Optimization of Logistic Supply Missions in Army Special Border Platoons Through a Heuristic Method

Daniel Alberto Pamplona and Claudio Jorge Pinto Alves

***Abstract*—This article aims to show the application of Heuristic Methods for the optimization of logistical supply missions in Special Border Platoons in the Amazon region. In remote and distant from each other, the use of air transportation is necessary, and its correct planning an ongoing challenge. Using heuristic methods, particularly the Clarke & Wright heuristics adapted to the context, allowed a better allocation of resources seeking to avoid waste of time and especially fuel in a modal that stands out for its high cost compared to other.**

***Keywords*— Logistics, Optimization and Heuristic Method**

I. INTRODUCTION

Logistics is a decisive factor for victory in a war campaign. History has proven that effective planning means proper distribution and a steady stream of resupply guarantee in the Operational Theater. It is the keystone in Modern Warfare. The logistical support available for the Military Commander will dictate the success in the modern battlefield. Logistics provides the means for the commencement of military operations, and the maintenance of troops, whether through the fuel, spare parts and support for the wounded. An effective logistics does not mean wealth of means, but a wise and intelligent administration of them.

From the time that Brazil was a colony of Portugal, the Amazon region became the subject of intense disputes involving mainly the English, Dutch, French and Spaniards all hopeful of finding the promised riches of the "new world." The first of the military garrisons established with the purpose of protection was the Fort of the Crib, in 1616 at the mouth of the Amazon River [1]. For conservation and territorial protection of Brazil in the region and implementing a doctrine of constant presence in the region, seeking combat the various transnational crimes, particularly drug trafficking and weapons, the actions of non-state military groups that move in the border region, the fight against illegal mining and protecting indigenous groups in the region, the Brazilian Army created the Special Platoons Frontier (SBP). In remote and inaccessible regions, the logistical supply of these military units, comprising a population of approximately 100 people, represents a major challenge. Logistical supply, often, is made by air by the Brazilian Air Force.

The aim of this paper is to apply the Clark & Wright heuristics for optimization of the logistical supply missions in the Army Special Border Platoons. Maximizing existing resources becomes of paramount importance to the logistics planner. We conducted an applied research objectifying the generation of knowledge for the practical application and directed the solution of a specific problems. We approached the problem in a quantitative way with the selection of the variables that would directly affect the object of the study. By these research methodologies, it was possible to examine the problem of optimization by a heuristic method and how it influences the resolution of logistic problems.

This paper is organized as follows: Section II shows the historical background, showing the presence of the Brazilian Army at the Frontiers of the Amazon Region. Section III describes the process of the logistic supply for a Special Border Platoon. Section IV analyzes the studied routing problem. Section V shows the results and Section VI presents the conclusion of the present study.

II. THE PRESENCE OF THE BRAZILIAN ARMY AT THE FRONTIERS OF THE AMAZON REGION

The Brazilian Army is present in the Amazon Region by the Jungle Infantry Brigades (JIB). Subordinated to the Brigades, are the Special Border Battalions (SBB), military organizations whose function is to protect a certain area in the Amazon, and in the Brazilian border strips are located the Special Border Platoons (SBP). Its function is to be the Army's remotest presence in the border region. The area selected for this optimization study is placed between three countries Colombia, Venezuela and Peru. The Army maintains six Special Border Platoons Yauarete, Querari, São Joaquim,

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Cucui, Maturacá, and Pari-Cachoeira. This region was selected due to its strategic importance.

A. The challenges of logistics supply in the region

By establishing the location of the SBP in strategic locations and because it is an inhospitable region rich, the logistical supply of organizations has become a challenging task. Near the Rio Negro Frontier, only the SBP of Cucui has a road, being possible to supply it by land. However, since it is a dirty road and is a region with high rainfall, its traffic becomes difficult to access, as seen from the road map of the State of Amazonas shown in the Fig. 1.

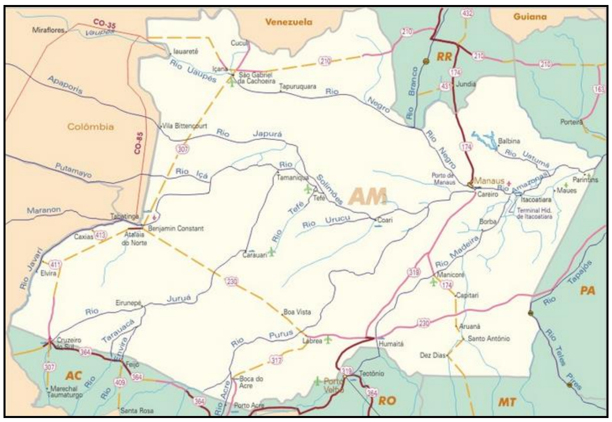

Fig. 1. Road network of the state of Amazonas [2].

For the other battalions, boat or plane is the only logistic options available. Using boats for the logistic supply presents peculiarities. First, the rain flow in the region is not always constant, having had several occasions when rivers were dry and navigation was not possible. By boat, the journey from São Gabriel da Cachoeira to Cucui has a total travel time of 24 hours. Using the aircraft, despite being more expensive, represents a more reliable, faster and more efficient means of transportation. For the aerial operation, the main constraint is meteorology. The runway inside the SBP is designed for Visual Flight Rule (VFR) procedures, restricting aerodrome operations to visual conditions only.

B. The process for the logistic supply of a Special Border Platoon

The SBP are units of the Brazilian Army. The needs of all SBP are consolidated at a Central Depot in São Gabriel da Cachoeira. According to joint planning between the Brazilian Air Force and the Brazilian Army, it is allocated to a C-105 Amazonas aircraft to transport the supplies.

On the planned day and with the availability of the aircraft on the ground in São Gabriel da Cachoeira, the cargo is moved by truck from the Army warehouse, in the city to the airport. The distance is 30 km. At the airport, the cargo is palletized. Cargo transport by pallets allows for less ground time compared to manual loading. While the load-master, a crew member responsible for loading and balancing the load on the aircraft, carries the aircraft, the flight mechanic performs the aircraft fuel supply. Unloading of aircraft cargo can occur in two ways: by forklift or by hand. After the unloading, the aircraft returns to São Gabriel da Cachoeira. With the landing, the aircraft is ready to start a new process, if it has not reached the maintenance period of the same.

The aircraft used for the supply of SBP is C-105 Amazonas, manufactured by CASA-EADS (Spain). The C-105 is a twin-engine aircraft developed for small and medium distances, capable of performing tactical and logistical transport missions. Equipped with two Pratt & Whitney P & W 127G engines, with a maximum ceiling of 25.000 feet and a maximum speed of 254 knots. To carry out the logistic supply, the Air Force built runways alongside SBP. The configuration of the aerodromes is simple, composting it by an apron, where the loading and unloading of the aircraft take place and the runway which presents limited dimensions for the type of aircraft that can operate in the region.

III. THE STUDIED ROUTING PROBLEM

The analyzed problem is based on Vehicle Routing Problem (VRP). It is considered a classic optimization problem. Its application involves problems involving several routes to be traveled where the lowest cost is desired, being a route for each vehicle, starts and ends at the same point. Each vehicle must serve customers with their respective demands, and the total capacity of the vehicle must be respected, visiting a series of customers at the lowest cost and considering all other impositions of the problem [3].

Reference [4] first introduce the formulation of the VRP as a generalization of the Traveling Salesman Problem (TSP). The TSP was presented by Reference [5]. The VRP is generally defined on a graph $G = (v, \mathcal{E}, C)$, where $v = \{v_0, \ldots., v_n\}$ is the set of vertices; $\mathcal{E} = \{(v_i, v_j) \mid (v_i, v_j) \in v^2, i \neq j\}$ is the arc set; and $C = (c_{ij})_{(vi,\, vj) \in \varepsilon}$ is a cost matrix defined over $\mathcal{E}$, representing distances, travel times, or travel costs. Traditionally, vertex v0 is called the depo, while the remaining vertices in v represent customers (or requests) that need to be served. The VRP consists in finding a set of routes for K identical vehicles based at the depot, such that each of the vertices is visited exactly once, while minimizing the overall routing cost [6].

One variable of the VRP is when the problem involves the time restriction and is known as Vehicle Routing Problem with Multiple Trips (VRPMT) routing problem, with the total duration of the route (service and travel time) and may exceed a pre-set time, with the total duration of a journey not exceeding a predetermined duration [3]. The problem may involve a deposit as the base where the shipments occur and where each journey begins and ends. The major difference between PRVMV and PRV is to allow a vehicle to serve over one route during a planning period [7].

Because of the operational characteristics of the aerodromes, some restrictions were assumed to solve the problem. First, the time for loading and unloading will be of one hour. The loading operations start daily at 06:00 a.m. with the engines running at 07:00 a.m. Maximum time for takeoff from an SBP, because the airport does not operate overnight, is at 06:30 p.m. (meantime of the sunset in the region). No aircraft will take off from São Gabriel after 04:30 p.m., as it would be an overnight stay in a SBP. Table I shows the total flight time in minutes.

TABLE I
ORIGIN, DESTINATION AND TOTAL FLIGHT TIME IN MINUTES

Origin	Destination	Total Flight time (min)
São Gabriel da Cachoeira	Yauarete	58
São Gabriel da Cachoeira	Querari	73
São Gabriel da Cachoeira	São Joaquim	73
São Gabriel da Cachoeira	Cucui	48
São Gabriel da Cachoeira	Maturacá	46
São Gabriel da Cachoeira	Pari-Cachoeira	68

For the calculation of the total flight time, the following conditions were assumed: (a) total departure time and taxi time is 5 minutes; (b) climb with the speed of 160 knots at the rate of 1500 feet per minute; (c) cruise flight levels are Flight Level (FL) 075 or FL 085 conditioned to the existing flight rules; (d) cruising speed of 180 knots; descent with the speed of 180 knots at the rate of 1500 1500 feet per minute; and (e) traffic time for landing is 5 minutes and time of landing and engines shutdown is 3 minutes.

IV. RESULTS

The weekly needs of an SBP vary monthly. For planning, it was assumed the monthly needs for each battalion, including transport of food, war products, construction material, fuel, and finally all the products necessary for life in the Platoon, as shown in Table II.

TABLE II
HYPOTHETICAL MONTHLY NEEDS PER BATTALION IN KILOGRAMS

Battalion	Monthly needs (kg)
Yauarete	30,000
Querari	32,500
São Joaquim	15,000
Cucui	22,000
Maturacá	31,250
Pari-Cachoeira	40,000
Total	170,750

We solved the problem using the Clarke & Wright's Savings Algorithm. This methodology is structured in an economic model of a saving type that has as its backbone the replacement of the most expensive arcs within the route by lower-cost arcs, seeking to form an improved route. The savings method aims to minimize the total distance traveled by all vehicles and indirectly minimize the number of vehicles needed to serve all stops. The developing solutions to the problem of vehicle routing and programming is a task that becomes increasingly complicated as new constraints are imposed. Using this algorithm in problems with a few constraints can cause solutions close to 2% in relation to the optimal solution, with the C & W algorithm being one of the best-known techniques used to solve this problem. The algorithm proceeds as following [8]:

1. Make n routes: $v_0 \rightarrow v_i \rightarrow v_0$, for each $i \geq 1$;
2. Compute the savings for merging delivery locations i and j, which is given by $s_{ij} = d_{i0} + d_{0j} - d_{ij}$, for all $i,j \geq 1$ and $i \neq j$;
3. Sort the savings in descending order;
4. Starting at the top of the (remaining) list of savings, merge the two routes associated with the largest (remaining) savings, provided that:
   a. The two delivery locations are not already on the same route;
   b. Neither delivery location is interior to its route, meaning that both notes are still directly connected to the depot on their respective routes:
   c. The demand G and distance constraints D are not violated by the merged route.
5. Repeat step (3) until no additional savings can be achieved.

The basic constraints of the model are [9]:

- Each routine starts and ends in the warehouse;
- Each customer belongs to only one route;
- The demand of each customer cannot exceed the capacity of the vehicle; and
- The total time of a route does not exceed the availability of the driver's total working time;

The basic needs of an SBP are, according to Table II, in most cases, greater than the maximum permissible load of a C-105 Amazonas aircraft (9,700 kg), and this was the main restriction that prevented the direct use of only one airplane. Seeking to solve this impasse, and using an adaptation of the Scanning Method, when adopting initially the closest points of the Distribution Center, the following methodology was performed:

a) Check the total load required by SBP;
b) Check which platoons require full loading;
c) Begin delivery by the platoon closest to the central base, only to deliver in another platoon, the second closest, after exhausting the total of full loads in the platoon; and
d) Upon completion of all full loads, incomplete loads should be collected and applied to Clarke & Wright's heuristics for routing.

Following the proposed method, the order of full load delivery was: Maturaca; Cucui; Yauarete; Pari-Waterfall; São Joaquim and Querari, as shown in Table III.

TABLE III
FULL AND REMAINING CARGO TRIPS IN KILOGRAMS

Batallion	Full cargo trips	Remaining cargo (kg)
Yauarete	3	9,000
Querari	3	3,400
São Joaquim	1	5,300
Cucui	2	2,600
Maturacá	3	2,150
Pari-Cachoeira	4	1,200
Total	16	23,650

The remaining cargo to be transported was 23,650 kg. To optimize the rest of the load, the Clarke & Wright heuristic was applied, as shown in Fig. 2.

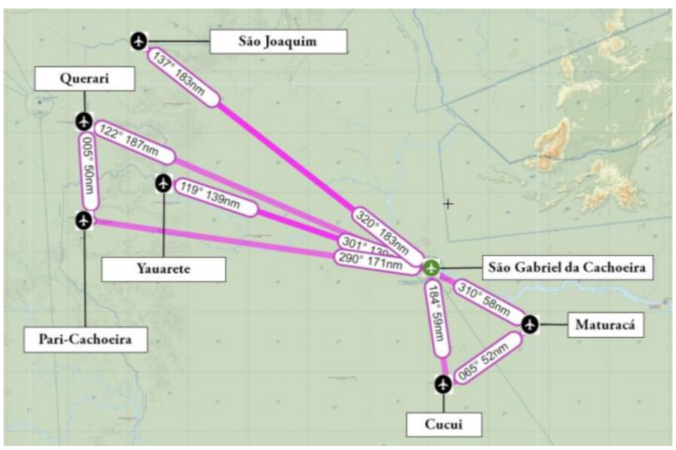

Fig. 2. Optimized trips with the remaining cargo.

The heuristic proposed the following routes:

- São Gabriel da Cachoeira – Yauarete - São Gabriel da Cachoeira, carrying 9.000 kg;
- São Gabriel da Cachoeira – Pari-Cachoeira –Querari carrying 4600 kg;
- São Gabriel da Cachoeira – Cucui – Maturaca, carrying 4,750 kg; and
- São Gabriel da Cachoeira – São Joaquim – São Gabriel da Cachoeira carrying 5,300 kg.

Due to the nature of the problem, it was not possible to immediately use Clarke & Wright's heuristics for routing. The adaptation of the Savings Method was chosen because it represents a fast way of routing, mainly in the aerial modal and in a region of low density of air traffic, that allow direct navigation point to point.

Another alternative for the initial choice of deliveries could be the use of Multi-criteria Methods the Hierarchical Process Analysis method because of their flexibility and use in complex problems.

Because of the large amount of materials to be transported, the first five days were dedicated to the delivery of full loads. Once the problem of full loads has been overcome, the use of the Clarke & Wright heuristic demonstrates solutions close to 2% of the optimal solution [8].

A key issue for aerial operations, especially in the Amazon region, is meteorology. This question was not considered in the model. All delivery places do not operate per instrument, which can lead to delays and changes in planning. An extension of this work would be the analysis of the index of missions delayed or that could not be fulfilled for the meteorology.

V. CONCLUSION

Logistics is one pillar of support for the Armed Forces. The transportation problem is a problem that has always accompanied logistics operations. Knowing how, how and how organizations should be supplied has always posed a challenge to planners.

This work focused on optimizing a logistics resupply mission to Special Border Platoons in the Amazon. Looking for the best meeting the needs of people in the most remote corners of our country, is extreme importance, especially in a time of cost containment.

The solution of the problem by heuristic methods represented a scientific approach to the Brazilian Air Force's transport activities, not a substitution of the experience of the professional who works and plans in the region.

No model should be applied without the deep knowledge of the region where it operates. The method presented in this article is a tool to support professionals responsible for the supply of regions with difficult access.

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