Scenario analysis as a decision-support tool: a maritime patrol case study

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***Abstract* — This article argues for the use of scenario analysis as a decision-support tool, regarding incentives and investments on either the development or the acquisition of new military systems. In particular, it presents a study on the maritime patrol operations scenario with the availability of synthetic aperture radar satellite images during its planning process. Through a proper analysis, the images may serve as a powerful subsidy for enhancing mission effectiveness and reducing costs. The effectiveness may be measured by the number of encountered vessels and the cost reductions may come from the fewer flight hours necessary for the mission through path optimization. As a conclusion, not only it is possible to observe clear improvements on the mission success, but also the potential this kind of analysis has for force sizing and capacity development.**

***Key words* — Scenario analysis, Optimization, Maritime patrol.**

I. Introduction

The growth and development of the Armed Forces is closely related to the optimization on the employment of its means. In this context, the analysis of the incorporation of new technologies on diverse operational scenarios has great value in terms of either effectiveness enhancement or cost-reduction.

This paper presents an initial study on the impacts and consequences of the insertion of new technologies in Brazilian Air Force maritime patrol scenario. Studies like this may serve as a powerful decision-making tool, basing decisions regarding the incentive and investment on either the development or the acquisition of new military systems.

In particular, the synthetic aperture radar (SAR) satellite images are analyzed as a planning support tool for the maritime patrol missions detailed on the following sections of this work.

The second section of this paper presents the general maritime patrol mission as the Brazilian Air Force currently performs it, illustrating how the same mission could be performed in case synthetic aperture radar enabled satellite images were available during planning and execution. The third section proposes a methodology for evaluation of the operational impacts of those images. The fourth section presents the results obtained through the proposed methodology and the fifth section finally draws conclusions from these results, pointing some future developments that may be conducted from this study.

II. Maritime Patrol Operations

The mission of the maritime patrol aviation is to watch over the Brazilian territorial waters, detecting and identifying objectives according to its assignments. Among diverse factors to be considered during mission planning, the knowledge about a Naval Force (NF) and its military capacity are the preponderant aspects to define the tactics of search and attack, according to the doctrine adopted by the Brazilian Air Force. The surveillance of extensive areas such as the Brazilian coast as well as its Exclusive Economic Zone (EEZ) is a operational and technological challenge to the Armed Forces, where the initial uncertainty about the location of the NF jeopardizes mission success, that is finding the NF and staying out of its weapons range.

Under this view, there is a need for gathering intelligence information to anticipate the positioning of each and any element within this maritime theater of operations, investigating from the macro scenario (with observations of a large region from the space) to the micro scenario (with air and naval means) [1]. Synthetic Aperture Radar (SAR) enabled satellites are a fundamental tool for surveillance, since they present the capacity of generating images day and night, virtually under any meteorological condition.

With the satellite images at hand, it is possible to trace an optimized path for the aircrafts to perform. Moreover, there is no need to investigate the area in the sense the vessels' positions are known beforehand, focusing on their identification.

III. Scenario Evaluation Methodology

The modeled scenario states that a given aircraft should leave an origin airfield, visit exactly each of the previously identified vessels, and land on another airfield, which may be the same as the first one. To encompass the gains the satellite information may bring, it is imperative to obtain the optimized route, which is the tour of minimal length, defining then a traveling salesman problem. This is a classic NP-complete problem, commonly modeled as an undirected weighted graph, containing information regarding the distances that may be utilized as a solution to the minimization problem.

In this class of problems, it is hardly possible to find deterministic algorithms for optimal solutions with a computational effort being proportional to any power of the system size [2]. This is the reason why several powerful optimization methods of approximation have arisen as an alternative to the costly exact solutions, such as Ant Colony Optimization [3], Christofides Algorithm [4], Simulated Annealing, and Metropolis Algorithm [5].

We adopted an evolutionary search algorithm called Extremal Optimization (EO). This is a general-purpose heuristic based on non-equilibrium dynamics of large fluctuations that rearrange major parts of the system, also know as “avalanches”, which potentially make any configuration accessible, avoiding local minima [Boettcher].

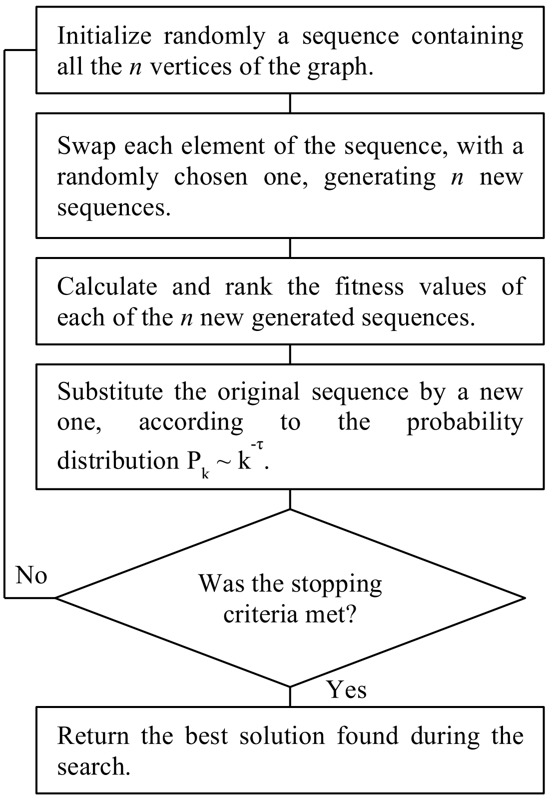

Fig. 1. Extremal Optimization with Swap Mutation.

In this particular application, swap mutations were utilized as a means to generating new sequences. Besides, the τ-EO variation of the traditional was employed to allow a parameterization of the “avalanches”.

The heuristic was implemented on a computational framework called AEROGRAF, developed by the Brazilian Air Force Institute of Advanced Studies (IEAv). This is a C++ coded platform that enables either calculations or visualizations of operational scenarios.

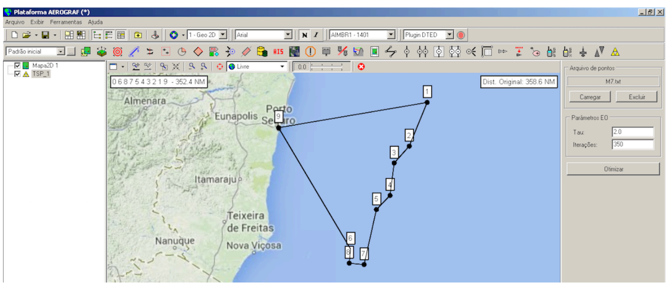

Fig. 2. AEROGRAF view of optimized path

A plugin was developed during this study incorporating the proposed extremal optimization methodology. This plugin reads from a dataset that contains the geographic information of the airfields from and to the aircraft flew as well as the vessels’ locations found on a given mission. Then it plots on a georeferenced fashion all these points, being visualized on a map. Concomitantly, it builds the distances array that characterizes the traveling salesman problem graph. After performing the steps presented in Fig. 1, it draws the graph edges that illustrate the minimum path to connect all the vertices. It also shows the path length in nautical miles and the vertices sequence.

From the path length, it is possible to calculate the estimated time to perform the mission, considering the aircraft average speed. This time may be compared to the real time flown, providing means of quantitatively evaluate the cost-reduction and effectiveness.

IV. Results

The first set of results consists of optimized paths from real maritime patrol mission reports. These logs state the location of the vessels at a given time.

We selected ten mission reports; presenting seven, eight, or nine encounters as presented in Table I and II.

TABLE I Results for missions with seven vessels

Number of Vessels	7	7	7	7	7
Optimized Path (NM)	531	408	453	441	664
Optimized Time	2:57	2:16	2:31	2:26	3:41
Investigation Added Time	3:47	3:06	3:21	3:16	4:31
Mission Time	4:05	3:20	3:40	4:05	5:10
Time Reduction	0:18	0:14	0:18	0:48	0:38

TABLE II Results for missions with eight and nine vessels

Number of Vessels	8	8	8	9	9
Optimized Path (NM)	499	451	659	406	519
Optimized Time	2:46	2:30	3:39	2:15	2:53
Investigation Added Time	3:41	3:25	4:34	3:15	3:53
Mission Time	4:30	4:05	4:50	3:45	4:05
Time Reduction	0:48	0:39	0:15	0:29	0:11

The values presented on the Time Reduction line state the difference between the informed hours flown and the optimized path added by a five minute investigation time for each vessel found and a fifteen minute take off and landing time. An example of route is presented in (Fig. 2)

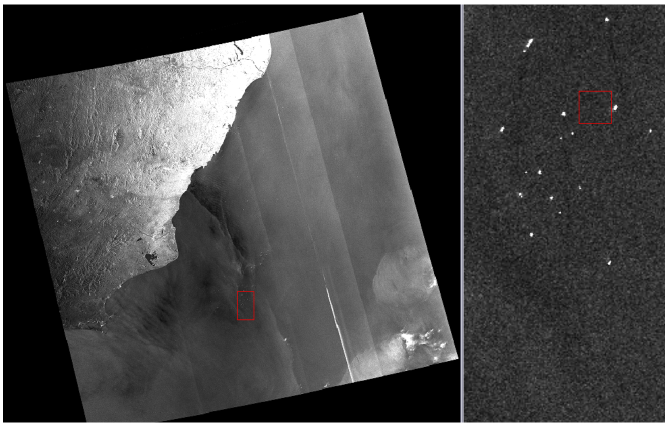

Fig. 3. SAR image of a targeted area.

Besides the time reductions coming from path optimization, there is an even more significant advantage of using SAR satellite images. There is a potential of greatly increase the number of vessels encountered with no or little time increase.

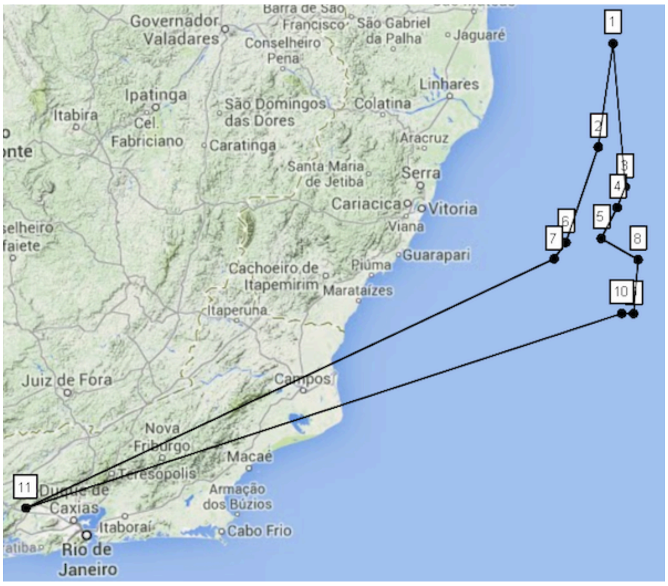

Fig. 4. Original approximated mission path.

Considering the identified vessels from the satellite image (Fig. 5), the mission could be performed according to (Fig. 6), greatly increasing the mission effectiveness.

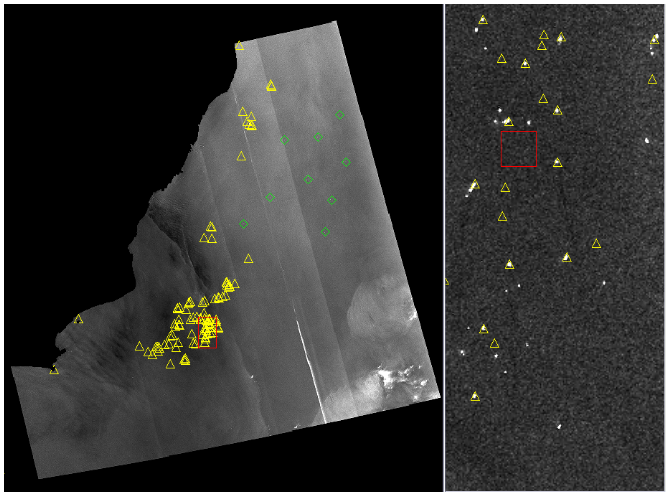

Fig. 5. Extremal Optimization with Swap Mutation.

For quantifying this advantage, we present a satellite image that was taken right before a real maritime patrol mission (Fig. 3). The mission plot with its optimized path is showed in (Fig. 4).

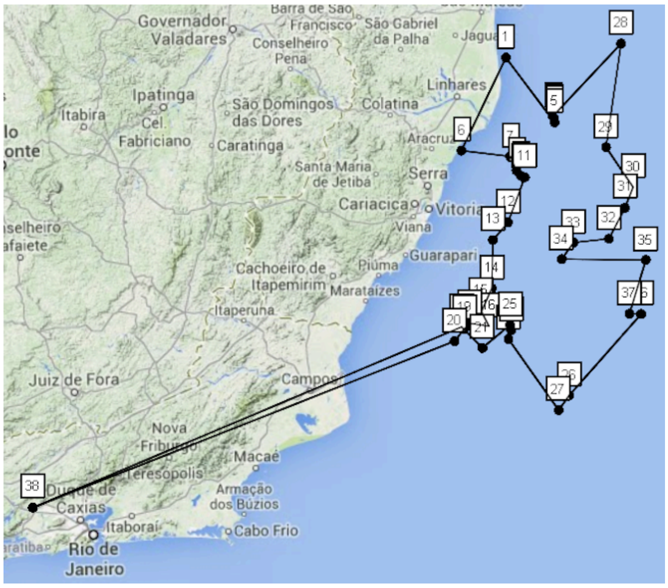

Fig. 6. Extremal Optimization with Swap Mutation.

After running twenty times the optimization heuristic algorithm, the average path was 1055,9 NM, with the minimum of 1048,1 NM. This represents an approximate 27% increase relative to the 837,7 NM from the original number of vessels encountered in the maritime patrol mission flown, generating almost 4 times the number of vessels, since it takes to 38 the original number of 10.

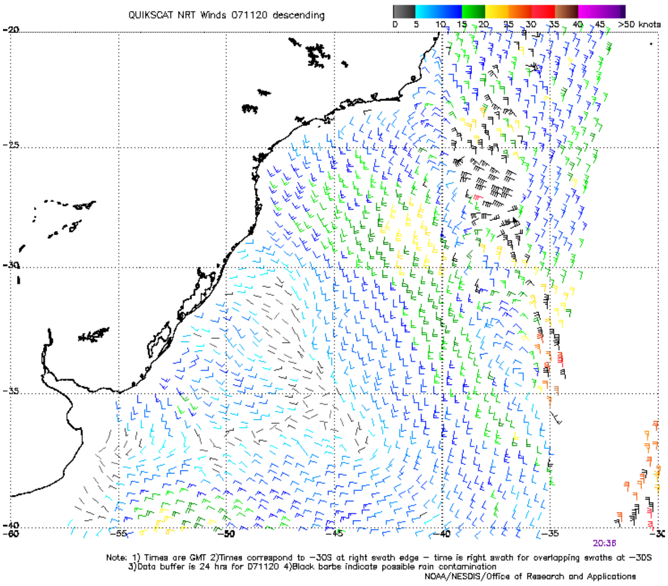

Fig. 7. Wind distribution before the mission.

It is interesting to note that weather conditions at the mission time were not favorable for an imaging effort, as showed by wind (Fig. 7) and cloud (Fig. 8) formations.

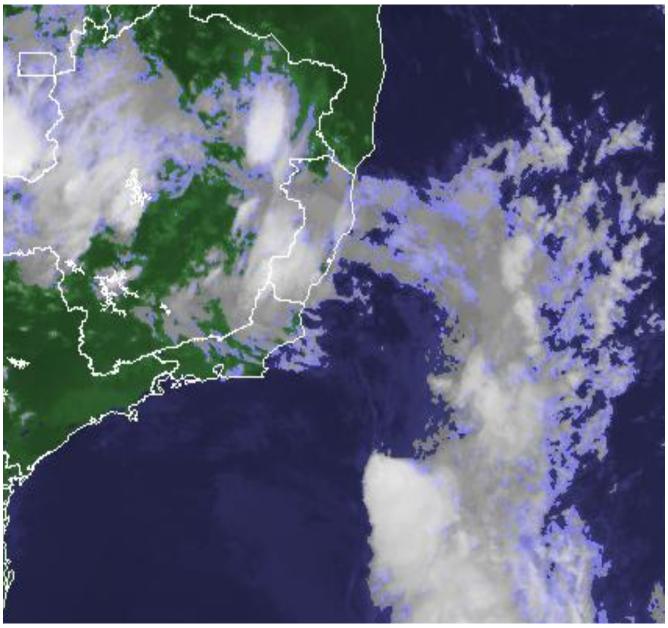

Fig. 8. Cloud formations before the mission.

V. DISCUSSION AND CONCLUSIONS

From the last section, it is possible to draw several conclusions regarding the SAR satellite images availability impact on maritime patrol air missions.

First, with the presented dataset from those missions, it was possible to obtain considerable time reductions, which result on less flight hours and, consequently, less fuel, crew and maintenance costs.

Second, considering the presented satellite image, the mission effectiveness was greatly increased with a little increase on flight hours, finding many more vessels.

Lastly, there are conclusions about the decision process that may be drawn. The scenario created shows that a new technology – SAR satellites – may have a great impact on the Air Force operations. This is extremely valuable considering that this technology is costly and could not be fully tested without spending large sums. Therefore, a computational analysis may provide good subsidies for taking a decision in this field, or even taking the next step on evaluating the new possibilities the technology may bring.

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