A Methodology for Location of Logistics Platforms Using Geographic Information Systems

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***Abstract*—Currently the supply chain management is important to the companies, mainly due to technology advances which have allowed decentralizing several logistics operations. So, we have seen a growing of the third-party logistics providers in the supply chains to perform several operations. These new partners help to reduce the lead time involving the operations and distribution of goods, and keep a good level of service for the customers. Thus, transportation and logistics operations have become important activities to reach the companies' goals. In this context, the logistics platforms arise to give quick answers, however they must be located in strategic points to reduce costs but taking into account tangible and intangibles factors. Then, this paper presents a methodology for locating logistics platforms using geographic information systems. This methodology was applied to locate Brazilian logistics integration centers devoted to solid bulk (soybeans and corn), considering a road-rail integration.**

***Index Terms*—GIS, logistics platforms, location problem, case study**

I. Introduction

According to [1], in the beginning of the 80's arises in the literature the concept of logistics chain or supply chain management that rapidly gained wide acceptance and notoriety. Its main importance is associated to the growing fragmentation of the logistics processes, driven by the outsourced activities in the key factors of a supply chain: stock, transportation and facilities [2]. Since then, it was observed a marked increase of the complexity of several supply chains like the automobile, electronics, computers, among others [3].

Focusing the decentralization of the activities, the supply chain management has gained importance in the company's management, mainly due to the technological advances in the logistics area [2]. This decentralization provided the growth of logistics operators which have joined the companies' logistics chain. These new members try to help reducing the lead time in the operation and products distribution, aiming at the level of service projected and expected by the customer [4] [5]. Thus, the transportation and the logistics operation have become important activities to achieve the desired goals.

However, variations of market and the logistics infrastructure available affect the supply chains which need to respond rapidly to the necessary changes. In this context, as indicated by [4], the logistics platforms, used as macro business units, and the specialized terminals, as micro business units, are an option for the supply chain to respond appropriately to the variations. However, the strategic location of these facilities constitutes a key factor and so it needs to be well defined considering tangible (e.g., fixed installation cost) and intangible factors (e.g., environmental measures).

The decision about the most appropriate location to install a logistics platform is associated to what is desired from the supply chain involved. The centralization generates economies of scale, while the decentralization makes the chain more responsive, reducing the distance between supply and consumption points [6] [2].

In an integrated way, the logistics platforms must be inserted in a transportation network which can be multimodal. The location of their positions must take into account the supply and demand of the products to which the logistics platforms will provide logistics support. Thus, besides specific criteria for the platforms location, it must be taken into account the cost reductions from transportation.

So, the objective of this paper consists on the development of a methodology for the location of logistics platforms that can be used in various studies which integrates localization and transport, using Geographic Information Systems – GIS. To illustrate the proposed methodology, it was applied in Brazil to locate Brazilian logistics integration centers devoted to solid bulk (soybeans and corn), from data of the National Plan of Logistics and Transportation – NPLT of 2007 [7].

The remainder of the paper is organized as follows. Section 2 presents some concepts about logistics platforms. Section 3 shows some definitions about location and highlights the importance of the interface with GIS. The methodology proposed is presented in Section 4. Section 5 shows a practical application, and finally Section 6 presents the conclusions.

II. Logistics Platforms

Reference [8] defines logistics platform as an area of logistics services, delimited in the territory or not, located in a point of the transportation and logistics chains, from which important contributions of the value chain can be obtained, through the provision of services of added value, whether through the transportation network, the

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telecommunications network or through only specific services to the stakeholders (users, operators, and customers), to the vehicles and to the equipment.

A more complex definition given by the European Association of Freight Village – Europlatforms (www.europlatforms.eu) describes logistics platform as a delimited zone within which different operators perform all activities related to transportation, logistics and distribution of goods, both for the national and international transit.

A classification to logistics terminals proposed by [9] can be used to logistics platforms, and so, logistics platforms can be classified as the transportation mode (road, air, rail, port, and multimodal); as the range (urban, regional, interstate, and international) and as the services provided (load, unload, transshipment, storage, beneficiation, logistics activities, and customs service).

Thus, the logistics platforms must be inserted in a transportation network which can be multimodal. So, the location of them must take into account the supply and demand of the products to which the logistics platforms will give logistics support. Thus, besides specific criteria to the location of the platforms, the cost reductions from the transportation must be taken into account.

III. Location of Logistics Platforms

The mathematical models of location are often used to determine the ideal places for facilities. Facility or installation is a generic term used to represent, for example, emergency units, schools, and also logistics platforms. Reference [10] presents a description for groups of location models which differ in the way in which the demand is distributed over a service area and how the facilities can be located in this area. This classification divides the models into analytical, continuous, of networks and discrete. In particular, we highlight the discrete location models known as p-median and the maximum coverage, which present high level of difficulty, even to small problems, however they are associated to several practical applications. For details, see [10].

When considering the product demands, the production places, the candidate places to receive logistics platforms, and a multimodal transportation network, the problem of logistics platforms location can be compared to the problem of multi-commodity facility location introduced by [11] and [12]. The original mathematical formulation proposed by [11] does not present capacity constraints of facilities. This characteristic was incorporated one year later by [13]. Thus, the mathematical formulation which minimizes the transportation costs, the fixed facility costs and the platforms operation costs, is presented as follows [13]:

$$\text{Minimize} \quad \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{l\in L} c_{ijkl}x_{ijkl} + \sum_{k\in K}\left(f_k z_k + v_k \sum_{i\in I}\sum_{l\in L} d_{il} y_{kl} \right) \tag{1}$$

Subject to:

$$\sum_{k\in K}\sum_{l\in L} x_{ijkl} \le s_{ij} \qquad \forall i \in I, j \in J \tag{2}$$

$$\sum_{j\in J} x_{ijkl} = d_{il} y_{kl} \qquad \forall i \in I, k \in K, l \in L \tag{3}$$

$$\sum_{k\in K} y_{kl} = 1 \qquad \forall l \in L \tag{4}$$

$$\underline{v}_k z_k \le \sum_{i\in I}\sum_{l\in L} d_{il} y_{kl} \le \bar{v}_k z_k \qquad \forall k \in K \tag{5}$$

$$x_{ijkl} \ge 0 \qquad \forall i \in I, j \in J, k \in K, l \in L \tag{6}$$

$$y_{kl} \in \{0,1\} \qquad \forall k \in K, l \in L \tag{7}$$

$$z_k \in \{0,1\} \qquad \forall k \in K\,. \tag{8}$$

where:

- d_{il} is the demand of product $i \in I$ by zone $l \in L$;
- s_{ij} is the supply capacity of the product $I \in I$ by plant $j \in J$;
- $\underline{v}_k$ and $\bar{v}_k$ are the total minimum and maximum volumes allowed, respectively, passing through the facility $k \in K$;
- f_k is a fixed cost to install the facility $k \in K$;
- v_k the variable cost associated to the facility $k \in K$; and
- C_{ijkl} is the average unit cost of production and shipping of the $i \in I$ product, of the plant $j \in J$, using the facility $k \in K$, to the zone $l \in L$.

Regarding the decision variables:

- x_{ijkl} determines the volume of product $i \in I$, shipped in the plant $j \in J$ which is sent to the zone $l \in L$ by facility $k \in K$;
- $y_{kl} \in \{0,1\}$ is a binary decision variable for all $k \in K$ and $l \in L$. If $y_{kl} = 1$, facility k serve zone l, otherwise $y_{kl} = 0$;. and
- $z_k \in \{0,1\}$ is also a binary decision variable for all $k \in K$. If $z_k = 1$, facility k is opened, otherwise $z_k = 0$.

The objective function (1) includes all the costs and must be minimized. Constraints (2) ensure that the whole quantity of products $i \in I$ shipped in the plant $j \in J$ and received by the facility $k \in K$ with destination to the zone $l \in L$, must be less than or equal to the quantity of product $i \in I$ available at plant $j \in J$. Constraints (3) ensure that the whole quantity shipped of all plants $j \in J$ to the facility $k \in K$, will be equal to the demand of zone $l \in L$, if a facility is opened in $k \in K$ and serves zone $l \in L$. Constraints (4) ensure that only one facility $k \in K$ will serve all the customers of zone $l \in L$. Constraints (5) guarantee that the annual volume of products which uses the facility $k \in K$ is between the minimum and maximum values definied to it. Constraints (6)-(8) are applied to the domain of the decision variables.

Reference [13] applied the mathematical model (1)-(8) to a food chain problem with 17 classes of commodities, 14 plants, 45 possible locations to receive facilities, and 121 customer zones. The authors used Benders decomposition to solve the problem. There are several works in the literature which expanded the study of [13] to incorporate new characteristics such as [14], [15], [16], and [17]. A good review about location problems can be obtained in [18], [19], [20] or in [21].

Location problems are influenced by several factors and thus, the Geographic Information Systems (GIS) can be used to help in this task. Reference [22] presents a study which has as objective to locate urban logistics terminals using GIS tools. The authors apply the methodology presented in the problem of the city of Uberlândia. According to the authors, a GIS can be defined as an organized collection of hardware, software, personnel and geographic data, aiming to capture, store, manipulate, update, map the spatial data and present georeferenced objects.

Some authors like [23], [24], [25], [26] and [27], have highlighted the GIS potentiality in solving facilities location problems. Reference [25] shows in details the GIS contributions in locating facilities in terms of data input, visualization, solution methods and also theory.

IV. Methodological Proposal for Location of Logistics Platforms

The methodology proposed is divided into phases, as shown in Fig. 1, and each of them is described below.

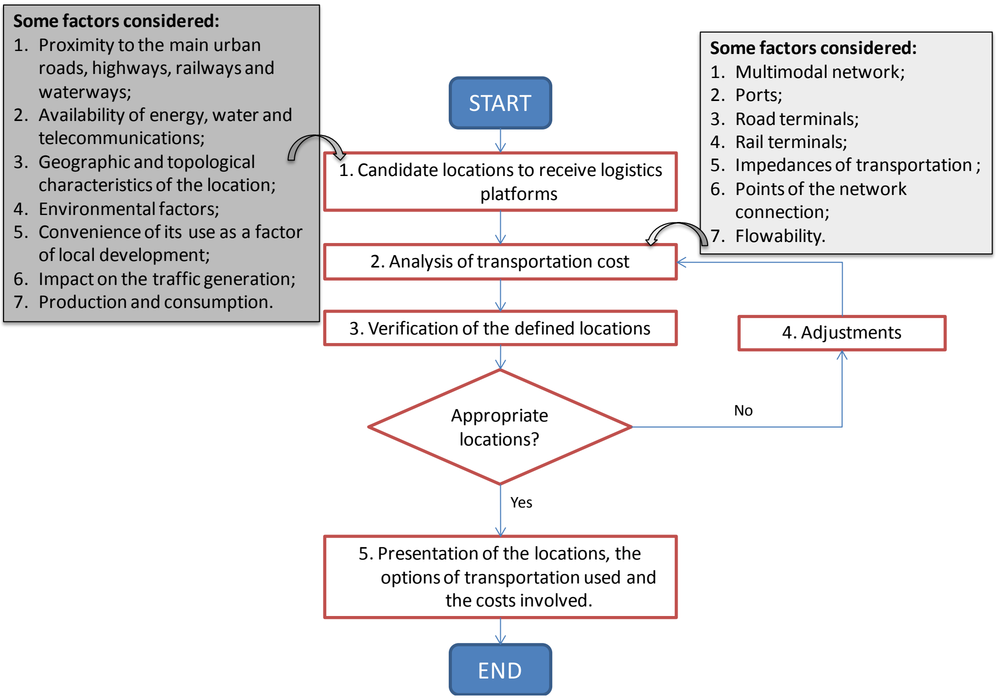

Figure 1. Methodology proposed.

Phase 1: Candidate Locations to Receive Logistics Platforms

To accomplish the location of logistics platforms in a multimodal network, several tangible and intangible factors must be taken into account. Several studies like those from [28], [29], [30], [31] and [9], point out conflicting factors which influence in the facilities location like the proximity to main urban roads, highways, railways and waterways; availability of energy, water and telecommunications; geographic and topological characteristics; environmental factors; convenience of use as a factor of local development; impact on traffic generation; production and consumption; among others.

So, the first phase of the methodology proposed consists in defining possible locations to receive logistics platforms through a multi-criteria analysis.

Phase 2: Analysis of Transportation Cost

Once defined the set of candidate locations of the facilities, starts the second phase which is an analysis of the transportation costs reduction. The aim is to assess if the locations initially defined allow using appropriately the available transport infrastructure to meet demand. In this phase, a mathematical model adapted from the formulation (1)-(8) could then be used and solved. In parallel, studies about logistics networks [32] and about impact of the terminal cost on the total transportation cost [33] also must be accomplished in order to better define the mathematical model. Fig. 2 shows an example of transportation cost variation due to the distance, comparing the road cost with the intermodal transportation cost including the terminal operations. A GIS must help in the definition of locations to receive the logistics platforms, as well as in the solution of the location models, if possible. Depending on the complexity of the mathematical location model, commercial solvers like CPLEX [34] can be used. If the commercial solvers are not able to solve the problem in an acceptable computational time, heuristic methods must be developed based on the literature available.

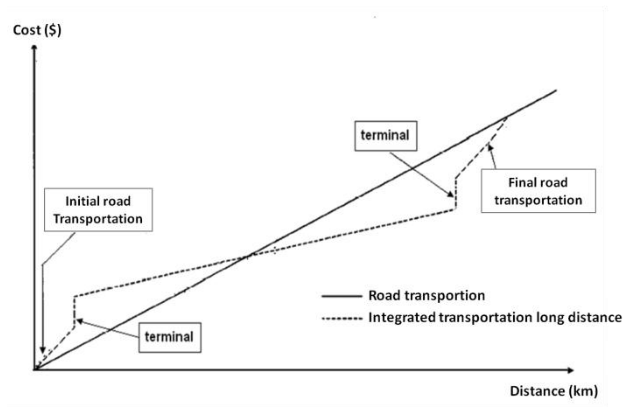

Figure 2. Structure of the intermodal and road transportation costs [33].

Phase 3: Verification of the Defined Locations

Once solved the mathematical location model, the set of selected platforms must be verified according to the flows of products, to verify if exist or not inappropriate transportation flows. This phase is important to correct possible problems in the definition of the candidate locations or in the multimodal network structure or in the mathematical model used.

Phase 4: Adjustment

This phase depends on the result of Phase 3, and has as objective to make the adequate adjustments in the mathematical model used to define the candidate locations, and in the mathematical model to assay the transportation cost.

Phase 5: Presentation of the locations, the options of transportation used, and the costs involved

In this stage will be assessed the results generated. All facilities located, the transportation modes used, the transportation routes and the costs are presented. This tasks use a GIS to help the decision maker to understand the solution obtained.

V. CASE STUDY

With the resumption of the strategic planning of the logistics system and transportation systems in Brazil, both in regional and national terms, we can see that the recent governmental investment plans need of improvements regarding scientific methodologies which, applied, provide indications of Logistics Integration Centers, or as previously mentioned, indications of installation and operation of logistics platforms.

The Brazilian governmental targets related to multimodality, aiming at the transportation cost reduction in the logistics chains of production and of supply, are extremely relevant points. However for them be effective, activities must be performed to concentrate operations and transportation services, promoting the operation of logistics platforms.

There is a large number of integrated logistics centers and logistics platforms successfully operating in the world. Nevertheless, to date there is not any enterprise that can be classified as effective logistics platform, in full operation in Brazil. The initiatives are still in an embryonic level, in the form of plans, projects, or at most in the phase of preparation of the ground (such as the case of the proposal of Goiás), not allowing a safe evaluation.

Many state governments in Brazil are investing in logistics infrastructure, as a way to attract companies to be installed in their states or near of the states making use of the benefits of logistics and customs infrastructure. In Rio Grande do Sul, the study of regional development and logistics to the State of Rio Grande do Sul (RS) – Project Rumos 2015, in "Component 2 – Logistics and Transportation" [35] has indicated as important a careful analysis of the proposals for installation of terrestrial platforms in the state, classifying them during the studies according to the methodology developed, as logistics integration centers or logistics platform from their minimum requirements and potential stakeholders to run them, also defining the stages of its implantation and pointing out possible financing mechanisms.

Thus, in this section is presented an application of the methodology proposed for the location of Logistics Integration Centers – LIC in the national territory using the georeferenced database of the National Plan for Logistics and Transportation – NPLT, presented by the Ministry of Transportation in 2007 [7]. For examples, we seek to locate LIC for the following solid bulk: soybeans and corn, considering road-rail integration.

The georeferenced database of the NPLT has a multimodal network with more than 16,260 segments and 559 regions which produce products, as shown in Fig. 3. For 2007, from this total of regions, 255 produce soybeans and 553 produce corn. In the consumption side, 54 regions demand soybeans and 552 demand corn.

Applying Phase 1 of methodology and considering as relevant the factors "Production" and "Proximity to roads and railways", 93 regions are responsible for 80% of all national production of soybeans and corn. Based on this information, we sought among these 93 regions, those with at least one road-rail integration in operation or under project with forecast to be in operation until 2023 (This is the NPLT planning horizon). This task was performed using a GIS. So, as a result 61 regions became part of the set of candidate locations to receive LIC. Fig. 4 shows the result of this phase.

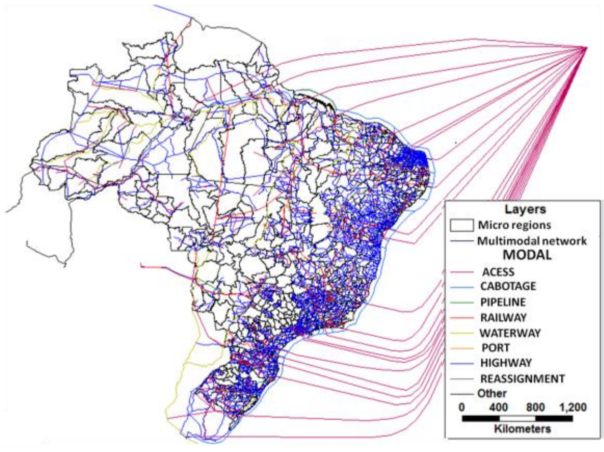

Figure 3. Georeferenced database of the NPLT.

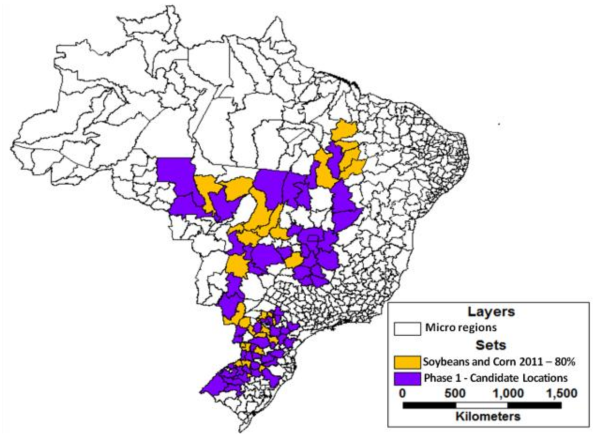

Figure 4. Result for Phase 1 of the methodology.

For Phase 2, it is necessary to obtain some unit costs, as mentioned in the mathematical model (1)-(8). Initially, it was considered that all cargo transportation between a production site and a candidate location to receive a LIC would use the road mode. On the other hand, from the candidate location to receive a LIC to the demand point, it was considered that the cargo transportation could be used both through road and/or rail.

Thus, again with the help of a GIS, the distances between all the points (producing regions, candidate locations to a LIC, and regions of demand) were obtained, and the transportation unit cost was computed using values of road and rail freight in R$/ton.km. In the road transportation, we used reference values from SIFRECA – Freight Information System published by the Brazilian Department of Economics, Management and Sociology, School of Agriculture "Luiz de Queiroz", University of São Paulo – ESALQ/USP, and in the rail transportation, we used a methodology to calculate the fare published by the Brazilian National Land Transportation Agency.

In relation to the installation fixed cost of a logistics platform, a constant value was used for all candidate location much lower than the transportation cost. In relation to the variable cost of a facility, it was chosen to use R$ 20.00 per ton handled in the logistics platform. This reference value was considered, in a simplified way, based on the recent construction cost of a road-rail terminal, considering the ratio between the total investment and the capacity by year.

This strategy allowed us to evaluate and study the transportation and cargo handling costs in the logistics platform to define the location. In terms of minimum and maximum volume handled in a logistics platform, it was considered that each candidate location could handle, per product (soybeans or corn), a total cargo between zero and the total volume produced by the regions. This strategy allows, for example, that only one logistics platform be opened because it will have capacity to handle everything that was produced/demanded.

Nevertheless, this approach can be corrected, considering as limit the capacity of transportation by rail or through a determination of the engineering project which establishes the maximum tones that a platform can handle a year.

So, according to what was indicated in Phase 2, a mathematical model adapted from (1)-(8) was used for computational tests. It was introduced in the model a constraint that limits the maximum number of LIC located, allowing the creation of scenarios. The computational experiments were performed with CPLEX 12.2 [34] in a computer equipped with Processor Pentium Intel Dual Core 1.73 GHz with 1.50 GB RAM. The results are shown in Table I, where the first column indicates the scenario, the second the maximum number of LIC to be installed, the third indicates the computational time used by CPLEX, and finally the fourth column presents the regions selected.

With the results of Table I, we can see that as the maximum number of platforms increases, there is a setting of certain regions. For example, two regions are selected in Scenario 1 (South-west of Goiás-GO and City of Canoinhas-SC) and they continue to appear in the remaining scenarios.

TABLE I. RESULTS OBTAINED WITH CPLEX

Scenario	Maximum number of LIC	Time (s)	Micro regions selected to receive LIC*
1	2	1,095.42	1. South-west of Goiás (GO); 2. City of Canoinhas (SC)
2	3	5,609.19	1. South-west of Goiás (GO); 2. City of Canoinhas (SC); 3. City of Rondonópolis (MT)
3	4	2,090.87	1. South-west of Goiás (GO); 2. City of Canoinhas (SC); 3. City of Rondonópolis (MT); 4. City of Toledo (PR)
4	5	704.28	1. South-west of Goiás (GO); 2. City of Canoinhas (SC); 3. City of Rondonópolis (MT); 4. City of Toledo (PR); 5. City of Uberlândia (MG)
5	6	1,068.34	1. South-west of Goiás (GO); 2. City of Canoinhas (SC); 3. City of Rondonópolis (MT); 4. City of Toledo (PR); 5. City of Uberlândia (MG); 6. City of Barreiras (BA)
6	7	976.07	1. South-west of Goiás (GO); 2. City of Canoinhas (SC); 3. City of Rondonópolis (MT); 4. City of Toledo (PR); 5. City of Uberlândia (MG); 6. City of Barreiras (BA); 7. City of Passo Fundo (RS)

7	8	493.35	1. South-west of Goiás (GO); 2. City of Canoinhas (SC); 3. City of Rondonópolis (MT); 4. City of Toledo (PR); 5. City of Uberlândia (MG); 6. City of Barreiras (BA); 7. City of Passo Fundo (RS); 8. City of Londrina (PR)
8	9	210.80	1. South-west of Goiás (GO); 2. City of Canoinhas (SC); 3. City of Rondonópolis (MT); 4. City of Toledo (PR); 5. City of Uberlândia (MG); 6. City of Barreiras (BA); 7. City of Passo Fundo (RS); 8. City of Londrina (PR); 9. Around City of Brasília (DF)
9	10	195.80	1. South-west of Goiás (GO); 2. City of Canoinhas (SC); 3. City of Rondonópolis (MT); 4. City of Toledo (PR); 5. City of Uberlândia (MG); 6. City of Barreiras (BA); 7. City of Passo Fundo (RS); 8. City of Londrina (PR); 9. Around City of Brasília (DF); 10. City of Dourados (MS)

*In parenthesis we can see the Brazilian state of the region.

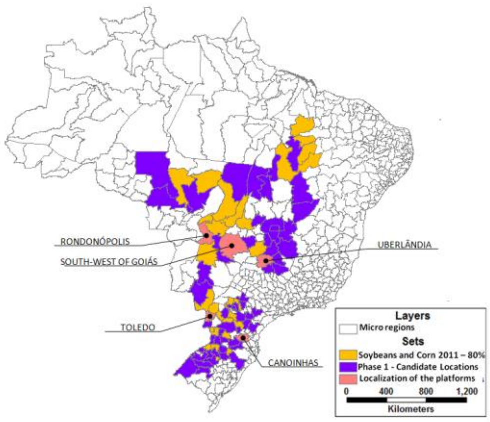

Figure 5. Result of the location for Scenario 4.

Considering that we can add value to the products in the logistics platforms, this fixation of some locations can indicate prioritization of investments to them. Table I is part of Phases 4 and 5 of the methodology. At last, only to exemplify a possible result of Phase 5, Fig. 5 presents the regions selected for Scenario 4.

VI. Conclusions

This paper presented a methodology to locate logistics platforms with the help of geographic information systems. Generally, the methodology proposed is composed of five phases, where the two firsts are decisive to determine the ideal locations to receive the logistics platforms.

A practical application to locate Brazilian logistics integration centers was performed to exemplify the use of the methodology. In particular, we have used data from two products (soybeans and corn) and the Brazilian multimodal network of the National Plan for Logistics and Transportation – NPLT published in 2007. Even with a large multimodal network (more than 16 thousand segments), with a considerable number of production and consumption locations (more than 500), and with 61 candidates places to receive facilities, it was possible to do some analysis with the results from CPLEX which used an adapted mathematical model of (1)-(8). However, it is noteworthy that if we increase the number of products and the number of candidate locations, commercial optimization solvers, like CPLEX, fails, and so, approximation methods, like heuristics and metaheuristics, must be used.

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