Defence Science Journal, Vol. 71, No. 3, May 2021, pp. 410-417, DOI : 10.14429/dsj.71.13902


# Resources Package Modelling Supporting Border Surveillance Operations

F.A. Cardoso[#,*], F.T.M. Abrahão[#], and W.B. Saba[@]

[#]*Aeronautics Institute of Technology, Brazil*
[@]*São Paulo State Technological College, Brazil*
[*]*E-mail: cardosoaf@yahoo.com.br*

**ABSTRACT**

The purpose of this work is to propose a military planning tool capable of providing logistical bases and patrol packages to most effectively support border surveillance. Presently, military patrols are employed along geographical borders to combat transnational crimes; acts such as drug trafficking, smuggling of goods and illegal natural resources exploitation. The patrols make temporary stops within specific time windows at specific places characterised by a high incidence of crime (hotspots). These hotspots have different criticalities within given time windows. To optimise the results, the proposed model allows additional stops in more critical hotspots. It achieves this using a mathematical optimisation model. Considering that there are not adequate logistical-military capacities (logistical bases and patrols) at all needed locations, developing a border surveillance plan that optimises resource use is imperative. The model was run using black hole-based optimisation and a real patrol mission's database to ensure timely solutions. The solutions were then evaluated in terms of quality (number of bases and patrols, coverage efforts, and travel time) and computational processing time. Next, they were compared with solutions using the traditional method, thereby demonstrating the model's robustness in providing timely surveillance schemes that ensure high coverage with minimum resources.

**Keywords:** Military patrol; Logistical base; Maximal covering patrol routing problem; Black hole-based optimisation

## 1. INTRODUCTION

In response to the growing challenges of homeland security, Brazil has mobilized and supported its military forces along its geographic borders, in order to combat transborder and transnational crimes, such as drug trafficking, smuggling of electronic products, traffic of people and wildlife, illegal immigration, unlawful extraction of natural resources, and clandestine mining activities[1-2]. Military forces are employed at borders to conduct surveillance, enforcement, roadblocks/checkpoints, and other crime suppression operations[3-4]. These searches are performed within specific time windows in places called hotspots, characterized by a high incidence of crime, each of them having different criticalities – probabilities of detecting criminal activities within a given time window.

Military bases in the border segments provide the logistical support to garrisons involved in those constabulary operations[5]. A problem, however, is that there is not a logistical-military capacity in all needed locations, and so the establishment of temporary bases has become imperative. This requires developing a border surveillance plan that can define:

(i) A minimum number of patrols to visit all hotspot
(ii) A minimum number of logistical bases on which these patrols should be allocated
(iii) The allocation of all patrols assigned to the surveillance operation
(iv) Each patrol's start and end surveillance times
(v) Each patrol's route to reach the designed hotspot and
(vi) Arrival and departure times of each patrol at each hotspot.

This paper proposes a military planning tool capable of providing logistical bases and patrol packages to most effectively support border surveillance. There are two main reasons this work is needed:

(i) The current institutional and cultural changes in the Brazilian defence area have required the optimal use of military resources and
(ii) There is a verified lack of academic studies capable of guiding surveillance plans that balance operational and logistical requirements.

## 2. LITERATURE REVIEW

Empirical research concerning patrolling problems started in the 1970s and dealt mainly with rapid police response to crimes[6]. The approaches included graph[7] and queuing theory[8], heuristics[9], and simulation[10]; all focused on maximizing the routing effectiveness. In 2012, the concept of "Maximum Covering and Patrol Routing Problem" (MCPRP) was proposed[6]. With this approach, patrol moves are integrated with temporary stops at specific highways points (hotspots) to optimise surveillance missions and to reduce crash occurrences. The MCPRP is a classification of "Team Orienteering Problem with Time Window" (TOPTW), which is a variant of the "Selective Traveling Salesman Problem."[11] The aim of this

Received : 29 November 2018, Revised : 10 January 2021
Accepted : 17 February 2021, Online published : 17 May 2021

approach is to maximize the total fixed "gain" with multi-point visits executed within predefined time windows. The main difference between MCPRP and TOPTW is the lack of a fixed "profit" associated with each hotspot in TOPTW, with focus instead upon the total time each patrol invests in the hotspots visited. The main MCPRP characteristics are:

(i) The objective function to maximize the coverage or total patrolling time by visiting all hotspots;
(ii) All patrols are identical and travel at constant speeds; iii) patrols are not compelled to stay at the hotspots during all the time windows;
(iv) There is no difference between hotspots;
(v) Bases have unlimited capacity;
(vi) Patrols start the mission from the same base and at the same time;
(vii) Meeting of many patrols on the same hotspot does not increase the surveillance value; and
(viii) Patrols must return to the same source base.

Using real and randomly-generated data, the model was solved using Tabu/Local Search-based heuristics. This provided recommendations for patrols coverage and routes options.

There were only two works found concerning MCPRP improvements/modifications. The first one introduced a model entitled "Improved Formulation for Patrol Routing Problem" (IPRP) and added new conditions based on real surveillance engagements:

(i) Patrols started from different geographical points
(ii) Delayed starts were allowed and
(iii) Mandatory patrols rest stops.

This model also was run using Tabu/Local heuristics, and these results were compared with MCPRP solutions[12]. The second modelled the MCPRP as a "Multi-commodity Minimum Cost Network Flow Problem" (MCMCNFP), minimizing the total cost of patrolling. In this modification, patrols travelled along a limited capacity network, taking into account visit scheduling[13].

The proposed model, implemented using commercial off-the-shelf software CPLEX 12, was different from MCPRP and IPRP in the following respects:

(i) Different start and end locations of patrols were allowed; and
(ii) It considered possibilities of overlapping shifts for patrols.

Current mathematical models deal with patrolling problems, connecting routing, and temporary stops restricted by time windows, but do not consider the minimal number of resources required. A border military surveillance operations plan should consider the distinctive character of each hotspot and should compel patrols to satisfy the hotspot default time windows.

## 3. METHODOLOGY

### 3.1 Objective Function

Aiming to optimise border surveillance operations, minimizing the number of logistical bases and constabulary patrols to be involved and maximizing the total coverage effort on the hotspots, the objective function chosen to represent this goal is expressed as follows:

$$Min\left(\frac{X}{Max_X}+\frac{Y}{Max_Y}-\frac{Z}{Max_Z}\right) \tag{1}$$

The variables $X$ and $Y$ represent, respectively, the minimum number of bases and patrols, covering the so-called "logistical dimension" of problem. $Z$ represents the total weighted covering time at hotspots, reflecting the "operational dimension" of the problem. In order to guarantee the sum of different goals, each of the parcels is normalized, divided by the maximum value allowed for each one.

#### 3.1.1 Indexes

The following indexes are used in the modelling:

(a) $i$: geographical point indicator (where $i$=0, logistical base; and $i \neq 0$, hotspot).
(b) $k$: patrol indicator.

#### 3.1.2 Problem Parameters

The parameters, in the form of problem input, which characterize the surveillance, are:

(a) $h$: number of hotspots to be inspected by patrols.
(b) $b$: number of logistical bases available.
(c) $p$: maximal number of patrols.
(d) $T_{Ii}$: predefined surveillance start time to visit point $i(i \neq 0)$.
(e) $T_{Fi}$: predefined surveillance end time to visit point $i(i \neq 0)$.
(f) $T_F$: limit time for completing surveillance missions (operation day).
(g) $C$: logistical base capacity.
(h) $t_{prep}$: patrol preparation time to start and end inspection at the hotspots.

#### 3.1.3 Decision Variables

The decision variables are called $P_{ki}$, which include the all the geographical points (base and hotspots) used by each patrol to conduct the surveillance mission. $k$ indicates the patrol index and $i$ indicates location index, where $i$=0 is used exclusively to represent the source base index, whereas the rest represents the hotspots indexes. All the variables are properly ordered and form the "patrol-vector $k$", below. Each vector has $h$+1 positions, which may be different for each solution $S$.

$$P_k^{(s)} = \boxed{P_{k0}}\boxed{P_{k1}}\boxed{P_{k2}}\boxed{\phantom{P}}\boxed{\phantom{P}}\boxed{\phantom{P}}\boxed{P_{kh}} \tag{2}$$

#### 3.1.4 Result Variables

The set of result variables is used to organize and consolidate data, regarding the use of bases, the use of patrols, and the patrols' routes. It is divided into four basic categories: i) routing variables; ii) patrol employment variable; iii) scheduling variables; and iv) synthesis variables.

##### 3.1.4.1 Routing Variables

This variable, called $R_{ki}$, stores the points which each patrol effectively used during its surveillance mission, including the source base ($R_{k0}$). It differentiates from $P_{ki}$ by including only viable routes, only itineraries those which respect surveillance time windows.

*3.1.4.2 Patrol Employment Variable*

This binary variable, $Status_{pk}$, marks the patrols $k$ effectively employed in the surveillance mission, here called "active patrols." The least efficient patrols are discarded.

*3.1.4.3 Scheduling Variables*

These variables aim to record the schedules for each patrol arrival and departure time for each hotspot visited. They are $T_{Iki}$ and $T_{Fki}$, respectively, the start and end surveillance times. The difference between these variables indicates the time in which the patrol stays at the hotspot, inspecting it.

*3.1.4.4 Synthesis Variables*

These variables guide planners regarding the number of resources for surveillance operations.

(a) $X$: the number of "active patrols", calculated from the sum of all patrols used in the mission (with $Status_{pk}$ =1).
(b) $Y$: the number of logistical bases used, calculated from the sum of $R_{k0}$ (only of the patrols with $Status_{pk}$ =1).
(c) $Z$: the sum of the all inspection times($T_{Fi}$ -$T_{Ii}$), for each hotspot visited, multiplied by their respective criticality (considering only "active patrols").

## 3.2 Proposed Algorithm

The algorithm developed to optimise the resources involved in the border surveillance mission (bases, patrols, and time) is defined through four stages.

**Step 1: Initialisation:** This involves all the processes of reading the data for calculating and generating initial solutions by the metaheuristics:

(a) Routine 1: parameters problem reading $(T_F, b, h, p, t_{prep}, P_k^{(s)})$, predefined for each surveillance scenario. Before starting, the metaheuristic built patrol-vectors $P_k^{(s)}$, containing values of $P_{ki}$.
(b) Routine 2: repeated points in $P_{ki}$, except $P_{k0}$, are replaced by hotspots not visited yet.

**Step 2: Viability:** This phase creates solutions in which the number of visits respects both time windows and criticalities. It is composed of two routines:

(a) Routine 3: viability check of the itineraries in $P_k^{(s)}$, verifying all $P_{ki}$ connections, based on the adjacency matrix. With this routine, the $R_{ki}$ are generated, for all $k$, which are sets of points whose visits meet time windows.
(b) Routine 4: based on viable routes, this routine calculates the arrival and departure times for each hotspot. This involves a deterministic procedure, in which additional stops at the most critical hotspot are always guaranteed. If a next hotspot to be inspected is more critical, then the patrol departs for it as soon as it has fulfilled the time window (added to $t_{prep}$). Otherwise, the patrol stays at a hotspot until it needs to leave for the next one, so that it arrives on time, considering $t_{prep}$.

**Step 3: Optimality:** this phase is designed to reduce the number of patrols to the minimum necessary for surveillance.

Routine 5: all patrols are organized in ascending order according to the number of hotspots visited. If the hotspot in a given patrols first position was already visited, the patrol is discarded and receives $Status_{pk}$ =0. Otherwise, the patrol is maintained and called an "active patrol."

**Step 4: Finalisation:** divided into two routines, uses the data generated by the previous steps, and covers the final calculations of the algorithm.

(a) Routine 6: solutions where hotspots were not covered and/or the capacity of source logistical bases was exceeded are penalised as bad solutions.
(b) Routine 7: the objective function is calculated, considering "active patrols" only.
    - $Max_X$ : the maximum number of logistical bases, defined as $b$.
    - $Max_Y$ : the maximum number of patrols, defined as $p=h$.
    - $Max_Z$ : the maximum surveillance weighted time, considering the "active patrols" concentrated at the most critical hotspots.

The $X$ value is obtained by summing the number of variables $R_{k0}$ of "active patrols." Then, the $Y$ value is calculated using "active patrols," summing all $Status_{pk}$ with values equal to 1. Finally, $Z$ is the sum of stop times for each hotspot visited by "active patrols" ($T_{Fi}$ -$T_{Ii}$), multiplied by the respective criticalities. Figure 1 summarises the main algorithm steps and routines.

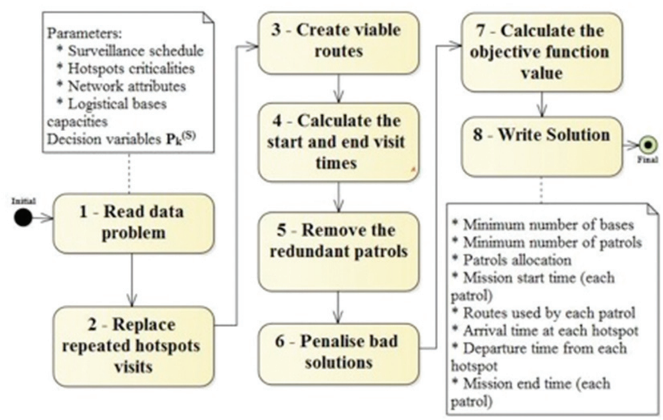


**Figure 1. Main algorithm routines.**

# 4. RESULTS

## 4.1 Experimental Results

The mathematical model was implemented in C++ language, and it was used linked with the LOF-MH (LEV Optimization Framework – Metaheuristics), version 1.0, developed by the Institute for Advanced Studies (IEAv). Among all the metaheuristics algorithms available in the LOF-MH, the Black Hole-based Optimization (BHO) was selected because it is a recently-developed tool (2013)[14-15], waiting to be explored, and its small number of control parameters makes it user-friendly.

In terms of BHO parameters, the experiments covered five different real instances (10, 20, 30, 40, and 50 hotspots at the Brazilian border, including real surveillance schedules). It was used 20, 40, and 80 starts; with 100, 1,000, and 10,000 iterations. This was repeated 100 times. Values for cover time

(*CT*) and transit time (*TT*), both in hours, were also calculated. The first one represents the total time the patrols have spent inspecting the hotspots within time windows; while the second one represents the time that all patrols spent traveling between points (bases and hotspots).

For all non-penalised solutions (80 starts and 10,000 iterations, using BHO), Table 1 contains the best and worst results for the instances tested, including Objective Function (*O.F.*), *X* , *Y, Z, CT,* and *TT* values. The last column shows the average processing time, in seconds.

Solutions' quality provided by the model is verified by comparing the results with the reference values for each instance, which correspond to the minimal number of synchronous inspections, based on the surveillance schedule for each scenario. Table 2 presents the reference values used to evaluate the quality of solutions found.

### 4.2 Logistical-Operational Military Planning Tool

In order to illustrate the value of this modeling to help military planners quantify and allocate resources for border inspections, the best result obtained from 50 hotspots was used. In this context, 11 real logistical bases at the Brazilian border, numbered from 0 to 10, are available to be used for surveillance missions, each with the capacity to support up to 10 patrols. For all the hotspots, the preparation time was considered to be 05 minutes.

The Surveillance Routing and Scheduling Description (examples in Fig. 2 and Fig. 3) presents in graphic form the routes of patrols employed and their respective source bases. Yellow boxes depict geographical points, both logistical bases and hotspots, whereas the patrols are indicated as numbered red arrows. The functions of logistical bases as start and end mission loci are represented by different boxes.

Furthermore, this figure also describes the routes followed by each patrol, including the arrival and departure times for each hotspot. It facilitates the visualization of patrol allocation between the bases, the identification of the most visited hotspots, and the identification of hotspots where a confluence of patrols occurs. This information can guide the planner to deactivate a logistical base that was little-used and can suggest eliminating some patrols from visiting already-crowded hotspots. Based on this information, the military planner can adjust the surveillance schedule to suit the logistical-operational needs.

**Table 2. Reference Values (Solution Quality).**

| Hotspots | Resources | Expected value | Obtained value |
|---|---|---|---|
| 10 | Y: Number of patrols | 6 | 6 |
| 20 | Y: Number of patrols | 14 | 14 |
| 30 | Y: Number of patrols | 18 | 19 |
| 40 | Y: Number of patrols | 27 | 27 |
| 50 | Y: Number of patrols | 31 | 33 |

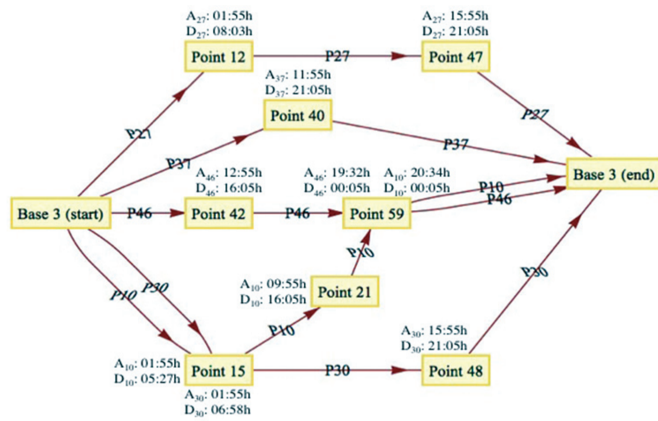


**Figure 2. Surveillance routing and scheduling description (Base 3).**

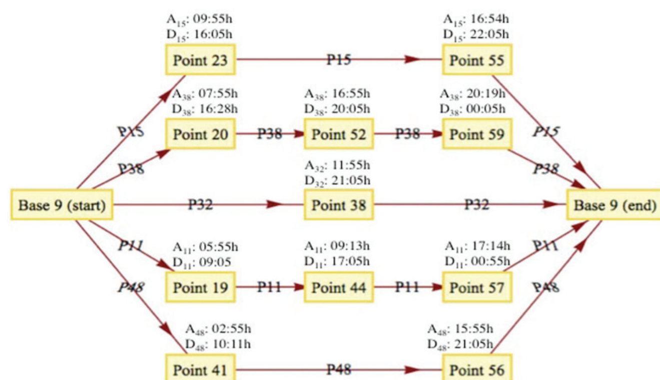


**Figure 3. Surveillance routing and scheduling description (Base 10).**

**Table 1. Main Results in the Tested Instances.**

| # | *O.F.* | Result | *X* | *Y* | *Z* | *CT*(*h*) | *TT*(*h*) | *CT/TT* | Processing time (s) |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 0.163274 | Best | 1 | 6 | 11.1 | 96.77 | 56.74 | 1.70 | 23.369 |
| | 0.229919 | Worst | 3 | 6 | 10.1 | 57.10 | 77.84 | 0.73 | |
| 20 | 0.280281 | Best | 3 | 14 | 31.85 | 183.41 | 157.86 | 1.16 | 69.420 |
| | 0.375469 | Worst | 6 | 14 | 28.75 | 137.33 | 124.32 | 1.10 | |
| 30 | 0.285588 | Best | 4 | 19 | 47.95 | 243.99 | 163.93 | 1.78 | 200.672 |
| | 0.384685 | Worst | 7 | 19 | 39.55 | 206.99 | 172.67 | 1.19 | |
| 40 | 0.334977 | Best | 5 | 27 | 64.60 | 282.16 | 301.02 | 0.93 | 244.074 |
| | 0.434742 | Worst | 8 | 28 | 66.15 | 274.41 | 353.06 | 0.77 | |
| 50 | 0.414428 | Best | 8 | 33 | 85.53 | 403.23 | 330.01 | 1.22 | 393.210 |
| | 0.519381 | Worst | 11 | 35 | 89.37 | 402.76 | 361.99 | 1.11 | |

### 4.3 Traditional Method Solution Comparison

The results provided by the model were compared with the solution generated by the currently-used method. The model employs the data obtained from Operation Agata, performed at the northern border of Brazil, in the Roraima region. It consists of 20 hotspots, 11 logistical bases, and a programming table. The patrol preparation time is 5 minutes for all patrols.

Currently, the process of defining the number of military patrols considers only the number of hotspots and their spatial distribution within the area of operations. The region of operation is divided into military zones (garrisons or logistical bases), and the hotspots are then distributed according to proximity to each base. Patrols of a given garrison do not inspect hotspots in another military zone.

The surveillance operation data, provided by a Brazilian government agency, generated by the traditional planning method are: *X*=06 (the number of logistical bases used); *Y*=17 (the number of patrols allocated); *Z*=27.60 (the total weighted inspection time invested by patrols); *CT*=102.89 (the time the patrols invested in hotspots); *TT*=74.30 (the total time spent by patrols to move between bases and hotspots); *CT /TT*=1.3847 (the ratio between cover time and transit time). It took about 20 minutes to produce.

Table 3 presents the data related to the patrols distribution among logistical bases, each patrol's start and end surveillance times, the hotspots inspected, and arrival and departure times of each patrol at each hotspot.

From Table 3 and Fig. 4 (next), it is possible to verify that many logistical bases (06 installations) were employed in the surveillance operation because military areas of responsibility were respected. Besides that, most patrols (14 units) visited only one hotspot, the others (03 units) inspected two, and no hotspot was visited by more than one patrol. The geographical distribution of hotspots (yellow color) among the logistical bases (blue color) used is shown in Fig. 4, confirming the covering option using patrols allocated near hotspots.

For this real scenario, employing BHO (80 stars and 10,000 iterations) as the search tool, the optimisation model was run, 100 times, and provided 43 different non-penalised solutions. This is depicted in Table 4, ordered according to the objective function, including the frequency of each solution.

All solutions provided (one generated every 69 seconds) by the model suggested the use of 14 military patrols, fewer than defined by the current method. The number of logistical bases ranged from 03 to 06 installations; and the maximum and minimum weighted surveillance times were, respectively, 31.35 and 28.35 hours. The values of cover time (*CT*), transit time (*TT*), the ratio between them (*CT/TT*), and the frequency of each solution, can also be seen in the table. The best solutions are shown in Table 5.

Solutions 1 and 17 are favourable. Solution 1 proposes a package with only 03 logistical bases, half the number suggested by the traditional method. It also reduces the number

**Table 3. 20-hotspot Scenario (Surveillance scheduling and routing description)**

| Base number | Patrol number | Start mission | Inspection data | | | End mission |
|---|---|---|---|---|---|---|
| | | | Hotspot | Arrival | Departure | |
| 0 | 0 | 06:15h | 15 | 09:55h | 20:05h | 00:45h |
| | 1 | 08:00h | 21 | 11:55h | 21:05h | 01:00h* |
| 1 | 2 | 01:35h | 12 | 01:55h | 05:05h | 05:25h |
| | 3 | 04:50h | 13 | 04:55h | 09:05h | 09:15h |
| 2 | 4 | 10:55h | 24 | 13:55h | 17:05h | 20:05h |
| | 5 | 13:30h | 27 | 16:55h | 20:05h | 23:35h |
| | 6 | 16:15h | 29 | 19:55h | 23:05h | 02:45h* |
| 3 | 7 | 00:45h | 11 | 00:55h | 06:00h | 20:25h |
| | | | 14 | 09:55h | 16:05h | |
| | 8 | 13:30h | 25 | 13:55h | 17:05h | 23:15h |
| | | | 30 | 17:10h | 23:05h | |
| | 9 | 12:25h | 26 | 15:55h | 21:05h | 02:00h* |
| 4 | 10 | 09:25h | 16 | 10:55h | 20:05 | 21:15h |
| | 11 | 07:30h | 17 | 10:55h | 16:05h | 19:30h |
| 5 | 12 | 10:30h | 18 | 10:55h | 16:05h | 16:25h |
| | 13 | 10:40h | 19 | 10:55h | 16:05h | 16:20h |
| | 14 | 10:50h | 20 | 10:55h | 16:05h | 16:10h |
| | 15 | 10:45h | 22 | 11:55h | 21:05h | 22:15h |
| | 16 | 10:50h | 23 | 12:55h | 16:05h | 23:40h |
| | | | 28 | 18:50h | 22:05h | |

*Note: Arrivals at the source bases the next day.

**Table 5. 20-hotspot scenario (Best solutions)**

| Decision criterion | Resources | | | *CT*(*h*) | *TT*(*h*) | *CT/TT* | Solution number |
|---|---|---|---|---|---|---|---|
| | *X* | *Y* | *Z* | | | | |
| Min X | 3 | 14 | 31.85 | 171.22 | 157.86 | 1.0846 | 1 |
| Min Y | 3 | 14 | 31.85 | 171.22 | 157.86 | 1.0846 | 1 |
| Max Z | 3 | 14 | 31.85 | 171.22 | 157.86 | 1.0846 | 1 |
| Max CT | 3 | 14 | 31.85 | 171.22 | 157.86 | 1.0846 | 1 |
| Min TT | 5 | 14 | 31.35 | 165.46 | 69.70 | 2.3739 | 17 |
| Max CT/TT | 5 | 14 | 31.35 | 165.46 | 69.70 | 2.3739 | 17 |

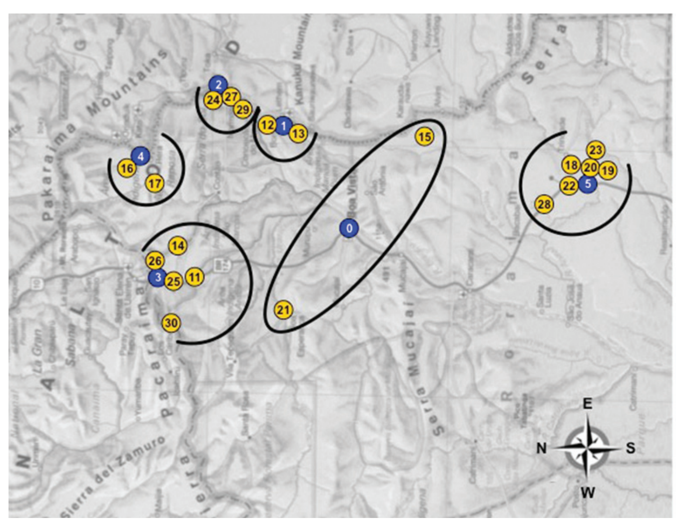


**Figure 4. Hotspots distribution among logistical bases (current method solution).**

**Table 4. 20-hotspot Scenario (Modelling solutions)**

| Hotspot number | Objective function | Resources | | | *CT*(*h*) | *TT*(*h*) | *CT/TT* | Freq. |
|---|---|---|---|---|---|---|---|---|
| | | *X* | *Y* | *Z* | | | | |
| 1 | 0.280281 | 3 | 14 | 31.85 | 171.22 | 157.86 | 1.0846 | 1% |
| 2 | 0.311274 | 4 | 14 | 31.35 | 159.72 | 100.63 | 1.5872 | 1% |
| 3 | 0.311412 | 4 | 14 | 31.25 | 165.22 | 149.88 | 1.1024 | 1% |
| 4 | 0.311550 | 4 | 14 | 31.15 | 167.35 | 108.31 | 1.5451 | 1% |
| 5 | 0.311826 | 4 | 14 | 30.95 | 158.98 | 162.86 | 0.9762 | 1% |
| 6 | 0.312102 | 4 | 14 | 30.75 | 156.17 | 100.01 | 1.5615 | 3% |
| 7 | 0.312654 | 4 | 14 | 30.35 | 160.16 | 136.61 | 1.1724 | 2% |
| 8 | 0.312793 | 4 | 14 | 30.25 | 148.50 | 112.04 | 1.3254 | 1% |
| 9 | 0.313069 | 4 | 14 | 30.05 | 157.82 | 109.73 | 1.4383 | 1% |
| 10 | 0.313207 | 4 | 14 | 29.95 | 140.04 | 116.19 | 1.2053 | 2% |
| 11 | 0.313483 | 4 | 14 | 29.75 | 143.92 | 142.30 | 1.0114 | 1% |
| 12 | 0.313759 | 4 | 14 | 29.55 | 150.63 | 97.22 | 1.5494 | 2% |
| 13 | 0.314035 | 4 | 14 | 29.35 | 140.53 | 84.03 | 1.6724 | 1% |
| 14 | 0.314311 | 4 | 14 | 29.15 | 138.82 | 94.85 | 1.4636 | 1% |
| 15 | 0.314587 | 4 | 14 | 28.95 | 132.61 | 111.18 | 1.1928 | 4% |
| 16 | 0.315415 | 4 | 14 | 28.35 | 132.60 | 121.89 | 1.0879 | 2% |
| 17 | 0.341577 | 5 | 14 | 31.35 | 165.46 | 69.70 | 2.3739 | 2% |
| 18 | 0.341853 | 5 | 14 | 31.15 | 164.93 | 101.01 | 1.6328 | 1% |
| 19 | 0.341991 | 5 | 14 | 31.05 | 157.01 | 110.17 | 1.4252 | 1% |
| 20 | 0.342129 | 5 | 14 | 30.95 | 166.29 | 112.91 | 1.4728 | 1% |
| 21 | 0.342267 | 5 | 14 | 30.85 | 163.81 | 79.11 | 2.0707 | 1% |
| 22 | 0.342681 | 5 | 14 | 30.55 | 153.17 | 121.27 | 1.2631 | 1% |
| 23 | 0.342819 | 5 | 14 | 30.45 | 146.88 | 152.70 | 0.9619 | 1% |
| 24 | 0.342958 | 5 | 14 | 30.35 | 159.85 | 99.63 | 1.6044 | 7% |
| 25 | 0.343234 | 5 | 14 | 30.15 | 152.09 | 116.57 | 1.3047 | 1% |
| 26 | 0.343510 | 5 | 14 | 29.95 | 153.79 | 93.67 | 1.6418 | 2% |
| 27 | 0.343648 | 5 | 14 | 29.85 | 143.59 | 123.78 | 1.1600 | 1% |
| 28 | 0.343786 | 5 | 14 | 29.75 | 154.52 | 99.23 | 1.5572 | 5% |
| 29 | 0.344062 | 5 | 14 | 29.55 | 145.18 | 123.28 | 1.1776 | 2% |
| 30 | 0.344200 | 5 | 14 | 29.45 | 142.11 | 91.56 | 1.5521 | 1% |
| 31 | 0.344338 | 5 | 14 | 29.35 | 140.28 | 89.45 | 1.5683 | 5% |
| 32 | 0.344614 | 5 | 14 | 29.15 | 141.77 | 120.95 | 1.1721 | 4% |
| 33 | 0.344752 | 5 | 14 | 29.05 | 137.49 | 112.23 | 1.2251 | 2% |
| 34 | 0.344890 | 5 | 14 | 28.95 | 128.48 | 118.48 | 1.0844 | 1% |
| 35 | 0.345166 | 5 | 14 | 28.75 | 124.30 | 110.96 | 1.1202 | 6% |
| 36 | 0.345718 | 5 | 14 | 28.35 | 124.09 | 96.23 | 1.2895 | 3% |
| 37 | 0.373537 | 6 | 14 | 30.15 | 149.75 | 93.96 | 1.5938 | 3% |
| 38 | 0.373813 | 6 | 14 | 29.95 | 148.21 | 158.21 | 0.9368 | 1% |
| 39 | 0.374089 | 6 | 14 | 29.75 | 143.93 | 127.24 | 1.1312 | 2% |
| 40 | 0.374641 | 6 | 14 | 29.35 | 135.15 | 147.75 | 0.9147 | 1% |
| 41 | 0.374917 | 6 | 14 | 29.15 | 140.59 | 139.59 | 1.0072 | 2% |
| 42 | 0.375193 | 6 | 14 | 28.95 | 139.43 | 95.15 | 1.4654 | 2% |
| 43 | 0.375469 | 6 | 14 | 28.75 | 130.75 | 124.32 | 1.0517 | 2% |

of units by about 20%, from 17 to 14. Solution 17 designates 05 bases and 14 patrols, which is a savings; it also provides very short transit time.

Figure 5, a graph relating the objective function value to the *CT/TT* ratio, depicts all solutions generated by the model in red and the traditional solutions in blue. The blue line represents the range in which the solution is to be found, considering that there is no objective function value for the traditional results. Solutions 1 and 17 are shown. Also shown in the abscissa are the different numbers of logistical bases.

Considering that the left-upper solutions on the graph above represent better packages for surveillance operations, the solution created by the traditional approach is relatively poor. Moreover, with the time required to develop a single surveillance plan it is possible to generate about 17 better solutions using the proposed model.

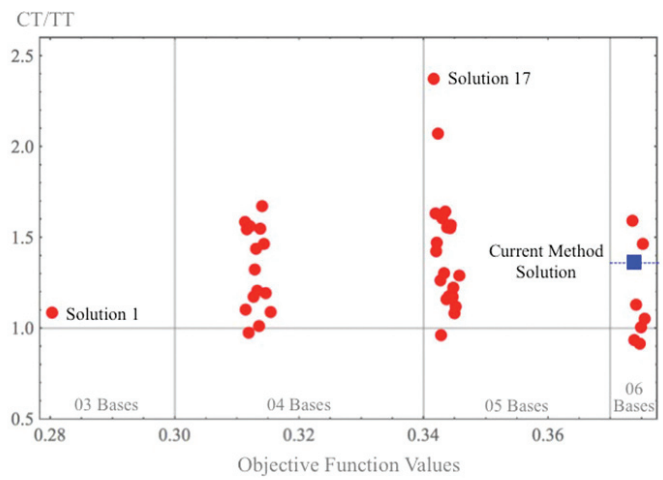


**Figure 5. Objective function versus *CT/TT*.**

## 5. CONCLUSION

In order to deal with the growing challenges of homeland security in the context of border security, an algorithm was elaborated that, connected to a metaheuristic tool (black hole-based optimisation), provided solutions for real instances in a satisfactory time. That algorithm can assist military planners in optimizing the number of logistical bases and patrols employed in surveillance inspections, balancing operational and logistics requirements. The algorithm was structured in 04 phases (initialisation, viability, optimality, and finalisation) and focused on the patrol-vectors manipulation. Through the arrangement of patrol-vectors and the less-efficient patrols exclusion, it is possible to generate a lean military package with a high level of weighted coverage, serving all hotspots with time windows. Graphical descriptions of routing and programming of patrols were used to help visualize the generated solutions. The data used in the surveillance operation configuration provided information regarding total transit and coverage times, which can guide the decision maker. Lastly, the efficiency of the model was evaluated compared to the current planning technique; presenting a set of better, more effective solutions.

## REFERENCES

1. Raza, S.G. Proposition of a Brazilian Border Security System: An Effort to Transform the Force Design. In: Nasser, R. M.; Moraes, R. F. (Ed.). Brazil and Security in Strategic Environment: South America and South Atlantic. IPEA. 2014, 59-85 (Portuguese). http://www.ipea.gov.br/portal/index.php?option=com_content&view=article&id=21592 [Accessed on 24 October 2018].
2. Valladão, A.G.A. Brazil: Defense without Threat. *In* Multilateral Security Governance. Rio de Janeiro: Konrad Adenauer Stiftung. 2014, 147-155. doi: 10.13140/2.1.4631.3280.
3. Brazil, Ministry of Defence. Joint Staff of the Armed Forces. Joint Operations Doctrine. 2012.
4. Brazil, Ministry of Defence. Brazilian Army. Land Operations Command. Patrols – Instruction Book (CI 21-75), 2004.
5. Hartley III, D. S. Ontology structures for modeling irregular warfare. *Military Operations Res.,* 2012, **17**(2), 5-18. doi: 10.5711/1082598317205.
6. Keskin, B.B.; Li, S. R.; Steil, D. & Spiller, S. Analysis of an integrated maximum covering and patrol routing problem. *Transportation Res. Part E: Logistics and Transportation Review.* 2012, **48**(1), 215-232. doi: 10.1016/j.tre.2011.07.005.
7. Chawathe, S.S. Organizing hot-spot police patrol routes. Intelligence and Security Informatics, 2007 IEEE, 79-6. doi: 10.1109/ISI.2007.379538.
8. Birge, J.R. & Pollock, S.M. Modelling rural police patrol. *J. Operational Res. Society*, 1989, **40**(1), 41–54. doi: 10.20307/2583076.
9. Lauri, F. & Koukam, A. A two-step evolutionary and ACO approach for solving the multi-agent patrolling problem. *In* IEEE Congress on Evolutionary Computation, 2008. CEC 2008 (IEEE World Congress on Computational Intelligence), 861-868. doi: 10.1109/CEC.2008.4630897.
10. Santana, H.; Ramalho, G.; Corruble, V. & Ratitch, B. Multi-agent patrolling with reinforcement learning. In: AAMAS-2004 - Proceedings of the Third International Joint Conference on Autonomous Agents and Multi Agent Systems, **3**, 1122-1129. doi: 10.1109/AAMAS.2004.180.
11. Vansteenwegen, P.; Souffriau, W. & Van Oudheusden, D. The orienteering problem: A survey. *European J. Operational Res*., 2011, **209**(1), 1-10. doi: 10.1016/j.ejor.2010.03.045.
12. Çapar, I; Keskin, B. B. & Rubin, P. An improved formulation for the maximum converage patrol routing problem. *Comput. Operations Res.,* 2015, **59**, 1-10. doi: 10.1-16/j.cor.2014.12.002.
13. Dewil, R.; Vansteeinwegen, P.; Cattrysse, D. & Oudheusden, D. V. A. Minimum cost network flow model for the maximum covering and patrol routing problem. *European J. Operational Res*., 2015, **247**(1), 27-36. doi: 10.1016/j.ejor.2015.05.067.
14. Bouchekara, H.R.E.H. Optimal design of electromagnetic devices using a black-hole-based optimization technique.

*IEEE Trans. Magnetics*. 2013, **49**(12), 5709-5714. doi: 10.1109/TMAG.2013.2277694

15. Ibrahim, Z.; Mohammed, S. K.; Subari, N.; Adan, A.; Yosuf, Z. M.; Ab Aziz, Z. M.; Aziz, H. A.; Ab Rahamn, T. A.; Shapiai, M. I.; Mokhtar, N. A Survey on Applications of Black Hole Algorithm. *In* ICAROB-2018 Conference, 2018. The 2018 International Conference on Artificial Life and Robotics. Oita, 245-248, 2018. http://umpir.ump.edu.my/id/eprint/21018/ [Accessed on 11 August 2018].

## CONTRIBUTORS

**Dr Fabio Ayres Cardoso** received his BA (Business and Public Administration) from Brazilian Air Force Academy, in 1999, MSc (Logistics and Supply Chain Management) from Air Force Institute of Technology (AFIT), USA, in 2010, and DSc (Technology Management) from Aeronautics Institute of Technology, Brazil, in 2019. His research interests include: combat logistics and defence management.
In the current study he formulated the problem statement, developed the algorithm, defined its constraints and requirements, undertook the literature review, provided all data sets, and carried out the overall experiments, analysis and validation of the results found.

**Prof. Fernando Teixeira Mendes Abrahão** received his BA (Aeronautical Sciences) from the Brazilian Air Force Academy, in 1988, MSc (Logistics Management, Maintenance Management, and Acquisition Logistics Management) from Air Force Institute of Technology (AFIT), USA, in 1998, and DSc (Transport Engineering) from Polytechnic School of the University of São Paulo, Brazil, in 2006. He is currently an Associate Professor from Aeronautics Institute of Technology (ITA) and is the Chief Coordinator of the Logistics Engineering Laboratory (AeroLogLab/ITA). His research interests include: Integrated Logistics Support (ILS) and design and development of ILS for complex air aerospace systems.
In the current study he was responsible for final review and approval of the article.

**Mr Wakim Boulos Saba** received his BA (Computer Engineering) from Braz Cubas University, Brazil, in 2005, and MSc (Physics and Applied Mathematics) from Aeronautics Institute of Technology (ITA), Brazil, in 2016. He is currently a DSc student at Aeronautics Institute of Technology (ITA). Since 2005, he has been projecting, designing, and building IT solutions for companies in the fields of business financial, telecommunication, and logistics. His research interests include: software engineering and development, optimization models, and big data.
In the current study he carried out the implementation of the algorithm in C++ language linked with the LOF-MH (LEV Optimization Framework – Metaheuristics).