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Procedia Computer Science 221 (2023) 146–153

Procedia Computer Science

www.elsevier.com/locate/procedia

Information Technology and Quantitative Management (ITQM 2023)

Toward an IAMSAR-compliant naval shipboard application and validator for maritime SAR decision systems

Leonardo A. M. Pessôa[a], Carlos Eduardo Barbosa[a,b,1], Roberto B. David[a]

[a]*Centro de Análises de Sistemas Navais (CASNAV), Rio de Janeiro 20091-000, Brazil*
[b]*Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro PO 68511, Brazil*

Abstract

SAR is an internationally recognized acronym for search and rescue operations of people in distress, executed with emergency procedures, using personnel and available resources to rescue human lives. In Brazil, maritime SAR is under the responsibility of the Commander of Naval Operations (CON), which has developed a new decision support system designed for SAR. However, they have to guarantee compliance with the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual. Therefore, the Brazilian Navy needs an adequate tool to validate the compliance of the new SAR decision support system from the Brazilian with the IAMSAR Manual. We propose a computational tool that contemplates the search calculation models contained in chapters 4 and 5 of Volume II of the IAMSAR Manual and presents the data in graphical form depending on various factors involved (such as available units, meteorology, search target, search distance, elapsed time, among others) and validates CON's new SAR decision support system. Besides validating the CON's SAR decision system, we expanded our tool, providing a user interface. This standalone tool can be executed as a naval shipboard application, which is helpful for ships without direct access to the SAR system. We expect to aid in optimizing SAR services, ultimately reducing costs and time in the SAR operation to save more lives.

Keywords: Search and Rescue; Maritime SAR; IAMSAR; Validation; Decision Support System

1. Introduction

Search and Rescue (SAR) can be modeled and studied as an optimization problem [1]. SAR services should be optimized to achieve the desired results in minimal time to save as many lives as possible. The reduced costs of SAR are a beneficial side effect. Although SAR has high costs [2, 3], rescue services are usually free.

In Brazil, maritime SAR is under the responsibility of the Commander of Naval Operations (*Comando de Operações Navais* – CON), a Navy agency. CON promotes, coordinates, and controls SAR services in ports, inland waterways, Brazilian jurisdictional waters, and seas areas established by international convention.

The Brazilian Navy uses the *International Aeronautical and Maritime Search and Rescue* (IAMSAR) Manual [4] to provide standard procedures to help in planning SAR missions. The IAMSAR Manual is published jointly by the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO). This

*Corresponding author.
E-mail address: eduardo.barbosa@marinha.mil.br.

10.1016/j.procs.2023.07.021

work focuses on determining the *search area* calculations and tables covered in Chapters 4 and 5 of Volume II of the manual and complemented by the standards of the Brazilian Navy. CON has developed a new decision support system designed for SAR. However, they have a problem evaluating its compliance with the IAMSAR Manual.

This work is more straightforward since it translates the IAMSAR procedures to a computational tool to calculate the SAR search area, called datum, as the standard procedure for SAR. The datum is a geographic reference for the search area [5]. Although our original intention was to provide a verification tool for a complex SAR decision system, we see that the system has the capability for broader use, and we developed a practical tool to be used by non-experts, especially as a standalone decision aid (no internet connection needed) capable of supporting small vessels in SAR duties.

Therefore, we present two computational tools that contemplate the SAR search area calculation following the models in chapters 4 and 5 of Volume II of IAMSAR [6]. The first one validated the CON's new SAR decision support system – the CON's new SAR decision support system itself is out of the scope of this work. The second tool uses the same framework to receive inputs and output results graphically, depending on factors involved – such as available units, meteorology, search target, search distance, and elapsed time.

In addition, our tool can also be used as a standalone resource that runs as a naval shipboard application to help ships without direct access to the SAR system. Shortwave radios transmit the necessary data to perform IAMSAR calculations in this case. We used R for this task based on its flexibility, with many scientific packages freely available and comprehending geographical and graphical features, which are valuable for calculating estimated positions and depicting possible search patterns. Although the IAMSAR algorithm is public, the development of such an algorithm in R enables us to contribute to providing both a tool for verifying SAR applications and a simple SAR shipboard application.

The structure of the paper presents this introduction, followed by a brief review of the background of SAR and SAR in Brazilian waters in Section 2. Section 3 presents the validation tool, its main elements, and their input data. Section 4 presents the standalone SAR tool, while Section 5 discusses the results. Finally, in Section 6, we present a brief conclusion.

2. Background

2.1. Search and Rescue

The maritime rescue of persons in distress at sea is a tradition enforced by international treaties such as the International Convention for the Safety of Life at Sea (SOLAS). A very important mark is the Search and Rescue Convention of 1979, which presented the development of an international SAR plan standard [7].

The SAR system has three levels of coordination: On-scene Coordinators, SAR Mission Coordinators, and SAR Coordinators. The On-scene Coordinator is responsible for coordinating the activities of all participating SAR facilities on a mission. The SAR Mission Coordinator guides a SAR operation until a rescue has been effected or further efforts would be of no avail. The SAR Coordinators are the top-level SAR managers at the national level [5].

When proceeding to the area of distress, we must establish a traffic coordinating system, maintain Automatic Identification System (AIS) data and active radar plots, estimate the estimated time of arrivals (ETAs) to the distress site of other assisting vessels, and assess the distress situation to prepare for on-scene operations. Effective communication and coordination between all levels of the SAR system are crucial for a successful search and rescue operation [5]. A SAR operation needs as much Command and Control (C2) as any other military operation. In addition to the legal instruments to improve the probability of success in SAR operations at sea, which involve incidents and accidents, good awareness and communication processes are also necessary [8].

Wang [9] states, "safety accidents are always the key issue for enterprises to prevent and avoid, and offshore accidents are tough to resolve due to their special geographical characteristics." However, despite prevention efforts, when maritime accidents occur, a top priority for SAR is survivors search [10]

Furthermore, due to environmental characteristics, SAR operations at sea deal with a "large number of factors that affect maritime disasters, which makes it difficult to develop maritime search and rescue measures in a short period" [9]. The probability of survivors can be found at a particular location changes over time due to wind and sea effects [10].

Wang [9] brings another essential subject to discussion. In addition to environmental variables, the SAR team influences the operation and can interfere with SAR decisions. Therefore, reducing human-based interference is another reason for using decision support systems for SAR operations.

Several decision-support systems based on physical models of sea drift have been developed to provide a fast and reliable decision aid for maritime SAR. Bellantuono et al. [11] presents the background, methodology, and results of the research project ”Decision Support System for Marine Environment Emergency Management,” which intended to assist the Maritime Rescue Coordination Centers and Subcenters in planning and managing SAR operations at sea.

Wang [9] advocates the development of Artificial Intelligence for maritime search and rescue. Pescatore and Beery [12] use the agent-based simulation program Map-Aware Non-Uniform Automata (MANA) to assess organizational, operational, and technical interoperability decisions and highlight dependencies between decisions at each level of interoperability.

Other studies are devoted to optimizing the procedures used in SAR or preventing it. Lee and Morrison [10] use Mixed Integer Linear Programming to generate efficient search and rescue operation plans using UAVs. Assimizele et al. [13] use a non-linear binary integer program integrated into a receding horizon control algorithm to cleverly position tugboats before potential vessel distress calls.

2.2. *SAR in Brazilian waters*

The Brazillian maritime SAR area is extensive, as shown in Figure 1. In this context, the Brazilian Maritime Traffic Control Command plays a fundamental role in SAR. The Brazillian Navy uses the Sistram system that allows the Brazilian government to track vessels in the SAR area under its jurisdictional responsibility and combat illegal activities such as fishing, piracy, drug, and weapons trafficking. Sistram is integrated into the SisGAAz (*Sistema de Gerenciamento da Amazônia Azul* – Blue Amazon Management System). This strategic program aims to develop continuous monitoring and control systems for jurisdictional and SAR areas. SisGAAz’s integration of information and decision support networks through satellites, radars, and sensing equipment will increase the safety and efficiency of SAR operations and contribute to developing dual technologies that apply to defense and civilian areas. Monitoring and control systems in South Africa, Australia, Canada, France, India, and Italy are similar to what SisGAAz seeks to accomplish, highlighting its importance in ensuring SAR operations in Brazilian waters are practical and efficient [14].

The Ministry of Defense can get involved in important SAR operations in Brazil. For example, the Air France AF 447 accident had the participation of the Ministry of Defense, which used a Command and Control (C2) system named *SIPLOM* to coordinate the search efforts. Although the SIPLOM system was developed to support military operations, it can be used in humanitarian and SAR operations.

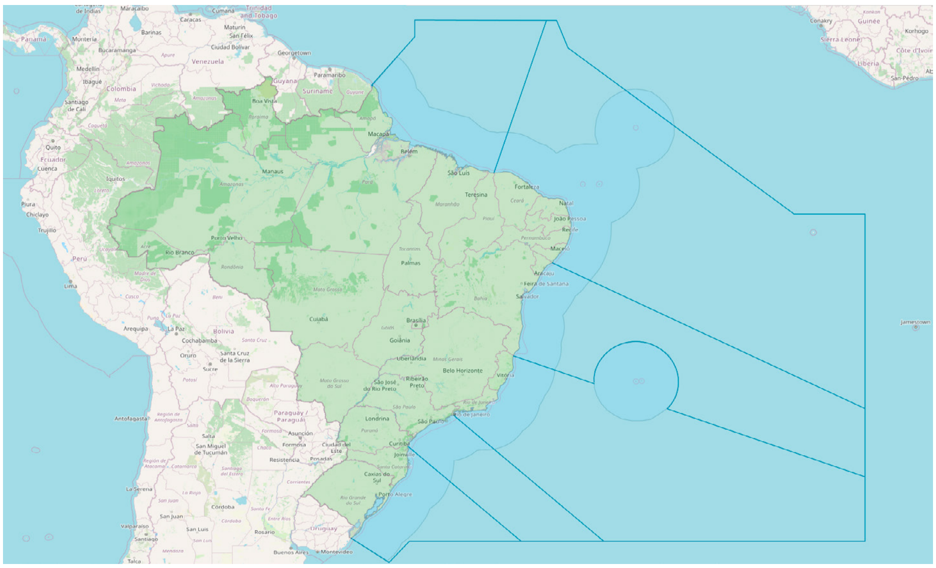

Fig. 1. The Brazillian maritime SAR area.

At sea, maritime surface current maps are crucial inputs for SAR operations, as they model the drift trajectories of floating objects and people. During the SAR operation for the Air France AF 447 accident, surface current maps were used to evaluate debris trajectories and locate potential survivors or victims. The maritime surface current maps and the surface wind maps are essential for running SAR computational models [15].

In addition to Brazil's extensive coastline, the problem of maritime SAR in Brazil is exacerbated by the transportation of workers and supplies to the offshore oil platforms in deep waters far from the coast. Brazil has several oil basins along the coast, with the Campos Basin and the Santos Basin being the main source of oil. Petrobras has two air bases in the north of Rio de Janeiro state for fast and efficient air transport for transshipment, responsible for more than 180 daily takeoffs and landings. Although safety measures are in place to minimize risks, such as the contingency plan immediately activated in the event of air accidents, fatal accidents were recorded in 2003 and 2004. Due to the significant air traffic in the Campos Basin region and many takeoff and landing operations, mechanisms and procedures to effectively support search and rescue operations are necessary to face accidents and other SAR events [16].

3. The IAMSAR Validation Tool

The International Aeronautical and Maritime Search and Rescue manual [5] provides a standardized approach to conducting search and rescue operations. The SAR algorithm is divided into three main phases: the alert phase, the search phase, and the rescue phase.

- **Alert Phase:** This phase begins when a distress signal is received, or a potential distress situation is identified. The alert phase involves gathering information related to the incident, such as the nature of the distress, location, and available resources. The information is then used to initiate the appropriate response.
- **Search Phase:** The search phase begins once the alert phase is complete. This involves a systematic and coordinated search of where the distress signal originated or the potential distress situation was identified. The search is conducted using a variety of search patterns, such as expanding square, parallel track, or sector search. This phase is focused on maximizing the chances of locating the distressed person(s) or object(s).
- **Rescue Phase:** The rescue phase begins if the search is successful and the distressed person(s) or object(s) are located. This involves providing immediate assistance and medical attention if necessary and transporting the person(s) or object(s) to a place of safety.

In the search phase of a SAR operation, one of the key steps is defining the search area. Several factors must be considered when deciding the search pattern. These include the available number and types of assisting craft, the area to be searched, the type and size of the distressed craft, meteorological visibility, cloud ceiling, sea conditions, time of day, and the arrival time at the datum. The area selection considers factors such as the reported position and time of the incident, supplementary information like direction finding bearings or sightings, and the estimated surface movements of the distressed or survival craft based on the drift. The leeway and the total water current determine the datum position drift. The observed wind speed can be used to estimate the leeway speed of liferafts, while the total water current can be estimated using the computed set and drift of vessels at or near the scene. These factors help determine the most effective search pattern during the SAR operation [5]. Figure 2 shows the most probable area, plotted from a datum. The radius R for the initial area increases over time as it represents the location uncertainty. Therefore, our work focuses on determining the SAR search area on the sea.

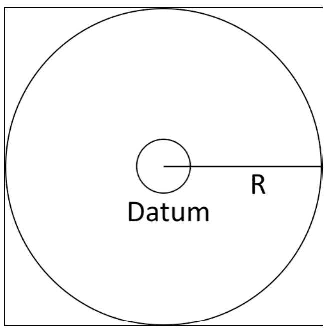

Fig. 2. Most probable area of a SAR. IAMSAR notation.

Table 1. Validation Tool input fields.

Group	Group Description	Items
Identification	The identification comprises the case title and the case number, used as a reference to identify each result.	Case Title Case Number
Time	The date group comprehends the date and time of the event and also the time meant for the calculi projection.	DateTime Event DateTime Projection
Inital Position	The initial position group presents the latitude and longitude in the format degree, minutes, and seconds.	Latitude Longitude
Sea Current	The current-related data comprehend both sea current, tidal current, and other water currents that could be considered. Sea Current is ”The residual current when currents caused by tides and local winds are subtracted from the local sea current. It is the main large-scale flow of ocean waters” [6]. Tidal current relates to ”Near-shore currents caused by the rise and fall of the tides”, whereas the Other Current is a possible entry for other effects that may compose the total water current.	Sea Current Direction Sea Current Speed Sea Current Error Tidal Current Direction Tidal Current Speed Tidal Current Error Other Current Direction Other Current Speed Other Current Error
Wind	The wind group relates to the wind-related data. The average wind on the surface has more components to describe. First, the direction and speed are considered an average already calculated on the available information.	Surface Wind Direction Surface Wind Speed Surface Wind Error Surface Wind Direction Error
Leeway	The leeway information is based on vessel characteristics or the SAR object, using the average surface wind as a parameter to retrieve the speed and the error.	Leeway Divergence Leeway Speed Leeway Error
Positional Errors	The positional errors group relates to factors that can induce errors in the SAR object. These fields are related to the positional method used to determine the estimated position of the SAR object and the error of a possible observer. We highlight that some fields are exclusive for some SAR. For example, Glide Distance refers to the distance an airplane or parachute can glide before touching the water.	Navigational Fix Error (NFe) Dead Reckoning Error (DRe) Dead Reckoning Distance (DRdist) Glide Distance NFey Navigational Fix Error Dead Reckoning Error relative to observer (DRey) Dead Reckoning Distance relative to observer (DRdisty)

The mathematical formulation of the solution is presented in Appendix K from the IAMSAR Manual Volume II, using the input parameters as asked in the *”Datum worksheet for computing drift in the marine environment”* – a section that shows a step-by-step algorithm to calculate the drift distance. Some inputs refer to tables and graphs presented in Appendix N, and we used the example provided in the Appendix Q of the IAMSAR Manual to verify the correctness of the output.

Implementing the validation and standalone Decision Support tools relied heavily on R packages. These packages enabled rapid prototype development and efficient comparisons of results. The validation tool utilized the *readxl* package [17] to simplify the input process, which allowed for the simultaneous input of many SAR cases using Excel. This input using spreadsheets made the comparison task much more manageable. The validation tool also utilizes a markdown document generated by *knitr* package [18, 19, 20] to present a dynamic report for comparisons. The *geosphere* package [21] was used in both tools for geographical calculations, with functions such as *bearingRhumb* and *distRhumb* particularly useful. Both tools utilize the *measurement* package [22] to facilitate data and time manipulation, allowing several conversion units. Finally, the Standalone SAR application used the *shiny dashboard* package [23] to build the user interface. The user interface is useful for non-expert users and facilitates a faster evaluation of different scenarios.

The Validation Tool has a more straightforward input-output methodology. The user uses a spreadsheet (in XLSX format) to provide the details of the SAR event and the *expected results* of SAR area following the IAMSAR manual. The SAR input contains 29 fields, divided into seven groups, as shown in Table 1. The SAR output follows the calculations of the *”Datum worksheet for computing drift in the marine environment”* of the IAMSAR Manual Volume II, Appendix K. The most important are the datum and the divergence distance. Using a spreadsheet file as input allows us to verify many cases simultaneously. Our test included the examples provided by the IAMSAR manual, and we could verify that the application developed for the Brazilian Navy works correctly.

4. The Standalone SAR application

Using the core of the validation tool, we developed a standalone application for ships of the Brazilian Navy. This standalone tool requires no Internet connection to operate. We built this application in R, using the *shiny* *dashboard* package [23] to provide an easy interface for the user. Although a user can perform the IAMSAR SAR area calculation manually, the standalone tool can help the user to perform the calculations faster and less prone to error. Thus, a computational tool can be a valuable assistance to help the *in-loco* SAR team.

Figure 3 presents the application's initial screen. On the left panel, the operator enters the initial information about the incident, comprising the vessel, last known position, date-time of the last position, and the date time used to forecast. Additional information regarding wind, leeway, sea currents, and errors is entered in the central panel. The right panel presents the results in a tabular or graphical format, as shown in Figure 4.

The standalone tool is easy to use: after the data entry, the user should press the *Calcular!* (Calculate!) button on the left panel to perform the needed calculations. The results adhere to IAMSAR instructions, despite the tool's simplicity, which helps to deal with the special geographical characteristics, as mentioned by Wang [9], and using the *geosphere* package to improve the user awareness of the incident by allowing automatic plot of the SAR area on the map – as shown in Figure 4 (right). Although performing a sensitivity analysis of the wind parameter is out of the scope of this paper, the IAMSAR model considers the object's shape in the sea, suffering drift from wind and sea currents. Variables such as the average *wind* and *sea current* speed, direction, and error) compose the Leeway components.

5. Discussion

Developing the IAMSAR Validation Tool and a standalone SAR application in R has significantly contributed to the SAR decision-making process in the Brazilian Navy. The R *geosphere* package offers a direct conversion of geographical coordinates and rhumb/distance calculations in an automated manner, which reduces human influences and cognitive demands during manual calculations. This feature is critical in SAR decision-making, as it eliminates errors and potential biases that could interfere with SAR outcomes, as previously discussed by Wang [9].

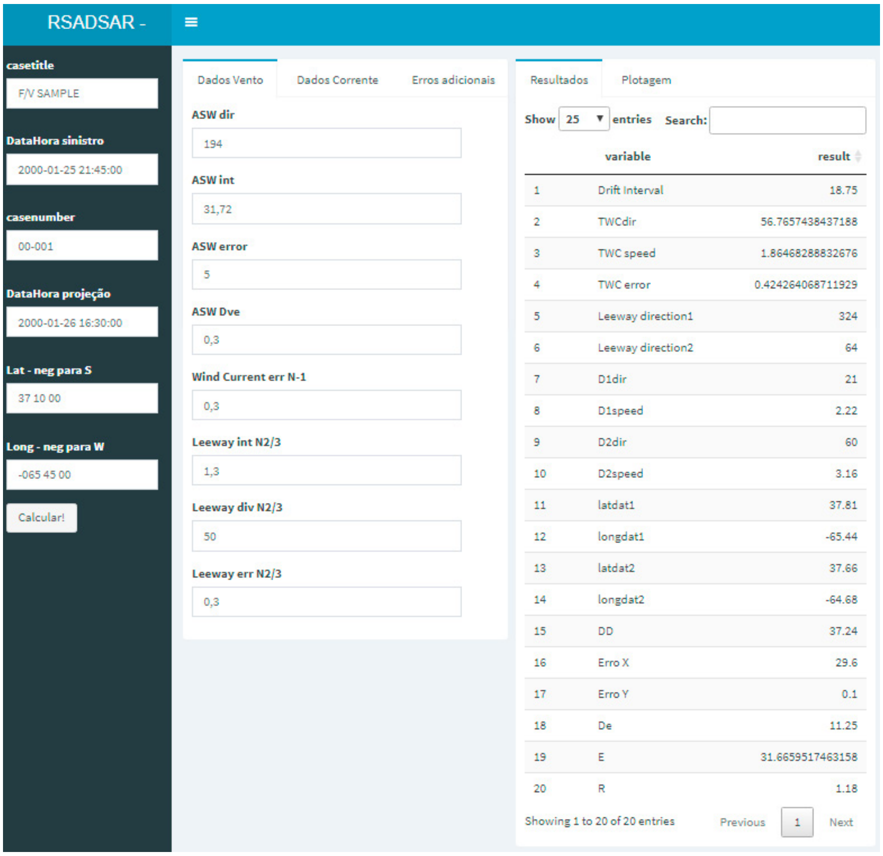

Fig. 3. The standalone application initial screen.

	variable	result
1	Drift Interval	18.75
2	TWCdir	56.7657438437188
3	TWC speed	1.86468288832676
4	TWC error	0.424264068711929
5	Leeway direction1	324
6	Leeway direction2	64
7	D1dir	21
8	D1speed	2.22
9	D2dir	60
10	D2speed	3.16
11	latdat1	37.81
12	longdat1	-65.44
13	latdat2	37.66
14	longdat2	-64.68
15	DD	37.24
16	Erro X	29.6
17	Erro Y	0.1
18	De	11.25
19	E	31.6659517463158
20	R	1.18

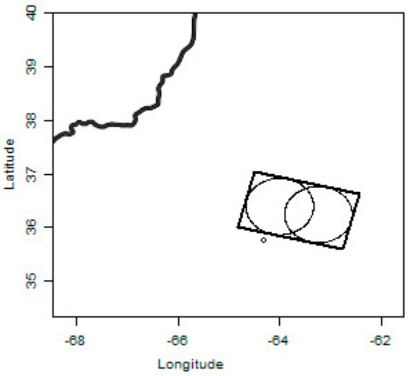

Fig. 4. Results in the tabular format (left) and graphical format (right).

In addition to reducing human influences, the IAMSAR Validation Tool and standalone SAR application offer fast execution compared to manual calculations. This increased speed enables expedited updates of the probable location due to wind and sea effects, contributing to survival search. Lee and Morrison [10] have previously discussed the importance of this feature, emphasizing that it is critical to SAR outcomes.

The IAMSAR Validation Tool and the standalone SAR application are complementary to improve SAR decision aid systems. Both provide an IAMSAR-based calculation, allowing for the quick comparison of the calculation of the datum, errors, and partial results. However, they offer even more practical contributions, such as being easy to operate, requiring modest computational resources, and being based on free software.

The IAMSAR Validation Tool offers several features to validate a SAR system. The tool provided a simplified input-output methodology, using a spreadsheet file with details of the SAR event and expected SAR area, allowing for the verification of multiple cases simultaneously. Overall, the Validation Tool offers a streamlined and efficient approach to the search phase of a SAR operation, making it a valuable asset for any search and rescue team.

The standalone SAR application can estimate the SAR area aboard ships without an internet connection. This feature is particularly useful as it can reduce the required time to update SAR calculations. Overall, the standalone SAR application in R is valuable to the SAR decision-making process and offers practical solutions for SAR support aboard ships.

6. Conclusion

The Brazillian maritime SAR area is extensive. The Brazilian Navy promotes, coordinates, and controls SAR services in ports, inland waterways, Brazilian jurisdictional waters, and seas areas established by international convention. In this work, we presented a computational tool that validated the new SAR decision support system of the Brazilian Navy, using the search calculation models contained in chapters 4 and 5 of Volume II of IAMSAR Manual. We also presented a standalone application that runs as a naval shipboard application, helping ships without direct access to the SAR system.

Optimizing techniques for SAR services is of utmost importance to achieve the desired results in a minimal time. We hope that the presented tools can improve SAR services in Brazil and other countries and assist in saving more lives in distressed situations. Continued research and development of SAR optimization tools are crucial to improving the effectiveness of these services, reducing costs and time in the SAR operation to save more lives.

Although our work is focused on implementing a standard algorithm, the standalone application can be an easy-to-operate decision aid, requires modest computational results, and is based on free software. Despite its simplicity, it can contribute as a standalone tool for SAR support aboard ships without an Internet connection.

Future work can be devoted to enhancing the user experience concepts of the software interface. Other desirable features are related to search planning aspects. Upgrades may provide search pattern plans adapted to meteorological conditions and the defined search area. Additionally, the standalone application and the validator should be updated yearly to the latest version of the IAMSAR Manual. We can also use these tools to evaluate the IAMSAR model by analyzing real data and proposing changes to improve its accuracy.

Acknowledgements

We would like the Sistram project, from the Brazilian Navy, for information support and the SIPLOM project, from the Brazilian Ministry of Defense, for financial support.

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