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Simulation Environment in Python for Ship Encounter Situations

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ABSTRACT: To assess the risk of collision in radar navigation distance-based safety measures such as Distance at the Closest Point of Approach and Time to the Closest Point of Approach are most commonly used. Also Bow Crossing Range and Bow Crossing Time measures are good complement to the picture of the meeting situation. When ship safety domain is considered then Degree of Domain Violation and Time to Domain Violation can be applied. This manuscript provides a description of a ship encounter simulation software tool written in Python accompanied by a case study, implementing all the measures mentioned above. It offers a radar-like Graphical User Interface (GUI), is able to track AIS-based traffic or encounter scenarios stored in local files. The tool features several additional functions e.g. Variable Range Marker (VRM) or Electronic Bearing Line (EBL). The simulator might be a test sandbox for advanced collision avoidance algorithms.

1 INTRODUCTION

Safe operation of both traditional manned ships and unmanned or autonomous vessels cannot exist without appropriate collision avoidance systems based on reliable safety indicators staying in line with IMO's COLREGs rules [1]. To be sure whether a proposed solution is valuable for the aforementioned collision avoidance system, first it is necessary to determine their suitability for currently operated manned ships. For this purpose, it is important to design a navigation support tool capable of mapping the encounter situation, calculating the proposed safety indicators in the context of a given collision avoidance situation and presenting the result that can be interpreted by the navigator.

When safety indicators in ship encounters are considered, the most obvious choice are Distance at the Closest Point of Approach (DCPA) and Time to the Closest Point of Approach (TCPA). They both are implemented in variety of on-board hardware and software tools. Sometimes they can be supplemented by Bow Crossing Range (BCR) or Bow Crossing Time (BCT). But if one is about to apply some more sophisticated indicators or metrics like e.g. domain-based Degree of Domain Violation (DDV) [2], a problem appears that virtually no tool is available implementing this indicator. Thus, a necessity arose to build such a ship traffic monitoring and simulation tool, having access to AIS data stream and implementing selected safety measures. The tool would allow to monitor the encounter situation by utilizing these measures, thus resulting in improved situation awareness. That would also make possible to test some newly designed collision avoidance algorithms designed for traditional or unmanned (MASS) vessels. This paper documents exactly such a traffic simulation tool implemented in Python.

The manuscript is organized as follows. Section 2 presents basic information on AIS as a source of data of nearby traffic. Section 3 briefly recalls definitions of basic risk-related metrics applicable in ship encounter situations. Section 4 introduces the Python simulation tool including details on its initial assumptions, applied technologies, GUI design and key features. The section concludes with possible further development of the tool. A case study with exemplary encounter situation analysis with assistance of the tool is presented in Section 5. The final section concludes and summarizes the material presented.

2 AIS AS SOURCE OF INFORMATION ON NEARBY TRAFFIC

Ship situation awareness seems a crucial element of her safety when maritime traffic is considered. The situation awareness is especially important for autonomous vessels. Typically for such marine units, they can gather information on the other vessels in the vicinity based on their radar and ARPA displays. However, due to its analogue roots, radar/ARPA can suffer e.g. from the shadow effect and are able to cover a limited range around a ship. Thus, in practice the most common way of building the situation awareness for autonomous vessels is by utilization of Automatic Identification System (AIS).

The AIS is a radio device enabling automatic:
- transmission to suitably equipped shore stations, other vessels and aircrafts: data identifying the ship and its type, and specifying its current position, course, speed, navigation status and transported dangerous goods, as well as short safety information,
- receipt of such information from similarly equipped vessels,
- position monitoring and vessel tracking,
- data exchange with devices ashore.

The AIS device can be installed:
- on ships,
- on the shore as a so-called base and relay device,
- at the centre of the Vessel Traffic Control Service (VTS),
- on Aids to Navigation (AtoN).

AIS devices are equipped with a Very High Frequency (VHF) receiver operating on:

- channel 70 using the Digital Selective Calling (DSC) technique,
- channel 87B or 88B using the Time Division Multiple Access (TDMA) technique.

AIS utilizes special technique to provide an algorithm that distributes transmit frames to individual time devices. The transmission time is divided into time frames. A single frame lasts one minute, and its beginning and end coincide with the beginning and end of the UTC minute.

All receivers must have the same reference time, because it is used to number the elementary frames in which these devices work. In the case of a non-uniform time pattern, there could be a different numbering of elementary frames, which would cause transmission conflicts, such as overlapping. This phenomenon can occur when receiving a weak signal transmitted by a device at a considerable distance. If the message transmitted by them is incomplete or there is a format distortion or data errors, its transmission is discriminated, i.e. the allocated elementary frame will be received and the entire transmission schedule ceases to exist. This frame, if necessary, is allocated to another AIS having a stronger signal. In order to eliminate the problems associated with the reception of weak or distorted signals from distant devices, messages transmitted by AIS at distances greater than 100 nautical miles are automatically discriminated.

Additionally, the following transmission access methods are distinguished:
- ITDMA - extended TDMA (Incremental Time Division Multiple Access) system,
- RATDMA - access to TDMA (Random Access Time Division Multiple Access),
- FATDMA – frequency multiple access (Fixed Access Time Division Multiple Access),
- SOTDMA - self-organizing time division multiple access.

Depending on the adopted method of access to transmission, the following AIS work methods are distinguished:
- autonomous also called continuous - transmitting at time intervals:
  - static - every 6 minutes and on request,
  - dynamic - at intervals depending on the situation,
  - regarding travel - every 6 minutes, on request and after each change of any data,
  - safety information - after entering and on request.
- assigned mode - the frequency and time moments of transmission of position reports are determined automatically by an authorized base device acting independently or via a so-called relay device (AIS transponder),
- pooling mode - the ship's AIS transmits the data upon receipt of an interrogation signal sent by the AIS of another vessel or aircraft or by the base unit.

As not all vessels operating at sea are subject to the SOLAS convention [3], the ship AIS equipment has been divided into two basic classes, namely:
- Class A, intended for sea-going ships, on which the device is required in accordance with the provisions of Regulation 19.2.4.1-3 "Carriage requirements for shipborne navigational systems and equipment", Chapter V of the 1974 SOLAS International Convention for the Safety of Life at Sea.
- Class B, intended for units on which the equipment does not have to be installed in accordance with the requirements of the SOLAS regulation (ships of less than 300 gross tonnage engaged on international voyages, ships of less than 500 gross tonnage not engaged on international voyages, and fishing vessels).

3 RISK-RELATED METRICS IN SHIP ENCOUNTER SITUATION

When situational awareness is achieved by means of available AIS data, then risk of possible collision or damage in an encounter situation can be estimated.

Usually, instead of a direct risk estimation, the navigator utilizes sets of accompanying distance and time metrics. Among them the most popular are Distance at the Closest Point of Approach (DCPA) together with Time to the Closest Point of Approach (TCPA). When bow distance is taken into account then one can apply Bow Crossing Range (BCR) and Bow Crossing Time (BCT). However, when ship safety domain is considered none of the above metric applies perfectly. In such situation one can utilize Degree of Domain Violation (DDV) and Time to Domain Violation (TDV). The following subsections briefly recall definitions for all of the abovementioned metrics.

3.1 *DCPA & TCPA*

The most popular approach parameters - DCPA and TCPA have long been present in every radar equipped with ARPA. To this day, they are an important component of risk assessment during seagoing encounters. The advantage is the simplicity of their determination, but at the cost of the lack of a perfect representation of the situation. To begin determining the formulas for DCPA & TCPA, it is assumed that calculations concerning the above mentioned are carried out in the Cartesian coordinate system. This has the following benefits [4]:

– simplicity of the equations of motion,
– reduction of circular and trigonometric functions that carry some accuracy errors.

Let's assume that the Cartesian coordinate system with its own ship in its centre is a movable plane tangent to the earth's surface. The objects in the area of interest will be plotted on the adopted system by means of a geographic projection made with the use of WGS-84, the result of which will be X coordinates for longitude and Y for latitude. Thus, let the vector of true velocity along the x axis be V_{tx} and along the y axis V_{ty}. Similarly with the relative velocity vector: V_{rx} for the x axis and V_{ry} for the y axis.

The relations between the own ship's motion parameters and the object's motion parameters are as follows [4]:

$$V_{Tx} = V_{rx} + V_x$$
$$V_{Ty} = V_{ry} + V_y$$
$$V_T = \sqrt{V_{Tx}^2 + V_{Ty}^2}$$
$$V_r = \sqrt{V_{rx}^2 + V_{ry}^2}$$

where V_x,V_y are own ship movement parameters,

$$V_x = V sin\psi$$
$$V_y = V cos\psi$$
$$V = \sqrt{V_x^2 + V_y^2}$$

where ψ is a course over ground of own ship.

It follows from the above:

$$V_{Tx} = V_{rx} + V sin\psi$$
$$V_{Ty} = V_{ry} + V cos\psi$$
$$V_{rx} = V_{Tx} - V sin\psi$$
$$V_{ry} = V_{Tx} - V cos\psi$$

Now, it is possible to apply the following formulas:

$$D_{CPA} = \left| \frac{XV_{ry} - YV_{rx}}{V_r} \right|$$
$$T_{CPA} = -\frac{XV_{rx} + YV_{ry}}{V_r^2}$$

3.2 *BCR & BCT*

Early 1980s saw the implementation of the BCR & BCT ship to ship collision risk indicators in radar systems. BCR stands for Bow Crossing Range and is understood as the distance at which one ship crosses ahead of another's bow (or astern, if negative) [5]. BCT, in turn stands for Bow Crossing Time and is the time when BCR occurs.

Even though BCR & BCT pair is listed as a safety indicator that should be used and appropriately interpreted by the OOW (Officer On the Watch), in the official, required IMO's Model Course on Radar Navigation at Operational Level it is only a feature of INS (Integrated Navigation Systems) that is optional. Today navigators use it as a secondary indicator of the type of ship-ship encounter as a supplement to DCPA safety measure utilization. As shown in Fig 1, BCR & BCT are used to describe the distance (and time to reach it) between two ships when they are crossing one another.

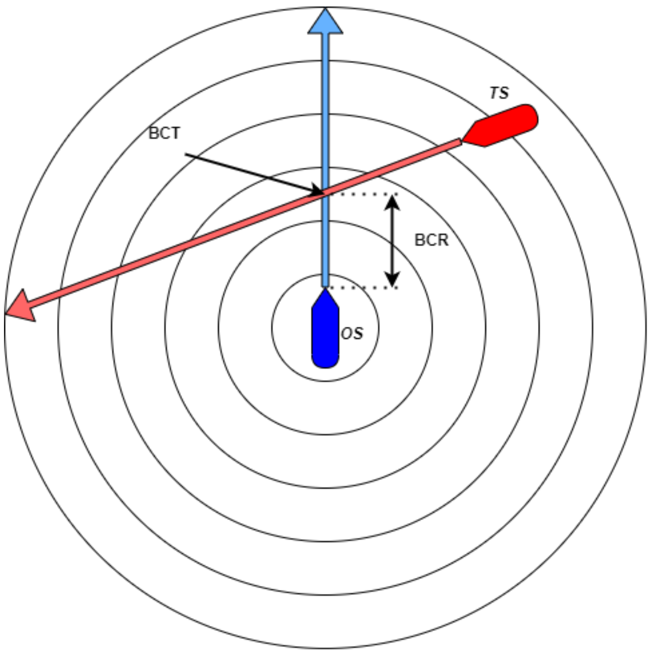

Figure 1 Visual representation of BCR & BCT

On the basis of the distance criterion, a meeting situation is recognized as an instance of BCR. Although the general recommendation is to take into account distances not less than 1 NM, the rigorous range of values, as in the case of DCPA, is not imposed. However, there is no strict literature concerning sustained conditions in encounter situations [6] and the scientific literature contains diverse values [7].

It is important to recognize that the crossing is a specific kind of encounter that occurs when one ship approaches another from the COLREG visibility sector (regardless if ahead or astern) of just one sidelight. Head-on encounters and overtaking are not regarded as instances of the Bow Crossing Range. Therefore, it becomes clear that BCR might be a useful measure when neither of the aforementioned statements is accurate. The BCR & BCT value (positive or negative) informs the navigator of the ship passing ahead or astern and their respective COLREG Rule 15 requirements [6].

For BCR & BCT all calculations are made in the two-dimensional space of Cartesian coordinates:

relative bearing to TS is assumed as

$$brg_{rel(OS)} = brg_{true(OS)} - hdg_{OS(t)}$$

where

$$brg_{true(OS)} = wrap\_angle\left(deegres\left(\arctan\left(\frac{Y}{X}\right)\right) - 180°\right)$$

where

$$X = X_{OS(t)} - X_{TS(t)}$$
$$Y = Y_{OS(t)} - Y_{TS(t)}$$

aspect is assumed as

$$aspect = \begin{cases} brg_{rel(TS)} - 360° & if \quad brg_{rel(TS)} > 180° \\ brg_{rel(TS)} & if \quad brg_{rel(TS)} \leq 180° \end{cases}$$

where

$$brg_{rel(TS)} = brg_{true(TS)} - hdg_{TS(t)}$$

where

$$brg_{true(TS)} = wrap\_angle\left(deegres\left(\arctan\left(\frac{Y}{X}\right)\right) - 180°\right)$$

where

$$X = X_{TS(t)} - X_{OS(t)}$$
$$Y = Y_{TS(t)} - Y_{OS(t)}$$

According to [6] BCR is understood as

$$BCR = nearest\_points\left(\left(X_{bow(OS)}, Y_{bow(OS)}\right), hull\left(TS\right)\right)$$

therefore

$$BCT = \frac{BCR_{TS\ perspective}}{TS_{SOG}}.$$

3.3 *DDV & TDV*

When distance-based ship safety domain [8] is considered, neither DCPA & TCPA nor BCR & BCT are able to provide apt and direct information on possible domain violation. Thus, in [2] Szlapczynski and Szlapczynska proposed a brand new pair of domain-based risk metrics, namely Degree of Domain Violation (DDV) and Time to Domain Violation (TDV). They provided there analytical formulae for DDV & TDV calculation for a standard Coldwell's elliptical domain. These metrics have been recently applied to near-miss analysis and Collision Alert System frameworks in [9].

In order to calculate values of DDV & TDV for configurable Coldwell's domain (with a, b, da and db parameters) it is assumed that the coordinate system is a two-dimensional Cartesian one with its own ship in its centre, as presented in Fig 2. Please note that the rotation angle α is calculated unlike in sea navigation i.e. counter clockwise from the X axis.

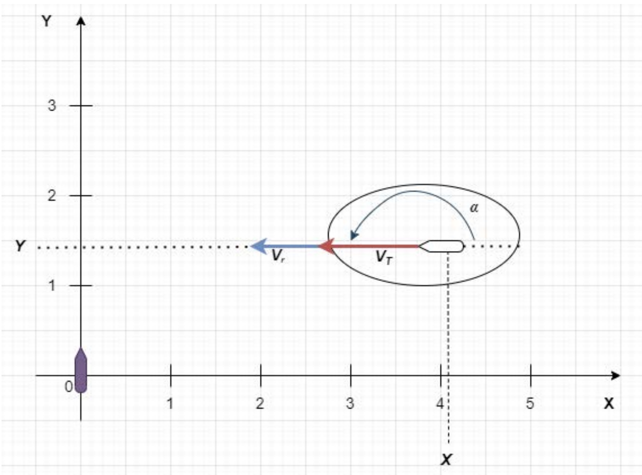

Figure 2 Assumptions for DDV & TDV: elliptical domain presented in Cartesian coordinate system with own ship in its centre

Therefore:
(X, Y) – relative position of a target,
(Xe, Ye) – relative position of the centre of an ellipse being the target's domain,
$Xe = X + h$
$h = \Delta a\cos\alpha + \Delta b\sin\alpha$
$Ye = Y + k$
$k = \Delta a\sin\alpha - \Delta b\cos\alpha$
(Vx, Vy) – components of the relative velocity of a target,
α – the rotation angle of the target's domain (being equal to course angle of the target), measured counter clockwise from X axis to the tip of a target's true speed vector

The elliptic domain moves with the relative speed of a target:

$$X_e(t) = X + hf + V_x t$$
$$Y_e(t) = Y + kf + V_y t$$

The parametric equation of a rotated ellipse with a centre in ($X_e(t)$, $Y_e(t)$) as a function of time is:

$$\frac{\left(X_e(t)cos\alpha + Y_e(t)sin\alpha\right)^2}{a^2} + \frac{\left(X_e(t)sin\alpha - Y_e(t)cos\alpha\right)^2}{b^2} = 1$$

The parametric equation of the f-scaled ellipse (with the same centre) as a function of time is:

$$\frac{\left(X_e(t)cos\alpha + Y_e(t)sin\alpha\right)^2}{f(t)^2 a^2} + \frac{\left(X_e(t)sin\alpha - Y_e(t)cos\alpha\right)^2}{f(t)^2 b^2} = 1$$

Solving the latter gives a formula for $f(t)$, as presented in:

$$f_{1,2}(t) = \frac{-\left(B_{21} + B_{22}t\right) \pm \sqrt{D_1 t^2 + E_1 t + F_1}}{2A_2}$$

where

$$A_2 = A_1 h^2 + B_1 hk + C_1 k^2 - 1$$
$$D_1 = B_{22}^2 - 4A_2 C_{23}$$
$$E_1 = 2B_{21}B_{22} - 4A_2 C_{22}$$
$$F_1 = B_{21}^2 - 4A_2 C_{21}$$

where

$$B_{21} = \left(2A_1 X + B_1 Y\right)h + \left(2C_1 Y + B_1 X\right)k$$

with

$$t_{min1,2} \frac{-E_2 \pm \sqrt{E_2^2 - 4D_2 F_2}}{2D_2},$$

where

$$D_2 = D_1\left(B_{22}^2 - D_1\right)$$
$$E_2 = E_1\left(B_{22}^2 - D_1\right)$$
$$F_2 = F_1 B_{22}^2 - E_1^2$$

where

$$B_{22} = \left(2A_1 V_x + B_1 V_y\right)h + \left(2C_1 V_y + B_1 V_x\right)k$$

whose $f(t)$ minimum over time t is the approach factor f_{min}. DDV is then obtained by substituting the f_{min} to DDV=max(1-f_{min},0). We assume that the following should be substituted:

$$A_1 = \frac{cos^2\alpha}{a^2} + \frac{sin^2\alpha}{b^2}$$
$$B_1 = 2sin\alpha cos\alpha\left(\frac{1}{a^2} - \frac{1}{b^2}\right)$$
$$C_1 = \frac{sin^2\alpha}{a^2} + \frac{cos^2\alpha}{b^2}$$

To determine TDV it is necessary to solve following equations:

$$t_1 = \min\left(\frac{-B_3 - \sqrt{B_3^2 - 4A_3C_3}}{2A_3}, \frac{-B_3 + \sqrt{B_3^2 - 4A_3C_3}}{2A_3}\right)$$
$$t_2 = \max\left(\frac{-B_3 - \sqrt{B_3^2 - 4A_3C_3}}{2A_3}, \frac{-B_3 + \sqrt{B_3^2 - 4A_3C_3}}{2A_3}\right)$$

assuming that:

$$A_3 = A_1 V_x^2 + B_1 V_x V_y + C_1 V_y^2$$
$$B_3 = 2\left(A_1 X_e V_e + C_1 Y_e V_e\right) + B_1\left(X_e V_y + Y_e V_x\right)$$
$$C_3 = A_1 X_e^2 + B_1 X_e Y_e + C_1 Y_e^2 - 1$$

where $t_1 < t_2$,
t_1 – the time remaining to entering the target's domain,
t_2 – the time remaining to leaving the target's domain.

According to [2] there are three possible cases here:
$t_1<0$ and $t_2<0$ says that a domain has already been entered and left,
$t_1\leq 0$ and $t_2\geq 0$ says that a domain has already been entered but not left,
$t_1>0$ and $t_2>0$ says that a domain will be violated in time t_1 and left in t_2.

4 PYTHON-BASED SHIP ENCOUNTER SIMULATION ENVIRONMENT

This section describes a simulation tool for ship encounters implemented using Python language. We have chosen Python as one of the most popular high level languages these days, offering a wide range of built-in functions and easily available open source modules or packages covering various applications. Moreover, the tool being described here has been a part of a wider software and hardware solution, built in the course of ENDURE project. Thus, a unified policy towards software implementation was an important factor here.

Obviously, there are numerous tools available, e.g. [11-17], offering similar ship traffic simulation or ship navigational decision support functionality. Some of the recent ones are also implemented in Python, the other are written in C/C++, MatLab or other high level languages. Majority of the solutions are not in the public domain nor have open source licence and even if they are open sourced, they have got a non-compatible functional range [11]. Thus, it was necessary to design and implement our own tool, fully customizable, offering the exact functionality that was required in the course of the ENDURE project.

The tool described here is able to monitor live encounter traffic situation AIS data. It is also possible to utilize offline situation data stored in a local file. Moreover, the tool implements the following risk-related measures: TCPA, DCPA, BCR, BCT, DDV and TDV, their values can be monitored throughout the encounter. The following subsections present initial assumptions of the tool, the applied technologies, GUI and key features of the tool and finally directions for further tool development.

4.1 *Initial assumptions*

The application was designed with utilization of Model-View-Controller design pattern. The model consists of the application operation logic that interacts with an external source of information (AIS, database). It includes functionality responsible for data management and processing. All data that will be presented to the user is contained here. The view consists of all interactive and non-interactive objects that will be displayed to the user. It is a set of features responsible for the visualization of data managed by the model. The controller is a set of features responsible for intermediation between the view and the model. This is where events are captured and carried out.

The application can be autonomous, provided that it receives AIS reports. In the case of this software, user intervention is not obligatory for the program to function. The role of the program operator can only be based on observing a self-updating decision support program. The program allows the user to customize the way information is displayed by changing the display, and to use additional tools to facilitate navigation.

All the presented algorithms assume that vessels are in sight of one another and no other special circumstances (e.g. restricted visibility) apply.

4.2 *Applied technologies*

The software was developed using Python version 3. The pygame graphic module was used which made graphic visualization possible, the module is a set of Python submodules designed for writing video games. The vast majority of the simulation tool was written from the scratch using pure Python. However, the need to use the following python modules turned out to be indispensable:
– pyais for encoding and decoding AIS message,
– pandas for data analysis and manipulation,
– numpy for arrays handling and linear algebra,
– pyproj for cartographic projections and coordinate transformations,
– geopy for calculation of geographic distances.

4.3 *GUI and key features of the application*

The software is a window application with a user interface operated by the mouse. The application interface was inspired by the interfaces of radar devices and ECDIS. The advantage of this solution is a relatively intuitive and easy-to-use interface for navigators.

Figure 3 shows an overview of the program's GUI. In the central part, on the azimuth dial, target vessels visible in a given range are displayed.

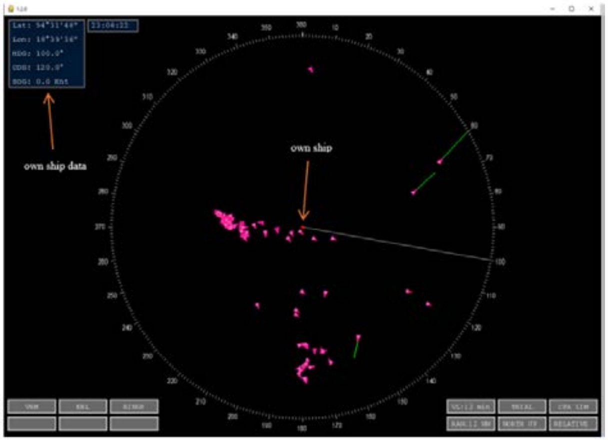

Figure 3. Overview of the program's GUI

The range and the orientation as well as motion mode are configurable parameters. The range can be set between 0.75 and 48 NM, motion mode parameter offers relative or true motion options, while the orientation can be north up or head up. By default, the range is set to 12 miles and displayed in relative motion north up as this is the IMO recommended setup for collision avoidance purposes.

As shown in Figure 4 it is possible to use in this tool Variable Range Markers (VRM) and Electronic Bearing Lines (EBL) simultaneously. They provide the ability to quickly measure bearing and distance to any visible object.

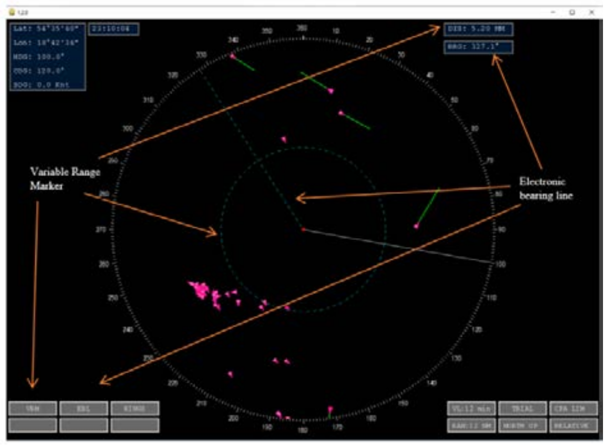

Figure 4. Usage of Variable Range Markers (VRM) and Electronic Bearing Lines (EBL)

Variable range marker is a navigational aid for the operator. After clicking the VRM button it displays a circle that allows to quickly measure the distance to an object without the need to take it for an acquisition. The electronic bearing line activated with the button indicated in the Figure 4 is another tool supporting the navigation process, which allows, similarly to VRM, without the need to acquire a target ship, to determine the bearing to any object.

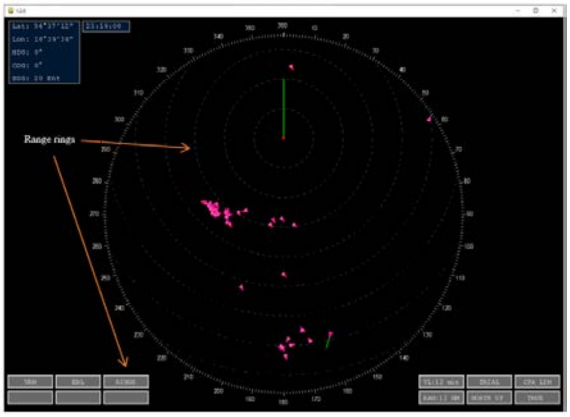

Figure 5. Range rings, true motion mode

Similarly to radars, the option of displaying distance circles has also been introduced. As presented in Figure 5, the range rings are drawn after pressing the RINGS button. The distance rings enable better orientation of the spatial position of objects, because they divide the range of the displayed area into six equal parts.

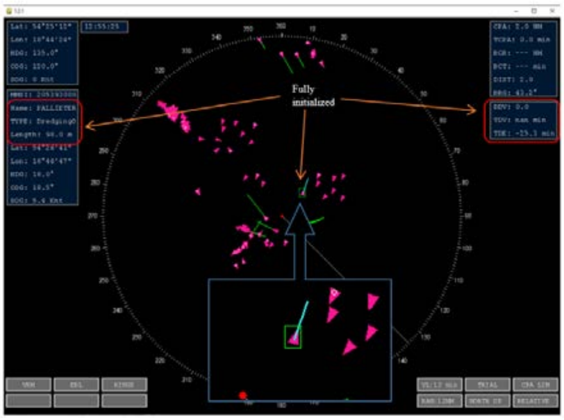

Figure 6. Acquisition of fully initialized target vessel

In this software, target ship acquisition is done differently from the ARPA equipped radar. Since the source of the data is AIS, and not the radar pulse as in the case of a radar, it is not necessary to wait a certain amount of time for the target echo to start being tracked. The information is available immediately after clicking the cursor on the desired triangle symbolizing the target ship. To be precise, it is almost available because, as described in section 2, the target ship data is transmitted in two separate reports. One relates to the dynamic information of the ship, the other to static information, transmitted less frequently. For this reason, ships that have not received a matching type 5 report containing static data will be referred to as not fully initialized and will be marked with a white circle in the centre of their triangle symbolizing the ship's abstract silhouette. Although the vessel is not fully initialized, indicators such as DCPA & TCPA and BCR & BCT are calculated. The difference between fully initialized ships and those without a static data report received is shown in the Figures 6 and 8.

For a fully initialized target, besides DCPA/TCPA & BCR/BCT, the software is possible to calculate DDV & TDV as this requires the length of the target ship, which can be calculated on the basis of the information contained in the type 4 report. Additionally, the CADCA (Collision Avoidance Dynamic Critical Area), presented in the Figure 7, can be drawn for a fully initialized vessel. CADCA [10] is a deterministically defined area that geometrically limits the manoeuvring area of the vessel for which it is designated. The CADCA shape and size depends on the movement parameters of the vessel such as rudder angle, initial forward speed, or planned alteration of the course. The main assumption of the CADCA concept is to support navigational decisions in collision situations. For a detailed description, please refer to the article [10].

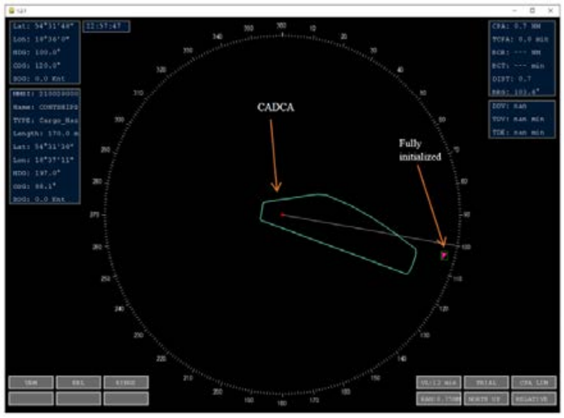

Figure 7. Collision Avoidance Dynamic Critical Area (CADCA)

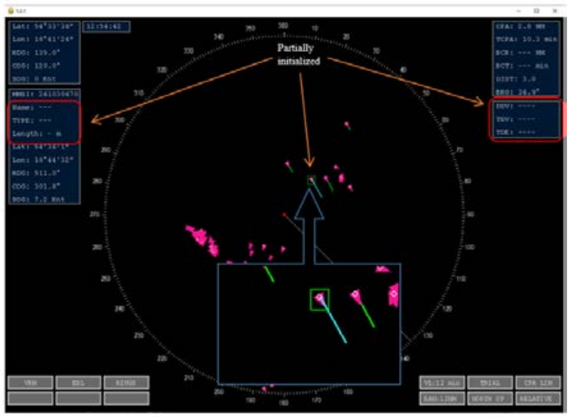

Figure 8. Acquisition of partially initialized target ship

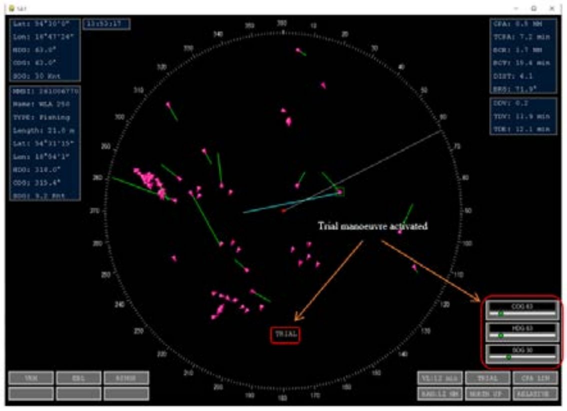

Figure 9. Trial manoeuvre

The situation in which a ship is taken for the acquisition that is not fully initialized (with a white circle on a triangle) is shown in the Figure 8. In this case, the calculations of the DDV & TDV safety indicators are omitted due to the lack of all data. In this situation, however, it is suggested to rely on DCPA & TCPA until report of type 4 is received and consequently the required safety indicators are calculated.

The tool offers the trial manoeuvre calculations for planning the collision avoidance manoeuvre. After clicking the TRIAL button, three controls appear to allow the user to change: course, heading and speed. The word TRIAL appears on the screen, which indicates that all changes to the parameters of the own ship's movements are carried out on a trial basis, without actually changing them. The functionality of the trial manoeuvre here consists in presenting the changes in the relative motion vectors of the target ship and the change in the value of safety indicators depending on the planned course, heading or speed change. The manoeuvre has no time delay, all planning is done live, the own vessel and target vessels continue to move during the planning process, according to the received AIS reports. Figure 9 shows an example of a trial manoeuvre. The own ship as well as the target ship moves at a given speed and heading. After the planned increase of the own ship's speed, the appearance of the vector of the relative speed of the target ship in relation to the own ship, in the form of a cyan line, symbolizing future positions in given moments of time, is observed.

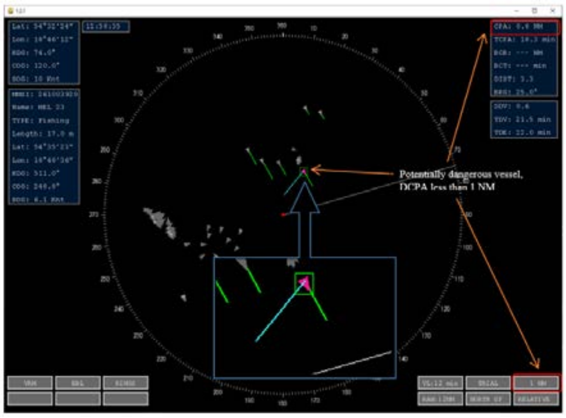

Figure 10. Filtering of target vessels based on DCPA value

The software features a function of filtering target ships due to their potential collision risk. The filter is based on the DCPA value - when this value drops below 1 NM, the target ship against which the DCPA is measured is considered as potentially dangerous. In the filtering mode, ships that do not pose a threat are marked in grey, while potentially dangerous ships appear in magenta as in the Figure 10. When filtering is disabled, all ships are treated as potentially dangerous and display magenta coloured by default.

When filtering is enabled, all ships that do not meet DCPA < 1NM are not considered as dangerous ships. However, it should be considered that the ships currently not posing a threat may pose a potential threat in the future - then the program would catch this and update the information displayed. The value of the filter is of course customizable.

4.4 *Possible further development of the tool*

Further possible application development includes implementation of the functionality enabling the visualization of electronic maps. This would allow the program to be used in difficult navigational areas without the risk of a collision with a stationary object. Considering the development of the maritime industry, it is possible to adapt the existing software functionality to the requirements of collision avoidance systems of unmanned ships. However, this is a topic for the long run.

An interesting aspect of the software is its open architecture. It allows the application to be used as a test environment enabling relatively simple implementation of, for example, experimental safety indicators. A potential prospect for the development of the application may also be the use of the current operating logic to create a proprietary functionality consisting in the analysis of the movement of ships using AIS. There are many possibilities, but the issue of their use in the era of rapid scientific and industrial development is a topic for a separate discussion. At present, the program may turn out to be useful as an experimental decision support system, which may be of interest to the scientific community, the maritime industry as well as enthusiasts of new technologies.

5 CASE STUDY – ANALYSIS OF A CROSSING ENCOUNTER BY THE SIMULATOR TOOL

This case study presents an encounter of crossing from the port side. According to COLREG Rule 15 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 [1]. The encounter situation, recorded in the Stavanger area of the North Sea is depicted in Figure 11. Duration of the entire recorded meeting is about 26 minutes. The encounter took place on November 7th, 2022 at 18:08 CET. The meeting parameters of the vessels involved in the considered situation are presented in Table 1. As for the ship domain Coldwell's one is assumed with parameters: a=0.794NM, b=0.397NM, da=0.198NM and db=0.099NM.

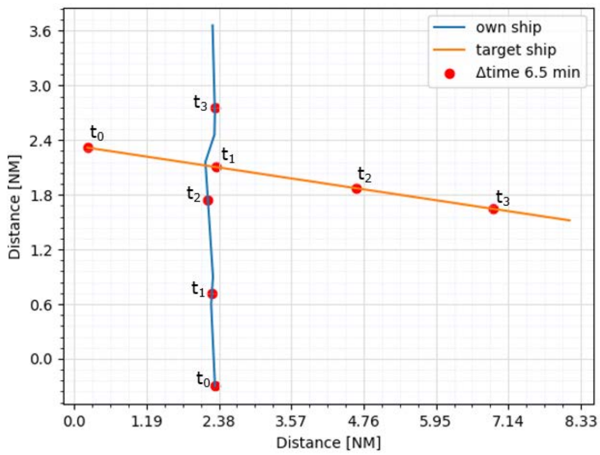

Figure 11. Case study – situation overview: crossing from starboard

According to the COLREGs, the give-way vessel is the target ship, while the stand-on vessel is the own ship. The situation requires that the target ship keeps clear of the own ship by making a clear course manoeuvre to starboard. However, no such course change took place in the first 6 minutes of encounter. Thereafter, minimal course changes are made, which contradicts the COLREG recommendation to use significant course changes. As shown in Figure 12, the DCPA(t) graph indicates that the vessels have kept a minimum distance of 0.5 NM from each other during entire meeting. The upward trend of DCPA indicates that the target vessel was performing a speed increase manoeuvre. The effect of this manoeuvre become clearly visible from about 14 minutes. In comparison with DCPA as the main predictor of collision risk, the confidence that the risk decreases was obtained after about 14 minutes - at this point the distance at the closest point of approach (DCPA) grows exponentially. Considering the graph of the BCR(t), shown in Figure 13, the target vessel crossed the course of the own vessel at a distance of 1.6 NM.

Table 1. Case study – parameters of the ships in meeting

	Own ship	Target ship
Name	m/t “Bit Power”	“Viking Prince”
Length	116.9 m	89.6 m
Beam	18.0 m	21.0 m
Initial coordinates	59° 3' 18'' N	59° 5' 55.0608'' N
	004° 10' 44.112'' E	004° 8' 37.1544'' E
Final coordinates	59° 7' 15.6036'' N	59° 5' 7.1736'' N
	004° 10' 41.7'' E	004° 16' 36.768'' E
Initial COG	358.0°	101.0°
Initial SOG	9.8 kn	11.5 kn

The conclusion resulting from the comparison of the two safety indicators so far is that used individually, they are a poor way to assess the risk of a collision. It can be safely said that using only BCR it is possible to determine only the type of meeting situation, and in a rather vague way. On the other hand, using only DCPA it is possible to ascertain only the effect of the situation. Combining these two indicators together, we get a more complete picture of the situation, including the type of encounter situation and the effect that will be achieved with the current movement parameters.

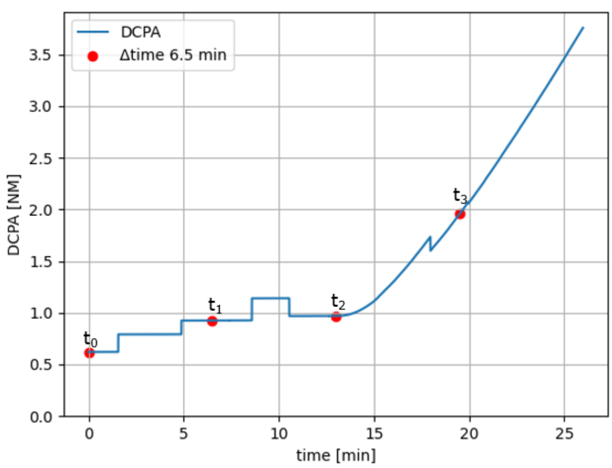

Figure 12. Case study – DCPA values during the encounter

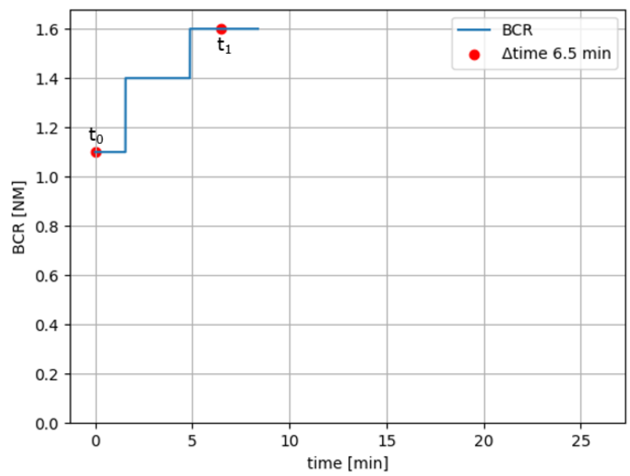

Figure 13. Case study – BCR values during the encounter

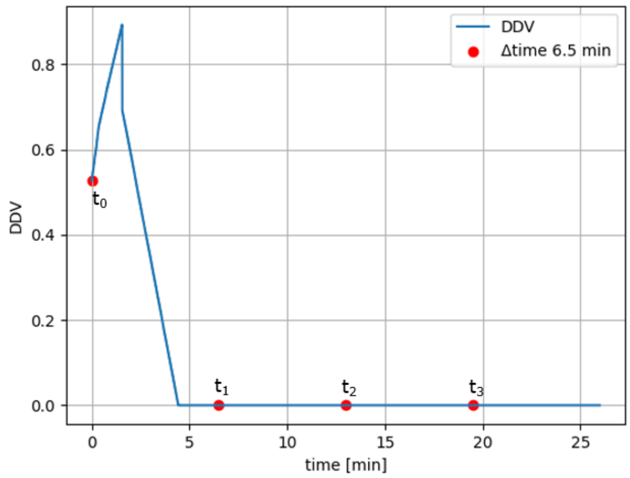

Figure 14. Case study – DDV values during the encounter

Slightly different tendency is presented by the DDV indicator, depicted in Figure 14. It is noticeable that DDV measure provides useful information in less time than the previously considered DCPA and BCR. It was also observed that this indicator was more sensitive to changes in the parameters of the ship's motion and its position. It is particularly visible in the time interval 0 - 2.5 minutes, where the shape of the curve indicates a sudden change in the nature of the situation and the successive decrease in the risk of collision (the Degree of Domain Violation decreases).

In this scenario in case of DCPA, the reliable collision risk assessment was possible after 12 minutes. In the case of BCR – it was possible after approximately 8 minutes. In this particular scenario based on DDV one is able to assess the collision risk in no more than 4.5 minutes. As depicted in Figure 14, there is an immediate suggestion (at the start of the recorded situation) of a DDV value of around 0.5, which shows a severe domain violation, moreover with upward trend of DDV values during first 2 min. of the encounter. After reaching the value of 0.9 in about 3 minutes of observation, the situation improves until reaching the value of DDV equal to 0, meaning no domain violation. Thus, one might conclude that relying on the DDV value alone in the risk assessment, the situation in this case was safely cleared up after approximately 4.5 minutes.

For the examined crossing case, for which the situation allowed the use of DCPA and BCR indicators for comparison purposes, it is clear that DDV proves its superiority. The DDV answers the question of whether there is a risk of collision not only in a binary way, but, when the risk does exist, provides also the risk magnitude.

However, the use of the DDV indicator is not without its drawbacks. Application effectiveness of metrics like DDV or BCR is indirectly limited by the use of AIS as its base source of data. One of the serious limitation here is the specification of the AIS itself. For example, the user is forced to wait for a static data report because the length of the target vessel is required for the DDV or BCR calculation. It is not uncommon that during a collision avoidance manoeuvre every minute saved might be crucial, thus waiting for an AIS report with static data in a critical situation may end up at best with a conflict with COLREG Rule 8. The conclusion is that any ship-length dependant indicator, as e.g. the DDV or BCR metrics, should be used with caution in real-time collision avoidance systems.

6 SUMMARY

The presented here ship encounter simulation and traffic monitoring tool offers features allowing for easy customization and making possible to test various collision avoidance solution within its graphical environment. It is worth noticing that the tool implements a number of safety indicators, namely DCPA, TCPA, BCR, BCT, DDV and TDV and is ready for implementation any new metric, if such necessity arise. As presented in the previous section, the tool has been validated on live AIS data stream and real ship encounter scenario. It is planned to continue development of the tool towards integration with the s-57 map and/or with the s-100 map. Also it seems promising to extend the tool in future by including weather forecast, hydrographic information and ship stability decision support.

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