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Development of Search and Rescue Aid Tool–Integrated (SARAT-I) to simulate the probable drift area of a missing aircraft at sea

by

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Abstract (100 words):

The Indian National Centre for Ocean Information Services (INCOIS) developed Search And Rescue Aid Tool (SARAT) to aid the Indian authorities involved in Search And Rescue (SAR) operations at sea. The SARAT application can simulate the probable trajectory of a range of objects lost at sea, when provided with the information of time and location of when an object was lost. To further enhance the capability of the SARAT to track an aircraft lost in mid-air that descended in the sea, SARAT-Integrated (SARAT-I) is developed following the procedures laid in the

International Aeronautical and Maritime Search and Rescue (IAMSAR) manual. Theoretical details of estimation of position where the aircraft might have landed in the sea and integrating this information with SARAT to simulate the probable drift area of the aircraft are discussed in the report. Operational instructions are also provided for a quick usage of SARAT-I application. This application is expected to contribute to SAR operations involving missing aircrafts at sea.

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Author Contributions

TB developed the codes and website interface of SARAT-I applicaiton. TB and VP prepapred the theoretical framework and design of the application. VP and AM prepared the the technical report. SJ, TMB and TSK provided the guidance. YR and AS, representing the AAI and ICG, respectively, ensured the usability and applicability with their valuable comments. TSK facilitated the development of the application by providing the necessary infrastructure.

Abstract

The Indian National Centre for Ocean Information Services (INCOIS) developed Search And Rescue Aid Tool (SARAT) to aid the Indian authorities involved in Search And Rescue (SAR) operations at sea. The SARAT application can simulate the probable trajectory of a range of objects lost at sea, when provided with the information of time and location of when an object was lost. To further enhance the capability of the SARAT to track an aircraft lost in mid-air that descended in the sea, SARAT-Integrated (SARAT-I) is developed following the procedures laid in the International Aeronautical and Maritime Search and Rescue (IAMSAR) manual. Theoretical details of estimation of position where the aircraft might have landed in the sea and integrating this information with SARAT to simulate the probable drift area of the aircraft are discussed in the report. Operational instructions are also provided for a quick usage of SARAT-I application. This application is expected to contribute to SAR operations involving missing aircrafts at sea.

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1. Introduction

When a person or an object is lost at sea, Search and Rescue (SAR) operations involve locating the lost person or object, stabilising and extracting the person or object from water. SAR can also help to find ships in danger and contain the spreading of oil spills. In other words, it is an air-sea rescue over water. The efficacy of SAR is determined by the accuracy of the data available regarding the missing time and position of the object or person, and current and wind which further drift the lost object.

Indian National Center for Ocean Information Services (INCOIS), Hyderabad has developed a tool called 'Search and Rescue Aid Tool (SARAT)' for the Indian Ocean region to aid the concerned authorities in their SAR operations. SARAT is based on a Leeway model first developed by Breivik and Allen, 2007 and later enhanced by contributions from the US Coast Guard. The SARAT tool is based on a Monte Carlo based stochastic ensemble search and rescue model (Oyvind Breivik, Arthur A. Allen, 2007). It gives a probabilistic framework for the position of ensemble members or identification of the element. It estimates the motion of an object on the surface relative to the ambient surface wind and current. A complete description of the trajectory model suit is given by Hackett et al. (2006). Major factors like local wind, surface current, shape and buoyancy of the object directly influence the motion of the search object. The aerodynamic force from the wind has a drag and a lift component due to asymmetry of the overwater structure of the object (Richardson, 1997).

SARAT is designed mainly for SAR operations at sea. However, if an aircraft was lost mid-air and landed in the sea, SARAT cannot directly help us. Therefore, to enhance the capabilities of SARAT, the Search and Rescue Aid Tool–Integrated (SARAT-I) was conceived at INCOIS in collaboration with the Airports Authority of

India (AAI) and the Indian Coast Guard (ICG). The development of SARAT-I is discussed in this technical document. Briefly, SARAT needs the input of time and position where the object was lost. If the information on the position of where the aircraft landed is not known, using methods described in Chapter 3, a probability map of positions where the aircraft might have landed, is generated. SARAT is run starting from each of these probable positions to generate a convex hull of probable regions where the object might be found. These probability regions can be used for planning SAR operations at sea by the Coast Guard. Chapter 2 sets the background on search planning and evaluation, and Chapter 3 discusses the methodology of calculating the probability map where the aircraft might have landed in the sea. Chapter 4 introduces how SARAT operates and generates the convex hulls of probability regions. Chapter 5 gives the details of integration of SARAT and Chapter 6 provides operational instructions. While Chapter 7 discusses the scope and limitations of the application, Chapter 8 concludes the report. Chapters 2 and 3 draw heavily from the IAMSAR manual.

2. Search planning and evaluation

Searching is the most expensive, risky, and complex aspect of the SAR system. Often, it is also the only way survivors may be located and assisted. Before a search is undertaken and at frequent intervals during its progress, all information received must be carefully analysed and evaluated.

Search planning involves the following steps:

i) Evaluating the situation, including the results of any previous searching

ii) Estimating the distress incident location and probable error of that location

iii) Estimating the survivors' post-distress movements and probable error of that estimate

iv) Using these results to estimate the most probable location (datum *) of survivors and the uncertainty (probable error of position) about that location

v) Determining the best way to use the available search facilities so the chances of finding the survivors are maximised (optimal search effort allocation)

vi) Defining search sub-areas and search patterns for assignment to specific search facilities

vii) Providing a search action plan that includes a current description of the situation, search object description(s), specific search responsibilities to search facilities, on-scene coordination instructions, and search facility reporting requirements.

These steps are repeated until either the survivors are located or evaluation of the situation shows that further searching would be futile.

2.1 Evaluating the situation

The primary concerns are ensuring all clues about the survivors' probable status and location are properly evaluated, and ensuring the safety of the search facilities and their crews. Some of the clues which may indicate the survivors' location or situation include:

(a) Intentions: The intended route of the distressed craft is always an important clue to the probable location of the distress incident. If the position is close to where the craft intended to be at that time, the search planner should place a high level of confidence in it. However, if the position does not agree with the craft's intentions, then other possibilities need to be investigated.

(b) Last known position (LKP): The craft's last known position and its associated time is an important clue because it eliminates all the possibilities associated with earlier times. It is also an indicator of how well the craft was following its intended route and its true rate of progress up to that point. If the time of the distress is known, but not the position, this information allows the search planner to make a better estimate of the distress location.

(c) Hazards: Careful estimates of the craft's pre-distress motion coupled with information about the movements and intensity of weather fronts, storms, etc., may allow the search planner to estimate the probable location and time of the distress incident.

d) Condition and capability: The airworthiness or seaworthiness of the craft may be an indicator of whether the craft is likely to have suffered a casualty that would slow its progress or cause a change in plans. The availability, type, and condition of survival craft (such as liferafts) provides a clue about post-distress survivor movements.

e) Crew behaviour: The experience, training, habits, medical condition, and probable actions of the craft's crew provide clues about both pre- and post-distress behaviour, which, when analysed with other clues, may provide better estimates of the time and location of the distress incident and any subsequent voluntary survivor movements.

f) On-scene environmental conditions: Conditions at the scene provide clues about the continued survival of the distressed persons. Survivors on land may move away from the distress scene to seek shelter, water, avoid or escape local dangers, etc. Survivors at sea will drift away from the distress scene under the influence of local winds and currents.

g) Results of previous searching: When search results are negative, that is, when searching was done but the survivors were not located, the impact on the search planning process is not obvious. However, negative search results do provide important clues which may help locate the survivors in later searches.

2.2 Estimating the distress incident location

The first step in either marine or land search planning is to determine the limits of the area containing all possible survivor locations. This is usually done by determining the maximum distance the survivors could have travelled between the time of their LKP and the known or assumed time of the distress incident, and drawing a circle of that radius around the LKP. However, systematic search of such a large area is normally not practical. Therefore, the next step is to develop one or more scenarios, or sets of known facts plus some carefully considered assumptions, describing what may have happened to the survivors since they were last known to be safe. Each scenario must be consistent with the known facts of the case, have a high likelihood of being true, and allow the search planner to establish a corresponding geographic reference, or datum, for the survivors' most probable location.

A datum may be a point (or set of points), line, or area. The datum for the initial distress incident is first estimated from the known facts of the case, and possibly some assumptions which have a high likelihood of being true.

3. Computation of probability maps of aircraft landings in the sea

3.1 Distribution of possible search object locations

The distribution of search object location probabilities within the possibility area is an important consideration in search planning because it affects how the available search facilities should be deployed. Possibility areas may be centred upon a single datum point, centred along a datum line, or defined by a geometric figure or figures covering some portion of the earth's surface.

The location probabilities may be evenly distributed throughout the possibility area, or there may be some sub-areas which are more likely to contain the search object than others. When the available clues do not provide a clear indication of which sub-areas are more probable and which are less probable, then distress incident, search object, and survivor location probability distributions may be estimated by assuming a standard distribution.

The two types of standard distributions most frequently used are those based on the standard normal distribution (bell curve) and those based on the uniform distribution. For datum points and lines, appropriate variations on the standard normal distribution are usually used. For datum areas, a uniform distribution is most often used. However, when enough information is available, the search planner's analysis and judgement will often produce a better, and in some ways a less complicated, generalised distribution.

3.2 Initial distress incident location probability distributions

There are basically three types of information which may be available about the location of a distress incident.

(a) Point: This is the simplest and most specific type. It may be specified by latitude and longitude, range and bearing from a known point, or other method for specifying a geographic position. It is usually obtained from either the distressed craft itself or from external position-fixing equipment. If the time of the incident is known but not the datum, the incident position may be estimated based on the LKP and the craft's intentions. The distribution of incident location probabilities is generally assumed to be that given by a circular normal probability density function (Figure 1). Under this assumption, the probability density is highest near datum and decreases as the distance from datum increases. The incident's probable position error (X) is defined to be the radius of the circle having a 50% chance of containing the actual location of the incident.

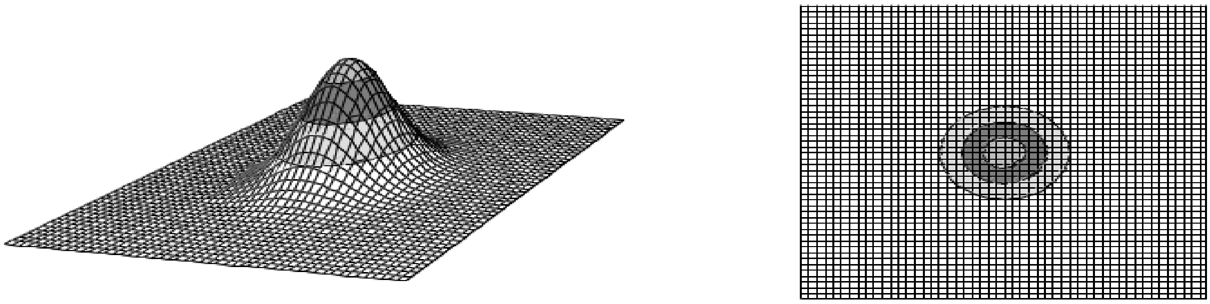

Figure 1: Probability density distribution for a point datum with top view

(b) Line: This can be either an intended or assumed track line or a line of bearing. The distribution of possible incident locations is generally assumed to be more concentrated near the line and less concentrated farther away. Specifically, the distribution of possible incident locations on either side of the line is assumed to follow a normal distribution. The distribution along the line is generally assumed to be uniform unless there is specific information favouring one part of the line over another (Figure 2 and Figure 3).

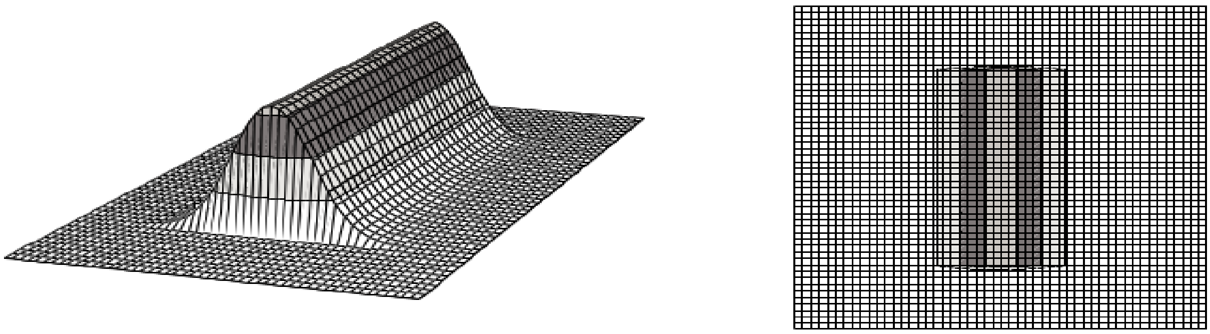

Figure 2: Probability density distribution for a line datum with top view

3.3 Survivor motion after the distress incident

Survivors of a distress incident may move away from the location where the incident occurred before assistance arrives. For aircraft incidents over land, it is usually best to first locate the site of the forced landing or crash and then search for survivors in the surrounding area. Survivors on the ocean drift with the winds and water currents, although they may affect their motion with a drogue or sail on their survival craft.

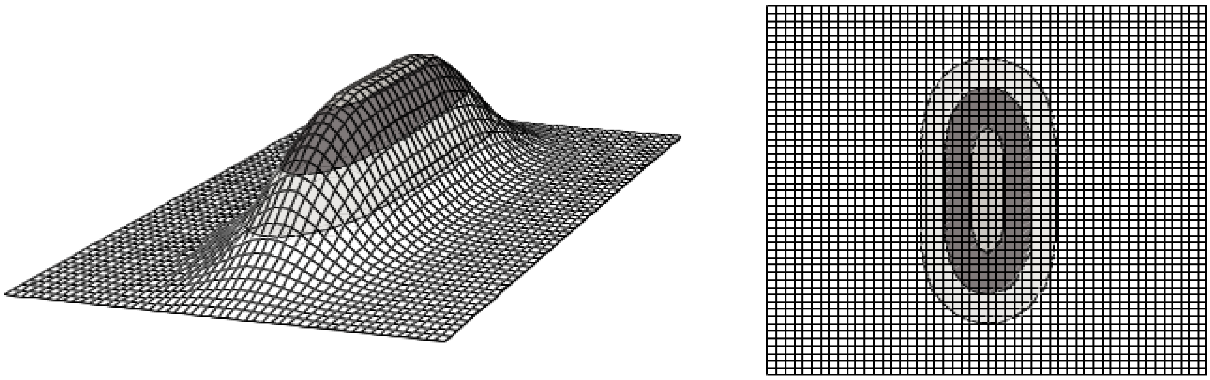

Figure 3: Probability density distribution for a line datum connecting two point datums with top view

When an aircraft experiences a casualty, such as an engine failure, which makes further flight unsafe or impossible, the pilot will normally attempt to descend in the safest possible manner by either gliding, using a parachute, or using a combination of these two methods.

Two types of forces cause survival craft on the ocean to move or drift: wind and current. To compute the area where the survivors may be located, it is necessary to estimate the rate and direction of drift. This requires estimates of the winds and currents in and around the area containing the possible distress locations. The two components of drift are leeway and total water current (TWC).

Leeway (LW): The force of the wind against the exposed surfaces of the craft causes it to move through the water in a generally downwind direction. Total water current (TWC) includes Sea current (SC), Tidal or rotary currents, River current,Local wind current (WC).

Estimating survivor drift:

Once the directions and speeds of the leeway and TWC vectors are estimated, the directions and rates of drift are computed by adding the leeway and TWC vectors. The estimated distance an object has drifted is computed as the number of hours since the last computed datum multiplied by the drift speed, using the familiar formula

distance = speed × time.

(a) Single point and leeway divergence datums: Updating a previous point datum to account for drift motion and to produce a new point datum is done by moving from the previous datum in the direction of the drift vector for a distance equal to the estimated drift distance.

(b) Line and area datums: If the drift forces (wind and current) are nearly the same everywhere in the search and surrounding areas, the new line or area datum location is found by moving it in the same fashion as point datums are moved using the average of the winds and currents.

Total probable error of position

For point datums, the total probable error of position (E) defines the circular area having a 50% chance of containing the survivors, taking into account the probable error in the incident position (X), the probable error in the drift estimate (D_e) if drift is a factor, and the probable error in the search craft's position (Y).

Search facility position error (Y). The search facility's ability to accurately locate the search area has an impact on the size of the area which needs to be covered in order to avoid missing important portions.

Total probable error of position (E). The total probable error in an estimated datum position is a function of the probable error in the estimated distress incident position (X), the probable error in estimated post-distress survivor movement (D_e), and the probable position error of the search facility (Y). The formula for computing total probable error of position is:

$$E = \sqrt{\left(X^2 + Y^2 + D_e^2\right)}$$

When post-distress survivor movement may be disregarded, this formula becomes:

$$E = \sqrt{\left(X^2 + Y^2\right)}$$

List of useful definitions to better understand the remainder of this report, are given in Appendix I.

3.5 Preparing initial probability maps for line datums instructions

Before the results of the first search can be fully evaluated, a probability map must be prepared. The following steps describe how to prepare an initial probability map for a line datum, using the standard line datum probability cross-sectionss. The line datum is adopted in the development of SARAT-I application as it is more general and applicable for a moving aircraft. Full evaluation of the second and later searches depends on keeping the probability map updated to reflect all searching that has been done and any search object motion that has been estimated. Procedures for updating probability maps are provided with the Search evaluation worksheet. To maintain the brevity of the report Tables and Graphs referred in the following are not reproduced here in this report but they can be found in the IAMSAR Manual Volume II available at https://www.imo.org/en/OurWork/Safety/Pages/IAMSARManual.aspx.

1. Total probable error of position: Enter the total probable error of position (E) from the line of the Datum worksheet.

2. Adjusted search area dimensions: Enter the length and width of the adjusted search area from line 14.b of the Effort allocation worksheet.

3. Adjusted search radius: Divide the Width from line 2 by 2.0 and enter the result.

4. Adjusted search factor Divide line 3 by line 1 and record the result.

5. Standard probability map: Enter table M-1 with the adjusted search factor from line 4, find the nearest value in the first column, and enter the letter which appears in the second column. If more than one letter appears, choose one of the alternatives. Usually, the first letter will be the best choice. When the adjusted search factor is the same as the search factor in column 1, the width of the adjusted search area will correspond to a whole number of cell widths.

6. Cell width Enter table M-2 with the letter from line 5, perform the multiplication indicated in column 2, and record the result.

7. Number of divisions along the datum line Enter the desired number of divisions along the datum line. This value will determine how many probability map cells will be required to match the length of the adjusted search area.

8. Cell length Divide the Length from line 2 by the number of divisions from line 7.

9. To plot the probability map on an overlay for the chart or map being used to plan the search, follow these steps:
(a) At each end point of the datum line, draw a line perpendicular to the datum line.
(b) On these perpendicular lines, mark the points which are a distance of 3.0 × E from the datum line on either side. Connect these four points to form a rectangle.
(c Divide the rectangle into the same number of strips as the selected standard probability cross-Chapter. Note the probability of containment for each strip, this is done for standard probability cross-Chapter C.

0.2%	**0.2%**	**0.2%**	**0.2%**	**0.2%**	**0.2%**	**0.2%**	**0.2%**
2.8%	**2.8%**	**2.8%**	**2.8%**	**2.8%**	**2.8%**	**2.8%**	**2.8%**
6.5%	**6.5%**	**6.5%**	**6.5%**	**6.5%**	**6.5%**	**6.5%**	**6.5%**
2.8%	**2.8%**	**2.8%**	**2.8%**	**2.8%**	**2.8%**	**2.8%**	**2.8%**
0.2%	**0.2%**	**0.2%**	**0.2%**	**0.2%**	**0.2%**	**0.2%**	**0.2%**

Fig. 4 Probability map for a line datum. The row of cells overlapping with the line datum is colored in blue.

Following the above procedure, a probability cell map can be prepared. Note that each cell is assigned with a probability with which an aircraft might have been lost in the mid-air and descended in the sea. The next task is to find out where the object (aircraft in this case) might drift in the sea. This is achieved by employing the SARAT tool operational already at INCOIS. The SARAT tool is described in the following.

4. Simulation of probable drift regions using SARAT

4.1 Background

Leeway is the motion of an object induced by wind (at 10 m reference height) and waves relative to the ambient current (between the depths of 0.3 and 1.0 m). The leeway is decomposed into components of downwind leeway and crosswind leeway with respect to the ambient current (Allen, 2005). The downwind has an almost linear relationship with the wind speed, which can be used to estimate the crosswind component. Objects such as sailboats have significant right (positive) and left (negative) crosswind components of leeway which implies equal possibility of two search areas i.e., one for left drifting and another for right drifting (Breivik et al. 2011). The wind and the surface current determine the direction of propagation of the object lost. Asymmetry of the drifting object can lead to a variation in the force which causes the object to lift along the current with an angle. The small shift or difference in the initial orientation of an object relative to wind can cause the object either to drift leftward or rightward of the wind direction, which cannot be known in advance. Therefore, equal probabilities are assumed for either direction.

Allen and Plourde, 1999 reported a list of empirical coefficients for leeway speed and divergence angle, which were converted by Allen [2005] into downwind and crosswind components of leeway, as a function of the 10 m wind speed. Allen, 2005 conducted field studies to determine the response of different classes of objects wrt wind direction. Magnitudes of downwind leeway (DWL) and crosswind leeway (CWL) components vary depending on the differing shapes and buoyancy characteristics of drifting objects.

Forces acting on drifting objects are briefly discussed in the following. Forces such as atmospheric wind, water current and wave motion drive a drifting object. The acceleration of a floating object can be given by (Oywind Brievik, Arthur A. Allen),

$(m+m') dV/dt = \sum F$,

where,

V is the object velocity

$\sum F$ is the sum of the forces

m' is the added mass which comes from the acceleration of water particles along the hull of the object (Mei, 1989; Richardson, 1997; Hodgins and Hodgins, 1998). The leeway speed and wind speed at 10 m with zero lag, are well correlated (Fitzgerald et al. 1994).

When an object moves under the influence of wind, it tends to diverge from the downwind direction due to hydrodynamic lift and drag of the subsurface (Oyvind Breivik, Arthur A. Allen). The shape of a drifting object is a main factor determining how the wind exerts force on the object. While the wind acts directly on the overwater structure of the object, waves apply a force in addition to advection with the strokes drift. Wave effects are small when the length scale of the object is smaller than the wavelength and then increase dramatically when the lengths are almost the same (Grue and Biberg, 1993, Hodgins and Hodgins,1998). Wind data used in the SARAT model is taken from the European Centre for Medium-Range Weather Forecasts (ECMWF). The spatial resolution of wind is 0.255 and the temporal resolution is 6 hours.

Surface current is another important factor determining the leeway of the object. Current used in the SARAT is an average of currents from the surface to a depth of 15 m. As the resolution of the current increases, the accuracy in forecasting the trajectory of the object increases. Even a small eddy can also strongly influence the drift of an object. Current is taken from a three dimensional hydrodynamic, free surface model known as Regional Ocean Modeling System (ROMS) operational at INCOIS (Francis et al., 2013). The vertical dimension is resolved by 40 unevenly spaced layers of terrain having the s-coordinates. ROMS provides forecasts of oceanographic state in terms of sea surface current, sea surface temperature (SST) and mixed layer depth at different spatial and temporal resolutions. ROMS model current data used as an input to SARAT model is at $1/48^0$ resolution and at every six hours.

Uncertainties in input parameters (POL, and time when the object was lost) and forcing fields (wind, current, and waves) of the SARAT model influence the quality of its output. Two types of forces act on a drifting object: i) surface forces such as winds, surface current and surface waves ii) body forces such as gravity and buoyancy. Errors in these forcing fields and their interaction with the geometry of the drifting object make it difficult to know the total motion of the object.

4.2 SARAT probability regions

First and foremost task in SAR is to determine the position where the search object was lost (POL). For instance, POL can be obtained from the distress call received from a ship with a GPS unit which met with an accident. POL is set as the starting point for the SARAT model initialization from which further propagation of the search object is continued. Depending upon the precision of the POL, the radius of propagation of the ensemble members is deduced. If the POL and time of losing the object are known accurately, the radius assigned for the search region is narrow. Otherwise, the radius tends to be larger and the time window grows wider. This is the stem and root of the SARAT model.

Next task of the leeway model (SARAT) is to deduce the location of the search area with time. Normally, an ensemble of 500 particles is released at the initial position (POL) of the SARAT model to simulate the trajectory of the lost object. The leeway model (SARAT) needs the inputs of wind and surface current in the POL region for the time period starting from the POL till desired number of hours or days (usually up to a few days). Ensemble members or particles are released in an entirely random manner at the POL from where it is driven by the input wind and current.

Based on the trajectories of ensemble members, the most probable search area is estimated accounting for possible uncertainties. Search objects are of variety type and is divided into classes as,

- A person in water (PIW)
- Aircraft
- Various classes of life rafts
- Small motor boats etc

Leeway coefficients are different depending on the class of an object. Here, for SARAT-I, we focus only on the object classes of an aircraft and a person in water.

The input for running SARAT model are the the object's class ID (aircraft in SARAT-I application), initial and final positions of a search object in terms of latitudes and longitudes, start date and end date, start and end radii up to which there is a probability of finding the drifting object (this is user specified).

With these input parameters and forcing fields, SARAT outputs include, the convex hull region which completes the search area, final position of individual ensemble members, probability of finding drifting object in each region. The convex hull is formed by joining the vertex of all maximum travelled trajectories (which forms a polygon structure; example is shown in Figure 5). Thus the hull completes the search region obtained from the model. High probability in a region within a convex hull indicates that there is a cloud of ensemble members in that region. In general, the region of highest probability is in the middle of the convex hull. This will be the most probable region for finding the drifting object. Accuracy of the model output directly depends upon the temporal resolution of forcing fields. As temporal resolution increases, the accuracy tends to increase.

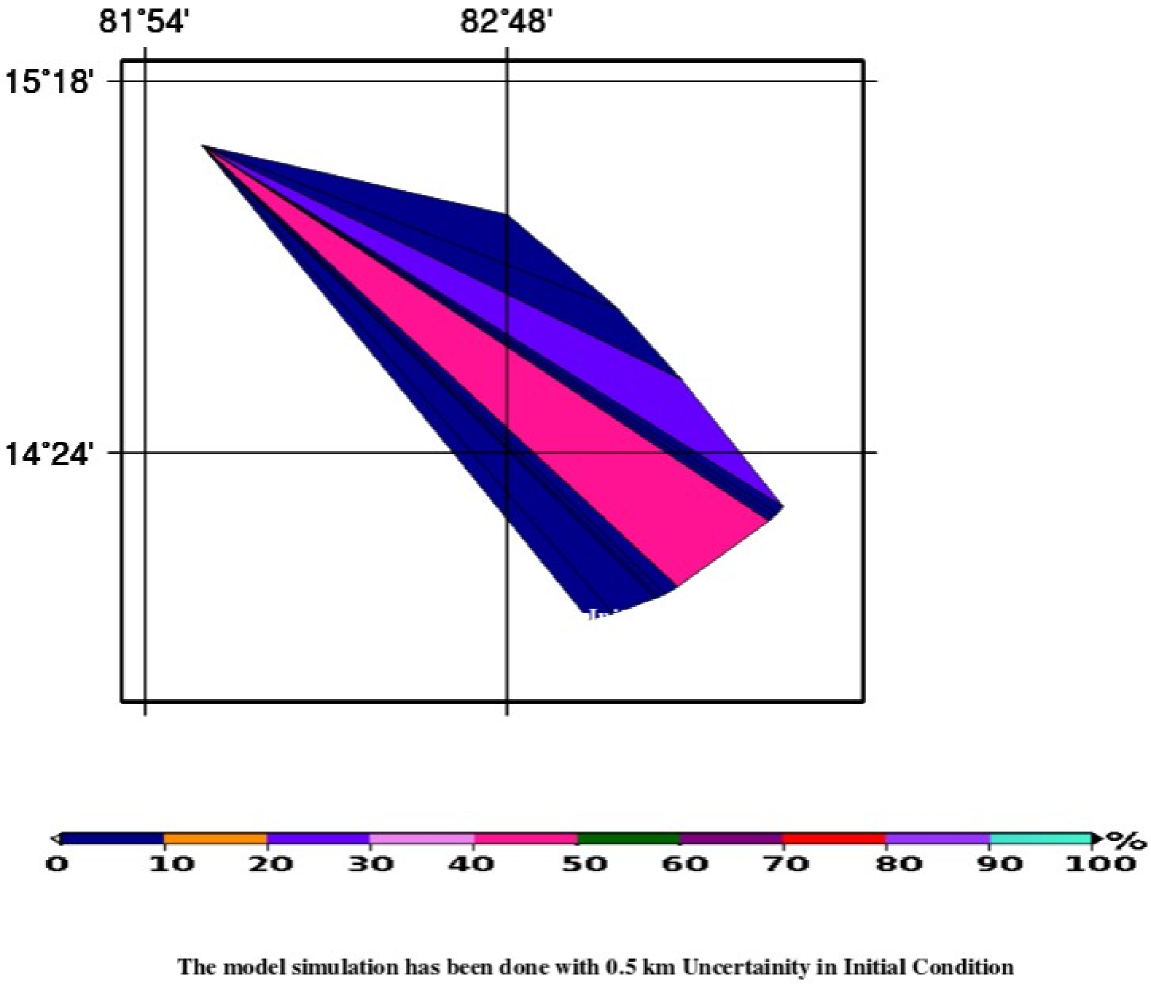

Figure 5. An example of SARAT output. Each probability region in the convex hull is colour-coded with its corresponding probability. The probability regions originate from the POL input to the SARAT model.

5. SARAT Integration

To find out the region where the missing aircraft that may have landed in the sea can be found in the sea, the SARAT model needs to be employed as discussed in Chapter 3.5. The SARAT model is initialised at each cell centre of the probability map generated in Chapter 3.5 and run for the user specified period. For instance, if there are 10 cells in a row along the planned flight path (section of the ATC route; for example, see Figure 6), SARAT is run 10 times starting from each cell centre (taken as POL). Note that each time SARAT model is run, it gives a convex hull of probability regions discussed in Chapter 4.2. A superimposed map of all convex hulls is given as SARAT-I output (Figure 7). The SAR operations can be planned based on SARAT-I output as shown in Figure 7.

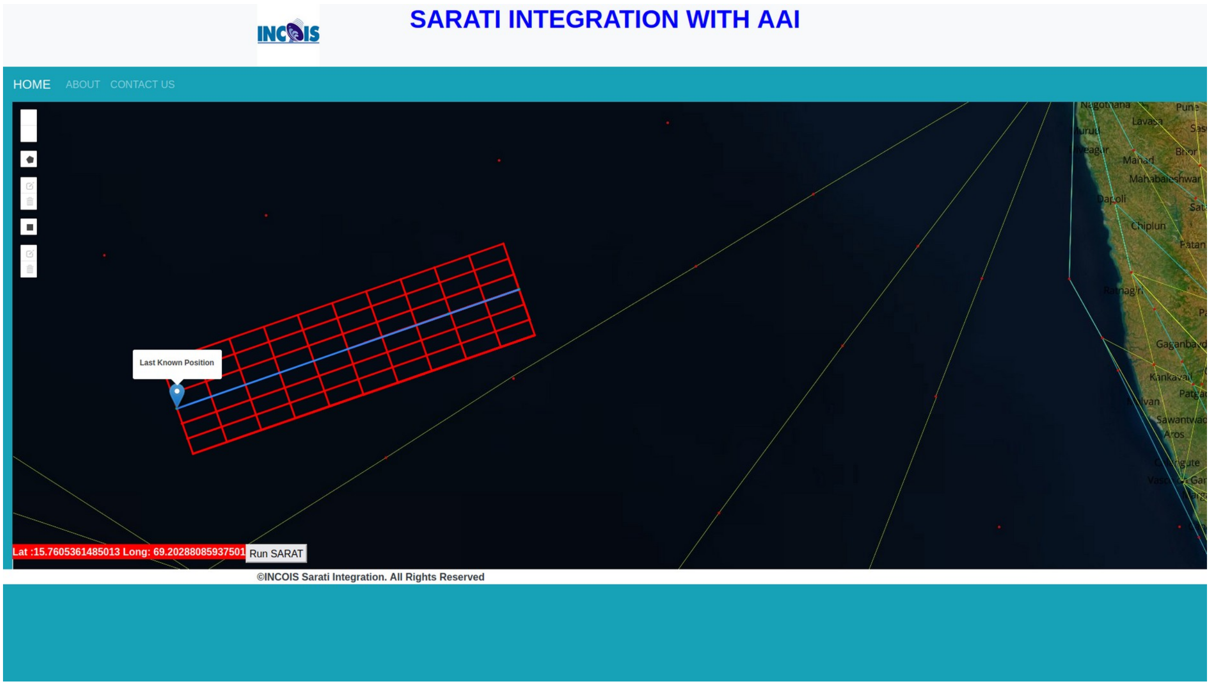

Figure 6. An example probability map. The planned flight path is shown in blue colour line and the probability map is divided into cells (rectangles in red colour) each with a certain probability.

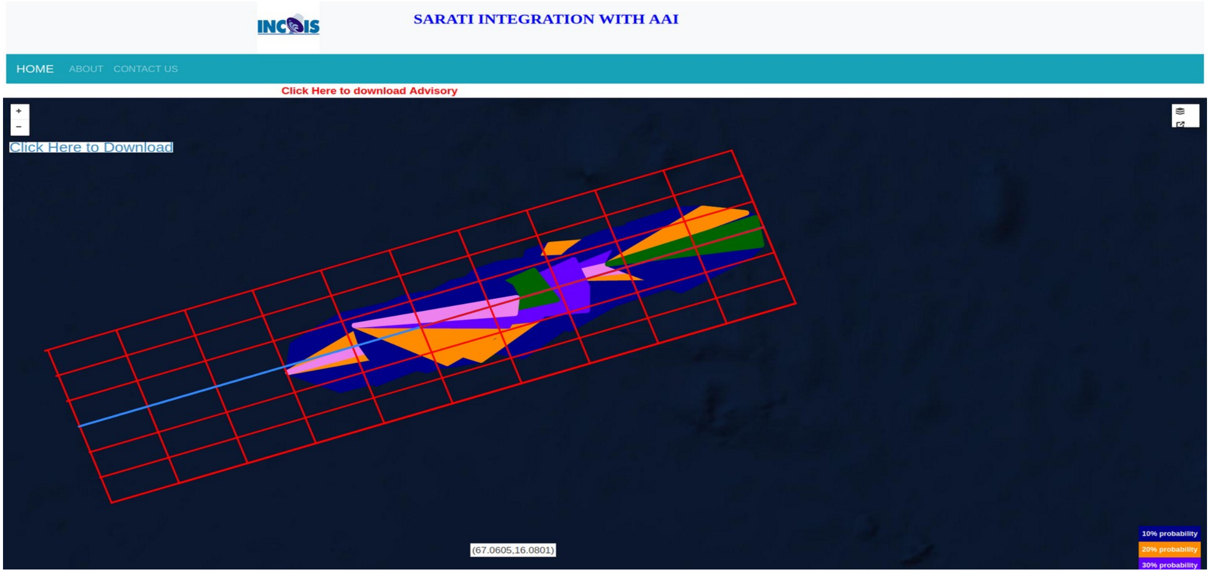

Figure 7. An example SARAT-I output. Convex hull SARAT outputs of several runs are superimposed on the probability map shown in Figure 6. SARAT is run only for a few cells to clearly show the cell centres and their corresponding SARAT outputs.

6. Operational Instructions for using SARAT-I

The usage of SARAT-I involves two steps. A) Filling the basic detail form B) Providing inputs to run SARAT-I. A user needs to have an account to be able to use SARAT-I. An account can be created by supplying user details. The user registration is required to monitor and improve the SARAT-I application.

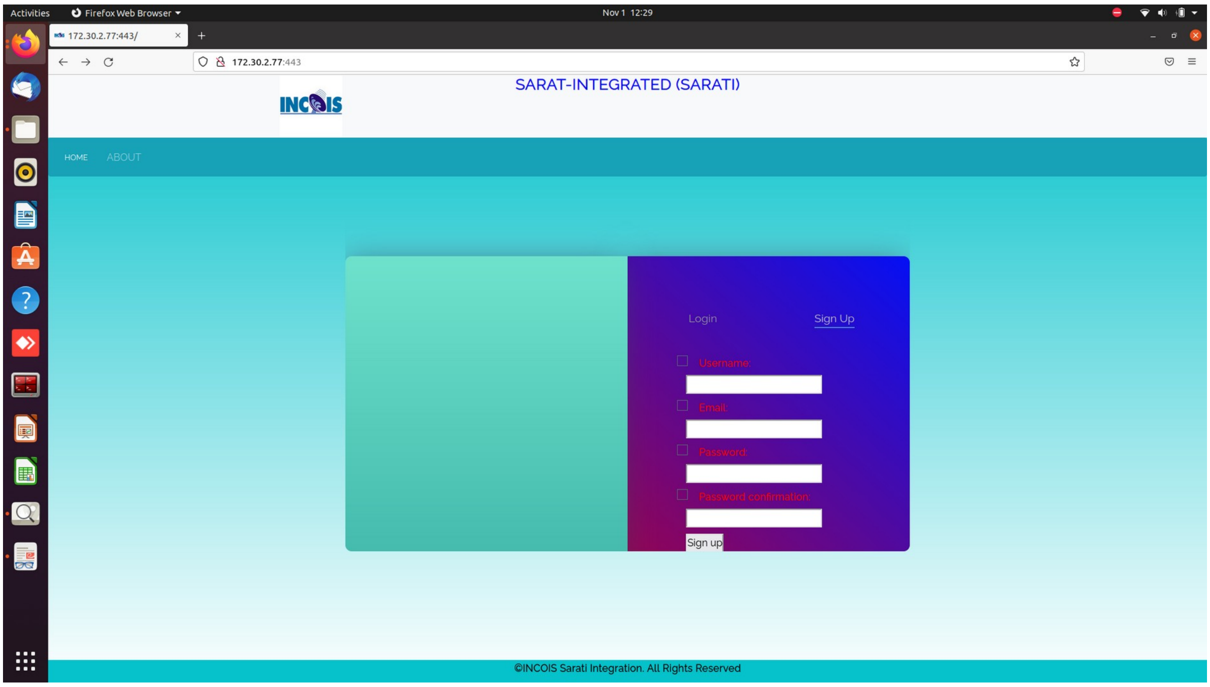

Figure 8. Login screen of SARAT-I application

1 Enter the IP Address 115.113.76.77:443 in your web browser and to access the SARAT-Integrated (SARAT-I) application.

2 Click 'Sign Up' and enter your details to become a registered user, if you are using the application for the first time. If you are already a registered user, simply click 'Login' and enter your user name and password.

3 Basic Detail Form appearing right after the login, collects details of a SAR incident to be able to generate a search map.

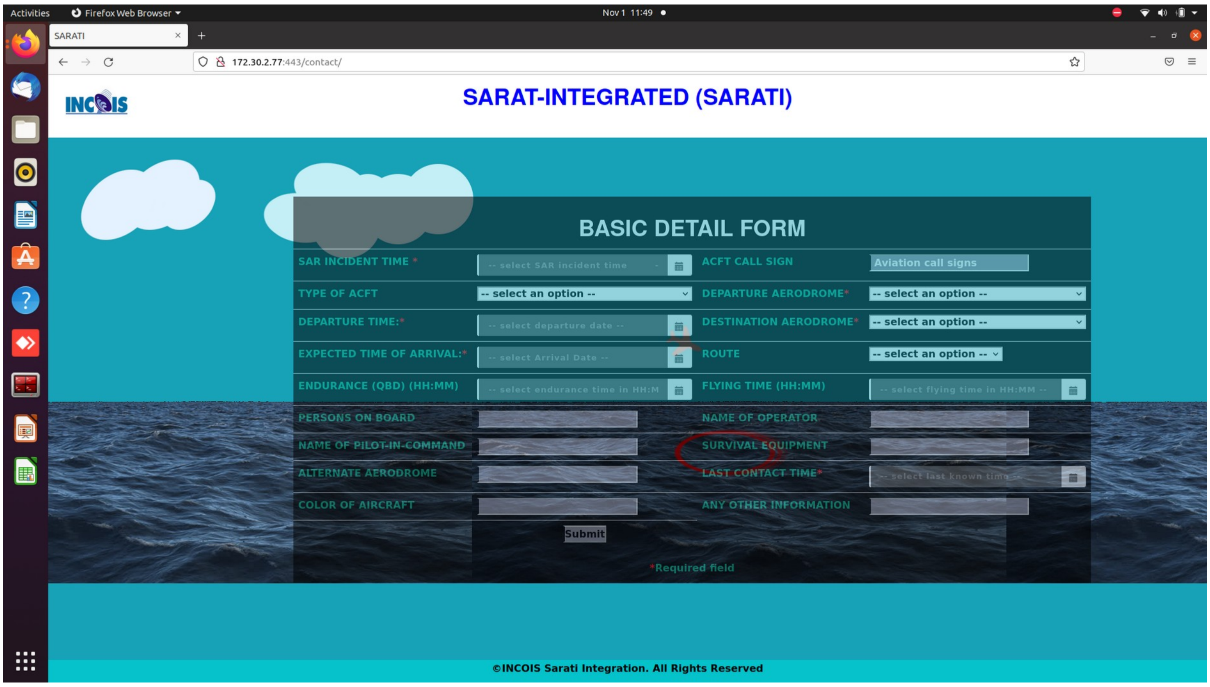

Figure 9. Basic details form.

4 Basic details:

- SAR Incident Time: Select 'Date' from the calendar and then 'TIme' in UTC by clicking the symbol
- Type of ACFT: Type of Aircraft can be chosen from a dropdown menu.
- Time of departure and expected arrival of the aircraft need to be entered (date and time)
- Endurance is the time in hours and minutes for how long the aircraft may continue to fly with the available fuel on board.
- The other basic details can be filled in a similar manner

5 After filling the basic details form, click the 'Submit' button. It redirects to the input page shown in Figure 10

6 Select the 'Datum Type' as 'Line Datum'. 'Line Datum' gives a good representation when an aircraft goes missing from the radar while traversing a flight route

7 Condition: Distress condition was 'Ideal' or 'Normal' ('Normal is supposed to be closer to reality)

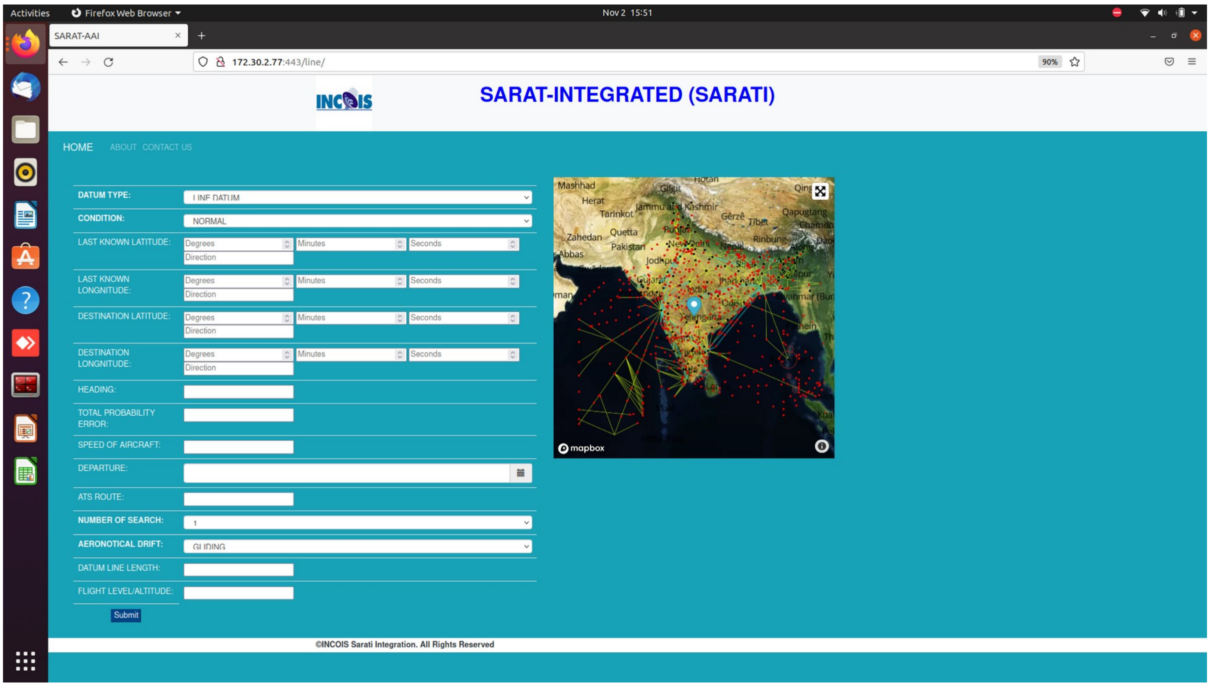

Figure 10. SARAT-I input page.

8 Enter the last known latitude and longitude in Degrees, Minutes and Seconds format. Similarly, enter the position (latitude and longitude) of the destination. The minus symbol can be used to enter a southern latitude or a western longitude. For example, 10^0S can be entered as -10

9 Heading: This is the direction in which the aircraft was moving at the last known position

10 Total Probability Error: This is the total probable error of position. Usually, this value is 15 nautical miles.

11 Speed of aircraft: last reported speed of aircraft

12 Endurance is the estimated time for which aircraft would be in the air before crashing into the sea

13 All other fields are self-explanatory. Enter all of them and click ‘Submit’

After a couple of minutes, a probability map is generated. Now, click ‘Run SARAT’ to find the probable regions where the person or wreckage of the aircraft can be found. Depending on line length, it takes a couple of minutes to run SARAT application of INCOIS taking each cell centre as the point where the object was lost. After a while a map of overlapping probability regions where the object may be found, is displayed. This output can be downloaded in .pdf format by clicking

‘Download PDF’. Each colored section of a convex hull is denoted with a region of probability. SAR operations can be planned using these probability regions.

7. Scope and Limitations

The SARAT-I application is developed to aid the authorities charged with SAR operations at sea. As the name suggests, SARAT-I is the same as existing SARAT application but with an enhanced capability to track a missing aircraft over sea. In a normal case, usage of SARAT requires the last known position (LKP) of a missing object 'at sea'. However, if an aircraft is reported missing while flying over sea, the LKP of the aircraft is in the air at an altitude from the sea surface. Assuming that the aircraft descends somewhere in the sea and drifts on the sea surface, the LKP of the aircraft (in the air) cannot be directly used as an input to the SARAT application to simulate the probable trajectory of the drifting aircraft. The enhanced SARAT-I application takes the LKP of the aircraft in the air and computes a probability map where the aircraft could descend in the sea, following the IAMSAR manual. In general, the speed of an aircraft is much higher compared to the ambient wind speed in the atmosphere. Therefore, the effect of winds is not taken into account in the computation of the probability map. The SARAT-I application makes use of certain statistical methods, as described in the report, to estimate the probable area/position of the aircraft descent over sea. It must be noted that the application is limited in scope and cannot cover all possible scenarios. For instance, the ambient winds might play a role in determining the probable position of descent over sea, if the aircraft stops propelling and simply glides. Further, the post-incident movement by the crew members cannot be predicted by this application and hence the aircraft descent over sea is likely to be different from that estimated by the application. While SARAT-I gives the probability map of aircraft descent irrespective of what lies beneath (sea or land or mountains), it estimates the probable drift area of the aircraft only for that part of the probability map lying above in the sea. In other words, SARAT-I cannot be used to estimate the probabilistic region of the aircraft if it crashes on land. Furthermore, SARAT-I cannot estimate the probable region if the aircraft dives into sea at an angle with a speed. Except for the enhanced capability to take the LKP directly from the ‘mid-air’ instead of ‘at asea’, SARAT-I inherits all lacunae of the existing SARAT. SARAT-I is designed to be a tool in aiding the SAR authorities but as a replacement for an experienced human SAR operator, hence it must be used wisely.

8. Conclusion

Conducting Search and Rescue operations at sea can be compared to searching for a needle in a haystack. Any aid to inform the authorities involved in SAR operations on where to look for the lost person or object at sea and can save lives and properties by minimising the time to reach the location of the object or person. To help the concerned authorities and general public, INCOIS developed a Search and Rescue Aid Tool. In order to make use of this tool, a user must know when and where the object or person was lost. To enhance the capability of the existing tool to be able to simulate an aircraft lost in the mid-air and descended in the sea, INCOIS developed Search And Rescue Aid Tool-Integrated (SARAT-I) in collaboration with Airports Authority of India and the Indian Coast Guard.

This report documents the development of SARAT-I, which has two components: 1) Generation of a probability map where the aircraft might have descended in the sea and 2) Generating SARAT outputs based on the probability map to give probable regions where the aircraft may be found in the sea. Operational instructions to use the SARAT-I application are also described in this report. The output probability regions can help the concerned authorities in their SAR operations.

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Appendix I

List of Definitions

Scenario – A consistent set of known facts and assumptions describing what may have happened to the survivors. It usually consists of a sequence of actual and assumed events starting sometime prior to the distress incident and continuing to the present time. The most likely scenario(s) are used as a basis for planning searches.

Possibility area - (1) The smallest area containing all possible survivor or search object locations. (2) For a scenario, the possibility area is the smallest area containing all possible survivor or search object locations which are consistent with the facts and assumptions used to form the scenario.

Search object – A ship, aircraft, or other craft missing or in distress, or survivors or related search objects or evidence for which a search is being conducted. That is, any object or signal from the survivors or their craft which may lead search facilities to the survivors or provide additional clues about the survivors' status or location.

Probability of containment (POC) – The probability that the search object is contained within the boundaries of an area, sub-area, or grid cell.

Probability map – A set of grid cells covering a scenario's possibility area where each grid cell is labelled with the probability of the search object being in that grid cell. That is, each grid cell is labelled with its own POC value.

Sweep width (W) – A measure of the effectiveness with which a particular sensor can detect a particular object under specific environmental conditions. Sweep width values for combinations of sensor, search object and environmental conditions are computed from the sweep width tables.

Search effort (Z) – The area effectively swept by a search facility within its assigned search sub-area. Search effort is computed as the product of search speed (V), search endurance (T), and sweep width (W). $Z = V \times T \times W$.

Effort factor (f_Z)* – (1) For single point and leeway divergence datums, the effort factor is the square of the total probable error of position (E). $f_{Zp} = E^2$. (2) For line datums, the effort factor is the product of the total probable error of position (E) and the length of the datum line (L). $f_{Zl} = E \times L$.

Relative effort (Z_r)* – The amount of available search effort (Z) divided by the effort factor. The relative effort relates the size of the effort available for a particular search to the size of the search object's location probability distribution for that search. $Z_r = Z/f\ Z$

Cumulative relative effort (Z_{rc})* – The sum of all previous relative efforts plus the relative effort for the next planned search effort. This value determines the optimal search factor.
$Z_{rc} = Z_{r-1} + Z_{r-2} + Z_{r-3} + ... + Z_{r\text{-next search}}$.

Optimal search factor (f_s)* – A value which, when multiplied by the total probable error of
position (E), produces the optimal search radius. $R_o = E \times f_s$. The width of the optimal search square (point datums) or rectangle (leeway divergence and line datums) is always twice the optimal search radius. Width $= 2 \times R_o$.

Coverage factor (C) * – The ratio of the search effort (Z) to the area searched (A). $C = Z/A$.
For parallel sweep searches, it may be computed as the ratio of sweep width (W) to track
spacing (S). $C = W/S$.

Probability of detection (POD)* – The probability of the search object being detected, assuming it was in the areas that were searched. POD is a function of coverage factor, sensor, search conditions and the accuracy with which the search facility navigates its assigned search pattern.

Probability of success (POS)* – The probability of finding the search object with a particular search. For each sub-area searched, POS = POC × POD. For several simultaneous searches or several searches within a specific period of time (for example, on a particular day) for the same search object, the total POS is the sum of all the individual search sub-area POS values.

Cumulative probability of success (POS_c) * – The accumulated probability of finding the search object with all the search effort expended over all searches to date. POS_c is the sum of all individual search POS values.

Grid – Any set of intersecting perpendicular lines spaced at regular intervals.

Grid cell – A square or rectangular area formed by pairs of adjacent, perpendicular grid lines.

On-scene endurance – The amount of time a facility may spend at the scene engaged in search and rescue activities.

Optimal search plan – A plan that maximises the probability of success attained using the available search effort.

Search area – The area, determined by the search planner, that is to be searched. This area may be subdivided into search sub-areas for the purpose of assigning specific responsibilities to the available search facilities.

Search endurance (T) – The amount of productive search time available at the scene. This
figure is usually taken to be 85% of the on-scene endurance, leaving a 15% allowance for investigating sightings and navigating turns at the ends of search legs.

Search speed (V) – The speed (or velocity) with which a search facility moves over the ground when searching.

Search sub-area – A designated area to be searched by a specific assigned search facility or possibly two facilities working together in close coordination.

Sensors – Human senses (sight, hearing, touch, etc.), those of specially trained animals (such as dogs), or electronic devices used to detect the object of a search.

Possibility sub-area – Any sub-division of the possibility area. Possibility areas are usually divided into sub-areas to develop a probability map or description of the distribution of probable search object locations within the range of all possible locations. When used in this way, each possibility sub-area is assigned a Probability of Containment (POC) value based on the likelihood of the search object being in that sub-area. Possibility sub-areas are usually cells in a grid but use of grids is not required. Possible sub-areas may or may not correspond to designated search sub-areas.

Track spacing (S) – For searches using equally spaced parallel sweeps, track spacing is the distance between the centres of adjacent sweeps, or, in other words, the spacing between adjacent search facility tracks or search legs.

Search objects: While the ultimate goal of searching is to locate and assist distressed persons, searchers need to be alert for objects or signals which may provide clues about their location. Search objects include such things as:
– boats, rafts and other survival craft

– debris or other evidence of the distress incident

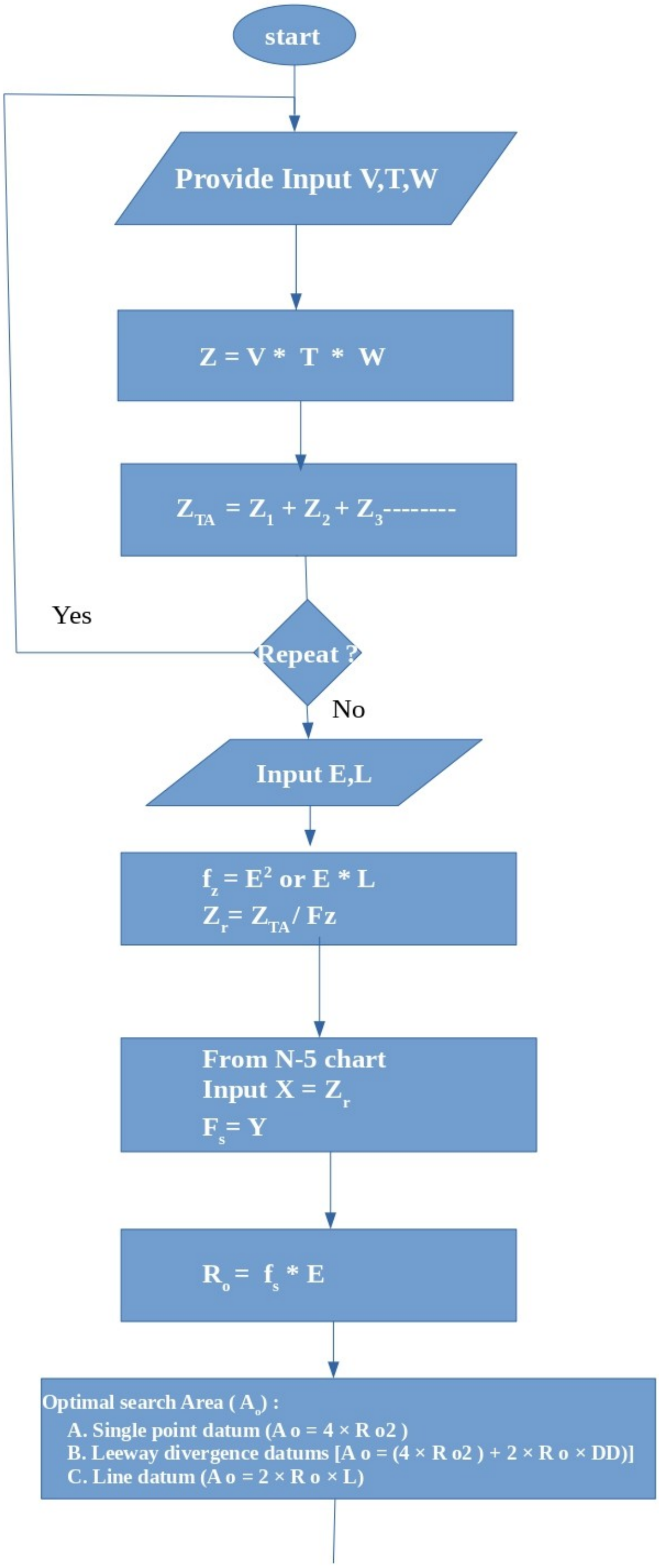
– signals, from the survivors or their equipment. Such signals may be visual, aural or electronic.

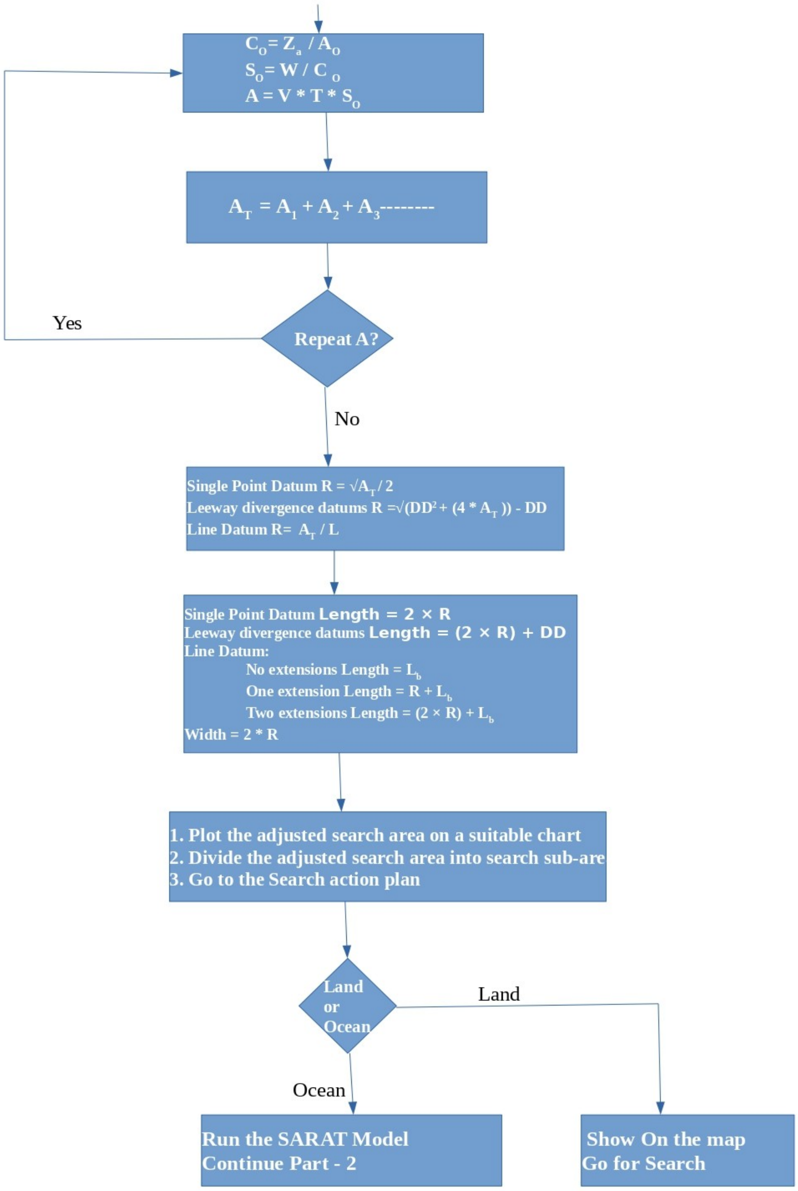
All search objects have characteristics that determine how well they can be detected by various sensors under various environmental conditions. Some search objects, particularly in the marine environment, also have motion characteristics which determine the possible range of their post-distress movements.

Probability of containment (POC): Once a datum for a search has been established, the search planner must decide exactly where and how to search the surrounding area. The possibility area is defined as the smallest area which contains all possible survivor locations (POC = 100%) consistent with the facts and assumptions (scenario) under consideration. Even a single scenario's possibility area can be too large to search effectively with the available search facilities. Often, some sub-areas are more likely to contain survivors than others. In this case, the search planner should divide the possibility area into sub-areas and estimate the POC for each sub-area.

Appendix II

Flow chart of computer code of SARAT-I




$C_O = Z_a / A_O$
$S_O = W / C_O$
$A = V * T * S_O$
$A_T = A_1 + A_2 + A_3$--------
Repeat A?
Yes
No
Single Point Datum R = $\sqrt{A_T} / 2$
Leeway divergence datums R = $\sqrt{(DD^2 + (4 * A_T))}$ - DD
Line Datum R= A_T / L
Single Point Datum Length = 2 × R
Leeway divergence datums Length = (2 × R) + DD
Line Datum:
No extensions Length = L_b
One extension Length = R + L_b
Two extensions Length = (2 × R) + L_b
Width = 2 * R
1. Plot the adjusted search area on a suitable chart
2. Divide the adjusted search area into search sub-are
3. Go to the Search action plan
Land or Ocean
Land
Ocean
Run the SARAT Model
Continue Part - 2
Show On the map
Go for Search

Search Facility Speed –	V
Search Endurance -	T
Sweep Width -	W
Total Availiable Search Efforts –	Z_{TA}
Effort Factor -	fZ
Total probable Error of Position –	E
Length of datum -	L
Relative Effort -	Z_R
Optimal Search Factor -	f_Z
Optimal Seach Radius -	R_O
Optimal Seach Area -	A_O
Optimal Coverage Factor -	C_O
Optimal Track Spacing -	S_o
Adjusted Search Area -	A
Total Adjusted Area -	A_T
Adjusted Search Radius -	R
Adjusted Seach Factor -	f_{sa}