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Assessment of the Potential Effectiveness of the WIG Craft in Search Action at Sea Using SARMAP Software

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ABSTRACT: Selection and choice of search and rescue units is an important stage in planning SAR operations at sea. The different characteristics of units enable them to be used for specific tasks at sea to varying ranges. The main advantage of WIG crafts is their speed, but they also have other features necessary for marine rescue. The assessment of the unit's potential effectiveness is based, among other things, on defining and determining the parameters influencing its ability to achieve success. Computer software such as SARMAP can be used for action planning. The article contains calculations for simulated actions of searching for several objects, additionally a graphical solution of the situation has been shown.

1 EFFECTIVENESS OF SAR ACTION

In every search and rescue (SAR) operation at sea the coordinator seek out to maximize the result while minimizing the risk of conducting the action (Burciu, 2012). The result of the action is influenced by many factors, including the quantity and quality of available situation data (type of search object, last known position, etc.), on hydro-meteorological conditions, on available search and rescue units (SRUs), their capabilities and distance to the scene. The effectiveness can be assessed after completion the task by measuring the ratio of the result obtained to the assumed one. The first volume of the IAMSAR Manual (International Aeronautical and Maritime Search and Rescue Manual "*Organization and Management*") recommends a use of performance indicators by measuring the number of people saved in relation to people in danger. This approach allows to analyse determination of prevention and response efforts in SAR system. Effectiveness of an action or of a given period can be calculated from the basic formula (1):

$$EFF\left(L\right)=\frac{LS}{LS+LLA} \tag{1}$$

where, EFF(L)=Programme Effectiveness for Preventing Loss of Life, LS =Lives Saved, LLA=Lives Lost After Notification.

However, since the result is composed of many factors, it can be modelled by selecting and modifying these factors, during the planning stage. The way in which the search or rescue action is prepared and the way it is conducted has a huge impact on the result. Therefore, the potential (theoretical) effectiveness of the action can be determined before the action starts. This potential effectiveness will be the expected capacity to achieve the goal. Potential effectiveness can be expressed, among others, by using the indicator of probability of success (POS) and by selecting the most useful rescue units for a given task.(IMO/ICAO, 2016)

POS is the probability of locating the search object. It is the true measure of effectiveness. The ability to find an object depends on having a sensor capable of detecting the object and placing this sensor close enough to the search object that its detection would be probable. This value is calculated from the following relation:

$$POS = POC \; x \; POD \tag{2}$$

where, POC=Probability of Containment, POD=Probability of Detection.

Probability of containment (POC) – expresses the probability that the searched object is within the search area. The probability area is defined as the smallest area that contains all possible object locations (in this case POC = 100%). In many situations, the area is so large that it cannot be searched by available SRU. It happens often that some sub-areas are more likely to contain the search object than others. Therefore, the area can be divided into smaller sectors, for which the SRUs would be deployed. The POC measures the probability of a chance to detect an object if it is actually located within the area. The exact way to determine the POC is described in the IAMSAR Manual vol. II "*Mission Co-ordination*" and will not be discussed in detail in this paper.

Probability of Detection (POD) is the probability that the searched object will be found, assuming that in fact it is in the search area. POD dependent on coverage coefficient, detector sensor, search conditions and accuracy with which rescue units navigate the designated search pattern. The coverage factor (C) compares the amount of searching that can be done to the size of necessary search. The coverage factor can be expressed as the ratio of search effort (Z) to the size of the search area (A), or as the ratio of sweep width (W) and the track spacing (S). Coverage factor is to be calculated as follows: C=Z/A or C=W/S.

Search effort (Z) of a SRU represent the area that can be effectively searched by particular unit. The search effort is computed as the product of search speed (V), search endurance (T), and sweep width (W) Z=V*T*W. Sweep width defines how wide is the scanning strip for a SRU. It's a measure of the ability to detect a search object. It takes into account environmental conditions (visibility, sea state), size of the object and the operator fatigue. It is provided as a guide for setting the track spacing. The track spacing is the distance between the centres of adjacent SRU paths. A track spacing that is less or equal to one-half the corrected sweep width results in POD of 100%. The greater the search effort compared to the search area, the higher the coverage ratio (analogically sweep width to track spacing).

Selection of SRU for a given task bases on effectiveness indicators. The SRU perform different potential effectiveness depending on the speed, observation altitude, seaworthiness, range and detection equipment.

2 WIG CRAFT

In recent years, the development of technology for vehicle moving in the ground effect has been resumed. The WIG Craft means *Wing-In-Ground-Effect Craft*. The ground effect is a physical phenomenon of creation an air cushion between the flying vehicle and the surface over which it moves. As a result air pressure difference between the area under the wings and over the wings appears, and an additional lifting force directed upwards is created. Consequently, the craft achieves relatively high speed with very low fuel consumption. Birds use this physical principle when overcome very large distances above the surface of a lake without moving the wings. The craft operating in ground effect flies at a low altitude, which is equal about 1/3 of the span of its wings, usually a few meters. The main constraints for the operation of WIG craft are hydro-meteorological conditions. A large waves can hinder or destabilize a flight of a craft in the ground effect, since it needs a flat surface. The WIG Crafts are classified under a ship in accordance to the IMO (International Maritime Organization). WIG units are cheaper to build and maintain than traditional airborne units, and crew training costs are also lower (comparable to marine staff training costs). WIG units do not also require any special aviation infrastructure as they are stationing at the ports. The *WISE Craft (Wing-In-Surface-Effect Craft*) or *Ekranoplan* are the common names for WIG Crafts. (Górtowska, 2012)

Examples of modern WIG crafts used for search and rescue tasks at sea are: Rescue Unit Aron-7 (Figure 1) or Multi-Task Marine Ekranoplan ES-108.

Aron-7 is a IMO type B* WIG craft for search tasks (*type B means that in addition to a flight in the ground effect, the unit has the option of leaving it and elevates). The craft has been registered by Germanischer Lloyd.

The craft aviates within an altitude of 5 m in ground effect, at a maximum speed of 200 km/h (108 knots). The cruising speed is 120-150 km/h (65-81 knots). The vehicle has a length of 10 meters, wingspan 12 meters, height 2.9 meters. The range of the craft is 800 km (432Nm). The number of passengers is 5 (two-person crew).

Figure 1. WIG Craft Aron-7 during take-off phase. Source: www.cnsamt.com

A motor is placed at the top of the cabin. The wings are in the shape of an elongated trapezoid, and the ballasts are mounted to the main part of the hull.

The T-shaped tail is moved away from the cabin. The unit elevates up to 40 m within 30 seconds with a jump-up feature, and elevates up to 100 m within 60 seconds. The maximum flight altitude is limited to 150 m (IMO standard). The limit does not apply to military units. Fuel consumption in the ground effect is only 25 l/h. The craft is equipped with thermal vision system, field of view indication via LCD monitor and operates at various environments with its wavelength IR spectrum. Stabilization of the flight allows to take pictures of good quality. Aron-7 possess underwater propulsion system allowing craft to manoeuvre through port and channels. The maximum draft is 0.5 m. The vehicle has the option of wing folding. The assembly or disassembly time is about 10 minutes. After folding the wings, the unit is ready for transport on the carriage to the launching site.(C&S AMT, 2007)

3 SARMAP SIMULATOR

The SARMAP computer application (Version 6.5 license available for Maritime University of Szczecin) enables modeling of search and rescue operations based on Geographic Information System (GIS). The SARMAP model system consist of several integrated components. The model itself predicts the movement of various floating objects (e.g. person in the water, raft, boat) on the sea surface in compressed time mode. For these purpose, the model relies mainly on inputted environmental data (wind, current) and the drift characteristics of the floating object in question. The application includes the ability to deploy SRU, set their search patterns, observe the animation of conducting the search in compressed time mode and calculate the various indicators i.e. probability of containment, probability of detection, probability of success. (Applied Science Associates, 2008). Two methods are available for determining the drift of the object:

– IAMSAR Method;
– Monte Carlo Method.

The IAMSAR solution determines the most likely position of the search object based on the trajectory of three particles traveling left, right and strait down. An error estimate, increasing with time, is computed for each particle, and a box that circumscribes the error radius around each particle defines the most probable locations of the missing object after a given time period. This method is limited to single Last Know Position (LKP) initialization, but does allow multiple search objects in scenario. The Monte Carlo solution determines a probability grid based on the trajectory of a large number of representative particles, each moving with some randomness. The grid divides the area in sectors based on the probability of containment. The Monte Carlo solution allows for multiple search objects in single simulation, initialization based on single point LKP or track line, probability cells, POC based on probability.

4 SCENARIO

The analysis concerns on the situation of searching for the 8 crew members of a fishing vessel with whom there is no contact and there is a suspicion of a threat to life. The last known position (54°40′30′′N; 0014°49′17′′E) of the unit is past due by 12 hours. An assumption was made that the position error could be 0,5 Nm. The typical and random weather conditions for south Baltic were applied for the entire length of the simulation. The values of wind and current direction and speed were entered in a one-hour step (average wind NNW 5m/s, average current ESE 0,5 kn).

Due to the lack of important information concerning the distress situation the coordinator planning the action has high uncertainty and is not sure what object he is looking for, i.e. whether the crew is on the disabled vessel, whether the crew has left the vessel and stays on the life raft, or whether individual people are in the water. It is difficult case, because characteristic of those objects vary a lot. Different size and different sensitivity to the leeway makes that search more complicated. The search area is much larger, and adjusting the parameters for specific search pattern is not obvious.

The SARMAP program allows to simulate the movement of several different objects. Four following search objects assumed for the scenario:

1 the crew is on the vessel (red dots);
2 the crew is on a life raft (yellow dots);
3 individual crew members are in the water:
   – survivors wear immersion suits and are in a position on the back (green dots);
   – deceased persons, face down (blue dots).

The results of the IAMSAR calculation and the Monte Carlo method differ significantly in the size of the calculated search area, as these methods use different computation schemes. The area contains all possible locations (done by Monte Carlo) is five times larger then the area calculated with the IAMSAR (Figure 2). For the further analysis, a larger area was assumed.

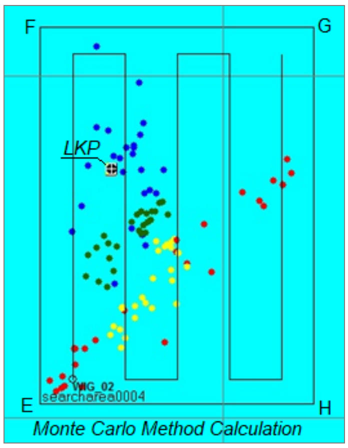

Figure 2. Prediction of search objects drift within 12 hours (dots) and parallel sweep search covering the search area. (Source: own study, print screen).

The location of deceased people concentrate around the LKP, their total drift is small, and the computation method spreads their possible positions randomly. Survivors dressed in immersion suit are more susceptible to wind influence and move over time in the average SSE drift direction. Life raft's and vessel's possible locations are furthest from the LKP in the average SE drift direction. The larger the objects surface area above the water level, the greater the influence of wind. The divergence angle for vessel is more than 45 degrees to the right and left of the average drift line.

The simulator enable to apply one of four main search patterns (parallel sweep search, sector search, creeping line, expanding square). In the study first two patterns has been used. The parallel sweep search is normally utilized when the uncertainty in locations is large. That search covers a rectangular area. The commence search point is in one of the corners. The search legs are parallel to the sides of the rectangle. The sector search pattern is intended to search circular area centred on a datum. It consist of tree triangular sectors, each composed of three legs intersecting the datum position. It is most effective when the datum is more accurate and the search area is relative small.

4.1 *Possible solutions*

Hypothetically the nearest SRU (WIG Aron-7) is located in port of Kołobrzeg away of the scene of distance 37,21 Nm. With the transit speed of 80 kn (the maximal speed is not applied for fuel saving reasons), the SRU will arrive at the scene in 28 minutes. For the basic computations, the search is rectangle area *EFGH* that contains all possible locations. The search area has been covered with the parallel sweep search pattern (Figure 1), adapted for the WIG craft Aron-7 characteristic, and taking into account following factors: drift error 0,3, safety factor 1,1 and fix error 0,25.

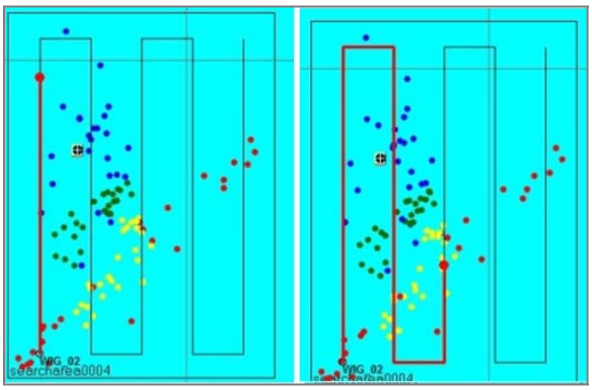

Figure 3. Animation of conducting the search by a SRU (red line); 15-minutes step (on the left), 45-minutes step (on the right). (Source: own study, print screen)

The SRU coverage area is equal 483 Nm^2. The suggest sweep width for that search (search object: vessel) is W=7,7 Nm, and the track spacing was set one-half of that value (S=3,65 Nm), cause that will effect in increasing the probability of detection up to 100%. The SRU will sweep the surface at distance of 1,83 Nm to the starboard and portside. Because all possible location are in the search area, the probability of containment is 100%.

The SRU begins the search in the corner *E*, heads north, and follows the planned route (Figure 3). It takes 1 hour 45 minutes to proceed the whole route. Total endurance of the Aron-7 is 4 hours. Subtracting the time for the transit to the scene and return do the port, the on-scene endurance is 2 hours 45 minutes. On-scene endurance is the productive available time for SRU. This value is usually taken to be 85% (t_{SRU} = 2 h 20 min), cause 15% of time will be dedicated for navigating turns and investigating sightings.

In this solution the SRU perform well. Search effort Z=680,36 Nm^2 is larger then the search area, coverage factor C=2 indicates that the detection is very likely and the final probability of success is 100%. The WIG is able to cover all area with available time, to detect missing fishing vessel, and with high likelihood to detect smaller objects too.

The results would be better with the appropriate adaptation of the shape of the area, to exclude areas where the probability of containment is low or equal zero. A probability distribution map serves this purpose (Figure 4). The simulation model determines a likelihood grid based on trajectory of a large numbers of representative particles, each moving with some randomness. The grid divides the area into shades of grey cells based of the probability of containment. The probability values are displayed in corner of the cell.

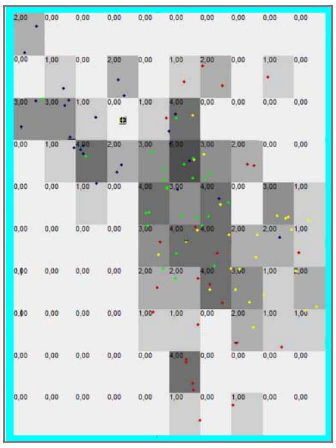

Figure 4. Example of probability grid map. (Source: own study, print screen)

The probability maps are helpful for optimizing the search by fragmentation the area. Conducting the search with available SRUs and modelling search patterns is next step for improving the effectiveness of the search.

The situation will change if the coordinator decides to search for persons-in-water (PIW) only. The search area has to modelled that contains the possible location of survivors in water only. In the study assumed two probable scenarios: the crew has abandoned vessel, they wear the immersion suits and their positon is on the back (acc. to survival techniques recommendation); or the crew did not survive the disaster, the bodies float on the water surface. The drift values in this two cases vary from each other. The deceased person is more submerged so the influence of the wind is less (smaller value of the leeway).

For this analysis new search sub-area (*OPRS*) has been set and two different search patterns compared (Figure 5). The search sub-area is placed over the predicted locations of the PIW (blue and green dotes).

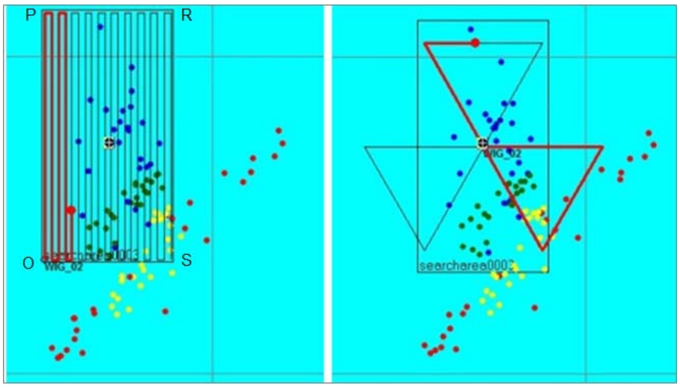

Figure 5. Parallel sweep search (on the left) and sector search (on the right) over the subarea. PIW search. (Source: own study, print screen)

For the parallel sweep search the suggested sweep width is 0,5 Nm and same track spacing was adopted. The lines must be quite close to each other, so that the SRU following the route can be able to detect as small objects as people in the water on its starboard and portside. Tight route layout reduces search effort. The SRU search effort Z= 93,2 Nm^2, while the search area is 161,8 Nm^2. The SRU is not able to cover the whole area due to its on-scene endurance limit. So one of the solution is to reduce the area taking into account the probability distribution map and excluding areas which are less likely. In this case the results are as follows: POD = 47,04 %, POC = 55%, and eventually POS = 25,85%

Another solution is to use a sector search pattern. The possible locations surround the datum, so this method will be effective. One search takes 65 minutes (on-scene endurance 2 h 20 min), The results for that search are as follows: POD = 47,04%, POC = 68%, and eventually POS=31,96%. If the search is unsuccessful the unit has still ability to perform the search again and therefore increase the chance for success. The pattern is to be rotated by an angle of 30 degrees and the unit carries out the search for a second time within the limits but not along the same route. This will escalate the probability of the location of the object. The cumulative probability of success (POS_C) is the sum of probability of success for the first search (POS_1) and the probability of success for the second search (POS_2). For that computation the updating value applies:

$$POC_{new} = \left(1 - POD\right) x POC_{old} \qquad (3)$$

where, POC_{new}=probability of containment for second serach; POC_{old} = probability of containment for the first search.

For that solution the POC_{new}=36,01% and the POS_2 is 16,94%. Therefore the cumulative probability of success POS_C is equal 48,09%.

In this case the use of sector search seems to be a better solution, as the probability of finding an object is almost twice as high as with the use of the method of parallel lines.

5 CONCLUSION

SARMAP modelling simulator is a flexible tool for assessing the potential effectiveness of search and rescue units. Objects' drift prediction, easy data entry, search patterns application, calculation of indicators, time compression, objects' drift animation and execution of search patterns by deployed SRUs are the most important advantages of the program SARMAP. The coordinator planning the action has a huge impact on the final result, through the selection of factors and components. It is easier to make mistakes while being under the pressure of time and consequences of decisions made. Analytical and graphical presentation of the situation can help by important decisions in SAR action planning.

One may have some doubts about the Monte Carlo method results of object's drift prediction. Some particles travel in the opposite direction to the drift. It seems more practical that dispersion may be useful when determining a datum with an error or a random movement of an object along the drift. In this case, it has resulted in a significant increase in the size of the search area, where the POC in some sub-areas is very low or equal to zero.

The WIG craft may actively carry out search and rescue tasks. In the examined scenario, it was able to find a missing ship or with a probability close to 50% to find people in the water. Using its high speed it can be a great support for coordinated actions. If another vessel is more likely to find people in the water, the WIG could at that time sweeping a larger area for a raft or a ship detecting purpose.

The biggest advantage of WIG is the quick arrival time, which significantly increases the chances of survival of people for whom the greatest threat is hypothermia. Flying in the ground effect gives high speed and reduces fuel consumption, which makes it economical and less polluting. If it's necessary, the WIG craft (type B) can elevates up to improve detection capability (POD will increase, therefore the POS will be greater). The WIG may navigate over the water surface and provide direct assistance to the injured persons, if weather conditions make it possible for the WIG. When completing a fleet of SRUs for particular SAR systems, the option of choosing WIG vehicles may be considered. Their search and rescue capabilities cover different aspects and may increase the effectiveness not only of specific action but also of the SAR system as a whole. In order to take full advantage of WIG crafts on a large scale in search and rescue and marine transport, further work and research is certainly needed on their design and the reduction of hydrometeorological constraints.

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