Allocation of SABER M-60 Radar Units in Antiaircraft Defense Operations

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Abstract — This study aims to improve the method of allocating SABER M-60 radar units used by Air Defense Groups. The SABER M-60 is a mobile radar developed for low altitude Antiaircraft defense and used by the Brazilian Air Force in peacetime operations and simulated war exercises. Due to the equipment short period in service, acquired in 2013, its employment doctrine has not yet been fully developed, so there are opportunities for improvement. Therefore, it was proposed an application of theoretical principles of Combinatory Optimization Problems, specifically the concepts of a Maximum Coverage Location Problem (MCLP), for the planning of radar allocation. The study revised the Brazilian Air Force (BAF) Antiaircraft defense and SABER M-60 manuals to identify the factors that should be included in structuring the problem. The MCLP concepts and the relevant factors were then organized in a programming environment, of R language, so that simulations could be made involving different parameters and resolution methods. With the results obtained, it was verified that, in fact, it is feasible to structure a SABER M-60 radar allocation as a MCLP. However, the heuristic methods, which are algorithms developed for the MCLP, cannot guarantee the optimality of the solution.

I. INTRODUCTION

Brazil has a network of radars throughout the territory that make up the Brazilian Airspace Control System (SISCEAB). In order to complement this system, the Brazilian Air Force (BAF) acquired the SABER M-60 (Air Target Monitoring Sensor Based on Radio Frequency Emission) radars. It is a modular radar designed to integrate a low-altitude Antiaircraft Defense system, aiming to protect Sensitive Points (P Sen) and Areas (A Sen) and can be classified as a search and surveillance radar.

As it is an equipment with recent implementation, there is still room for improvement in its operational tactics, techniques and procedures (TTP). That said, the following question can be made: what is the most efficient way to allocate the SABER M-60, considering its purpose of use? Problems of this nature can be addressed using the theoretical principles of Combinatorial Optimization Problems. In order to guide this study, the following objective was defined: to propose a method for the allocation of the SABER M-60 radar units based on a Maximum Coverage Location Problem (MCLP).

II. RADAR ALLOCATION

The process of positioning Antiaircraft Defense assets is governed, within the scope of the Brazilian Armed Forces, by specific manuals in this area such as [1], [2] and [3]. The allocation of a radar is a complex task that requires the consideration of several conditions: number of available radars; threats to be faced; probable routes of attack; 360º coverage – situation where the radar has a maximum range in all directions –; overlay – when using more than one radar, they must provide adjacent coverage –; and position of the antiaircraft weapons [3]. At this point, it is worth noting that an allocation of search and surveillance radars, aiming exclusively at the largest covered area possible, should not necessarily be understood as the best allocation, as Fig 1. shows probable routes of attack in red.

Fig. 1. Representation of the theoretical coverage of a radar network.

III. MAXIMUM COVERING LOCATION PROBLEM (MCLP)

The Maximum Covering Location Problem (MCLP) seeks to maximize the population served within a distance or length of service, in relation to an existing demand, having a limited number of resources for this [4]. The MCLP can be defined mathematically as shown below [4]:

Objective Function: Maximize $z = \sum_{i \in I} a_i y_i$ (1)

subject to:

$$\begin{cases} \sum_{j \in N_i} x_j \geq y_i & (2) \\ \sum_{j \in J} x_j = p & (3) \\ x_j = (0,1), \forall j \in J & (4) \\ y_i = (0,1), \forall i \in I & (5) \end{cases}$$

Where:

I = set of demand nodes;

J = set of nodes that receive a facility allocation;

S = distance at which a demand node located beyond it is considered "discovered" (the value of *S* may vary according to each demand node if desired);

d_{ij} = the shortest distance from node *i* to node *j*;

y_i ≡ binary variable that takes on the value 1 if node *i* is covered;

a_i ≡ demand at the vertex *i*;

p ≡ the number of vertices on which the facilities reside.

N_i is a set of possible locations for allocating a facility to cover the demand for a point *i*. A node is only considered covered when the distance between it and the nearest facility is less than or equal to *S*. The solution to the problem comprises both the largest population that can be served, with the available resources, as well as which places should be provided with facilities in order to achieve this maximum coverage.

To obtain maximum coverage, with a total of *p* facilities, considering their range, the Greedy Adding (GA) algorithm starts with the empty solution set and then adds the best facilities, one at a time [4]. Based on the GA algorithm, the Greedy Adding with Substitution (GAS) heuristic elects new locations at each iteration in the same way as the first one. In addition, the GAS algorithm tries to improve the solution set, also at each iteration, replacing one feature of the solution with another that has not been previously chosen and that will contribute more to the total coverage [4]. In this study, GAS will also be applied with two substitutions, adapting [5] design to a 2-optimal algorithm, similarly to that performed by [6].

IV. DESCRIPTION OF THE METHOD

First, the Sensitive Points, in the scenario, were chosen as the points to be protected. Then, the weights of importance of each P Sen, each sector of the P Sen and each altitude that is within the maximum altitude of the radar are defined. These weights are equivalent to the variable a_i in the mathematical formulation of the MCLP. Then parameters of the threat to be faced were also defined.

In possession of the data above, two more parameters must be determined: the Minimum Detection Distance and Desirable Detection Distance. The first corresponds to the shortest distance at which the enemy must be detected in order to be able to shoot him down before he uses his weaponry. The area formed between these two perimeters, illustrated in Fig. 2, is the threat Detection Zone, a region equivalent to the entire set *I* of the mathematical formulation and where the radar coverage should be maximized by the MCLP.

The radar parameters entered in the simulation were: the maximum and minimum ranges, operating ceiling, opening angle, angular adjustment (tilt) and minimum distance between radars. At last, the parameters of the optimization problem are defined: number of available radars; the resolution that is intended to be adopted, both horizontally and vertically; and the search region for possible radar allocation points. The dimensions of the resolution determine the three-dimensional space that corresponds to a node in the *I* set of the mathematical formulation. As for the radar search region, this corresponds to the lateral dimension of a square area where the highest point will be a candidate point for radar allocation, that is, a node in the *J* set of the mathematical formulation.

The executed code then searches for the highest points of the scenario, according to the size of the areas established by the user. After that, some tests are carried out to check if a point in the detection zone is within the coverage volume of a radar allocated in a candidate position. In these tests it is analyzed if the point is between the maximum and minimum ranges, within the opening angle (considering the tilt) and below the operational ceiling of the evaluated radar. If all requirements are met, that element of the binary matrix will be assigned a value of 1, otherwise, a value of 0. Fig. 3 represents - out of scale - the view of a side section of the radar coverage, indicating the value that the points receive in the coverage matrix according to their position.

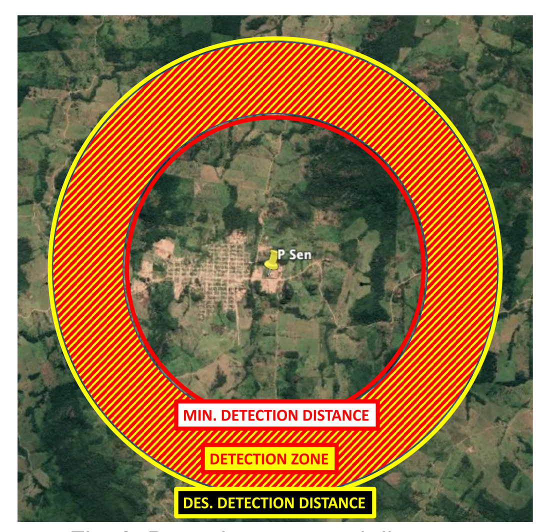

Fig. 2. Detection zone and distances

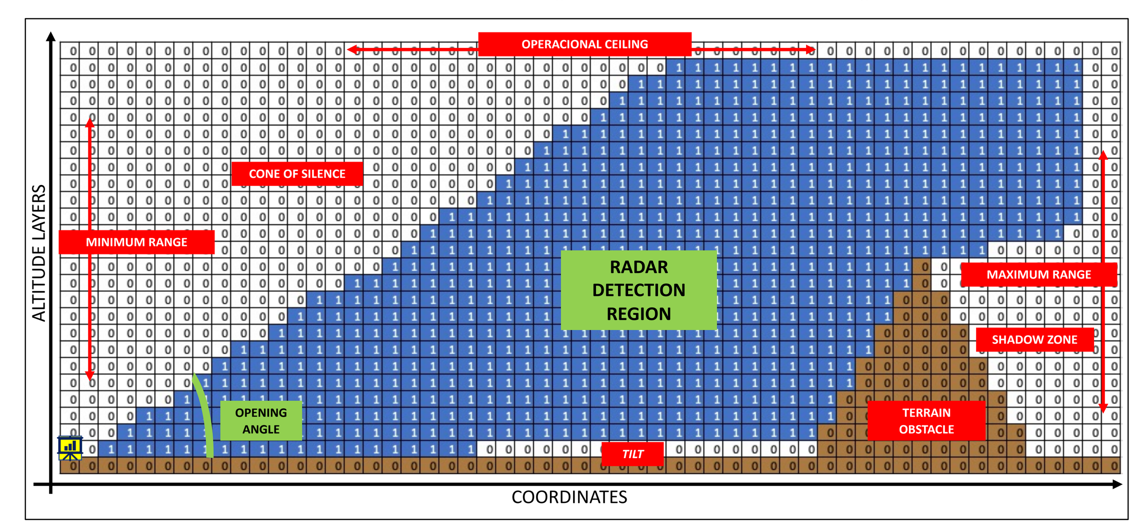

Fig. 3. Illustration of the values of the Binary Coverage Matrix

Finally, the weights (ai) that each point in the detection zone will have in the MCLP are defined. The final weight is the result of multiplying the three weights assigned to the point (the P Sen to which it is associated; the sector in which the point is located; and the layer to which the point belongs). After all those steps, the problem can be solved using the Greedy Algorithms and the obtained results can be compared.

V. RESULTS AND DISCUSSIONS

GAS with one substitution was the algorithm that presented the best performance, in general, followed by GAS with two substitutions and lastly GA. However, it is worth noting that there were situations in which the allocation with the highest percentage of coverage was obtained by GAS with two substitutions or even by GA. The times that each method took to solve the problem were also compared. As could be expected, the tests with the largest number of radars to be allocated were the most time consuming. The resolution that took the longest lasted 14 minutes.

VI. CONCLUSIONS

The general objective was to propose a method for the allocation of the SABER M-60 radar units based on a Maximum Coverage Location Problem (MCLP). It was found possible to structure and solve the problem as proposed. Therefore, the work succeeded in the development of a new method of allocating radars, based on combinatorial optimization and computational programming, which was able to consider several factors together.

Despite the impossibility of guaranteeing the optimality of the choice, given the characteristics of the heuristics methods, the results obtained should not be underestimated. In fact, research like [7] demonstrates that heuristic methods are capable of producing optimal or near-optimal solutions, and on top of that, in a rational runtime.

This methodology can actually assists in the planning and choice of radar installation locations, simultaneously combining several factors, in a reasoned manner. This idea complements [3], regarding the choice of place to install the radar. In addition, when applying the heuristic algorithms GA and GAS, the work complements the content of [8] and [9] which used the heuristic methods, GRASP (Greedy Randomized Adaptive Search Procedure) and Genetic Algorithm, respectively, to solve the problem.

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