

LOCATION OF A POSTAL FREIGHT TERMINAL USING GIS AND AHP

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1 – Introduction

Massive efforts have been observed towards solving terminal location problems in a large variety of approaches. Daskin ¹⁾ reports two categories of research approaches: network-location; and location on the space. The first category is subdivided into several sub-themes according to maximization / minimization criteria (demands, distances, time, etc). The second category is related to the evaluation of operational conditions such as integration aspects and external costs without using network ²⁾.

These formulations present some limitations mainly because they do not incorporate real spatial data and only use general simplifications. More specifically, the network approach uses link-node structure just incorporating distances and time factors. This is limited to express real conditions of the network and just considers basic traffic system (roads, streets, avenues, etc). On the other hand, location on the space models evaluate many different criteria (demand, linear distances, population, etc) without a deep and concrete reference to spatial reality compromising the comparison between potential locations for terminals.

In this paper, we present a methodology to determine the best location for a postal freight terminal, which intends to contribute to eliminate the gap between network and location on the space approaches. Specifically for a postal freight terminal, it is fundamental to represent the Postal Collection-Distribution System (PCDS) since the displacements executed in this system are narrowly related to the locational costs. We describe a methodology that provides a wide appreciation of the factors influencing the location. Exploring Geographical Information Systems (GIS), different data from various sources are combined and analyzed based upon a progressive evaluation that starts with a hierarchical evaluation using Analytic Hierarchy Process (AHP) and concluded by conducting a network optimization.

This paper is organized in four sections. After this introduction, in item two the proposed methodology is described. Next, we introduce the case study for the location of a postal freight terminal in Brazil. Finally, the fourth item presents the conclusion.

2 – Methodology for the location of a postal freight terminal

Three basic phases form this methodology: representation of the PCDS on a digital database; preliminary analysis based on AHP, that provides the identification of potential areas for the terminal location; and final / detailed analysis based on daily costs. From these phases the decision-maker or group can evaluate gradually the problem and after the entire process bearing in mind the necessary subsidies. The insertion of variables is carried out from the general to the specific level, providing a flexible structure of analysis. This framework is subdivided into five activities as described below:

- **Diagnosis of the PCDS:** it involves the description and understanding of the system, i.e., definition of collection / distribution areas, points to collect special mail, rental costs, inventory of public transportation, current location of the terminal;

- **Creation of a GIS database:** all the data collected in the diagnosis activities has to be incorporated in the GIS database;

- **Evaluation of potential locations:** as proposed by Yamashita *et al.* ³⁾, the analysis has to select those potential locations for the postal freight terminal. Then, be a set of f alternative locations, where $f=1, 2, \dots, n$ and considering the fundamental scale of judgements defined by Satty ⁴⁾, we have that each f is related to a priority $P(f)$ within a range of 0 to 1 and obtained through equation 1.

$$P(f) = \sum_{w=1}^q \psi_w^f \tag{1}$$

where f is the alternative number and ψ_w^f is the priority of the last level of criteria w in the AHP hierarchy that is obtained through equation 2 as following:

$$\psi_w^f = \prod_{s=1}^{nl} \Phi_s^w \tag{2}$$

Finally, using GIS's overlay operations thematic maps are created and from them it is possible to analyze $P(f)$ as the result of the final prioritization. Among n alternatives, it is selected those with highest scores of $P(f)$ in order to continue the analysis.

*Keywords: terminal location, GIS, AHP

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- **Daily cost model:** it is obtained from the sum of transportation and rental costs (obtained in phase one) according to the potential alternative f under evaluation. Rental Cost (R_f) is divided by 30 transforming the monthly cost in a daily cost that is added to the cost of Collection/Distribution activities (A_f) as presented in equation 3 generating the total cost (T_f) for alternative f .

$$T_f = A_f + \left(\frac{R_f}{30}\right) \quad (3)$$

where (A_f) is the composition of vehicle costs (V_f) and postman costs (M_f) as presented in equation 4.

$$A_f = V_f + M_f \quad (4)$$

Each component of this equation depends on daily displacements for Collection/Distribution activities. V_f is calculated from the sum of all the displacements processed in the vehicles circuits c considering an average cost per kilometer (ϖ), according to equation 5.

$$V_f = \varpi \times \left(\sum_{c=1}^{nc} D_c[f] \right) \quad (5)$$

where $D_c[f]$ is the distance for Collection/Distribution activities in a circuit c ($c \in \{1, 2, \dots, nc\}$) for alternative f .

Postman cost (M_f) is obtained through the sum of the all the displacements for the all districts d as presented in equation 6.

$$M_f = \sum_{d=1}^{nd} E_d[f] \quad (6)$$

where $E_d[f]$ is the cost for postman displacements in district d ($d \in \{1, 2, \dots, nd\}$) for alternative f .

$E_d[f]$ is the combination of postman and public transportation movements that is computed by hour. Thus, the equation 7 provides the calculation of this cost.

$$E_d(f) = \alpha \times (X_d[f] + Y_d[f]) \quad (7)$$

where α is the hour cost (or fraction) for postman displacements, $X_d[f]$ and $Y_d[f]$ are the total equivalent time for displacements on foot and by public transportation, respectively, for district d and alternative f . $X_d[f]$ and $Y_d[f]$ are obtained by considering the speed of each related mode as presented in equations 8 and 9.

$$X_d[f] = F_d[f] / \beta \quad (8)$$

$$Y_d[f] = B_d[f] / \gamma \quad (9)$$

where $F_d[f]$ and $B_d[f]$ are the distance for displacements on foot and by public transportation, respectively, in district d and alternative f considering the average speed of the pedestrian (β) and the transportation mode (γ).

These distances are obtained from a minimization process according to Traveling Salesman Problem (TSP) ². Considering a p ($p_1, p_2, p_3, \dots, p_n$) set of points to be visited is established, the TSP obtains the trail L denoted as $L(S)$ that minimizes the total distance attending the p set (Collection/Distribution points) and returning to the origin base (alternative f). In this case, we minimize the distance of a set of arcs called ($z(i, j)$) where (i, j) denotes the initial and final nodes of the arc. So, for a specific mode (on foot or bus) and a district d , the minimization is reached by applying the equation 10.

$$Z_d^{mode}[f] = \text{Min}\{L(S)\} = \sum_{(i,j) \in S} z(i, j) \quad (10)$$

where $Z_d^{mode}[f]$ is the total distance of the Collection/Distribution route on foot and / or by bus in order to attend district d starting from alternative f .

In order to incorporate the "real" distance into each arc of the network, $z(i, j)$, we apply the approach developed by ⁵. In this sense, a simple correlation is used, where for a slope (ϕ) the cosine ($\cos(\phi)$) is applied as presented in equation 11.

$$z(i, j) = l(i, j) / \cos \phi \quad (11)$$

where $l(i, j)$ is the distance of arc (i, j) in a plane surface.

- **Selection of the location:** considering daily costs, the model presented in equation 1 has to be minimized. Taking into account that the rental costs varies only with location of the postal terminal, the minimization is based upon the calculating of the daily distances for postman and vehicle movements. Thus, for each potential alternative f , the displacements have to be simulated. In this sense, $F_d[f]$, $B_d[f]$ and $D_c[f]$ are obtained by using a TSP algorithm, that are used to compute A_f . The best location for the postal terminal will be the alternative that minimizes the total cost T_f .

3 - Case Study

The case study was conducted in Sobradinho City, located 24 km far from Brasilia – Brazil, with population about 93,000 habitants (1996) in order to define the best location of a postal freight terminal of the Brazilian Postal and Telegraphic Enterprise (ECT). Firstly, in the diagnosis phase, data on the macro framework was collected. The postal freight terminal in Sobradinho is connected to the main administrative sector (Brasilia). The service area of terminal in Sobradinho is made up of 15 districts (areas of distribution for postman), 1 post office and 2 circuits (areas of collection and distribution for vehicles). The actual location of the terminal is in the commercial area inside the district 11. In this terminal, there are 26 employees - 16 are postmen, 7 have administrative functions, 2 are motorbike drivers and 1 is truck driver ⁶.

Using a digital base containing the transportation system, edification and topography iso-lines based in a coordinate system UTM, a group of six aerial photographs (Black & White, scale 1:8.000, 1992) was incorporated to the database. The

creation of the database was supported by MGE software using a PC-Workstation 300 MHz. Additional data was collected on public transportation by bus and rental costs that were directly transferred into the GIS database.

In the sequence, we performed the identification of potential alternatives based on land use classification. Next, we grouped all the potential areas into 19 alternatives. A decision-making group formed by ECT's staff judged these potential alternatives following AHP's theory and based on GIS database. The results of these judgements were discussed in detail in Yamashita *et al.* ³⁾ and they pointed out the alternatives 14, 15 and 16 as the best ones. In order to obtain a wide variety of comparative simulations, alternatives 7, 8, 10 were also selected for further analysis.

In order to elaborate the daily cost model, the necessary parameters were identified. The average cost per kilometer (ω) was given to be US\$ 1,04 and the cost per hour for postman displacements (α) was estimated by the ECT as US\$ 2,45 ⁷⁾. The average of the pedestrian speed (β) and bus mode (γ) were considered 1,0 and 7,0 meters/seconds, respectively. By using MGE Digital Grid Analysis, the DTM was created for Sobradinho City. Based on the DTM and applying the same MGE module, the slope patterns were obtained and transferred to the database. The slope patterns were divided in 4 range categories ($\geq 8\%$; [6,8%]; [3, 6%]; and [0, 3%]). The creation of the network was initiated from the identification of land use patterns for Collection/Distribution area. By using an aerial photograph mosaic, 7 distribution patterns were identified and from these, the pedestrian network was built and integrated with the bus system generating the postman network as shown in figure 1. Next, the motorized vehicle network was implemented as presented in Figure 2. Throughout the construction of the network the MGE Network module was used and this provided all the tools for automatic creation of all network structure. Finally, a GIS overlay operation was conducted to combine all plane distances $l(i,j)$ for each corresponding network arc with the average slope (ϕ) obtained previously from the DTM.

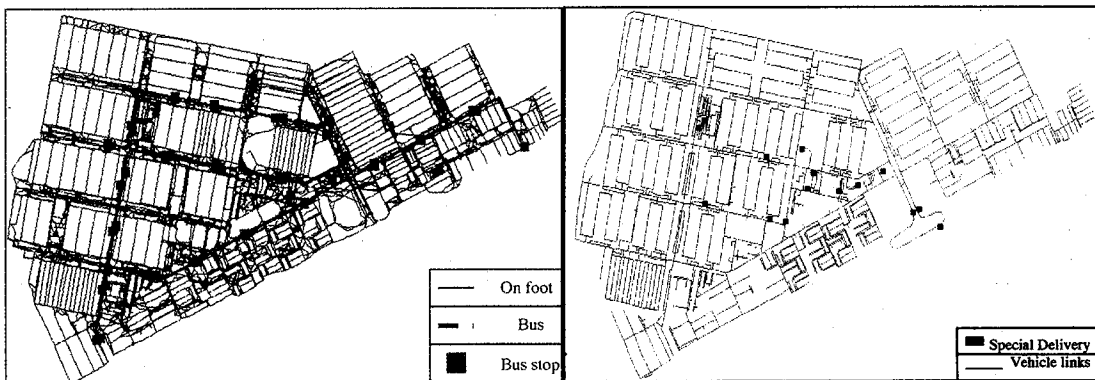


Figure 1: C/D network for Postman displacement

Figure 2: C/D network for vehicle displacements

Alternatives 7, 8, 10, 14 and 15 were simulated in order to compare the results for different potential locations. Additionally, it was established 16 scenarios as presented in Table 1 in order to evaluate how the insertion of special characteristics proposed in the methodology and how it affects the selection of the location of the postal terminal. In this sense, the influence of factors such as slopes, use of the traditional roads and street network in opposition to shortcuts and the limitation or not of the bus system were specifically evaluated. The procedure of simulation was carried out at the beginning by computing separately costs for postman M_f and motorized vehicle V_f . In postman network, the costs per district for each alternative f was computed by considering model parameters, so the costs for each scenario were calculated. The motorized vehicle network was considered in the same way, but only taking into account the distances since the network could not be changed, resulting in the A_f costs.

Table 1 - Scenarios for simulation

Scenario	Postmen costs	Motorized Vehicle Costs
1	Road network + Distances without correction	Distances Without Correction
2	Road Network + Distances with correction	
3	Shortcuts + Distances without correction	
4	Shortcuts + restriction in bus system use + Distances without correction	
5	Shortcuts + Distances with correction	Distances With Correction
6	Shortcuts + only pedestrian network + Distances without correction	
7	Shortcuts + restriction in bus system use + Distances with correction	
8	Shortcuts + only pedestrian network + Distances with correction	
9	Road network + Distances without correction	Distances With Correction
10	Road Network + Distances with correction	
11	Shortcuts + Distances without correction	
12	Shortcuts + restriction in bus system use + Distances without correction	
13	Shortcuts + Distances with correction	
14	Shortcuts + only pedestrian network + Distances without correction	
15	Shortcuts + restriction in bus system use + Distances with correction	
16	Shortcuts + only pedestrian network + Distances with correction	

Finally, considering the rental cost R_f for each potential alternative 7, 8, 10, 14 and 15 that were US\$1.450, 1.400, 1.350, 1.500 and 1.500, respectively, T_f was obtained. In the scenario 15, which is related to the proposed methodology, it can be

observed that Alternative 15 presents the minimum T_i cost (US\$146,96). Despite the initial impression that this result represents a small amount of money, in fact the cost of this postal freight terminal can be considered high since there about 27.000 terminals like this one in the ECT's system. Hence, small variations would lead to losses to this company that currently uses a methodology that just analyze the demands in the service area without using any mathematical model. This can be clearly observed if the results of the best alternative for scenario 15 (proposed methodology) and for the scenario 1 (traditional models) are compared. If we considered the conditions of the scenario 1, it would lead to select alternative 10 that would generate a 17% of additional costs.

Moreover, the result for scenario 15 is coherent with the previous analysis using AHP that points the alternative 15 as one of the best. This result shows the valuable contribution of the analysis based upon the AHP, which reduced significantly the amount of alternatives to be simulated. In both levels of analysis, it was possible to observe the essential influential of geographical-spatial variables that were comprehensively incorporated into the results.

4 - Conclusion

There are many nuances to be examined in this methodology. It is important to observe beyond the simple application and the results of the proposed method. It is crucial to understand the reason for using a hierarchical analysis and how GIS and AHP integration helps in this task. In addition, it must be understood why it is so important to process a selection of potential locations for DDC and what kind of impact it generates on the final context. Lastly, how the insertion of geographical-spatial variables in the network optimization model was reached and what it represents in terms of ultimate decision-making must be studied.

The selection of potential locations for the postal freight terminal is vital not only because it defines a limited number of alternatives to implement the terminal. It can be observed that the evaluation at this methodological level is preliminary, but computes the most important factors influencing the decision. It generates a satisfactory explanation of the problem and a strong indication regarding the probable choice of the best location. As verified in the case study, the best location in this phase was reaffirmed as the same in the network analysis. It shows that if a planner needs an instrument to decide quickly and securely about a terminal location, this phase can lead to very interesting results without consuming more time in further analysis. We believe that it could be used for strategic or long-term analysis.

The phase of network optimization involving the use of some geographical-spatial variables, unusual in traditional models, aimed to create a more realistic representation of ECT's activities. By incorporating land use patterns, topography (slopes) and the shortcuts, there was a changed from Euclidean and Rectangular metrics to the Spatial metric. It was possible due to GIS characteristics, since new variables such as the "real distance" as a new element of impedance was considered in the network optimization and innovating in the obtainment of geographical-spatial properties. In fact, the latter process is effectively the most important since it is based upon the DTM (slopes) and aerial photographs (shortcuts and land use patterns). It would be quite impossible to imagine a simple model as proposed here and which could insert these variables using *in loco* data given the question of variety and dimension.

In the case study, the methodology was validated by results that proved to be very realistic as intended at the beginning. The efficiency of the methodology was ratified in the sense that it considers ECT's system and incorporates urban characteristics. Through this approach, it is now possible for the company to conduct its own evaluation not depending in adapted models, observed to be inconsistent for the ECT's reality. Furthermore, it was verified that without considering the new variables of the proposed spatial model the final result could lead to financial losses to the company. These variables affect daily costs, especially in pedestrian displacements (postman), affected by slope considerations, especially for long distances. Finally, it was noticed that the network design has a directly influence on the final result, since the incorporation of shortcut paths generated differences when comparing with traditional network.

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