SARPlan : A decision support system for optimal planning of Search and Rescue operations

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Abstract

In this paper, we present SARPlan, a decision support system designed to assist search mission coordinators in their task of planning search and rescue operations. SARPlan is a geographic information system dedicated to the optimal allocation of the search effort. By using the available search effort in the way that maximizes the probability of success and reduces the search area, SARPlan can increase the chances of finding the missing aircraft and survivors. We also present some performance results that illustrate the benefits of SARPlan as compared to the current manual method.

1.0 Introduction

Over many years of successful overland Search And Rescue (SAR) operations by the Canadian Forces, procedures have been devised to identify appropriate search areas and to ensure that each is covered adequately. Among the current manual procedures used in Canada to plan searches for aircraft missing over land, we find the Canadian Search Area Determination (CSAD) method. CSAD is intended for use where the aircraft's intended route consists of one or more relatively long, straight lines. Although these methods have proven to be extremely useful over the past years, they do not take advantage of search theory or available computing power, they may not be specifically tailored to the search equipment on hand, and they do not address the optimality issue.

In Canada, Search Mission Coordinators (SMC) are responsible for planning, coordinating, and controlling the response to SAR incidents. Once the SMC has established that a search is to be conducted, he must begin the mission planning. He does this by verifying the resources available, by choosing the resources, by determining the area to be searched and developing a search plan. Time is a crucial factor and mission planning may get complex in the case of a large search area and multiple resources. And yet, most of these tasks are conducted manually without the assistance of an optimal planning system.

At the present time, there exist a few information systems for SAR. These include SARIS (UK, marine) [2], CANSARP (Canada, marine) [3], SARMASTER (Canada, land and marine) [4], USCG SAR tools (Logicon INRI) [9]. Most of these systems were designed for the marine environment. They provide a front-end to a database that the user can query as well as enter information into. Only CASP [1], an American product that runs on workstations, contains modules for optimal effort allocation in the marine environment.

Our objective in this paper is to present SARPlan, a decision support system designed to assist the SMC in the planning of SAR missions. SARPlan is a Geographic Information System (GIS) that provides an optimal allocation of the available search effort. We start in section 2.0 with a brief description of the search theory elements that were implemented in SARPlan. The workings of SARPlan are presented in section 3.0 while section 4.0 compares the evaluation results of both the manual CSAD method and SARPlan. We conclude in section 5.0.

2.0 The search theory within SARPlan

It has been known since the Second World War that significant gains in search effectiveness are achieved through the optimal allocation of the available search resources [8]. In fact, the use of search theory and organized planning doubled the success rates of surveillance mission as shown by Stone [13]. Further enhancements to search theory have been made since Koopman’s original work and substantial advancements in the practical application of search theory to a wide variety of problems have been made in recent years due to the availability of inexpensive computing power. SARPlan benefits from these advances and makes them available in a practical form for use in the optimal planning of overland searches for missing aircraft (aeronautical incidents).

Developing a search plan consists in determining the type of search pattern, the altitude, the desired coverage and the track spacing of the SAR unit assigned to the search. From a search theory point of view, a plan is considered optimal if it maximizes the Probability of Success (POS), which is the probability of finding the search object. The POS is related to two other quantities: The Probability of Containment (POC), which is the likelihood that the search object is contained within the boundaries of some area, and the Probability of Detection (POD) which is the probability of detecting the search object (as a function of effort) given that it is in the area searched. The relationship between these three probabilities is: POS=POC*POD. Figure 1 shows the steps involved in developing an optimal search plan from a search theory perspective. All these steps are supported in our implementation of SARPlan.

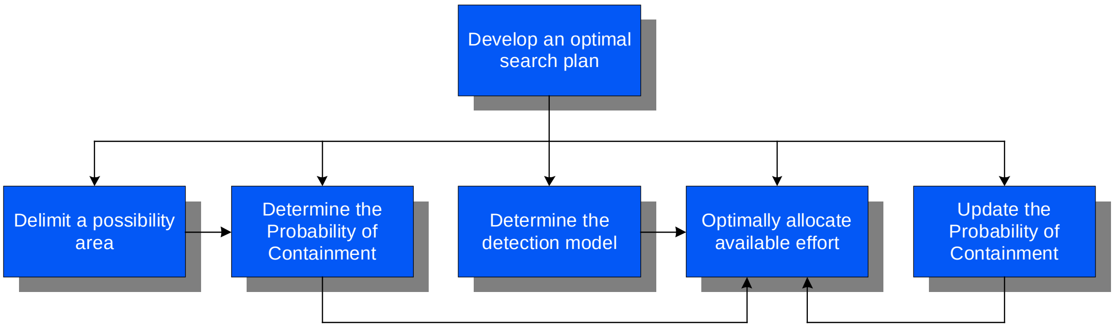

Figure 1 : Developing a search plan

2.1 Delimit a possibility area

Developing a search plan requires the user to first delimit the possibility area most likely to contain the search object. This area may be quite large, and it is not always easy to decide which sub areas to search first and in what order. The IAMSAR manual [7] contains guidance on how to establish this possibility area based on procedures from the ICAO SAR manual [11].

2.2 Establish a probability of containment map

Once the possibility area has been delimited, the next step is to construct a probability map of the whereabouts of the search object. This is a distribution of the probable location of the search object.

2.3 Determine a detection model

Let us define the different quantities used in order to obtain a detection model. These definitions are based on [12]:

- The sweep width W;
- The total effort available z;
- The detection function, POD(z).

<u>The sweep width</u>

This value is a measure of the average detection potential of a sensor under specific conditions. It has the units of a distance, as it is usually expressed in nautical miles for air searches. It could represent the distance on both sides of the Search and Rescue Unit (SRU) where the probability of detecting a target outside of W is equal to the probability of missing the target inside that distance. The ICAO manual provides a table of sweep widths for visual land searches as a function of the search object, the visibility and the altitude of the search aircraft [11].

<u>The total effort available</u>

The total effort z may be measured by track length, swept area, time, or whatever is appropriate. When it represents the distance that may be flown by an available SRU in the search area, it is often expressed in nautical miles.

<u>The detection function</u>

The detection function corresponds to the probability of detection as a function of the effort: POD(z). There are two interpretations to the POD. It can be seen as a measure of a sensor performance: The ability of a particular sensor to detect a particular type of search object under a given set of operational and environmental conditions; or as a measure of how well an area has been searched [12].

2.4 Allocate available effort

In this context, developing an optimal plan for given total search effort *f* is equivalent to allocating this effort in the possibility area such that we maximize the probability of success POS. The optimization problem may then be formulated as follows:

$$\text{Maximize } POS = \sum_{j \in J} POC(j) POD(j, z(j)) \quad \text{subject to: } z = \sum_{j} z(j)$$

where $POC(j)$ is the probability that the search object is in cell j of the possibility area J that is divided into cells, $z(j)$ is the search effort in cell j, and $POD(j,z(j))$ is the detection function in cell j.

3.0 SARPlan, from inside

We developed SARPlan to help the SMC put the pieces of the search theory puzzle together and to allow him to use his resources in an optimal fashion. While the ultimate goal of any SAR operation is first and foremost saving human lives, SARPlan provides an added value by making efficient use of available resources. SARPlan is designed to suggest to the SMC optimal search mission parameters such as: A search area, altitudes, tracks spacings, the number and types/origins of the SRU.

The basic entity handled by SARPlan is the possibility area represented by a grid with a certain number of cells of a fixed size. We then superimpose on this grid information layers of many types such as Vegetation, Topography, POC, POD, POS, Effort, and Coverage. Figure 2 presents the data flow between the SARPlan modules that manipulate these information layers.

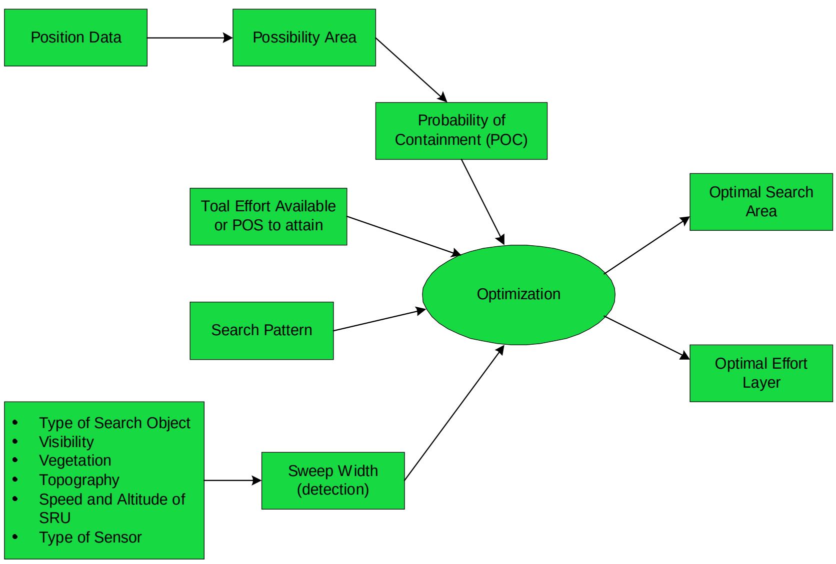

Figure 2 : Data flow in SARPlan

The initial position data on the Last Known Position (LKP), the destination, as well as an error estimate for the LKP are used as input in order to build the possibility area and the POC. The detection capability of the sensor is characterized by its sweep width under specific environmental conditions. The search pattern is an input to the optimization modules as it determines the algorithm for computing the POD(z). Various effort allocation algorithms may be used. For example, if the optimization criterion is to maximize the POS, then the user must provide the total available effort. If the user wishes to attain a certain POS, then he must enter the distribution of POS for which he wants a recommended effort allocation. In any case, SARPlan will produce as an output an effort distribution.

Information layers may be generated automatically or they may be built manually. The user can construct his layer by defining zones, a collection of cells with similar features, and assigning values to these zones. SARPlan contains three main modules for achieving these operations: A possibility area module, an information layer definition module, and a search operations module. We describe each of these modules below.

3.1 Possibility Area module

There are two ways to build a possibility area: Manually, where the user delimits the area, and automatically. The automatic possibility area generation is based on spatial reasoning. This feature, currently under development, is to generate various possible scenarios of what happened to the missing aircraft, where and why. The main spatial factors considered are the visual landmarks, the terrain topography, the cloud cover, the visibility, the plane's autonomy, the pilot's experience and habits, and the popular VFR (visual flight rules) routes. Credibility measures are assigned to these scenarios and weights are used to merge the various scenarios into the most likely one.

3.2 Information layer creation module

Once the possibility area has been delimited, the vegetation and topography within the possibility area must be characterized. These information layers are necessary input to the detection models and the computation of the sweep width. These layers may be generated automatically by using vector data of the VMAP type.

3.2.1 Sweep width layers

Once the necessary input layers that affect sweep widths have been created, namely the topography and vegetation layers, the user can generate the sweep widths. Other inputs include the type of detection profile, visual, for example, the weight of the search object, the on-scene visibility and the altitude of the SRU.

3.2.2 Probability of Containment layer

Once the elements for describing the detection model have been completed, the next step is to quantify the distribution of the search object location. Three methods for computing the POC are currently available: The point datum, the line datum and the area datum. At any time, the user can build his POC manually. This approach may be pertinent if the SMC has some information that may lead him to believe that certain locations are more probable than others.

3.3 Optimizing with SARPlan

SARPlan was mainly designed to recommend the optimal search areas and how to apply the available effort. It can also tell the user how much effort is necessary to achieve a certain probability of success. Many optimization algorithms are implemented. These include unconstrained optimization, constrained nonlinear optimization, Constraint Satisfaction Programming (CSP). The algorithm used for determining the optimal search areas is based on CSP [6]. However, the user may choose to delimit his own search areas and obtain from SARPlan how the available effort should be applied within these areas. In this case, the computations are based on the Nelder-Mead algorithm. We use penalty functions to ensure that the total available effort is not exceeded and that the effort is always positive.

Finally, it is important to note that the user can do a what-if analysis. As a matter of fact, the user can generate manually his own effort distributions and ask SARPlan to evaluate and compare them.

4.0 The manual CSAD method versus SARPlan

The CSAD method currently in use the SMC is based on a survey of 76 known aircraft incidents that occurred in the years 1981 through 1986 and whose intended routes met the requirements cited above (*c* . subsection 1.0) [10].

4.1 CSAD Areas

The CSAD method was developed based on the known crash sites and their relationship to the aircraft's intended track. Based on an analysis of this historical data, CSAD defines two probability areas to be searched. These areas are presented on Figure 3.

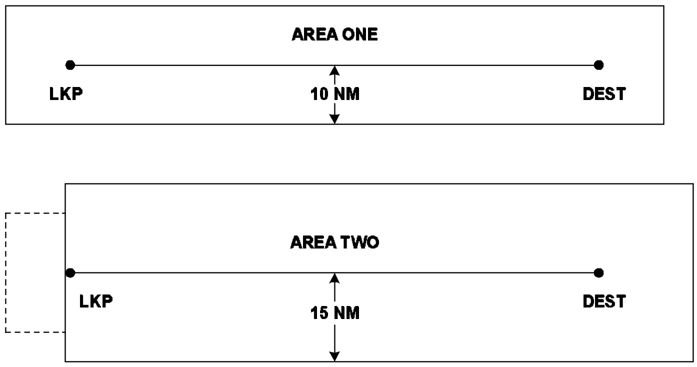

Figure 3 : CSAD Areas

The CSAD search strategy proceeds in three phases. Phase I is an initial effort that can be mounted quickly and requires little advance planning. Phase II is concerned with searching Area One and Phase III is concerned with searching Area Two. Due to space limitation, we will restrict our discussion to the Phase I.

4.2 Tests to evaluate SARPlan

The tests we present were developed by an independent company mandated to evaluate SARPlan [5]. We present here the tests applied to compare Phase I-a of the CSAD method and SARPlan. The POC used is based on the data that led to development of the CSAD [10]. Using this POC will favor CSAD. We represent this POC on a grid of 6 x 24 cells, each cell measuring 5 NM on a side. This grid represents the probability density distribution around a track that is 100 NM in length, starting on the longitudinal centerline 10 NM inside one end of the rectangular grid area and extending to 10 NM beyond the destination.

Having quantified the POC, we defined a sweep width layer with a constant value of 2.0 NM. This corresponds to a visual search of an aircraft of less than 5 700 kg and a SRU searching at 100 knots at an altitude of 2 000 feet and a visibility of 10 NM over a flat terrain with little vegetation. Using a constant sweep width actually favors the CSAD approach since it cannot take into account a variable sweep width.

The next step is to evaluate the POS of the strategy proposed by CSAD. The initial CSAD search would recommend in this case to apply 200 NM of effort to conduct a search along the intended track between the LKP and the destination as shown on Figure 5. The POS obtained from evaluating this search is 20.0%. SARPlan would have recommended the search area of Figure 6 thereby yielding a POS of 25.1%. The SARPlan approach concentrates the effort in a smaller area with a better coverage such that the chances of locating the search object are higher.

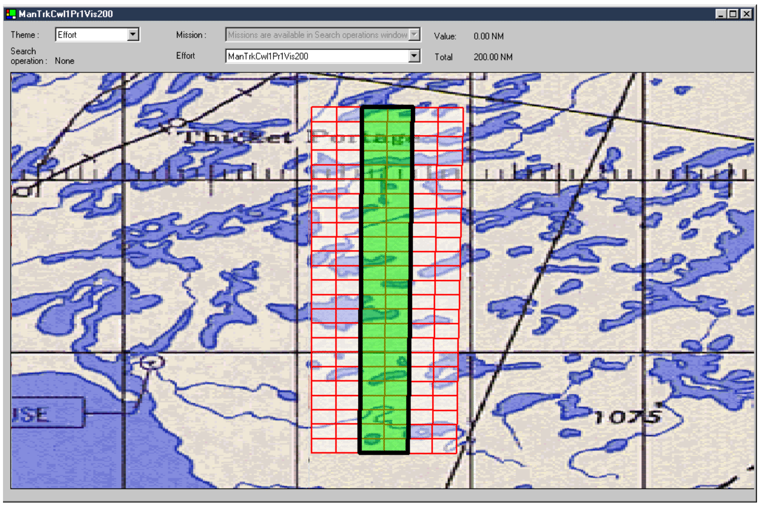

Figure 5 : Effort distribution following CSAD method (Phase I-a)

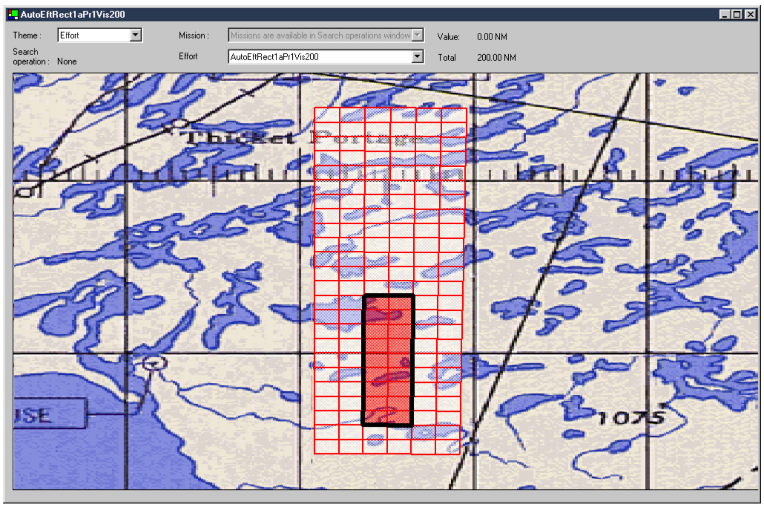

Figure 6 : Optimal effort area as suggested by SARPlan (Phase I-a)

After having evaluated each of the CSAD and the SARPlan search plan for phase 1-a, we computed their posterior POC respectively. This is the updated POC as a function of the unsuccessful effort that was expended. As the next step, CSAD would recommend to search in the vicinity of the LKP and the destination. Figure 7 shows the part b of CSAD Phase I using 200 NM while Figure 8 displays the search area recommended by SARPlan.

The POS of the CSAD 1-b effort distribution using the posterior POC, the same sweep width and the parameters "Parallel" and "Visual" is 11% while the corresponding SARPlan POS is 17.3%. This brings the total CSAD POS to date for the track-crawl and the vicinity searches after 400 NM to 31.0% and the total SARPlan POS for 400 NM to 42.4%.

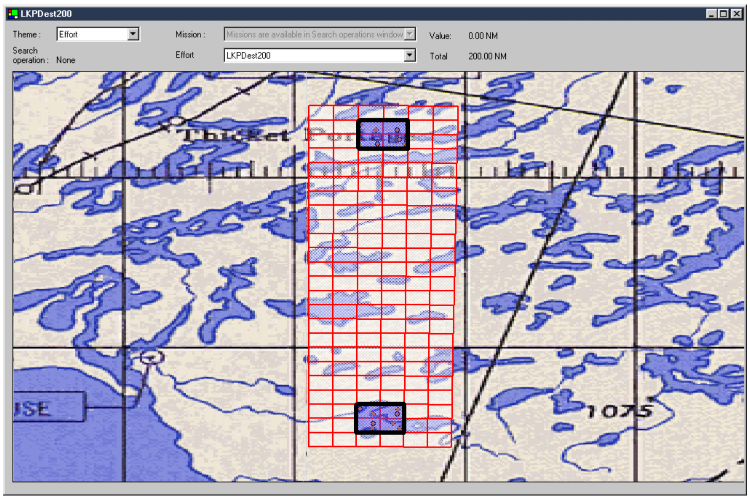

Figure 7 : Effort distribution following CSAD method (Phase I-b)

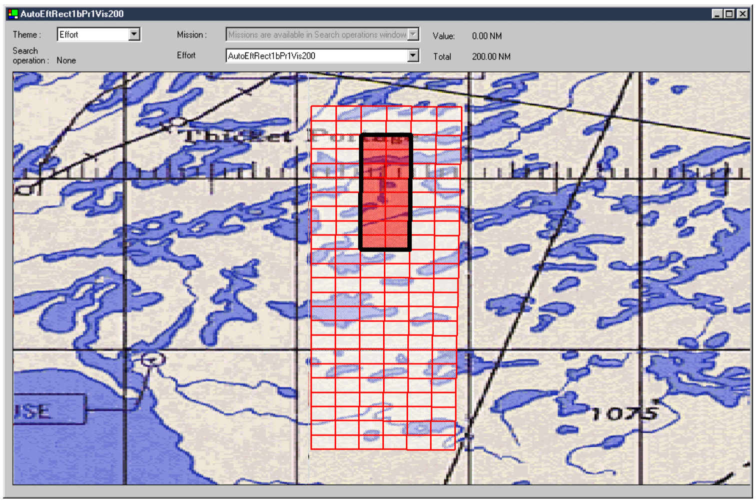

Figure 8 : Optimal effort area as suggested by SARPlan (Phase I-b)

4.4 Comparing the results

We summarize in Table 1 the results of other tests conducted with SARPlan. In the first test, we evaluated the POS of Phase I-a and b. We found a cumulative POS of

31%. If we let SARPlan decide where to put the effort, we get a cumulative POS of 42.4%. The SARPlan figures (6, 8) presented in the previous section were obtained with the rectangle algorithm. If we apply to the same inputs, another algorithm, namely the effort map algorithm, SARPlan can even improve its POS (a total of 44.7%). Finally, instead of spending 200 NM 2 times as CSAD recommends, SARPlan would have allocated in one search the 400 NM available. This results in a POS of 46.3% for the map algorithm and 41.2% for the rectangle algorithm. This allocation will always be better for the survivors whose chances of being found alive decreases with time. It is always better to apply all the available effort right away, and SARPlan would have prescribed to do so.

Table 1 : Simulation parameters and comparative results

Simulation parameters
Sweep width W = 2.0 Type of search = Parallel Detection profile = Visual

Effort (NM)	**POC**	**POS**	**Cumulative POS**	**Improvement**
200 (Phase I-a) CSAD	CSAD POC	20.0 %	20.0 %	
200 (Phase I-b) CSAD	updated CSAD POC	11.0 %	31.0 %	
200 (Phase I-a) SARPlan map	CSAD POC	30.7 %	30.7 %	53.5 %
200 (Phase I-b) SARPlan map	updated CSAD POC	14.0 %	44.7 %	44.2 %
200 (Phase I-a) SARPlan rect.	CSAD POC	25.1 %	25.1 %	25.5 %
200 (Phase I-b) SARPlan rect.	updated CSAD POC	17.3 %	42.4 %	36.8 %
400 (Phase I) SARPlan map	CSAD POC	46.3 %	46.3 %	49.4 %
400 (Phase I) SARPlan rect.	CSAD POC	41.2 %	41.2%	32.9 %

It is worth noting that the manual method, while quite simple, is not very flexible. It cannot take into account the characteristics of the terrain, the sensors and the search object. It does not address the issue of varying sweep widths on the effort allocation strategy. Furthermore, the question of how to allocate the available effort when it is either greater than or less than that is prescribed by the "standard" search is not addressed. Unlike the manual methods, SARPlan addresses all these issues.

5.0 Conclusions

We have presented SARPlan, a geographic decision support system for planning SAR missions. Its main features have been described and results obtained from both the current CSAD manual method and SARPlan have been compared. Although the tests presented are biased towards CSAD, they have nevertheless shown that SARPlan improves planning by producing search strategies with higher probabilities of success.

Future technical work includes extensive evaluation of search strategies with variable sweep width and more accurate POC. In addition, we also plan to extend our optimization algorithms to handle multiple criteria. These algorithms will take into account the type of SRU, its capabilities, its transit time, the type of sensors available and the associated costs. The algorithms will optimize with multiple SRU and de-conflicting constraints.

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