Prediction and Simulation of Trajectories of Drifting Objects off the Coast of Portugal

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ABSTRACT: This work aims at developing a tool to predict and simulate the drift of objects at sea to support Search and Rescue operations and compare it with existing software. First, the Maritime Search and Rescue operations in Portuguese waters as well as the related National and International Legislation are presented. A summary of the formulations associated with basic drifting models is provided according to the type of floating object. Some examples of tools used nowadays for object location prediction at sea are introduced and explained. A tool is developed to predict and simulate the trajectory of objects due to the effect of wind and current and taking into account the uncertainties in the process using Monte Carlo Simulation. Four different scenarios are analyzed and compared with the predictions of the Opendrift software and with empirical formulations. The simulation results are in line with the ones obtained by the comparing tool, making a good statement for the developed tool reliability. A bivariate Gaussian Mixture Model is adopted for probabilistic modeling of object final locations calculated using the developed tool and by Monte Carlo Simulation. This probability model is then used to define the area corresponding to a 95% probability of object containment for every scenario. A comparison between different scenarios and between three different objects off the Coast of Portugal is carried out.

Keywords: Search and Rescue; Drifting Dynamics; Leeway; Monte Carlo Simulation; Trajectory Prediction of Drifting Objects; Probabilistic Modeling.

1 INTRODUCTION

Search and Rescue (SAR) is a lifesaving operation aiming to assist people in distress or imminent life-threatening situations. The SAR operations have three main issues to overtake (Kratzke et al., 2010): management and coordination required to put into action an operation in the shortest possible time; acquiring of reliable probability distribution maps of the object location; choice of pattern to use over the searching area defined according to the means available. These three branches of SAR operations need continuous study and optimization.

Injuries or casualties, environmental pollution and material losses are the main consequences when dealing with marine accidents like collisions, sinkings, groundings, explosions, etc (Guedes Soares and Teixeira, 2001);(Zhang et al., 2013). That is a risk inherent to the maritime transportation in general.

Many research works have been carried out to study the effects of meteorological conditions on particles and objects drifting at sea. The spreading of oil spills has been studied through a model that takes in consideration the most typical processes that the oil particles are involved in (Sebastião and Guedes Soares, 1995). Also, the uncertainty of the predictions of oil spills trajectories both in coastal areas (Sebastião and Guedes Soares, 2006) and in open sea (Sebastião and Guedes Soares, 2007) have been studied. However, the most important type of study for SAR is the drifting of physical objects at sea, especially those able to transport people. The computation and information system required to support and planning fast and efficient SAR operations have been defined (Vettor and Guedes Soares, 2015) with special detail on the Portuguese coasts. All the existing probabilistic computational models for predicting trajectories of drifting objects at sea are based on simple drifting mathematical expressions that take into consideration the vectors of wind and current. The wave effects can also be considered, but these are usually ignored because the Stokes\textsuperscript{1} drift is mostly downwind, and it is hard to separate them from the direct wind effects on a floating object. Wind and

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\textsuperscript{1} “The Stokes drift is a downwave drift induced by the orbital motion that water particles undergo under the influence of a wave field.” (Breivik and Allen, 2008)
surface currents are defined by Fitzgerald et al. (1993) as wind from the surface level up to 10 meters high and currents from 0.3 to 1.0 meters below the surface. These currents are mainly induced by the wind and not by deep water currents, unless the wind velocity has a low value.

Following the definition of Hodgins and Mak (1995), Leeway (L) is the drift of a floating object subject to wind forces alone. Any object drifting on the sea surface is in contact with two different density fluids: air and water. Each fluid exerts a force on the object, which depends on the object shape and dimensions. Both of those forces can be decomposed into drag and lift components. According to Richardson (1997) the drag and lift components of the wind result from the asymmetrical shape of the overwater body area. The drag component is aligned with the relative downwind direction, and the lift component is perpendicular to that direction. So, according to the shape of the object floating and its position, the lift will make the object move to one side or another in the crosswind direction. The hydrodynamic lift component will balance the aerodynamic one, avoiding the object to roll, according to Breivik and Allen (2008). In this study it is also proved by experimental data that the probability of the object drift right or left of the downwind direction is the same. In order to fully understand the drifting dynamics model, a closer look should be taken on Zhang et al. (2017).

To get a reliable list of drift objects to use in trajectory simulations, Allen and Plourde (1999) conducted several field experiments and came up with a ninety-five leeway targets list with three different coefficients in order to characterize each target. That list was then updated by Breivik et al. (2011) into a format of nine different coefficients initially introduced by Allen (2005).

A new trajectory prediction tool called Leeway was introduced and explained by Breivik (2008) and furtherly updated and extended into Opendrift software explained in detail by Dagestad et al. (2018).

Ni et al. (2010) developed a basic drifting formulation that was recently applied into a probabilistic model to predict the object's velocity and position at every moment by Zhang et al. (2017).

Taking in consideration the probability maps developed from trajectory prediction tools, it is then necessary to choose the right search pattern to use depending on the situation in hands (Zhang et al., 2016).

The objective of this work is to develop a simple drifting model to obtain the probability distribution maps of the location of floating objects using Monte Carlo Simulation (MCS), taking into account the uncertainties in the drifting process. The Opendrift software, is used for comparison purposes and to validate the developed tool, through the analysis of four different scenarios of drifting objects off the coast of Portugal.

A bivariate Gaussian Mixture Model (GMM) is adopted for probabilistic modeling of the object final locations calculated using the developed tool and by Monte Carlo Simulation. This probability model is then used to define the area corresponding to a 95% probability of object containment for every scenario.

The paper is organized as follows. An overview of the Maritime SAR operations in Portugal is presented in Chapter 2. Chapter 3 introduces available trajectory prediction formulations and tools and the main types of search patterns used nowadays. Chapter 4 explains the implementation of a developed basic drifting model and the results of its utilization are discussed in Chapter 5. Finally, conclusions are presented in Chapter 6.

2 SAR OPERATIONS AT SEA

Knowing shipping transports the largest slice of the world trade (AGCS, 2017) shows the importance of the shipping industry in global values. Although commercial ships are getting bigger and bigger to save costs, this alone is not enough to keep up with the demanding of shipping transportation of goods, meaning the number of ships circulating is increasing, and so should be the risk of accidents at sea. However, merchant ships are not the only vehicles at sea. There is a large number of passenger ships, service ships, fishing vessels, pleasure crafts, as well as some aircrafts needing search and rescue operations at sea.

Portuguese waters have a great density of traffic with most of ships travelling through the Traffic Separation Scheme (TSS), as shown by Silveira et al. (2013).

The number of accidents did not grow up overtime linearly with the number of crafts at sea since the means of avoiding those accidents are getting more efficient and a culture of safety is spreading. The time duration of SAR operations is decreasing with all the new technologies available nowadays as well as the legislation that makes each country responsible for the SAR operations in its respective ocean area, making the number of
casualties at sea decrease when compared with the number of accidents. According to the European Maritime Safety Agency report (EMSA, 2017), as shown in Figure 1, the main type of vessels needing SAR operations are the fishing ones, due to the average age of the ships when compared to the other types. Both fishing and cargo ships are the most common in the ocean, so it is logic that these are the two types requesting more SAR operations, as shown in Figure 1.

![Figure 1 - SAR Operations by type of vessel over the years, taken from EMSA (2017)](image)

After the 1979 International Convention on Maritime Search and Rescue (ICMSR) was adopted by the International Maritime Organization (IMO), the water was divided in Search and Rescue Regions (SRR) where each country is responsible for the SAR operations in the respective SRR’s. Every SAR operation at sea proceed according to the regulations imposed by IMO and by the International Civil Aviation Organization (ICAO), all written in the International Aeronautical and Maritime Search and Rescue (IAMSAR) manual. The Portuguese waters are divided in two SRR’s: Lisboa and Santa Maria. These two areas are controlled by the Maritime Rescue Coordination Centers (MRCC) of Lisboa and Delgada respectively. There is also a Maritime Rescue Coordination Sub-Center (MRSC) called MRSC Funchal that coordinates the operations around the Madeira archipelago, being this a sub-region from the Lisboa SRR. All three coordination centers are managed by the Portuguese Navy in the name of the National Defense Minister, being him the the national authority responsible for the ICMSR compliance. In order to get a higher rate of success in its mission, the Portuguese Navy gets help from other State departments such as the Instituto de Socorros a Naufragos (ISN) that have 31 estações salvaguardas (ESV) along the Portuguese coast divided in three different types according to the means available in each one.

3 TRAJECTORY PREDICTION OF DRIFTING OBJECTS

The trajectory prediction of drifting objects can be deciphered as the movement of a specified object according to its characteristics depending on the wind and current forces applied on the object during a certain time period. This chapter is divided in three sections: basic drifting model; object location prediction tools; and search patterns.

3.1 Basic drifting model

Considering a steady drift and according to Newton’s laws of motion, the sum of the forces acting on a body equals zero. For this reason, using the expression of forces applied by fluids, the drifting object motion can be represented by equation 1:

\[
\frac{1}{2} (C_o, A_1, \rho_1) |U_w - U_o| (U_w - U_o) = \frac{1}{2} (C_o, A_2, \rho_2) |U_w - U_c| (U_w - U_c)
\]

(1)

where, \(U_w\) is the wind velocity, \(U_o\) is the object velocity and \(U_c\) is the current velocity. \(C_o\) is the drag coefficient, \(A\) is the cross-sectional area exposed to the respective fluid and \(\rho\) is the fluid density. Both \(C_o\) and \(A\) variables are a characteristic of the type of object floating. The subscripts 1 and 2 represent the air and water fluids respectively.

Assuming equation 2:

\[
\frac{C_o, A_1, \rho_1}{C_o, A_2, \rho_2} \equiv \lambda^2
\]

(2)

The model can be simplified as shown in equation 3:

\[
\lambda \cdot (U_w - U_o) = U_o - U_c
\]

(3)

Then, the object velocity can be represented as function of \(U_w\) and \(U_c\) by equation 4:

\[
U_o = \frac{\lambda}{1 + \lambda} U_w + \frac{1}{1 + \lambda} U_c
\]

(4)

The leeway drift velocity \(U_L\), or as usually called speed through water (STW), can be obtained as a function of \(U_w\) and \(U_c\), as in the following equation 5:

\[
U_L = U_o - U_c = \frac{\lambda}{1 + \lambda} U_w - \frac{\lambda}{1 + \lambda} U_c
\]

(5)

Assuming now the concept of leeway rate, \(f\), expressed in equation 6, the leeway velocity and the velocity of the object assume the form presented in equations 7 and 8:
\[
\lambda \equiv f
\]  
\[
U_L = f \cdot (U_W - U_C)
\]  
\[
U_D = U_C + U_L = U_C + f \cdot (U_W - U_C)
\]  

The leeway velocity vector can be decomposed in two projections parallel and perpendicular to the wind velocity vector respectively: Downwind Leeway (DWL) and Crosswind Leeway (CWL). The two respective equations are equations 9 and 10:

\[
DWL = \left[ U_L, \frac{u_W}{|u_W|}, \frac{u_W}{|u_W|} \right] = \left[ f \cdot (U_W - U_C), \frac{u_W}{|u_W|}, \frac{u_W}{|u_W|} \right]
\]  
\[
CWL = U_L - DWL = f \cdot (U_W - U_C) - f \left| |U_W| - U_C \frac{u_W}{|u_W|} \right|\frac{u_W}{|u_W|} = -f \cdot U_C + f \left| \frac{u_W}{|u_W|} \right|
\]  

The leeway angle, \( \alpha \), is independent from the leeway rate, \( f \), and it can be shown in equation 11 as:

\[
\tan \alpha = \frac{|CWL|}{|DWL|} = \frac{|U_C + U_W|}{|U_W| - |U_C| \frac{u_W}{|u_W|}}
\]  

To maintain a convention already defined on previous works, the leeway angle is said to be positive when the object drifts to right side of the downwind direction and negative to the left.

### 3.2 Object location prediction tools

Several software tools have been developed and are currently used in SAR operations for object location prediction. The goal of a drifting simulation model software is to determine the searching area for a floating object on the ocean surface. The models run a large number of simulations, different from each other to represent the uncertainty on the model parameters. This type of software can help shortening the time to locate an object lost at sea and therefore, the number of human lives lost at sea every year.

The Opendrift is an open source program developed by Dagestad et al. (2018). The software itself is very generic, working as a base for many different applications in which each user can edit the scrips, being able to use it for the intended purpose. This is the software used to compare the results in order to validate the developed tool.

Another object location prediction tool is the Oversee. It was created by Critical Software and it is compliant with the IAMSAR guidelines and SAR best practice. It is used by the Portuguese MRCCs and it is very important for trajectory prediction, determination of the search area, choice of the search pattern and coordination of the means available.

### 3.3 Search Patterns

The main goal of the drift models is to determine the most probable area where the search will take place, depending on different unknowns that need to be quantified.

The probability of success (POS) of a SAR operation is what is intended to be maximized according to Breivik and Allen (2008) and it is defined as the product of the probability of detection (POD) and the probability of containment (POC) as shown in equation 12:

\[
POS = POD \times POC
\]  

The probability of containment is the probability of the missing object being inside the defined searching area. The probability of detection depends on the resources available for the search of the floating object, on the dimensions, shape and color of that object and on the procedure used to locate the drifting object.

Once the searching area is determined, it is necessary to plan a systematic search for the target. Numerous factors can influence the planning: meteorological conditions; life-saving vessel or aircraft speed; aircraft altitude; detectability range; dimensions of the missing object, time available for the search, among others. Therefore, the distance between the search and rescue unit (SRU) and the floating object is highly important.

The selection of the search pattern is very important to maximize the probability of detection in the shortest possible time window. There are three main groups of search patterns: parallel track search pattern; expanding square search pattern; and sector search pattern. All of them have advantages and disadvantages, so they may be used in different situations.

### 4 IMPLEMENTATION OF A BASIC DRIFTING MODEL

This chapter describes the implementation of a basic drifting model in a tool developed to obtain the probability distribution maps of the object using
MCS, taking in consideration the uncertainties in the process. The formulation described in Section 3.1 is the basis of all the calculations used by the tool considering a list of objects developed by Breivik et al. (2011) with nine different parameters each, in order to fully characterize the leeway of the object.

This tool is based in two distinct methodologies. In the first and more manual one, it is possible to define every variable mean and standard deviation values, based on normal distributions by hand, for a more personalized input range, and in the second one all variable uncertainties are integrated in the object leeway variables, as done by Opendrift. The second methodology is used to compare to the Opendrift software because it uses the same object associated uncertainties.

The developed tool inputs are the initial location of the object with a given uncertainty that depends on how the last known position (LKP) was determined, the time of simulation, the object type, and the wind and current velocity vectors. The object type given by the table of objects updated by Breivik et al. (2011), is decomposed in nine coefficients: slope, offset and standard deviation for downwind, right crosswind and left crosswind. The slope and offset values are used to determine the leeway vector and the standard deviation values introduce uncertainties to that leeway vector. The uncertainties introduced represent both the object coefficients determination uncertainties and the wind and current vectors uncertainties.

The developed tool output is a sample of 1000 trajectories and final locations of the object considered. The final locations of the object are then compared with the predictions from Opendrift.

Four different scenarios are studied in order to get a wider range of results and to validate the developed tool more consistently. In the first scenario an eight hours simulation is analyzed, being the object studied a person-in-water (PIW) in an unknown state and position. The wind velocity considered is 20kt with a direction of 165deg and the current velocity considered is 0.1kt with a direction of 30deg. All the directions mentioned have as reference the North direction as 0deg and grow in the clockwise direction. The LKP of the object was a few miles west of Cabo da Roca, which is the position used by the developed tool as the initial location of the object in the simulation.

The same input parameters were used for scenarios 2, 3 and 4, except for the object type. The initial position is somewhere defined between Porto and the Azores archipelago, the wind velocity vector is 13kt pointing in the 20deg direction and the current vector is 0.1kt in the 260deg direction. The simulation time in these three scenarios is forty hours long. For scenario 2, a sailboat mono-hull with fin keel and shallow draft is considered. For scenario 3, the object considered is a PIW in a survival suit and with the face up. For the fourth and last scenario, the object studied is a 4 to 14 people capacity life-raft with a deep ballast system, canopy, drogue and light loaded.

5 RESULTS AND ANALYSIS

For each scenario, plots of the objects’ trajectories, initial and final locations are also created using Opendrift. These results are then compared with the trajectories and the initial and final locations of the objects calculated using the tool developed. After the comparison, the sample of the final locations of the object is used to define a bivariate GMM in order to obtain the closed curve that represents the 95% probability area. This area is then compared to the area defined by an empirical method proposed in the Australian SAR Manual (Australian National Search Rescue Council, 2018).

In the present paper the results of scenario 2 are presented in detail, as well as a comparison analysis between the different object types of scenarios 2, 3 and 4.

Figure 2 represents the initial location points in green, trajectory lines in grey and final object locations in blue, obtained by the Opendrift simulation for scenario 2.

Figure 3 and Figure 4 show the same type of results but now obtained using the tool developed. The first one represents the trajectories of 255 of
the 1000 particles and the second one represents the initial and final locations of all the 1000 particles obtained by MCS.

Figure 3 - 255 trajectories simulated using the developed tool for scenario 2

Figure 4 - Initial and final object locations of 1000 simulations using the developed tool for scenario 2

The sample of final object locations predicted by the tool is consistent with the one obtained by Opendrift in shape and size, just like in the other three scenarios, validating the developed tool. In this scenario the shape of the sample of object final locations is more spread than in the other scenarios, meaning the CWL has a stronger impact on the trajectory. This phenomenon is a consequence of the sailing boats asymmetry in shape between its bow and stern. Because in this case the time window of simulation is much longer than in scenario 1, the final locations of the object are much more spread than in scenario 1.

Having as basis the final locations of the particles in scenario 2 predicted by the tool developed, it is possible to derive the probability density function (pdf) of the points in order to obtain the 95% probability area in which the object can be. To find the adequate distribution, it is necessary to draw a histogram of the final locations in $X$ and $Y$ directions in order to determine if in each direction the histogram would be better represented by one or by a mixture of several normal distributions.

The histograms of the object final locations for scenario 2, shown in Figure 5 and Figure 6, indicate that a single bell shape curve would fit them the best, so a bivariate normal distribution is adopted to describe the location uncertainty, meaning that the resulting joint pdf, shown in Figure 7, has only one maximum. It is perceptible that the surface peak is narrower in the $Y$ direction than in the $X$ direction, just like the histograms shown in Figure 5 and Figure 6.

Figure 5 – Histogram of the object final locations in the X direction for scenario 2

Figure 6 – Histogram of the object final locations in the Y direction for scenario 2
The volume under the joint pdf is always equal to one. If a horizontal plane cuts that volume in order to obtain a volume above that plane equal to 0.95, the intersection between that plane and the joint pdf surface will be a closed curve. As the normal distributions in $X$ and $Y$ directions have different standard deviations, the curve obtained is necessarily an ellipse, clearly shown in Figure 8. That ellipse defines the 95% probability of an object being in its area ("P=95%"). The points ("positions") in blue represent the sample of final locations of the object, just like in Figure 4. Figure 8 also shows the empirical searching area suggested by the Australian National Search Rescue Council (2018) in red, that is also called drift error circle or "datum circle". In order to get the datum circle, it is necessary to add to the LKP point ("$t_i$") the current vector and the leeway vector for both right and left drifts. Adding both vectors to the "$t_i$" location point, the green points "$t_f R$" and "$t_f L$", are obtained for the right and left drifts, respectively, representing the final locations of the object. To get an area is necessary to have uncertainties associated, otherwise the graphic would only represent these two final location points. Because of that, a circle is drawn around each green point with the radius of 12.5% of the distance between the LKP and the respective final location point ("right circle" and "left circle"). The datum circle is the smallest circle containing both the right and left circles. The radius of the datum circle in red is the drift error itself. The center of the circle is called datum point and it is in line with the right and left points.

Analyzing the 95% probability areas calculated by the developed tool and the drift area calculated from the empirical formulae suggested by the Australian National Search Rescue Council (2018), one can see some differences between them. The main difference is the fact that the empirical formulae search area does not take into account the greater dispersion perpendicular to the wind speed that is characteristic from asymmetric objects like sailing vessels. The empirical formulas always use a circular shape for the searching area, no matter the object characteristics. Note that there is also a difference between the values of the areas from the developed tool and the empirical formulation meaning that the empirical formulae do not take into account as much uncertainties as the developed tool in the scenarios studied. Empirical formulae use 12.5% of the distance from the LKP for the radius of the right and left circles, which for the scenarios studied is not enough. The fact that the ellipse has more points inside its perimeter than the datum circle means that if the circle represents a probability value of the object being inside the closed curve, that value would have to be smaller than 95%. Considering the object final locations obtained by the developed tool, the empirical area corresponds to approximately a 93% probability of containment (POC) of the object. Another factor that slightly influences the differences between the areas is that the LKP in Opendrift and in the developed tool, also has an uncertainty associated, contrasting with the empirical formulation where the LKP is a fixed point.

The approximate POC values for the empirical search areas considering the object final locations developed by the developed tool are 17%, 93%, 82% and 69% for scenarios 1, 2, 3 and 4, respectively. This means that the developed tool takes in consideration more uncertainties than the empirical formulation, especially in shorter simulations (as in scenario 1). It is also interesting to note that between scenarios 2, 3 and 4, the one with the larger values of crosswind leeway is the second, followed by the third and finally the fourth,
which means the empirical search area is closer to the developed tool 95% POC area in size when the crosswind leeway is larger.

Although a bivariate single normal distribution has been the best option for the scenarios analyzed, in some cases the GMM is more adequate to represent the uncertainty on the object final location. For example, when the object does not jibe during the simulation time, two separate areas of final locations of the object are obtained, depending on the starting position of the objective relative to the wind direction. Considering the example from scenario 2 but with the probability of jibing equal to zero, the two samples of the object final locations create histograms with two peaks instead of one at least in one of the directions as clearly shown in Figure 9 and Figure 10.

The double peak shape in the histograms originate a bivariate GMM pdf surface with two maximums as shown in Figure 11.

This distribution causes Figure 12 to show two ellipses instead of one, for the right and left drifts separately. So, there is an approximate 95% chance of the object location be inside one of the two ellipses. However, it is not possible to change the jibing probability in the empirical formulae, so the circle obtained is exactly the same as in scenario 2. If the empirical formulae considered the same uncertainties than the developed tool, the datum circle should contain both ellipses and be tangent to both of them.

An interesting study is the superposition of the searching areas from scenarios 2, 3 and 4 since all of them have the same inputs with exception to the type of object. The graphic shown in Figure 13 provides a comparison between the 95% probability areas from scenarios 2, 3 and 4. The larger area represents the sailboat simulated final locations, the middle one represents the PIW in a survival suit simulated final locations and the smallest area represents the simulated final locations of the life raft. There is a large difference
between the sailboat area and the two other object areas given the influence of the wind in the sailboat in comparison to the PIW and the raft.

![Diagram](image)

**Figure 13 - 95% probability areas for scenarios 2, 3 and 4**

The fact that the sailboat searching area is much larger than the other two does not mean it is harder to find the sailing vessel. The sailboat can be spotted from a longer distance because of its dimensions. So, the area must always be compared taking in consideration the degree of difficulty to spot the object, either because of its size, color or shape.

6 CONCLUSIONS AND FUTURE WORK

This paper has implemented a basic drifting model used to simulate the trajectories of drifting objects at sea using MCS, taking in consideration the uncertainties associated to the process.

The trajectories of the objects obtained by the developed tool are in line with the ones provided by the *Opendrift* software, validating the tool developed.

In all four scenarios the probability model of the object final location consists of a bivariate single normal distribution model and, therefore, the searching areas obtained are single ellipses. The 95% probability curves (POC) obtained for the four different scenarios are consistent with the sample of the object final locations, showing more spread out areas when the crosswind leeway vector has higher values, as in the second scenario.

The search areas calculated according to the empirical formulation proposed by the Australian National Search Rescue Council (2018) are smaller than the POC curves obtained by the developed tool, particularly in the first scenario. The approximate POC values for the empirical search areas considering the object final locations developed by the developed tool are 17%, 93%, 82% and 69% for scenarios 1, 2, 3 and 4, respectively. This means that the developed tool takes in consideration more uncertainties than the empirical formulation, especially in shorter simulations (as in scenario 1). It is also interesting to note that between scenarios 2, 3 and 4, the larger the values of crosswind leeway, the closer the empirical search area gets to the developed tool 95% POC area in size. The empirical method adopts always a circular searching area that does not account for the asymmetrical characteristics of the sample of the object final locations, as clearly shown in scenario 2. All this together shows that the empirical formulation has limitations and does not account properly for the uncertainty on the drifting of the object, which is reflected on the size and shape of the searching area.

The influence of jibing on the trajectories and on the final location of the object has been illustrated by analyzing the second scenario with a probability of jibing of 0%. This created a sample of object final locations divided in two high-density areas that were well represented by a GMM and therefore the 95% POC area is described by two ellipses instead of only one.

This paper introduces a new topic with room for future deeper developments. This work can be further improved with a more detailed analysis of targets drifting at sea, taking in consideration the probability of surviving time of people onboard different objects. A study on the different communication methods for the determination of the LKP radius could be developed, defining a different standard deviation for the initial location of the drift according to the detection method. There is the possibility of further developing this model with the input of wind and current vector grids in real-time. It would be also interesting to use real known scenarios to compare to the predictions of the developed tool in order to validate it more consistently. As final suggestion, it would be interesting to simulate different search patterns for different scenarios to assess the best option in terms of time and probability of finding the missing object.

7 REFERENCES


