# MULTICRITERIA APPROACH TO RANK AREAS TO LOCATE SUPPORT FACILITIES FOR COMBAT TROOPS OF BRAZILIAN ARMY

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## ABSTRACT

One of the most relevant topics related to the success of an army is the logistics support. A set of logistical facilities, such as warehousing, workshops, hospitals and others are required to attend the multiple necessities of an army land force. These facilities must be located within an area referred to as area of logistics support. The process of decision making concerning this area is considerably complex. Not only because of the possible high number of candidate areas, but also because of the conflicting criteria that can be faced during this selection. The criteria can sometimes be subjective or dependent on different scales of value. In order to assist this task, this paper proposes a multicriteria approach using the Electre IV method and help to evaluate the candidate areas according to the rules established by the Brazilian military doctrine.

**KEYWORDS. Electre IV, multicriteria, ranking process.**

# 1. Introduction

In the scenario of modern warfare, with the strong use of technology and the highly mobile combat forces, one of the greatest challenges is to correctly choose the location and areas of logistics support described in Organização das armas e serviços (2009).

As prescribed on the Logística Militar Terrestre (2003), these areas of logistics support will concentrate high responsibilities, such as medical care to injured soldiers, distribution of all kinds of supplies as well fuel, lubricants, weapons and ammunition, and the maintenance of vehicles and general equipment.

The importance of the logistics support increases with the number of troops involved on a combat and the time they spend in a battlefield. Therefore, in addition to establishing and maintaining lines of supply to provide multiple types of support to its own army, another priority is to try to prevent the opening or even blocking the enemy supply lines, as described in Apoio Logístico na Divisão de Exército e na Brigada (2003).

According to Logística Militar Terrestre (2003), in order to perform their role, these areas must be situated as near as possible to the front line to ensure better close support to friendly forces. These areas should also be located within safe boundaries, so that they can perform their essential functions free from the influence of the enemy.

The localization of the areas of support depends on the final decision of the Commander of the Theater Operations and his General Staff. This decision is based upon suggestions proposed by the Supply Officer.

This officer performs a detailed analysis of the rear region. After carrying out the analysis, the supply officer chooses which of the areas can be prospective candidates to locate the logistics support. Then, the officer compares the candidate areas, ranking them and afterwards submitting these suggestions to his commander, as described in Organização das armas e services (2009) and Apoio Logístico na Divisão de Exército e na Brigada (2003).

The process of decision making involving these ranked areas is considerably complex, not only because of the possible high number of candidate areas, but mainly because of the conflicting criteria, different scale of values, and sometimes criteria of subjective nature. According to Apoio Logístico na Divisão de Exército e na Brigada (2003), a great amount of variables that must be considered, such as distances, type of soil and plant cover, presence of buildings and water sources, friendliness of the people and others.

Understanding the complexity of this mission and the difficulty of finding a purely mathematical solution to this problem, the goal of this paper is to propose a multicriteria approach to this problem in order to obtain a rank of candidate areas for logistics support. This approach will grant the Supply Officer with enough tools to discuss his suggestion with the Commander of the Theater Operations and his General Staff.

# 2. Logistics doctrine in the Brazilian Army

Some concepts and terminology are presented in this section to help understanding the rest of this article. Furthermore we will introduce a brief explanation of how the process of choosing the area of logistics support without the help of a computer aided decision.

## 2.1 Rear area

According to Apoio Logístico na Divisão de Exército e na Brigada (2003) and Glossário de termos e expressões para uso no Exército (2003), the rear area comprises a definite geographical space by the front edge of the combat zone and laterally by the boundaries of other rear areas. It is within the limits of the rear area that the area of logistics support must be located.

In this paper, we consider that the rear area has already been demarcated by the Commander and the General Staff.

## 2.2 Logistics support area

It is called the area of logistics support the region for the deployment of most facilities of logistics support for the troop considered.

It is considered that 6 to 9 square kilometers is an appropriate size to receive all the necessary facilities, such as: supply battalion, maintenance battalion, transportation battalion, service battalion, medical battalion, replenishing battalion, field hospital, and company of personnel assistance, like described in Apoio Logístico na Divisão de Exército e na Brigada (2003) and Glossário de termos e expressões para uso no Exército (2003).

## 2.3 Hierarchy process of choosing the areas of logistics support

After detailed recognition of the terrain, the supply officer conducts a comparative analysis based on practical methods not linked to mathematical reasoning, trying to rank the best locations to place the area of logistics support.

Then, the supply officer presents a proposal to of a deployment plan to the Commander of the Brigade. Following the decision of the Commander, the priority of the selected regions is submitted to the Army Division Commander, who will decide where the areas of logistics support will be located, like described in Apoio Logístico na Divisão de Exército e na Brigada (2003).

## 2.4 Criteria for choosing of area of logistics support

The Brazilian military doctrine, according to Logística Militar Terrestre (2003) and Apoio Logístico na Divisão de Exército e na Brigada (2003), prescribes logistics support the following criteria in order to guide the mission of the Supply Officer to evaluate the candidate areas to host the logistics support areas.

### 2.4.1 Close support criterion

It refers to the distance by road between the area of logistics support and the units to be supported. The support will be much closer and more efficient, the smaller this distance is.

### 2.4.2 Continued support criterion

It means the ability to support all the elements employed by the goal of the planned operation, with minimal changes of position. When the Supply Officer is aware of the future positions of the elements to be supported, he must use this information in considering the hierarchy of candidate areas for logistics support.

### 2.4.3 Existence of buildings, plant cover and shelters criterion

The higher the density of buildings, or vegetation to provide concealment and protection, the better should be ranked the area.

### 2.4.4 Consistency of the soil and presence of water criterion

The low consistency of the soil may hinder the assistance to be provided, as well as handicap the adoption of passive measures of protection (marking the tracks used, by compressing the ground). The amount and location of water sources available and their quality also influence the process of ranking of the area of logistics support.

### 2.4.5 Critical points criterion

A critical point located along a route used to transport supplies to the troops to be supported offers the enemy the possibility of acting on it, interfering with the flow, leading to a restriction or disruption. Critical points can be considered, among others: viaducts, bridges, level crossings, canyons, and in certain situations, small villages.

### 2.4.6 Criterion of exposed or protected flanks

It is analyzed as a function of the distance of an area compared to exposed flanks and penetration of the enemy or its proximity to the flanks safely protected by troops or by major obstacles.

### 2.4.7 Criterion of the range of enemy artillery

It consists of verifying if the selected region is in or out of reach of the enemy artillery. Due to the lack of recoverability of the facilities of the area of logistics support, it is a mandatory criterion.

### 2.4.8 Attitude of the population criterion

When a region is subjected to the influences of the local population, the attitude of this population (positive, indifferent or hostile to the presence of friendly forces) becomes a parameter that should be considered.

## 3. Choosing the ELECTRE IV methodology

To determine the most appropriate multicriteria methodology that could be used to help solve the problem of ranking the candidate regions for areas of logistics support, we first investigated how this mission is currently carried out by the supply officer. Nowadays the decision maker performs this task without the aid of computing tools, based only on the officer's own experience, and on what is prescribed by the military doctrine of Brazilian Army.

The current Brazilian military doctrine, according to Apoio Logístico na Divisão de Exército e na Brigada (2003), does not recommend a hierarchy of the criteria in evaluating candidate regions to areas of logistics support. This means that the main representatives of the American School of Multicriteria, the MAUT (Multi-Attribute Utility Theory) presented by Fishburn (1970), and the methodology of AHP (Analytic Hierarchy Process) described by Saaty are inappropriate to be applied in this case. One of the main fundamentals of these methodologies is the rigid hierarchy of criteria. Establishing values for each alternative in terms of utility is not an easy task to the decision maker. According to Keeney and Raiffa (1976), this represents another disadvantage of the MAUT method that needs to determine a utility function.

On the other hand, the family of methods Electre (Elimination et Choix Traduisant La Réalité), the main representative of the French School, does not require hierarchically structured

criteria, and does not need a mathematical function to explain the phenomenon. The Electre methods represent adaptations and improvement to different contexts of the first multicriteria method proposed by Bernard Roy (1968) in Paris. Another advantage that can be highlighted is the possibility of Electre methods work with a weak and strong preference for one alternative, which would better reflect the real preferences of the decision maker.

Among the representatives of the Electre methodology can be listed: Electre I presented by Roy (1968), Electre II presented by Roy and Bertier (1973), Electre III presented by Roy (1978), Electre IV presented by Roy and Hugonnard (1982), Electre IS presented by Roy and Skalka (1985) and Electre TRI presented by Yu (1992). However, the methods that focus on selection and classification like Electre I, Electre IS and Electre TRI will be useless for the purpose of this analysis. And as the decision maker also dismissed the use of weights to the criteria, then, the methods using weights like Electre II and Electre III were also discarded.

The method Electre IV, besides ranking the alternatives, grants the officer the possibility to show his Commander the amount of criteria that have strongly outranked and how it occurred, providing an analytical assessment of the results. Moreover, by employing pseudo-criteria, the Electre IV will express a scale of preferences closer to that adopted by the decision maker described by Gomes (2004).

# 4. Proposed Approach

The approach described in this section will be followed in order to employ the Electre IV method to the problem analyzed in this paper.

Querying a Geographical Information System database of the Instituto Brasileiro de Geografia e Estatística (2010), a region was chosen for the simulation of land conflict within the Brazilian territory, precisely in the state of Ceará. This area was chosen because it has urban areas (a small town and several villages), roads with different widths, a stretch of railroad, rivers and lakes. It is also known that the terrain is mostly flat and has low variation of plant cover along the entire area. We can visualize the whole area of interest for the simulation in Figure 1.

The dashed lines represent roads with lower traffic capacity, thin solid lines represent rivers, and thick solid lines represent roads with higher traffic capacity. A railroad line can also be observed at the top right corner in the figure. Dark areas represent lakes or reservoirs, and the lighter areas represent urban areas.
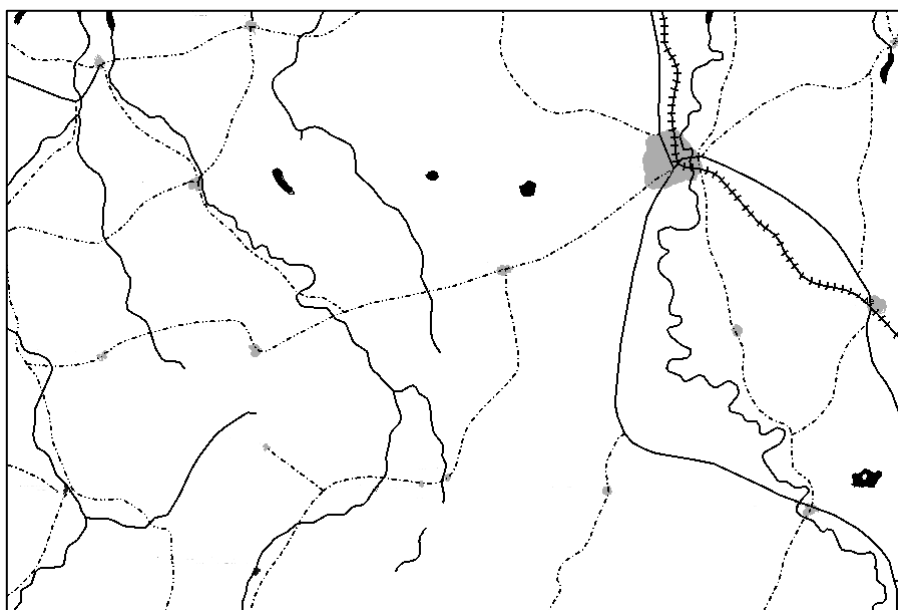


**Fig. 1.** The scenario where will be executed the simulation of military operations.

Following the actual Brazilian army doctrine according to Logística Militar Terrestre (2003) and Apoio Logístico na Divisão de Exército e na Brigada (2003), the Army Division Commander demarcated the rear area of the Brigade, where the area of logistics support can be located. The location of the troops to be supported and the area within range of enemy artillery can be seen in Figure 2.
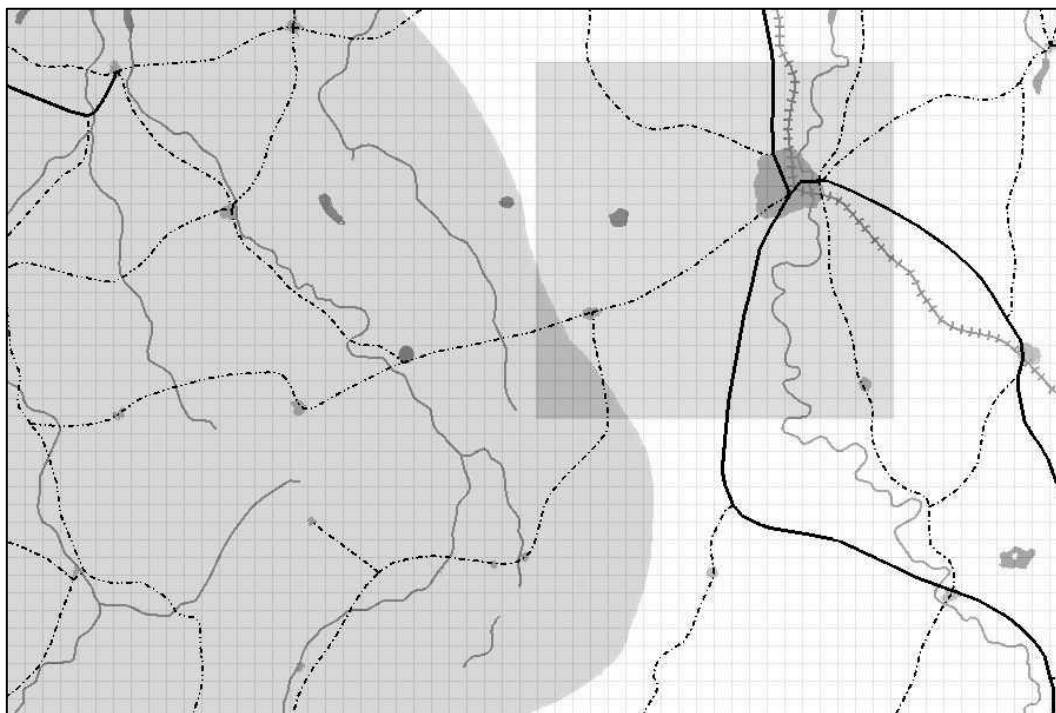


**Fig. 2.** The dark area on the left side is under the range of enemy artillery. The rectangular area shows the rear zone of the brigade.

All the elected criteria are well defined in the logistics doctrine of the Brazilian Army. They are: close support criterion, existence of buildings, plant cover and shelters criterion, consistency of the soil criterion, presence of water source criterion, critical points criterion, exposed or protected flanks criterion, and range of enemy artillery criterion. Criteria attitude of the population, and continued support will not be used in this simulation. It is possible to justify the exclusion of these criteria because of the area in question is entirely situated within Brazilian boundaries, where the population supports and cooperates with the national army, making the evaluation of the criterion attitude of the population unnecessary. Since the future locations of the troops to be supported are unknown, it is not possible to evaluate the criterion continued support.

The close support, presence of water source, critical points, and range of enemy artillery are measurable and can be obtained by calculation. The criteria existence of buildings, plant cover and shelters, soil consistency, exposed or protected flanks are not measurable and were evaluated through interviews with officers who knew the region.

The values of the limits of preference (p) and indifference (q) were defined as seen in Table 1. These values will help to establish the value from which the decision maker changes his degree of preference trying to reflect this sensitivity in employing chosen the method.

The limits of preference and indifference were determined through interviews with the decision maker, in this case, the supply officer. Relative limits were established to the criteria close support, and presence of water source. For all other criteria were determined absolute limits that was measured in standard deviations.

Table 1. Limits of preference and indifference.

| Criteria | - p | - q | 0 | + q | + p |
|---|---|---|---|---|---|
| heavy support | - 40% | - 20% | 0 | 20% | 40% |
| existence of buildings, and covered shelters | -3 | -1 | 0 | 1 | 3 |
| consistency of the soil | -3 | -1 | 0 | 1 | 3 |
| presence of water source | - 50% | - 25% | 0 | 25% | 50% |
| critical points | -2 | -1 | 0 | 1 | 2 |
| flanks exposed or protected | -2 | -1 | 0 | 1 | 2 |

One of the limitations of the method ELECTRE IV is the difficulty to work with a lot of alternatives. As each alternative should be compared to all the others, for each criterion, so as to build domination relation we used a mechanism to reduce the number of possible alternatives. The rear area was divided into sectors with one square kilometer of area and each sector was analyzed as a single block.

In the following two stages, described by Ukkusuri (2007) and Brasil Filho (2009), the construction of strong and weak outranking relations, and the construction of downward and upward ranks by distillation procedure were made to determine the final ranking.
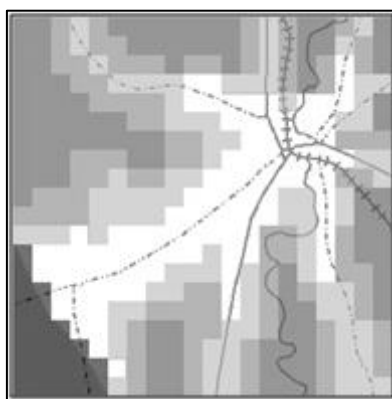


Fig. 3. The black blocks were discarded because they are under enemy artillery range. The clearer areas are the best.

To meet the needs of the Brazilian Army, the final ranking was organized as follows: the top 25% ranking blocks were marked in white in Figure 3 that represent the rear area, and following the decreasing order of rank the next 25% were marked in light gray, the 25% following in intermediary gray, and the remaining 25% were marked in dark gray. In order to meet the criterion of the range of enemy artillery, the blocks that were within range of enemy artillery have been discarded and were marked in black. The roads, rivers and railroad were preserved to give the idea of localization.

# 5. Analyzing the results

In order to analyze the results, it was asked to a supply officer to perform the ranking process of the areas of logistics support in the same region where the proposed approach was tested.

Without accessing the results of this paper, the supply officer evaluated and suggested a ranking of three areas for the final choice of the General Staff (Figure 4). According to the arguments that justified his choice, the official gave preference to area number one because it is an urban area (with a lot of buildings), with several road accesses and near a water source (a

river). Following his scale of preference, the next area suggested was the area number two, because it's very close to the troops to be supported, besides having a small village that can serve as shelter to the most sensitive part of the facilities and because it has a water source that is relatively close (a lake). The next and last option was the area number three, that despite having access to means of road transportation and water supply is a little farther from the troop to be supported, and has some critical points on the way to the troops to be supported.
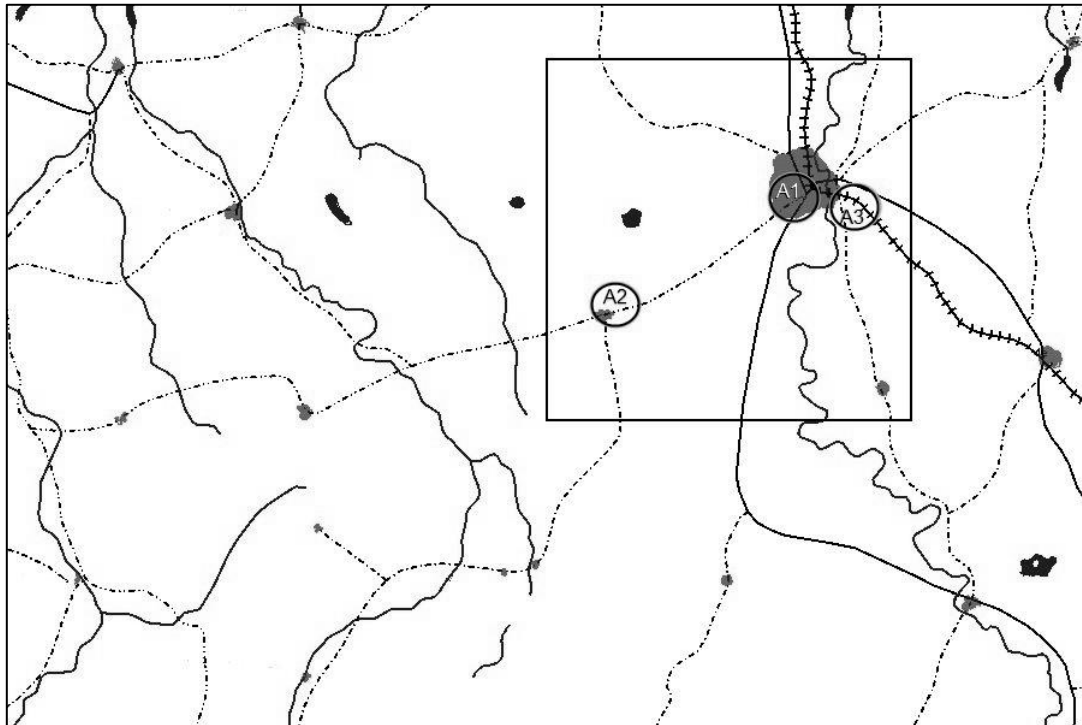


**Fig. 4.** Ranking made by Supply Officer without any computational support.

The choice of these areas and their ranking can be confirmed by observing the ranking of the same rear zone obtained in this paper (Figure 5). Both areas number one and number two are totally within the white zone, and therefore within the 25% of best evaluated blocks. In the area number three, the last option of the supply officer, some facilities will be installed within the light gray zone, which has a worse evaluation than the white zone, but better than the intermediary gray, and the dark gray zone. None of the areas were located within the black zone.
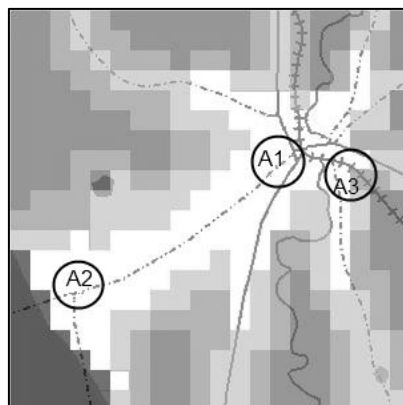


**Fig. 5.** Comparing the results between the traditional evaluation and using multicriteria methods.

# 6. Conclusions

The application of the multicriteria approach proposed in this paper demonstrated a satisfactory performance to rank feasible logistics support areas. The ranking performed by the decision maker, in this case, the supply officer, without the aid of computing tools was similar to the result obtained through the use of the approach proposed.

The presentation of the results through a thematic map is convenient, since it enables the supply officer to more easily show the results of ranking to his Commander and to the General Staff, not just the candidate areas of logistics support, but the entire rear area.

However, there are conditions in which the equal treatment to the criteria is not recommended, such as in desert environments, where water sources are critical. In these situations the adoption of equal weights for all of the criteria may not be the best option, making the use of the Electre IV method inappropriate. Therefore, in future works, it is recommended the study of other methods that can better reflect multicriteria decision making in these scenarios.

# 7. Acknowledgements

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