDARDS FOR RADAR EQUIPMENT

THE MARITIME SAFETY COMMITTEE,

RECALLING Article 28(b) of the Convention on the International Maritime Organization concerning the functions of the Committee,

RECALLING ALSO resolution A.886(21) by which the Assembly resolved that the functions of adopting performance standards and technical specifications, as well as amendments thereto, shall be performed by the Maritime Safety Committee on behalf of the Organization,

NOTING resolutions A.222(VII), A.278(VIII), A.477(XII), MSC.64(67), annex 4, A.820(19) and A.823(19) containing performance standards applicable to marine radars being produced and installed at different time periods in the past,

NOTING ALSO that marine radars are used in connection/integration with other navigational equipment required to carry on board ships such as, an automatic target tracking aid, ARPA, AIS, ECDIS and others,

RECOGNIZING the need for unification of maritime radar standards in general, and, in particular, for display and presentation of navigation-related information,

HAVING CONSIDERED the recommendation on the revised performance standards for radar equipment made by the Sub-Committee on Safety of Navigation at its fiftieth session,

1. ADOPTS the Revised Recommendation on Performance Standards for radar equipment set out in the Annex to the present resolution;

2. RECOMMENDS Governments to ensure that radar equipment installed on or after 1 July 2008 conform to performance standards not inferior to those set out in the Annex to the present resolution.

INDEX

1 SCOPE OF EQUIPMENT

The radar equipment should assist in safe navigation and in avoiding collision by providing an indication, in relation to own ship, of the position of other surface craft, obstructions and hazards, navigation objects and shorelines.

For this purpose, radar should provide the integration and display of radar video, target tracking information, positional data derived from own ship's position (EPFS) and geo referenced data. The integration and display of AIS information should be provided to complement radar. The capability of displaying selected parts of Electronic Navigation Charts and other vector chart information may be provided to aid navigation and for position monitoring.

The radar, combined with other sensor or reported information (e.g. AIS), should improve the safety of navigation by assisting in the efficient navigation of ships and protection of the environment by satisfying the following functional requirements:

- in coastal navigation and harbour approaches, by giving a clear indication of land and other fixed hazards;
- as a means to provide an enhanced traffic image and improved situation awareness;
- in a ship-to-ship mode for aiding collision avoidance of both detected and reported hazards;
- in the detection of small floating and fixed hazards, for collision avoidance and the safety of own ship; and
- in the detection of floating and fixed aids to navigation (see Table 2, note 3).

2 APPLICATION OF THESE STANDARDS

These Performance Standards should apply to all shipborne radar installations, used in any configuration, mandated by the SOLAS Convention 1974, as amended, independent of the:

- type of ship;
- frequency band in use; and
- type of display,

providing that no special requirements are specified in Table 1 and that additional requirements for specific classes of ships (in accordance with SOLAS chapters V and X) are met.

The radar installation, in addition to meeting the general requirements as set out in resolution A.694(17)*, should comply with the following performance standards.

Close interaction between different navigational equipment and systems, makes it essential to consider these standards in association with other relevant IMO standards.

TABLE 1

Differences in the performance requirements for various sizes/categories of ship/craft to which SOLAS applies

Size of ship/craft	**‹500 GT**	**500 GT to ‹10 000 GT and HSC‹10 000 GT**	**All ships/craft ≥10 000 GT**
Minimum operational display area diameter	180 mm	250 mm	320 mm
Minimum display area	195x195 mm	270x270 mm	340x340 mm
Auto acquisition of targets	-	-	Yes
Minimum ***acquired*** radar target capacity	20	30	40
Minimum, ***activated*** AIS target capacity	20	30	40
Minimum ***sleeping*** AIS target capacity	100	150	200
Trial manoeuvre	-	-	Yes

3 REFERENCES

References are in Appendix 1.

4 DEFINITIONS

Definitions are in Appendix 2.

5 OPERATIONAL REQUIREMENTS FOR THE RADAR SYSTEM

The design and performance of the radar should be based on user requirements and up-to-date navigational technology. It should provide effective target detection within the safety-relevant environment surrounding own ship and should permit fast and easy situation evaluation.

5.1 Frequency

5.1.1 Frequency Spectrum

* IEC Publication 60945.
Refer to MSC/Circ.878 - MEPC/Circ.346 on Interim Guidelines for the application of Human Element Analysing Process (HEAP) to the IMO rule-making process.

The radar should transmit within the confines of the ITU allocated bands for maritime radar and meet the requirements of the radio regulations and applicable ITU-recommendations.

5.1.2 Radar Sensor Requirements

Radar systems of both X and S bands are covered in these performance standards:

- X band (9.2–9.5 GHz) for high discrimination, good sensitivity and tracking performance; and
- S band (2.9–3.1 GHz) to ensure that target detection and tracking capabilities are maintained in varying and adverse conditions of fog, rain and sea clutter.

The frequency band in use should be indicated.

5.1.3 Interference Susceptibility

The radar should be capable of operating satisfactorily in typical interference conditions.

5.2 Radar Range and Bearing Accuracy

The radar system range and bearing accuracy requirements should be:

Range – within 30 m or 1 per cent of the range scale in use, whichever is greater;

Bearing – within 1°.

5.3 Detection Performance and Anti-clutter Functions

All available means for the detection of targets should be used.

5.3.1 Detection

5.3.1.1 Detection in Clear Conditions

In the absence of clutter, for long range target and shoreline detection, the requirement for the radar system is based on normal propagation conditions, in the absence of sea clutter, precipitation and evaporation duct, with an antenna height of 15m above sea level.

Based on:

- an indication of the target in at least 8 out of 10 scans or equivalent; and
- a probability of a radar detection false alarm of 10^{-4},

the requirement contained in Table 2 should be met as specified for X-Band and S-Band equipment.

The detection performance should be achieved using the smallest antenna that is supplied with the radar system.

Recognizing the high relative speeds possible between own ship and target, the equipment should be specified and approved as being suitable for classes of ship having normal (<30 kn) or high (>30 kn) own ship speeds (100 kn and 140 kn relative speeds respectively).

TABLE 2

Minimum detection ranges in clutter-free conditions

Target description	**Target feature**	**Detection range in NM**[6]	
Target description[5]	Height above sea level in metres	X Band NM	S Band NM
Shorelines	Rising to 60	20	20
Shorelines	Rising to 6	8	8
Shorelines	Rising to 3	6	6
SOLAS ships (>5000 gross tonnage)	10	11	11
SOLAS ships (>500 gross tonnage)	5.0	8	8
Small vessels with Radar Reflector meeting IMO Performance Standards[1]	4.0	5.0	3.7
Navigation buoy with corner reflector[2]	3.5	4.9	3.6
Typical Navigation Buoy[3]	3.5	4.6	3.0
Small vessel of length 10 m with no radar reflector[4]	2.0	3.4	3.0

[1] IMO revised performance standards for radar reflectors (resolution MSC.164(78)). Radar Cross Section (RCS) 7.5 m2 for X-Band, 0.5 m2 for S-Band.
[2] The corner reflector (used for measurement), is taken as 10 m2 for X-Band and 1.0 m2 for S-Band.
[3] The typical navigation buoy is taken as 5.0 m2 for X-Band and 0.5 m2 for S-Band; for typical channel markers, with an RCS of 1.0 m2 (X-band) and 0.1 m2 (S-band) and height of 1 metre, a detection range of 2.0 and 1.0 NM respectively.
[4] RCS for 10 m small vessel taken as 2.5 m2 for X-Band and 1.4 m2 for S-Band (taken as a complex target).
[5] Reflectors are taken as point targets, vessels as complex targets and shorelines as distributed targets (typical values for a rocky shoreline but are dependent on profile).
[6] Detection ranges experienced in practice will be affected by various factors, including atmospheric conditions (e.g. evaporation duct), target speed and aspect, target material and target structure. These and other factors may either enhance or degrade the detection ranges stated. At ranges between the first detection and own ship, the radar return may be reduced or enhanced by signal multi-path, which depend on factors such as antenna/target centroid height, target structure, sea state and radar frequency band.

5.3.1.2 Detection at Close Range

The short-range detection of the targets under the conditions specified in Table 2 should be compatible with the requirement in paragraph 5.4.

5.3.1.3 Detection in Clutter Conditions

Performance limitations caused by typical precipitation and sea clutter conditions will result in a reduction of target detection capabilities relative to those defined in 5.3.1.1 and Table. 2.

5.3.1.3.1 The radar equipment should be designed to provide the optimum and most consistent detection performance, restricted only by the physical limits of propagation.

5.3.1.3.2 The radar system should provide the means to enhance the visibility of targets in adverse clutter conditions at close range.

5.3.1.3.3 Degradation of detection performance (related to the figures in Table 2) at various ranges and target speeds under the following conditions, should be clearly stated in the user manual:

- light rain (4 mm per hour) and heavy rain (16 mm per hour);
- sea state 2 and sea state 5; and
- a combination of these.

5.3.1.3.4 The determination of performance in clutter and specifically, range of first detection, as defined in the clutter environment in 5.3.1.3.3, should be tested and assessed against a benchmark target, as specified in the Test Standard.

5.3.1.3.5 Degradation in performance due to a long transmission line, antenna height or any other factors should be clearly stated in the user manual.

5.3.2 Gain and Anti-Clutter Functions

5.3.2.1 Means should be provided, as far as is possible, for the adequate reduction of unwanted echoes, including sea clutter, rain and other forms of precipitation, clouds, sandstorms and interference from other radars.

5.3.2.2 A gain control function should be provided to set the system gain or signal threshold level.

5.3.2.3 Effective manual and automatic anti-clutter functions should be provided.

5.3.2.4 A combination of automatic and manual anti-clutter functions is permitted.

5.3.2.5 There should be a clear and permanent indication of the status and level for gain and all anti-clutter control functions.

5.3.3 Signal Processing

5.3.3.1 Means should be available to enhance target presentation on the display.

5.3.3.2 The effective picture update period should be adequate, with minimum latency to ensure that the target detection requirements are met.

5.3.3.3 The picture should be updated in a smooth and continuous manner.

5.3.3.4 The equipment manual should explain the basic concept, features and limitations of any signal processing.

5.3.4 Operation with SARTs and Radar Beacons

5.3.4.1 The X-Band radar system should be capable of detecting radar beacons in the relevant frequency band.

5.3.4.2 The X-Band radar system should be capable of detecting SARTs and radar target enhancers.

5.3.4.3 It should be possible to switch off those signal processing functions, including polarization modes, which might prevent an X-Band radar beacon or SARTs from being detected and displayed. The status should be indicated.

5.4 Minimum Range

5.4.1 With own ship at zero speed, an antenna height of 15 m above the sea level and in calm conditions, the navigational buoy in Table 2 should be detected at a minimum horizontal range of 40 m from the antenna position and up to a range of 1 NM, without changing the setting of control functions other than the range scale selector.

5.4.2 Compensation for any range error should be automatically applied for each selected antenna, where multiple antennas are installed.

5.5 Discrimination

Range and bearing discrimination should be measured in calm conditions, on a range scale of 1.5 NM or less and at between 50% and 100% of the range scale selected:

5.5.1 Range

The radar system should be capable of displaying two point targets on the same bearing, separated by 40 m in range, as two distinct objects.

5.5.2 Bearing

The radar system should be capable of displaying two point targets at the same range, separated by 2.5° in bearing, as two distinct objects.

5.6 Roll and Pitch

The target detection performance of the equipment should not be substantially impaired when own ship is rolling or pitching up to +/-10°.

5.7 Radar Performance Optimization and Tuning

5.7.1 Means should be available to ensure that the radar system is operating at the best performance. Where applicable to the radar technology, manual tuning should be provided and additionally, automatic tuning may be provided.

5.7.2 An indication should be provided, in the absence of targets, to ensure that the system is operating at the optimum performance.

5.7.3 Means should be available (automatically or by manual operation) and while the equipment is operational, to determine a significant drop in system performance relative to a calibrated standard established at the time of installation.

5.8 Radar Availability

The radar equipment should be fully operational (RUN status) within 4 minutes after switch ON from cold. A STANDBY condition should be provided, in which there is no operational radar transmission. The radar should be fully operational within 5 sec from the standby condition.

5.9 Radar Measurements. Consistent Common Reference Point (CCRP)

5.9.1 Measurements from own ship (e.g. range rings, target range and bearing, cursor, tracking data) should be made with respect to the consistent common reference point (e.g. conning position). Facilities should be provided to compensate for the offset between antenna position and the consistent common reference point on installation. Where multiple antennas are installed, there should be provision for applying different position offsets for each antenna in the radar system. The offsets should be applied automatically when any radar sensor is selected.

5.9.2 Own ships scaled outline should be available on appropriate range scales. The consistent common reference point and the position of the selected radar antenna should be indicated on this graphic.

5.9.3 When the picture is centred, the position of the Consistent Common Reference Point should be at the centre of the bearing scale. The off-centre limits should apply to the position of the selected antenna.

5.9.4 Range measurements should be in nautical miles (NM). In addition, facilities for metric measurements may be provided on lower range scales. All indicated values for range measurement should be unambiguous.

5.9.5 Radar targets should be displayed on a linear range scale and without a range index delay.

5.10 Display Range Scales

5.10.1 Range scales of 0.25, 0.5, 0.75, 1.5, 3, 6, 12 and 24 NM should be provided. Additional range scales are permitted outside the mandatory set. Low metric range scales may be offered in addition to the mandatory set.

5.10.2 The range scale selected should be permanently indicated.

5.11 Fixed Range Rings

5.11.1 An appropriate number of equally spaced range rings should be provided for the range scale selected. When displayed, the range ring scale should be indicated.

5.11.2 The system accuracy of fixed range rings should be within 1% of the maximum range of the range scale in use or 30 m, whichever is the greater distance.

5.12 Variable Range Markers (VRM)

5.12.1 At least two variable range markers (VRMs) should be provided. Each active VRM should have a numerical readout and have a resolution compatible with the range scale in use.

5.12.2 The VRMs should enable the user to measure the range of an object within the operational display area with a maximum system error of 1% of the range scale in use or 30 m, whichever is the greater distance.

5.13 Bearing Scale

5.13.1 A bearing scale around the periphery of the operational display area should be provided. The bearing scale should indicate the bearing as seen from the consistent common reference point.

5.13.2 The bearing scale should be outside of the operational display area. It should be numbered at least every 30° division and have division marks of at least 5°. The 5° and 10° division marks should be clearly distinguishable from each other. 1° division marks may be presented where they are clearly distinguishable from each other.

5.14 Heading Line (HL)

5.14.1 A graphic line from the consistent common reference point to the bearing scale should indicate the heading of the ship.

5.14.2 Electronic means should be provided to align the heading line to within 0.1°. If there is more than one radar antenna (see 5.35) the heading skew (bearing offset) should be retained and automatically applied when each radar antenna is selected.

5.14.3 Provision should be made to temporarily suppress the heading line. This function may be combined with the suppression of other graphics.

5.15 Electronic Bearing Lines (EBLs)

5.15.1 At least two electronic bearing lines (EBLs) should be provided to measure the bearing of any point object within the operational display area, with a maximum system error of 1° at the periphery of the display.

5.15.2 The EBLs should be capable of measurement relative to the ships heading and relative to true north. There should be a clear indication of the bearing reference (i.e. true or relative).

5.15.3 It should be possible to move the EBL origin from the consistent common reference point to any point within the operational display area and to reset the EBL to the consistent common reference point by a fast and simple action.

5.15.4 It should be possible to fix the EBL origin or to move the EBL origin at the velocity of own ship.

5.15.5 Means should be provided to ensure that the user is able to position the EBL smoothly in either direction, with an incremental adjustment adequate to maintain the system measurement accuracy requirements.

5.15.6 Each active EBL should have a numerical readout with a resolution adequate to maintain the system measurement accuracy requirements.

5.16 Parallel Index lines (PI)

5.16.1 A minimum of four independent parallel index lines, with a means to truncate and switch off individual lines, should be provided.

5.16.2 Simple and quick means of setting the bearing and beam range of a parallel index line should be provided. The bearing and beam range of any selected index line should be available on demand.

5.17 Offset Measurement of Range and Bearing

There should be a means to measure the range and bearing of one position on the display relative to any other position within the operational display area.

5.18 User Cursor

5.18.1 A user cursor should be provided to enable a fast and concise means to designate any position on the operational display area.

5.18.2 The cursor position should have a continuous readout to provide the range and bearing, measured from the consistent common reference point, and/or the latitude and longitude of the cursor position presented either alternatively or simultaneously.

5.18.3 The cursor should provide the means to select and de-select targets, graphics or objects within the operational display area. In addition, the cursor may be used to select modes, functions, vary parameters and control menus outside of the operational display area.

5.18.4 Means should be provided to easily locate the cursor position on the display.

5.18.5 The accuracy of the range and bearing measurements provided by the cursor should meet the relevant requirements for VRM and EBL.

5.19 Azimuth Stabilization

5.19.1 The heading information should be provided by a gyrocompass or by an equivalent sensor with a performance not inferior to the relevant standards adopted by the Organization.

5.19.2 Excluding the limitations of the stabilizing sensor and type of transmission system, the accuracy of azimuth alignment of the radar presentation should be within 0.5° with a rate of turn likely to be experienced with the class of ship.

5.19.3 The heading information should be displayed with a numerical resolution to permit

accurate alignment with the ship gyro system.

5.19.4 The heading information should be referenced to the consistent common reference point

(CCRP).

5.20 Display Mode of the Radar Picture

5.20.1 A True Motion display mode should be provided. The automatic reset of own ship may be initiated by its position on the display, or time related, or both. Where the reset is selected to occur at least on every scan or equivalent, this should be equivalent to True Motion with a fixed origin (in practice equivalent to the previous relative motion mode).

5.20.2 North Up and Course Up orientation modes should be provided. Head Up may be provided when the display mode is equivalent to True Motion with a fixed origin (in practice equivalent to the previous relative motion Head Up mode).

5.20.3 An indication of the motion and orientation mode should be provided.

5.21 Off-Centring

5.21.1 Manual off-centring should be provided to locate the selected antenna position at any point within at least 50% of the radius from the centre of the operational display area.

5.21.2 On selection of off-centred display, the selected antenna position should be capable of being located to any point on the display up to at least 50%, and not more than 75%, of the radius from the centre of the operational display area. A facility for automatically positioning own ship for the maximum view ahead may be provided.

5.21.3 In True Motion, the selected antenna position should automatically reset up to a 50% radius to a location giving the maximum view along own ship's course. Provision for an early reset of selected antenna position should be provided.

5.22 Ground and Sea Stabilization Modes

5.22.1 Ground and Sea stabilization modes should be provided.

5.22.2 The stabilization mode and stabilization source should be clearly indicated.

5.22.3 The source of own ships' speed should be indicated and provided by a sensor approved in accordance with the requirements of the Organization for the relevant stabilization mode.

5.23 Target Trails and Past Positions

5.23.1 Variable length (time) target trails should be provided, with an indication of trail time and mode. It should be possible to select true or relative trails from a reset condition for all true motion display modes.

5.23.2 The trails should be distinguishable from targets.

5.23.3 Either scaled trails or past positions or both, should be maintained and should be available for presentation within 2 scans or equivalent, following:

- the reduction or increase of one range scale;
- the offset and reset of the radar picture position; and
- a change between true and relative trails.

5.24 Presentation of Target Information

5.24.1 Targets should be presented in accordance with the performance standards for the Presentation of Navigation-related Information on Shipborne Navigational Displays adopted by the Organization and with their relevant symbols according to SN/Circ.243.

5.24.2 The target information may be provided by the radar target tracking function and by the reported target information from the Automatic Identification System (AIS).

5.24.3 The operation of the radar tracking function and the processing of reported AIS information is defined in these standards.

5.24.4 The number of targets presented, related to display size, is defined in Table 1. An indication should be given when the target capacity of radar tracking or AIS reported target processing/display capability is about to be exceeded.

5.24.5 As far as practical, the user interface and data format for operating, displaying and indicating AIS and radar tracking information should be consistent.

5.25 Target Tracking (TT) and Acquisition

5.25.1 General

Radar targets are provided by the radar sensor (transceiver). The signals may be filtered (reduced) with the aid of the associated clutter controls. Radar targets may be manually or automatically acquired and tracked using an automatic Target Tracking (TT) facility.

5.25.1.1 The automatic target tracking calculations should be based on the measurement of radar target relative position and own ship motion.

5.25.1.2 Any other sources of information, when available, may be used to support the optimum tracking performance.

5.25.1.3 TT facilities should be available on at least the 3, 6, and 12 NM range scales. Tracking range should extend to a minimum of 12 NM.

5.25.1.4 The radar system should be capable of tracking targets having the maximum relative speed relevant to its classification for normal or high own ship speeds (see 5.3).

5.25.2 Tracked Target Capacity

5.25.2.1 In addition to the requirements for processing of targets reported by AIS, it should be possible to track and provide full presentation functionality for a minimum number of tracked radar targets according to Table 1.

5.25.2.2 There should be an indication when the target tracking capacity is about to be exceeded. Target overflow should not degrade the radar system performance.

5.25.3 Acquisition

5.25.3.1 Manual acquisition of radar targets should be provided with provision for acquiring at least the number of targets specified in Table 1.

5.25.3.2 Automatic acquisition should be provided where specified in Table 1. In this case, there should be means for the user to define the boundaries of the auto-acquisition area.

5.25.4 Tracking

5.25.4.1 When a target is acquired, the system should present the trend of the target's motion within one minute and the prediction of the targets' motion within 3 minutes.

5.25.4.2 TT should be capable of tracking and updating the information of all acquired targets automatically.

5.25.4.3 The system should continue to track radar targets that are clearly distinguishable on the display for 5 out of 10 consecutive scans or equivalent.

5.25.4.4 The TT design should be such that target vector and data smoothing is effective, while target manoeuvres should be detected as early as possible.

5.25.4.5 The possibility of tracking errors, including target swap, should be minimized by design.

5.25.4.6 Separate facilities for cancelling the tracking of any one and of all target(s) should be provided.

5.25.4.7 Automatic tracking accuracy should be achieved when the tracked target has achieved a steady state, assuming the sensor errors allowed by the relevant performance standards of the Organization.

5.25.4.7.1 For ships capable of up to 30 kn true speed, the tracking facility should present, within 1 min steady state tracking, the relative motion trend and after 3 minutes, the predicted motion of a target, within the following accuracy values (95% probability):

TABLE 3

Tracked Target Accuracy (95% probability figures)

Time of steady state (minutes)	Relative Course (degrees)	Relative Speed (kn)	CPA (NM)	TCPA (minutes)	True Course (degrees)	True Speed (kn)
1 min: Trend	11	1.5 or 10% (whichever is greater)	1.0	-	-	-
3 min: Motion	3	0.8 or 1% (whichever is greater)	0.3	0.5	5	0.5 or 1% (whichever is greater)

Accuracy may be significantly reduced during or shortly after acquisition, own ship manoeuvre, a manoeuvre of the target, or any tracking disturbance and is also dependent on own ship's motion and sensor accuracy.

Measured target range and bearing should be within 50 m (or +/-1% of target range) and 2°.

The testing standard should have detailed target simulation tests as a means to confirm the accuracy of targets with relative speeds of up to 100 kn. Individual accuracy values shown in the

table above may be adapted to account for the relative aspects of target motion with respect to that of own ship in the testing scenarios used.

5.25.4.7.2 For ships capable of speeds in excess of 30 kn (typically High-Speed Craft (HSC)) and with speeds of up to 70 kn, there should be additional steady state measurements made to ensure that the motion accuracy, after 3 minutes of steady state tracking, is maintained with target relative speeds of up to 140 kn.

5.25.4.8 A ground referencing function, based on a stationary tracked target, should be provided. Targets used for this function should be marked with the relevant symbol defined in SN/Circ.243.

5.26 Automatic Identification System (AIS) Reported Targets

5.26.1 General

Reported targets provided by the AIS may be filtered according to user-defined parameters. Targets may be sleeping, or may be activated. Activated targets are treated in a similar way to radar tracked targets.

5.26.2 AIS Target Capacity

In addition to the requirements for radar tracking, it should be possible to display and provide full presentation functionality for a minimum number of sleeping and activated AIS targets according to Table 1. There should be an indication when the capacity of processing/display of AIS targets is about to be exceeded.

5.26.3 Filtering of AIS Sleeping Targets

To reduce display clutter, a means to filter the presentation of sleeping AIS targets should be provided, together with an indication of the filter status. (e.g. by target range, CPA/TCPA or AIS target class A/B, etc.). It should not be possible to remove individual AIS targets from the display.

5.26.4 Activation of AIS Targets

A means to activate a sleeping AIS target and to deactivate an activated AIS target should be provided. If zones for the automatic activation of AIS targets are provided, they should be the same as for automatic radar target acquisition. In addition, sleeping AIS targets may be automatically activated when meeting user defined parameters (e.g. target range, CPA/TCPA or AIS target class A/B).

5.26.5 AIS Presentation Status

TABLE 4

The AIS presentation status should be indicated as follows:

Function	Cases to be Presented		Presentation
AIS ON/OFF	AIS processing switched ON/graphical presentation switched OFF	AIS processing switched ON/graphical presentation switched ON	Alphanumeric or graphical
Filtering of sleeping AIS targets	Filter status	Filter status	Alphanumeric or graphical
Activation of Targets		Activation criteria	Graphical
CPA/TCPA Alarm	Function ON/OFF Sleeping targets included	Function ON/OFF Sleeping targets included	Alphanumeric and graphical
Lost Target Alarm	Function ON/OFF Lost target filter criteria	Function ON/OFF Lost target filter criteria	Alphanumeric and graphical
Target Association	Function ON/OFF Association criteria Default target priority	Function ON/OFF Association criteria Default target priority	Alphanumeric

5.27 AIS Graphical Presentation

Targets should be presented with their relevant symbols according to the performance standards for the Presentation of Navigation-related Information on Shipborne Navigational Displays adopted by the Organization and SN/Circ.243.

5.27.1 AIS targets that are displayed should be presented as sleeping targets by default.

5.27.2 The course and speed of a tracked radar target or reported AIS target should be indicated by a predicted motion vector. The vector time should be adjustable and valid for presentation of any target regardless of its source.

5.27.3 A permanent indication of vector mode, time and stabilization should be provided.

5.27.4 The consistent common reference point should be used for the alignment of tracked radar and AIS symbols with other information on the same display.

5.27.5 On large scale/low range displays, a means to present the true scale outline of an activated AIS target should be provided. It should be possible to display the past track of activated targets.

5.28 AIS and Radar Target Data

5.28.1 It should be possible to select any tracked radar or AIS target for the alphanumeric display of its data. A target selected for the display of its alphanumeric information should be identified by the relevant symbol. If more than one target is selected for data display, the relevant symbols and the corresponding data should be clearly identified. There should be a clear indication to show that the target data is derived from radar or from AIS.

5.28.2 For each selected tracked radar target, the following data should be presented in alphanumeric form: source(s) of data, actual range of target, actual bearing of target, predicted target range at the closest point of approach (CPA), predicted time to CPA (TCPA), true course of target, true speed of target.

5.28.3 For each selected AIS target the following data should be presented in alphanumeric form: Source of data, ship's identification, navigational status, position where available and its quality, range, bearing, COG, SOG, CPA and TCPA. Target heading and reported rate of turn should also be made available. Additional target information should be provided on request.

5.28.4 If the received AIS information is incomplete, the absent information should be clearly indicated as missing. within the target data field.

5.28.5 The data should be displayed and continually updated, until another target is selected for data display or until the window is closed.

5.28.6 Means should be provided to present own ship AIS data on request.

5.29 Operational Alarms

A clear indication of the cause for all alarm criteria should be given.

5.29.1 If the calculated CPA and TCPA values of a tracked target or activated AIS target are less

than the set limits:

- A CPA/TCPA alarm should be given.
- The target should be clearly indicated.

5.29.2 The preset CPA/TCPA limits applied to targets from radar and AIS should be identical. As a default state, the CPA/TCPA alarm functionality should be applied to all activated AIS targets. On user request the CPA/TCPA alarm functionality may also be applied to sleeping targets.

5.29.3 If a user defined acquisition/activation zone facility is provided, a target not previously acquired/activated entering the zone, or is detected within the zone, should be clearly identified with the relevant symbol and an alarm should be given. It should be possible for the user to set ranges and outlines for the zone.

5.29.4 The system should alert the user if a tracked radar target is lost, rather than excluded by a pre-determined range or pre-set parameter. The target's last position should be clearly indicated on the display.

5.29.5 It should be possible to enable or disable the lost target alarm function for AIS targets. A clear indication should be given if the lost target alarm is disabled.

If the following conditions are met for a lost AIS target:

- The AIS lost target alarm function is enabled.
- The target is of interest, according to lost target filter criteria.
- A message is not received for a set time, depending on the nominal reporting rate of the AIS target.

Then:

- The last known position should be clearly indicated as a lost target and an alarm be given.
- The indication of the lost target should disappear if the signal is received again, or after the alarm has been acknowledged.

- A means of recovering limited historical data from previous reports should be provided.

5.30 AIS and Radar Target Association

An automatic target association function based on harmonized criteria avoids the presentation of two target symbols for the same physical target.

5.30.1 If the target data from AIS and radar tracking are both available and if the association criteria (e.g. position, motion) are fulfilled such that the AIS and radar information are considered as one physical target, then as a default condition, the activated AIS target symbol and the alphanumeric AIS target data should be automatically selected and displayed.

5.30.2 The user should have the option to change the default condition to the display of tracked radar targets and should be permitted to select either radar tracking or AIS alphanumeric data.

5.30.3 For an associated target, if the AIS and radar information become sufficiently different, the AIS and radar information should be considered as two distinct targets and one activated AIS target and one tracked radar target should be displayed. No alarm should be raised.

5.31 Trial Manoeuvre

The system should, where required by table 1, be capable of simulating the predicted effects of own ships manoeuvre in a potential threat situation and should include own ship's dynamic characteristics. A trial manoeuvre simulation should be clearly identified. The requirements are:

- The simulation of own ship course and speed should be variable.
- A simulated time to manoeuvre with a countdown should be provided.
- During simulation, target tracking should continue and the actual target data should be indicated.
- Trial manoeuvre should be applied to all tracked targets and at least all activated AIS targets.

5.32 The Display of Maps, Navigation Lines and Routes

5.32.1 It should be possible for the user to manually create and change, save, load and display simple maps/navigation lines/routes referenced to own ship or a geographical position. It should be possible to remove the display of this data by a simple operator action.

5.32.2 The maps/navigation lines/routes may consist of lines, symbols and reference points.

5.32.3 The appearance of lines, colours and symbols are as defined in SN/Circ.243.

5.32.4 The maps/navigation lines/route graphics should not significantly degrade the radar information.

5.32.5 The maps/navigation lines/routes should be retained when the equipment is switched OFF.

5.32.6 The maps/navigation lines/route data should be transferable whenever a relevant equipment module is replaced.

5.33 The Display of Charts

5.33.1 The radar system may provide the means to display ENC and other vector chart information within the operational display area to provide continuous and real-time position monitoring. It should be possible to remove the display of chart data by a single operator action.

5.33.2 The ENC information should be the primary source of information and should comply with IHO relevant standards. Status of other information should be identified with a permanent indication. Source and update information should be made available.

5.33.3 As a minimum, the elements of the ECDIS Standard Display should be made available for individual selection by category or layer, but not as individual objects.

5.33.4 The chart information should use the same reference and co-ordinate criteria as the radar/AIS, including datum, scale, orientation, CCRP and stabilization mode.

5.33.5 The display of radar information should have priority. Chart information should be displayed such that radar information is not substantially masked, obscured or degraded. Chart information should be clearly perceptible as such.

5.33.6 A malfunction of the source of chart data should not affect the operation of the radar/AIS system.

5.33.7 Symbols and colours should comply with the performance standards for the Presentation of Navigation-related Information on Shipborne Navigational Displays adopted by the Organization (SN/Circ.243).

5.34 Alarms and Indications

Alarms and indications should comply with the performance standards for the Presentation of Navigation-related Information on Shipborne Navigational Displays adopted by the Organization.

5.34.1 A means should be provided to alert the user of picture freeze.

5.34.2 Failure of any signal or sensor in use, including; gyro, log, azimuth, video, sync and heading marker, should be alarmed. System functionality should be limited to a fall-back mode or in some cases, the display presentation should be inhibited (see fall-back modes, section 9).

5.35 Integrating Multiple Radars

5.35.1 The system should safeguard against single point system failure. Fail-safe condition should be applied in the event of an integration failure.

5.35.2 The source and any processing or combination of radar signals should be indicated.

5.35.3 The system status for each display position should be available.

6 ERGONOMIC CRITERIA

6.1 Operational Controls

6.1.1 The design should ensure that the radar system is simple to operate. Operational controls should have a harmonized user interface and be easy to identify and simple to use.

6.1.2 The radar system should be capable of being switched ON or OFF at the main system radar display or at a control position.

6.1.3 The control functions may be dedicated hardware, screen accessed or a combination of these; however the primary control functions should be dedicated hardware controls or soft keys, with an associated status indication in a consistent and intuitive position.

6.1.4 The following are defined as primary radar control functions and should be easily and immediately accessible:

Radar Standby/RUN, Range scale selection, Gain, tuning function (if applicable), Anti-clutter rain, Anti-clutter sea, AIS function on/off, Alarm acknowledge, Cursor, a means to set EBL/VRM, display brightness and acquisition of radar targets.

6.1.5 The primary functions may also be operated from a remote operating position in addition to the main controls.

6.2 Display Presentation

6.2.1 The display presentation should comply with the performance standards for the Presentation of Navigation-related Information on Shipborne Navigational Displays adopted by the Organization.

6.2.2 The colours, symbols and graphics presented should comply with SN/Circ. 243.

6.2.3 The display sizes should conform to those defined in Table 1.

6.3 Instructions and Documentation

6.3.1 Documentation Language

The operating instructions and manufacturer's documentation should be written in a clear and comprehensible manner and should be available at least in the English language.

6.3.2 Operating Instructions

The operating instructions should contain a qualified explanation and/or description of information required by the user to operate the radar system correctly, including:

- appropriate settings for different weather conditions;
- monitoring the radar system's performance;
- operating in a failure or fall-back situation;
- limitations of the display and tracking process and accuracy, including any delays;
- using heading and SOG/COG information for collision avoidance;
- limitations and conditions of target association;
- criteria of selection for automatic activation and cancellation of targets;
- methods applied to display AIS targets and any limitations;

- principles underlying the trial manoeuvre technology, including simulation of own ship's manoeuvring characteristics, if provided;
- alarms and indications;
- installation requirements as listed under section 7.5;
- radar range and bearing accuracies; and
- any special operation (e.g. tuning) for the detection of SARTs; and
- the role of the CCRP for radar measurements and its specific value.

6.3.3 Manufacturer's Documentation

6.3.3.1 The manufacturer's documentation should contain a description of the radar system and factors that may affect detection performance, including any latency in signal processing.

6.3.3.2 Documentation should describe the basis of AIS filter criteria and AIS/radar target association criteria.

6.3.3.3 The equipment documentation should include full details of installation information, including additional recommendations on unit location and factors that may degrade performance or reliability.

7 DESIGN AND INSTALLATION

7.1 Design for Servicing

7.1.1 As far as is practical, the radar system should be of a design to facilitate simple fault diagnosis and maximum availability.

7.1.2 The radar system should include a means to record the total operational hours for any components with a limited life.

7.1.3 The documentation should describe any routine servicing requirements and should include details of any restricted life components.

7.2 Display

The display device physical requirements should meet those specified in the performance standards for the Presentation of Navigation-related Information on Shipborne Navigational Displays adopted by the Organization (SN/Circ.243) and those specified in Table 1.

7.3 Transmitter Mute

The equipment should provide a mute facility to inhibit the transmission of radar energy over a preset sector. The mute sector should be set up on installation. An indication of sector mute status should be available.

7.4 Antenna

7.4.1 The antenna should be designed to start operating and to continue to operate in relative wind speeds likely to be encountered on the class of ship on which it is installed.

7.4.2 The combined radar system should be capable of providing an appropriate information update rate for the class of ship on which it is installed.

7.4.3 The antenna side lobes should be consistent with satisfying the system performance as defined in this standard.

7.4.4 There should be a means to prevent antenna rotation and radiation during servicing, or while personnel are in the vicinity of up-mast units.

7.5 Radar System Installation

Requirements and guidelines for the radar system installation should be included in the manufacturers. documentation. The following subjects should be covered:

7.5.1 The Antenna

Blind sectors should be kept to a minimum, and should not be placed in an arc of the horizon from the right ahead direction to 22.5o abaft the beam and especially should avoid the right ahead direction (relative bearing 000o). The installation of the antenna should be in such a manner that the performance of the radar system is not substantially degraded. The antenna should be mounted clear of any structure that may cause signal reflections, including other antenna and deck structure or cargo. In addition, the height of the antenna should take account of target detection performance relating to range of first detection and target visibility in sea clutter.

7.5.2 The Display

The orientation of the display unit should be such that the user is looking ahead, the lookout view is not obscured and there is minimum ambient light on the display.

7.6 Operation and Training

7.6.1 The design should ensure that the radar system is simple to operate by trained users.

7.6.2 A target simulation facility should be provided for training purposes.

8 INTERFACING

8.1 Input Data

The radar system should be capable of receiving the required input information from:

- a gyro-compass or transmitting heading device (THD);
- a speed and distance measuring equipment (SDME);
- an electronic position fixing system (EPFS);
- an Automatic Identification System (AIS); or
- other sensors or networks providing equivalent information acceptable to the Organization.

The radar should be interfaced to relevant sensors required by these performance standards in accordance with recognized international standards.*

8.2 Input Data Integrity and Latency

8.2.1 The radar system should not use data indicated as invalid. If input data is known to be of poor quality this should be clearly indicated.

8.2.2 As far as is practical, the integrity of data should be checked, prior to its use, by comparison with other connected sensors or by testing to valid and plausible data limits.

8.2.3 The latency of processing input data should be minimized.

8.3 Output Data

8.3.1 Information provided by any radar output interface to other systems should be in accordance with international standards*.

8.3.2 The radar system should provide an output of the display data for the voyage data recorder (VDR).

* Refer to IEC publication 61162.

8.3.3 At least one normally closed contact (isolated) should be provided for indicating failure of the radar.

8.3.4 The radar should have a bi-directional interface to facilitate communication so that alarms from the radar can be transferred to external systems and so that audible alarms from the radar can be muted from external systems, the interface should comply with relevant international standards.

9 BACKUP AND FALLBACK ARRANGEMENTS

In the event of partial failures and to maintain minimum basic operation, the fall-back arrangements listed below should be provided. There should be a permanent indication of the failed input information.

9.1 Failure of Heading Information (Azimuth Stabilization)

9.1.1 The equipment should operate satisfactorily in an unstabilized head-up mode.

9.1.2 The equipment should switch automatically to the unstabilized head up mode within 1 minute after the azimuth stabilization has become ineffective.

9.1.3 If automatic anti-clutter processing could prevent the detection of targets in the absence of appropriate stabilization, the processing should switch off automatically within 1 minute after the azimuth stabilization has become ineffective.

9.1.4 An indication should be given that only relative bearing measurements can be used.

9.2 Failure of Speed through the Water Information

A means of manual speed input should be provided and its use clearly indicated.

9.3 Failure of Course and Speed Over Ground Information

The equipment may be operated with course and speed through the water information.

9.4 Failure of Position Input Information

The overlay of chart data and geographically referenced maps should be disabled if only a single Reference Target is defined and used, or the position is manually entered.

9.5 Failure of Radar Video Input Information

In the absence of radar signals, the equipment should display target information based on AIS data. A frozen radar picture should not be displayed.

9.6 Failure of AIS Input Information

In the absence of AIS signals, the equipment should display the radar video and target database.

9.7 Failure of an Integrated or Networked System

The equipment should be capable of operating equivalent to a stand alone system.

Appendix 1 – References

IMO SOLAS chapters IV, V and X	Carriage rules.
IMO resolution A.278(VII)	Supplement to the recommendation on PS for navigational radar equipment.
IMO resolution A.424(XI)	Performance standards for gyro-compasses.
IMO resolution A.477(XII)	Performance standards for radar equipment.
IMO resolution A.694(17)	General Requirements for ship borne radio equipment forming part of the global maritime distress and safety system and for electronically navigational aids.
IMO resolution A.817(19), as amended	Performance Standards for ECDIS.
IMO resolution A.821(19)	Performance standards for gyro-compasses for high-speed craft.
IMO resolution A.824(19)	Performance standards for devices to indicate speed and distance.
IMO resolution MSC.86(70)	Performance standards for INS.
IMO resolution MSC.64(67)	Recommendations on new and amended performance standards (Annex 2 revised by MSC.114(73)).
IMO resolution MSC.112(73)	Revised performance standards for ship borne global positioning (GPS) receiver equipment.
IMO resolution MSC.114(73)	Revised performance standards for ship borne DGPS and DGLONASS maritime radio beacon receiver equipment.
IMO resolution MSC.116(73)	Performance standards for marine transmitting heading devices (THD).
IMO MSC/Circ.982	Guidelines on ergonomic criteria for bridge equipment and layout.
IHO S-52 appendix 2	Colour and symbol specification for ECDIS.
IEC 62388	Radar Test Standard (replacing 60872 and 60936 series of test standards).
IEC 60945	Maritime navigation and radio communication equipment and systems – General requirements - methods of testing and required test results.
IEC 61162	Maritime navigation and radio communication equipment and systems - Digital interfaces.
IEC 61174	Maritime navigation and radio communication equipment and systems - Electronic chart display and information system (ECDIS) - Operational and performance requirements, methods of testing and required test results.

IEC 62288	Presentation and display of navigation information.
ISO 9000 (all parts)	Quality management/assurance standards.

Appendix 2. Definitions

Activated AIS target	A target representing the automatic or manual activation of a sleeping target for the display of additional graphically presented information. The target is displayed by an activated target. symbol including: • a vector (COG / SOG); • the heading; and • ROT or direction of turn indication (if available) to indicate initiated course changes.
Acquisition of a radar target	Process of acquiring a target and initiating its tracking.
Activation of an AIS target	Activation of a sleeping AIS target for the display of additional graphical and alphanumerical information.
Acquired radar target	Automatic or manual acquisition initiates radar tracking. Vectors and past positions are displayed when data has achieved a steady state condition.
AIS	Automatic Identification System.
AIS target	A target generated from an AIS message. See activated target, lost target, selected target and sleeping target.
Associated target	If an acquired radar target and an AIS reported target have similar parameters (e.g. position, course, speed) complying with an association algorithm, they are considered to be the same target and become an associated target.
Acquisition/activation zone	A zone set up by the operator in which the system should automatically acquire radar targets and activate reported AIS targets when entering the zone.
CCRP	Consistent Common Reference Point: A location on own ship, to which all horizontal measurements such as target range, bearing, relative course, relative speed, closest point of approach (CPA) or time to closest point of approach (TCPA) are referenced, typically the conning position of the bridge.
CPA/TCPA	Closest Point of Approach / Time to the Closest Point of Approach: Distance to the closest point of approach (CPA) and time to the closest point of approach (TCPA). Limits are set by the operator related to own ship.

Course Over Ground (COG)	Direction of the ship's movement relative to the earth, measured on board the ship, expressed in angular units from true north.
Course Through Water (CTW)	Direction of the ship's movement through the water, defined by the angle between the meridian through its position and the direction of the ship's movement through the water, expressed in angular units from true north.
Dangerous target	A target whose predicted CPA and TCPA are violating the values as preset by the operator. The respective target is marked by a dangerous target symbol.
Display modes	**Relative motion:** means a display on which the position of own ship remains fixed, and all targets move relative to own ship. **True motion:** a display across which own ship moves with its own true motion.
Display orientation	**North up display:** an azimuth stabilized presentation which uses the gyro input (or equivalent) and north is uppermost on the presentation. **Course up display:** an azimuth stabilized presentation which uses the gyro input or equivalent and the ship's course is uppermost on the presentation at the time of selection. **Head up display:** an unstabilized presentation in which own ship's heading is uppermost on the presentation.
ECDIS	Electronic Chart Display and Information System.
ECDIS Display Base	The level of information which cannot be removed from the ECDIS display, consisting of information which is required at all times in all geographic areas and all circumstances. It is not intended to be sufficient for safe navigation.
ECDIS Standard Display	The level of information that should be shown when a chart is first displayed on ECDIS. The level of the information it provides for route planning or route monitoring may be modified by the mariner according to the mariner's needs.

ENC	Electronic Navigational Chart. The database standardized as to content, structure and format according to relevant IHO standards and issued by, or on the authority of, a Government.
EPFS	Electronic Position Fixing System.
ERBL	Electronic bearing line carrying a marker, which is combined with the range marker, used to measure range and bearing from own ship or between two objects.
Evaporation duct	A low-lying duct (a change in air density) that traps the radar energy so that it propagates close to the sea surface. Ducting may enhance or reduce radar target detection ranges.
Heading	Direction in which the bow of a ship is pointing expressed as an angular displacement from north.
HSC	High-speed craft (HSC) are vessels which comply with the definition in SOLAS for high speed craft.
Latency	The delay between actual and presented data.
Lost AIS target	A target representing the last valid position of an AIS target before the reception of its data was lost. The target is displayed by a lost AIS target symbol.
Lost tracked target	Target information is no longer available due to poor, lost or obscured signals. The target is displayed by a lost tracked radar target symbol.
Maps/Nav lines	Operator defined or created lines to indicate channels, Traffic Separation Schemes or borders of any area important for navigation.
Operational display area	Area of the display used to graphically present chart and radar information, excluding the user dialogue area. On the chart display this is the area of the chart presentation. On the radar display this is the area encompassing the radar image.
Past positions	Equally time-spaced past position marks of a tracked or reported target and own ship. The past positions. track may be either relative or true.

Radar (**Ra**dio **d**irection **a**nd **r**anging)	A radio system that allows the determination of distance and direction of reflecting objects and of transmitting devices.
Radar beacon	A navigation aid which responds to the radar transmission by generating a radar signal to identify its position and identity.
Radar detection false alarm	The probability of a radar false alarm represents the probability that noise will cross the detection threshold and be called a target when only noise is present.
Radar target	Any object fixed or moving whose position and motion is determined by successive radar measurements of range and bearing.
Radar target enhancer	An electronic radar reflector, the output of which is an amplified version of the received radar pulse without any form of processing except limiting.
Reference target	Symbol indicating that the associated tracked stationary target (e.g. a navigational mark) is used as a speed reference for the ground stabilization.
Relative bearing	Direction of a target's position from own ship's reference location expressed as an angular displacement from own ship's heading.
Relative course	Direction of motion of a target relative to own ship's direction. (Bearing).
Relative motion	Combination of relative course and relative speed.
Relative speed	Speed of a target relative to own ship's speed data.
Rate of turn	Change of heading per time unit.
SART	Search And Rescue Transponder.
SDME	Speed and Distance Measuring Equipment.
Selected target	A manually selected target for the display of detailed alphanumeric information in a separate data display area. The target is displayed by a selected target symbol.
Sleeping AIS target	A target indicating the presence and orientation of a vessel equipped with AIS in a certain location. The target is displayed by a sleeping target. symbol. No additional information is presented until activated.

Stabilization modes	**Ground stabilization:** Display mode in which speed and course information are referred to the ground, using ground track input data, or EPFS as reference. **Sea stabilization:** Display mode in which speed and course information are referred to the sea, using gyro or equivalent and water speed log input as reference.
Standard display	The level of information that should be shown when a chart is first displayed on ECDIS. The level of the information it provides for route planning or route monitoring may be modified by the mariner according the mariner's needs.
Standard radar reflector	Reference reflector mounted 3.5 m above sea level with 10 m^2 effective reflecting area at X-Band.
Steady state tracking	Tracking a target, proceeding at steady motion: – after completion of the acquisition process, or – without a manoeuvre of target or own ship, or – without target swap or any disturbance.
Speed Over Ground (SOG)	Speed of the ship relative to the earth, measured on board of the ship.
Speed Through Water	Speed of the ship relative to the water surface.
SOLAS	International Convention for the Safety of Life at Sea.
Suppressed area	An area set up by the operator within which targets are not acquired.
Target swap	Situation in which the incoming radar data for a tracked target becomes incorrectly associated with another tracked target or a non-tracked radar echo.
Target's predicted motion	Prediction of a target's future course and speed based on linear extrapolation from its present motion as determined by past measurements of its range and bearing on the radar.
Target Tracking (TT)	Computer process of observing the sequential changes in the position of a radar target in

	order to establish its motion. Such a target is a Tracked Target.
Trails	Tracks displayed by the radar echoes of targets in the form of an afterglow. Trails may be true or relative.
Trial manoeuvre	Graphical simulation facility used to assist the operator to perform a proposed manoeuvre for navigation and collision avoidance purposes, by displaying the predicted future status of at least all acquired or activated targets as a result of own ship's simulated manoeuvres.
True bearing	Direction of a target from own ship's reference location or from another target's position expressed as an angular displacement from true north.
True course	Direction of motion relative to ground or to sea, of a target expressed as an angular displacement from north.
True motion	Combination of true course and true speed.
True speed	Speed of a target relative to ground, or to sea.
Vector modes	**True vector:** Vector representing the predicted true motion of a target, showing course and speed with reference to the ground. **Relative vector:** Predicted movement of a target relative to own ship's motion.
User configured presentation	A display presentation configured by the user for a specific task at hand. The presentation may include radar and/or chart information, in combination with other navigation or ship related data.
User dialogue area	Is an area of the display consisting of data fields and/or menus that is allocated to the interactive presentation and entry or selection of operational parameters, data and commands mainly in alphanumeric form.

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ANNEX 3

SEAFARERS' TRAINING, CERTIFICATION, AND WATCHKEEPING CODE, AS AMENDED

TABLE A-II/1 (Excerpts concerning radar and ARPA use)

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluation competences**
Use of radar and ARPA to maintain safety of navigation **Note:** Training and assessment in the use of ARPA is not required for those who serve exclusively on ships not fitted with ARPA. This limitation shall be reflected in the endorsement issued to the seafarer concerned	Radar navigation Knowledge of the fundamentals of radar and automatic radar plotting aids (ARPA) Ability to operate and to interpret and analyse information obtained from radar, including the following: Performance, including: **.1** factors affecting performance and accuracy **.2** setting up and maintaining displays **.3** detection of misrepresentation of information, false echoes, sea return, etc., racons and SARTs Use, including: **.1** range and bearing; course and speed of other ships; time and distance of closest approach of crossing, meeting overtaking ships **.2** identification of critical echoes; detecting course and speed changes of other ships; effect of changes in own ship's course or speed or both **.3** application of the International Regulations for Preventing Collisions at Sea, 1972, as amended **.4** plotting techniques and relative- and true-motion concepts **.5** parallel indexing	Assessment of evidence obtained from approved radar simulator and ARPA simulator plus in-service experience	Information obtained from radar and ARPA is correctly interpreted and analysed, taking into account the limitations of the equipment and prevailing circumstances and conditions Action taken to avoid a close encounter or collision with other vessels is in accordance with the International Regulations for Preventing Collisions at Sea, 1972, as amended Decisions to amend course and/or speed are both timely and in accordance with accepted navigation practice Adjustments made to the ship's course and speed maintain safety of navigation Communication is clear, concise and acknowledged at all times in a seamanlike manner Manoeuvring signals are made at the appropriate time and are in accordance with the International Regulations for Preventing Collisions at Sea, 1972, as amended

Column 1 **Competence**	Column 2 **Knowledge, understanding and proficiency**	Column 3 **Methods for demonstrating competence**	Column 4 **Criteria for evaluation competences**
Use of radar and ARPA to maintain safety of navigation (icontinued)	Principal types of ARPA, their display characteristics, performance standards and the dangers of over-reliance on ARPA Ability to operate and to interpret and analyse information obtained from ARPA, including: **.1** system performance and accuracy, tracking capabilities and limitations, and processing delays **.2** use of operational warnings and system tests **.3** methods of target acquisition and their limitations **.4** true and relative vectors, graphic representation of target information and danger areas **.5** deriving and analysing information, critical echoes, exclusion areas and trial manoeuvres		

Section B-I/12

Guidance regarding the use if simulators

1 When simulators are being used for training or assessment of competency, the following guidelines should be taken into consideration in conducting any such training or assessment.

Training and assessment in radar observation and plotting*

2 Training and assessment in radar observation and plotting should:

.1 incorporate the use of radar simulation equipment; and

.2 conform to standards not inferior to those given in paragraphs 3 to 17 below.

3 Demonstrations of and practice in radar observation should be undertaken where appropriate on live marine radar equipment, including the use of simulators. Plotting exercises should preferably be undertaken in real time, in order to increase trainees' awareness of the hazards of the improper use of radar data and improve their plotting techniques to a standard of radar plotting commensurate with that necessary for the safe execution of collision-avoidance manoeuvring under actual seagoing conditions.

General

Factors affecting performance and accuracy

4 An elementary understanding should be attained of the principles of radar, together with a full practical knowledge of

.1 range and bearing measurement, characteristics of the radar set which determine the quality of the radar display, radar antennae, polar diagrams, the effects of power radiated in directions outside the main beam, a nontechnical description of the radar system, including variations in the features encountered in different types of radar set, performance monitors and equipment factors which affect maximum and minimum detection ranges and accuracy of information;

.2 the current marine radar performance specification adopted by the Organization**;

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*The relevant IMO Model Course(s) may be of assistance in the preparation of the courses.
**See relevant/appropriate performance standards adopted by the Organization.

.3 the effects of the siting of the radar antenna, shadow sectors and arcs of reduced sensitivity, false echoes, effects of antenna height on detection ranges and of siting radar units and storing spares near magnetic compasses, including magnetic safe distances; and

.4 radiation hazards and safety precautions to be taken in the vicinity of antenna and open waveguides.

Detection of misrepresentation of information, including false echoes and sea returns

5 A knowledge of the limitations to target detection is essential, to enable the observer to estimate the dangers of failure to detect targets. The following factors should be emphasized:

.1 performance standard of the equipment;

.2 brilliance, gain and video processor control settings;

.3 radar horizon;

.4 size, shape, aspect and composition of targets;

.5 effects of the motion of the ship in a seaway;

.6 propagation conditions;

.7 meteorological conditions; sea clutter and rain clutter;

.8 anti-clutter control settings;

.9 shadow sectors; and

.10 radar-to-radar interference.

6 A knowledge should be attained of factors which might lead to faulty interpretation, including false echoes, effects of nearby pylons and large structures, effects of power lines crossing rivers and estuaries, echoes from distant targets occurring on second or later traces.

7 A knowledge should be attained of aids to interpretation, including corner reflectors and radar beacons; detection and recognition of land targets; the effects of topographical features; effects of pulse length and beamwidth; radar-conspicuous and -inconspicuous targets; factors which affect the echo strength from targets.

Practice

Setting up and maintaining displays

8 A knowledge should be attained of:

.1 the various types of radar display mode; unstabilized ship's-head-up relative motion; ship's-head-up, course-up and north-up stabilized relative motion and true motion;

.2 the effects of errors on the accuracy of information displayed; effects of transmitting compass errors on stabilized and true motion displays; effects of transmitting log errors on a true motion display; and the effects of inaccurate manual speed settings on a true motion display;

.3 methods of detecting inaccurate speed settings on true motion controls; the effects of receiver noise limiting ability to display weak echo returns, and the effects of saturation by receiver noise, etc.; the adjustment of operational controls; criteria which indicate optimum points of adjustment; the importance of proper adjustment sequence, and the effects of maladjusted controls; the detection of maladjustments and corrections of:

.3.1 controls affecting detection ranges, and

.3.2 controls affecting accuracy;

.4 the dangers of using radar equipment with maladjusted controls; and

.5 the need for frequent regular checking of performance, and the relationship of the performance indicator to the range performance of the radar set.

Range and bearing

9 A knowledge should be attained of

.1 the methods of measuring ranges; fixed range markers and variable range markers;

.2 the accuracy of each method and the relative accuracy of the different methods;

.3 how range data are displayed; ranges at stated intervals, digital counter and graduated scale;

.4 the methods of measuring bearings; rotatable cursor on transparent discovering the display, electronic bearing cursor and other methods;

.5 bearing accuracy and inaccuracies caused by: parallax, heading marker displacement, centre maladjustment;

.6 how bearing data are displayed; graduated scale and digital counter; and

.7 the need for regular checking of the accuracy of ranges and bearings, methods of checking for inaccuracies and correcting or allowing for inaccuracies.

Plotting techniques and relative motion concepts

10 Practice should be provided in manual plotting techniques, including the use of reflection plotters, with the objective of establishing a thorough understanding of the interrelated motion between own ship and other ships, including the effects of manoeuvring to avoid collision. At the preliminary stages of this training, simple plotting exercises should be designed to establish a sound appreciation of plotting geometry and relative motion concepts. The degree of complexity of exercises should increase throughout the training course until the trainee has mastered all aspects of the subject. Competence can best be enhanced by exposing the trainee to real-time exercises performed on a simulator or using other effective means.

Identification of critical echoes

11 A thorough understanding should be attained of

.1 position fixing by radar from land targets and sea marks;

.2 the accuracy of position fixing by ranges and by bearings;

.3 the importance of cross-checking the accuracy of radar against other navigational aids; and

.4 the value of recording ranges and bearings at frequent, regular intervals when using radar as an aid to collision avoidance.

Course and speed of other ships

12 A thorough understanding should be attained of

.1 the different methods by which course and speed of other ships can be obtained from recorded ranges and bearings, including:

.1.1 the unstabilized relative plot,

.1.2 the stabilized relative plot; and

.1.3 the true plot; and

.2 the relationship between visual and radar observations, including detail and the accuracy of estimates of course and speed of other ships, and the detection of changes in movements of other ships.

Time and distance of closest approach of crossing, meeting or overtaking ships

13 A thorough understanding should be attained of

.1 the use of recorded data to obtain:

.1.1 measurement of closest approach distance and bearing, and

.1.2 time to closest approach, and

.2 the importance of frequent, regular observations.

Detecting course and speed changes of other ships

14 A thorough understanding should be attained of:

.1 the effects of changes of course and/or speed by other ships on their tracks across the display;

.2 the delay between change of course or speed and detection of that change; and

.3 the hazards of small changes as compared with substantial changes of course or speed in relation to rate and accuracy of detection.

Effects of changes in own ship's course or speed or both

15 A thorough understanding of the effects on a relative motion display of own ship's movements, and the effects of other ships' movements and the advantages of compass stabilization of a relative display.

16 In respect of true motion displays, a thorough understanding should be attained of

.1 the effects of inaccuracies of:

.1.1 speed and course settings, and

.1.2 compass stabilization data driving a stabilized relative motion display;

.2 the effects of changes in course or speed or both by own ship on tracks of other ships on the display; and

.3 the relationship of speed to frequency of observations.

Application of the International Regulations for Preventing Collisions at Sea

17 A thorough understanding should be attained of the relationship of the International Regulations for Preventing Collisions at Sea to the use of radar, including:

.1 action to avoid collision, dangers of assumptions made on inadequate information and the hazards of small alterations of course or speed;

.2 the advantages of safe speed when using radar to avoid collision;

.3 the relationship of speed to closest approach distance and time and to the manoeuvring characteristics of various types of ships;

.4 the importance of radar observation reports and radar reporting procedures being well defined;

.5 the use of radar in clear weather, to obtain an appreciation of its capabilities and limitations, compare radar and visual observations and obtain an assessment of the relative accuracy of information;

.6 the need for early use of radar in clear weather at night and when there are indications that visibility may deteriorate;

.7 comparison of features displayed by radar with charted features; and

.8 comparison of the effects of differences between range scales.

Training and assessment in the operational use of Automatic Radar Plotting Aids (ARPA)

18 Training and assessment in the operational use of automatic radar plotting aids (ARPA) should:

.1 require prior completion of the training in radar observation and plotting or combine that training with the training given in paragraphs 19 to 35 below*,

.2 incorporate the use of ARPA simulation equipment; and

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*The relevant IMO Model Course(s) and resolution MSC.64(67), as amended, may be of assistance in the preparation of courses.

.3 conform to standards not inferior to those given in paragraphs 19 to 35 below.

19 Where ARPA training is provided as part of the general training under the 1978 STCW Convention, masters, chief mates and officers in charge of a navigational watch should understand the factors involved in decision-making based on the information supplied by ARPA in association with other navigational data inputs, having a similar appreciation of the operational aspects and of system errors of modern electronic navigational systems, including ECDIS. This training should be progressive in nature, commensurate with the responsibilities of the individual and the certificates issued by Parties under the 1978 STCW Convention.

Theory and demonstration

Possible risks of over-reliance on ARPA

20 Appreciation that ARPA is only a navigational aid and:

.1 that its limitations, including those of its sensors, make over-reliance on ARPA dangerous, in particular for keeping a look-out; and

.2 the need to observe at all times the Principles to be observed in keeping a navigational watch and the Guidance on keeping a navigational watch.

Principal types of ARPA systems and their display characteristics

21 Knowledge of the principal types of ARPA systems in use; their various display characteristics and an understanding of when to use ground or sea stabilized modes and north-up, course-up or head-up presentations.

IMO performance standards for ARPA

22 An appreciation of the IMO performance standards for ARPA, in particular the standards relating to accuracy*.

Factors affecting system performance and accuracy

23 Knowledge of ARPA sensor input performance parameters - radar, compass and speed inputs and the effects of sensor malfunction on the accuracy of ARPA data.

24 Knowledge of:

*See relevant/appropriate performance standards adopted by the Organization.

.1 the effects of the limitations of radar range and bearing discrimination and accuracy and the limitations of compass and speed input accuracies on the accuracy of ARPA data; and

.2 factors which influence vector accuracy.

Tracking capabilities and limitations

25 Knowledge of:

.1 the criteria for the selection of targets by automatic acquisition;

.2 the factors leading to the correct choice of targets for manual acquisition;

.3 the effects on tracking of "lost" targets and target fading;

.4 the circumstances causing "target swap" and its effects on displayed data.

Processing delays

26 Knowledge of the delays inherent in the display of processed ARPA information, particularly on acquisition and re-acquisition or when a tracked target manoeuvres.

Operational warnings, their benefits and limitations

27 Appreciation of the uses, benefits and limitations of ARPA operational warnings and their correct setting, where applicable, to avoid spurious interference.

System operational tests

28 Knowledge of:

.1 methods of testing for malfunctions of ARPA systems, including functional self-testing; and

.2 precautions to be taken after a malfunction occurs.

Manual and automatic acquisition of targets and their respective limitations

29 Knowledge of the limits imposed on both types of acquisition in multi-target scenarios, and the effects on acquisition of target fading and target swap.

True and relative vectors and typical graphic representation of target information and danger areas

30 Thorough knowledge of true and relative vectors; derivation of targets' true courses and speeds including:

.1 threat assessment, derivation of predicted closest point of approach and predicted time to closest point of approach from forward extrapolation of vectors, the use of graphic representation of danger areas;

.2 the effects of alterations of course and/or speed of own ship and/or targets on predicted closest point of approach and predicted time to closest point of approach and danger areas;

.3 the effects of incorrect vectors and danger areas; and

.4 the benefit of switching between true and relative vectors.

Information on past positions of targets being tracked

31 Knowledge of the derivation of past positions of targets being tracked, recognition of historic data as a means of indicating recent manoeuvring of targets and as a method of checking the validity of the ARPA's tracking.

Practice

Setting up and maintaining displays

31 Ability to demonstrate:

.1 the correct starting procedure to obtain the optimum display of ARPA information;

.2 the selection of display presentation; stabilized relative motion displays and true motion displays;

.3 the correct adjustment of all variable radar display controls for optimum display of data;

.4 the selection, as appropriate, of required speed input to ARPA;

.5 the selection of ARPA plotting controls, manual/automatic acquisition, vector/graphic display of data;

.6 the selection of the time scale of vectors/graphics;

.7 the use of exclusion areas when automatic acquisition is employed by ARPA; and

.8 performance checks of radar, compass, speed input sensors and ARPA.

System operational tests

33 Ability to perform system checks and determine data accuracy of ARPA, including the trial manoeuvre facility, by checking against basic radar plot.

Obtaining information from the ARPA display

34 Demonstrate the ability to obtain information in both relative- and true-motion modes of display, including:

.1 the identification of critical echoes;

.2 the speed and direction of target's relative movement;

.3 the time to, and predicted range at, target's closest point of approach;

.4 the courses and speeds of targets;

.5 detecting course and speed changes of targets and the limitations of such information;

.6 the effect of changes in own ship's course or speed or both; and

.7 the operation of the trial manoeuvre facility.

Application of the International Regulations for Preventing Collisions at Sea, 1972, as amended

35 Analysis of potential collision situations from displayed information, determination and execution of action to avoid close-quarters situations in accordance with the International Regulations for Preventing Collisions at Sea, 1972, as amended, in force.