VALUATION OF ACCESSIBILITY INDEX THROUGH HIGH-RESOLUTION SATELLITE IMAGES AND GEOGRAPHIC INFORMATION SYSTEMS – A METHODOLOGICAL PROPOSAL FOR PLANNING THE TRANSPORTATION SYSTEM

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ABSTRACT

This paper develops a multidisciplinary methodology that aggregates remote sensing products and the resources available in geographic information systems – GIS, for transportation planning. The parameter analyzed is accessibility. Public managers can use accessibility measures in order to promote an appropriate urban planning, mainly the highway network infrastructure and the public transportation system planning. The objective is to build the database to get the commercial and industrial (C&I) accessibility index for Osasco Municipality, located in the Metropolitan Region of São Paulo. The proposed methodology consists in starting from an object-oriented (O-O) classification of the IKONOS II satellite images, to extract the information necessary to estimate the accessibility index. The goal of the O-O classification is to find the commercials and industrial establishments located in the study area. The spatial data are converted and analysed within a GIS environment and a C&I accessibility index is calculated using the parameters obtained from the satellite images. Many studies on accessibility measures have been conducted over the past decades. But, the contribution of this academic work lies in the fact that the accessibility is calculated using data obtained directly from remote sensing satellite images, unlike the conventional method, which uses data coming from field surveys The proposal of this methodology can be justified based on the fact that it can reduce cost and time spent on field researches or to bring up to recorded data. Thus, it is a convenient alternative to be used in places with no recorded data or with outdated recorded data. And also, where there are budget constraints and / or need for faster generation of results for urgent interventions in the transportation system. The validation of this method is done by calculating the same C&I accessibility index through conventional method, using recorded data available in the Osasco Municipality. The two accessibility indexes are compared, so it is possible to conclude about the applicability of the proposed methodology.

Keywords: Accessibility, Geographic Information System, Remote Sensing, Transportation System.

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1. AN OVERVIEW

It is known that each culture, each country has its own history, customs and traditions, which leads to specific processes of development (economic and social), and urbanization. However, there was no economy and society that have been developed without an intense spatial mobility of population, and high levels of accessibility available to this population. The economic interface is that accessibility adds value to land, and mobility is a development indicator.

The continuous and disordered urban growth is a world phenomenon and it consists of a serious problem that the cities face presently. Brazil has been undergoing an accelerated process of urbanization, which lasted about 50 years, from the second half of last century. The industrialization process has encouraged the growth of cities in Southeastern Brazil; it has attracted a great migration, from other parts of the country, made up of people seeking better living conditions. The result was a swelling urban, that is, the uncontrolled urban expansion, because cities were not prepared for this rapid growth. This way, was generated a process of out skirting the cities. Without economic resources, the population was forced to withdraw more and more central areas of town, where they were concentrated workplaces, hospitals, schools, recreation areas, etc. This situation has continued varying degrees of growth, no longer only in the Southeast, but in virtually all large and medium Brazilian cities.

The peripheral growth of the Brazilian cities is rarely accompanied by an integrated network of public transport and other services. Due to the lack of urban planning and an integrated model of transport and land use, over the time, this affected the transportation system, because, with the population increasingly removed from their places of destination, travel times and distances to be traveled increased. As a result, the transport supply failed to meet the growing demand for transport. This scenario, inevitably, reduces the accessibility levels and the population's mobility.

Accessibility is an inherent characteristic of a place with respect to overcoming some form of spatially operating source of friction, for example, time and / or distance (INGRAM, 1970). In this study, likewise Allen *et al*. (1993), the concept of accessibility is interpreted as a measure of the effort of overcoming spatial separation, in terms of distance, time, or costs. According to the authors, available opportunities of an individual or group of individuals to perform their activities by taking part in a transportation system characterize accessibility. It is important to emphasize that in this study the accessibility concept is not a characteristic of people. It means, places have accessibility index, and people have mobility levels.

Khisty and Lall (1998), argue that the basic concept that lies behind the relationship between land use and transport is accessibility. The more accessible an area is to the various activities in a community, the greater its growth potential. It demonstrates the relationship between accessibility and land development, and the advantages of adopting an integrated model of transport and land use, based on a realistic measurement of accessibility. Such a model would relate the accessibility of an area to the rate and intensity of the land development in that area (HANSEN, 1959).

According to Minocha *et al.* (2008), the accessibility concept offers a decision support tool for transportation planners and land use planners to *(a)* develop an in-depth understanding of the transportation demand and supply that can be served by the transportation system, mainly by transit, within an expected and desired level of service quality; *(b)* conduct analysis at a relatively small geographic level to develop targeted policies; and *(c)* allow for detailed analysis of the environmental justice implications of investments in transportation system.

Hanson (1995) affirms that the intimate relationship between transportation engineering and land use is explicitly acknowledged by the fact that at the heart of every city's long-term land use plan is a transportation plan. The author continues by arguing that it implies that the introduction of transportation facilities enable people to travel farther in a given amount of time than they could previously (particularly in privately owned vehicles). So, it is possible to conclude that transportation improvements contribute to the growing spatial separation between activity sites (mainly between home and work place) in urban areas. As a result, planners and policymakers now recognize that through attention to land use planning, that is, by creating high-density urban neighborhoods, accessibility can be achieved without increasing the spatial separation (in terms of distance, time, or monetary costs) activities sites. From this point of view, accessibility should be a central part of any measure of the quality of life.

So, the accessibility level affects the quality of the transportation system, and both affect the occupation of the urban land, *i.e.* the effective land use. The densification of human activities (*i.e.* the activities system, that is the distribution of opportunities in time and space, for instance: work, school, health system, leisure, so on), occurs around locations with high level of accessibility, both in terms of road networks (transport infrastructure), and transport services.

Many studies have been developed about accessibility measures. The issue has been discussed since the early second half of the last century until the present day. This sense can be cited the work conducted by Hansen (1959) that defines accessibility as the potential of opportunities for interaction (concept developed by Stewart, (1948)), and its measurement is the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome spatial separation; Ingran (1971) and Allen *et al* (1993), that use the concepts of relative accessibility (the effort of overcoming spatial separation between two points – Origin / Destination), integral accessibility (the measure of the effort to overcoming spatial separation between a point and all other points within an area), and overall accessibility (measures the effort of overcoming any spatial separation in an area); Vickerman (1974), that claims that the accessibility's studies involve a combination of two elements: location on a surface relative to suitable destinations, and the characteristics of the transportation network, and the accessibility measures are essentially alternative ways of describing the network in terms of the number of links (routes) and nodes (places of interest – origins / destinations) – the overall accessibility to all destinations; Hanson (1995) and Kwan *et al* (2003) who use the concept of accessibility of places and accessibility of people (unlike the concept adopted here); Gutiérrez *et al* (2010) use the geographical information system (GIS) to measure accessibility, the authors claim that accessibility analyses is one of the criteria considered in the assessment of plans and projects of transport infrastructure, and also, accessibility studies permit researchers to evaluate other criteria as spatial cohesion or economic development, and therefore, can be considered as a proxy of a set of related (economic, social, environmental) effects of transport infrastructure. Yet, these studies address the accessibility through the conventional method for its measurement, *i.e.* field research that were conducted in order to build the database to measure the accessibility index.

With the advent of the new generation of satellite sensors with high spatial resolution, the applications in the urban environment became feasible, and thus, another possibility of analysing, studying and measuring accessibility arose. In this sense can be mentioned the studies developed by Lee and Ryu (2004), and Wang and Trauth (2006).

What is proposed in this study is the adoption of tools that assist the transportation system planning and help to increase the quality of the transportation system, within an Integrated Land-Use and Transportation Model. The measure under consideration is the accessibility, obtained directly from Remote Sensing satellite images, with high spatial resolution.

2. OBJECTIVES

The purpose of the study is to develop a methodological framework that brings together products from Remote Sensing, with a large amount of computing resources that Geographic Information Systems (GIS) are capable of providing, in order to make analysis of Transport Planning. The main scope is to study levels of accessibility, that serve as tools of urban planning, because they can act to prevent problems relating to the transportation network. The accessibility indices assess how the destinations are such as workplaces, education, health, leisure, and so on, can be accessed by the population (users of the transportation system).

The required database is extracted directly from images of high spatial resolution from the remote sensing satellite IKONOS II. The study area is the city of Osasco, located in the Metropolitan Region of São Paulo, Brazil. The study consists in getting a thematic map of land use and occupation of the Osasco City, to locate spatially the companies. This allows the location of commercial and industrial (C&I) establishments of the municipality (with medium or large size). With this information the accessibility index of the business sector of the Osasco is determined (C&I accessibility index).

This methodology is validated by comparing the level of accessibility provided by the proposed method with another one obtained from recorded data (2003), provided by the Prefecture of Osasco, *i.e.* the accessibility index calculated by the conventional model, as calculated by Ingram (1970), and Allen *et al* (1993). Comparing these two indices of accessibility it is possible to conclude about the applicability of the proposed methodology.

The application of a multidisciplinary approach that uses the remote sensing technology to built the database, and the analysis in a GIS environment to study and measure the accessibility levels is justified by the fact that the construction of the database through research field is more time consuming and costly. The proposal is to reduce the cost and time spent in the research and updates of the recorded data, through a methodology that is useful to places that do not have recorded data or they are outdated and no longer reflect the reality of the region to be analyzed. The proposed method combines agility and costs reduction, because it eliminates the phase of database construction *in loco* (fieldwork).

3. MATERIALS AND METHODS

For this work, the adopted methodology started from the images of the satellite IKONOS II. They are images with high spatial resolution, and many researchers have studied and proved their geometric quality. In this regard is highlighted the work of: Baltsavias *et al*. (2001); Fraser *et al*. (2002); Ganas *et al*. (2002); Jacobsen (2002_A; 2002_B; 2004; 2006); Poon *et al*. (2005); Shan and Lee (2005); Topan *et al*. (2005); Kocaman *et al*. (2006) e Zoej *et al*. (2006).

The images were acquired through an agreement between the Government of the São Paulo State and the University of São Paulo. The original imaging was made in October 2002, and the scope of this collection of images includes the 39 municipalities of the São Paulo Metropolitan Region, with a total of approximately 8,000km^2.

The decision of performing an object-based image classification, such as the work presented by Walter, (2004), was due to the fact that the urban features necessary for the proposed method are mainly roads, and buildings (residential, commercial, and industrial). Although these types of features are easily viewed from high resolution images, such as IKONOS II satellite, the most laborious task is now to extract them in an automated mode. The image classification, which traditionally seeks to discriminate classes of land cover, in this approach, based in objects, seeks also to infer about the land use. However, the classification model based on contextual information (objects) is more than ever, a process supervised and, such as, is highly dependent of an analyst.

Considering the need to get results arising from automated extraction of features, and since many of these features are relatively small and represented in the images by a few pixels grouped, several studies comparing the traditional pixel-based classification with the object-based classification, and conclude that the second approach is the most accurate, and bring better results in urban areas. The reason for the improved performance of the object-based classification is due to the fact that through the higher spatial resolution of the new generation of sensors, the problem of mixed pixels is reduced. Nevertheless, the internal variance and the noise within the classes of land use are extended. Therefore, in conventional procedures of multispectral classification, whose compositions of groups (clusters) are based on spectral homogeneities, results in an excess of classes, *i.e.* ill-defined classes (SCHIEWE and TUFTE, 2007).

The applied methodology (figure 1), followed the following steps:

1. Digital image-processing (images from the satellite IKONOS II):
    a. The four bans (blue, green, red, and infrared) were stacked (overlapped) in order to obtain a single image to be worked.
    b. It was made the junction of the different sheets of images to compose the study area, *i.e*. a mosaic of the images.
    c. The next step was the segmentation of the image, to create the objects that would be classified in the next stage.
    d. Then, it was made the procedure of classification based in the segments (objects) generated by the segmentation phase.
    e. With the classification result was identified where the companies are located in the city.
2. Conversion, input, and analysis of the database in a GIS environment:
    a. Next was done manually the mapping and labelling of the classes generated by the classification algorithm.
    b. Were incorporated, through the visual interpretation and analysis of the image, as well the preliminary classification, some information about shape, context, and topology, and was done a new classification based on this additional information. This is an attempt to minimize the errors of the preliminary classification. These are called errors of commission (the segments that were classified as companies, but actually are not), and errors of omission (the segments that were not classified as companies but in fact are).
    c. The vectorial data of the Osasco's Prefecture record were analysed in this stage. These data refer to the spatial distribution of companies in Osasco (in 2003).
    d. So, input the data relating to the highway network of the city (recorded data from the Prefecture) was done. The streets, avenues, and roads were represented by their central axis, and each start and final point of each stretch corresponds to a node, which make up the intersections or the end of a stretch (the distances were calculated on the highway network).
3. Determination of the accessibility index
    a. First, it was calculated the accessibility index through the proposed method (database extracted directly from the satellite imagery and the highway network of the city). This calculation was performed using an index already proposed in the literature: the index of Ingram (1971), and Allen et al. (1993), which is a spatial separation index. Spatial separation indices take into account only physical aspects, such as measures of distances, time or cost between places of the travel origin and destination. The index adopted didn't consider factors of attractiveness, such as income, population, or number of jobs offered, because, although this index do not present behavioural aspects, it is operationally simple, and its results are easy to interpret. Considering that the main objective is to build the database for the determination of the accessibility through remote sensing products and GIS analysis, and not test what is the best accessibility index to be used (if the spatial separation or

gravitational), the adoption of a spatial separation index of accessibility is justified. The adopted index was:

$$E = \frac{1}{N}\sum_{i=1}^{N} A_i \qquad A_i = \sum_{j=1}^{N} a_{ij}$$

Where:

i. **E**: index of total accessibility of the study area (C&I total accessibility index)
ii. **A_i**: index of integral accessibility of the company I in relation to all other companies j (C&I integral accessibility index).
iii. **a_{ij}**: index of relative accessibility of the company I in relation to the company j (C&I relative accessibility index).
iv. **N**: number of the companies.

b. The same accessibility index described above was calculated to the same study area and highway network with the recorded database from the Osasco Prefecture.
c. The general accessibility index (E) was also calculated, using all the intersections of the highway network of the city. So, Ai became the general integral accessibility index of the point I in relation to all points j; aij became the general relative accessibility of the point I in relation to the point j; and N the number of intersection of the highway network.
d. These indices were compared, which allowed the verification of the validity of the proposed methodology, and the conclusions about its consistence and results.

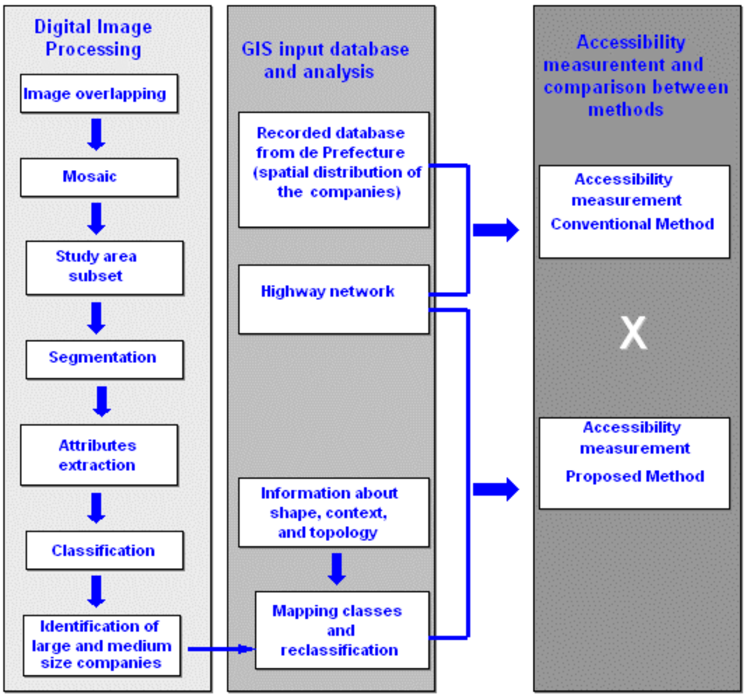

Figure 1 – Study methodology

4. DESCRIPTION OF THE STUDY AREA

The study area is the city of Osasco, located in São Paulo State, in the western portion of the São Paulo Metropolitan Region, Brazil (figure 2). Osasco has a total area of 66,9 km^2, according to the last update of the official census (2007) its population is 701,000 habitants.

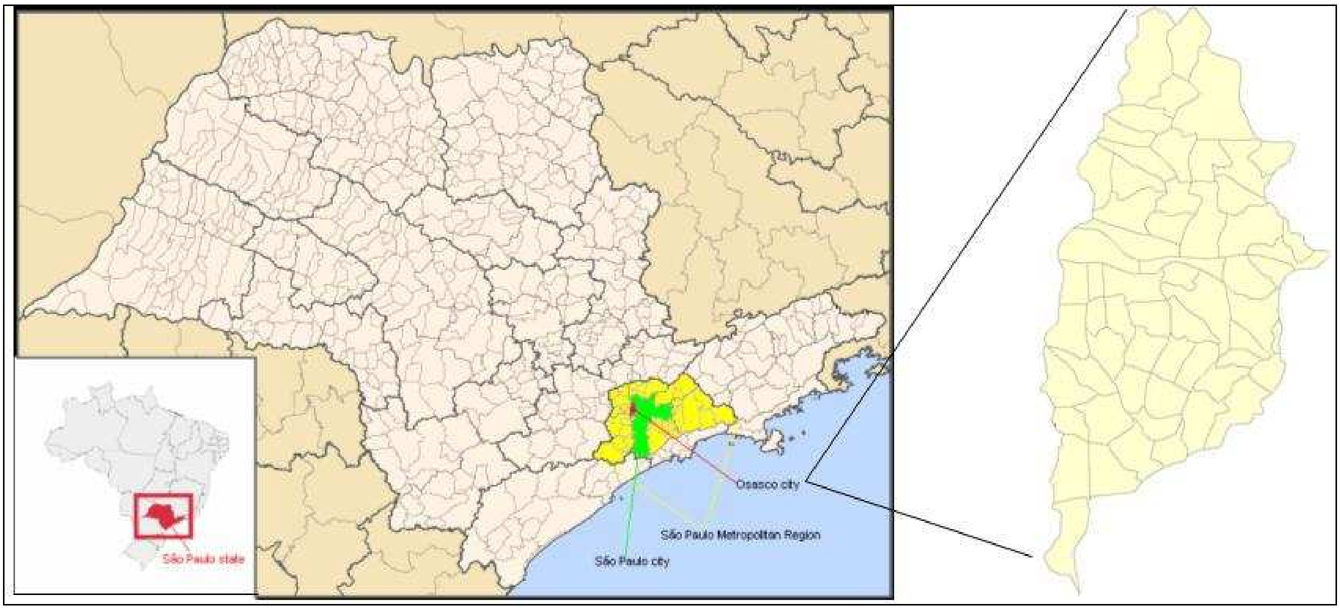

Figure 2 – Study area

The transportation system of Osasco consists of four express highways that cross its territorial boundaries, a wide urban highway network, and an urban passenger railway network. The city also has a system of mass transit by bus, which carries travel within the city, and also between Osasco and other municipalities of the metropolitan region.

Its proximity with the biggest city in the country (São Paulo), coupled with the fact that its transportation network (mainly the four express highways), facilitates the flow and distribution of goods, services, information and people.

5. RESULTS

The study was based on the extraction of the information that is necessary to calculate the accessibility index directly from high spatial resolution images of the satellite IKONOS II. The image overlapping to compose the mosaic was made in the remote sensing software ERDAS Imagine. The next step was the construction of the mosaic and the subset of the study area, also made in the software ERDAS Imagine.

The software ERDAS Imagine has been widely used by the remote sensing community to perform digital image processing, yet it can be applied only in traditional pixel-based classification, and as the scope of this research is the object-based classification, was necessary to export the results obtained by this software to another one capable of performing the object-based approach.

The first thing to do in order to perform the object-based classification is the image segmentation (generation of meaningful objects in the image). Each segment (object), contains a set of contiguous pixels with similar characteristics (e.g. texture, color, etc), and therefore, belonging to the same class. There are some softwares that perform image segmentation. Neubert and Meinel (2003), Meinel and Neubert (2004), and Knapp (2007), conducted comparatives studies among various segmentation programs for high resolution remote sensing applications, and according to the authors, the segmentation process available in the software SPRING, developed by INPE – Instituto Nacional de Pesquisas Espaciais, Brazil, is one of which gives the best results. The software SPRING is free; its download is available without charge to users on the Internet. The combination of these two factors, good performance and the easy availability, was decisive for its utilization in this work.

The segmentation process of the software SPRING is based on similarity. It uses the topological relations of the elements of the image, and applies the procedure of Region Growth, which is a technique of clustering data in which the regions spatially adjacent may be grouped. Initially, this segmentation process labels each pixel as a separate region. Then, it calculates a similarity criterion for each pair of spatially adjacent region. The similarity criterion is based on a statistical hypothesis test that tests the mean of the spectral attributes between regions. Next, the image is divided into a set of sub-images, and then performs the union between them, according to a defined threshold of aggregation.

The use of the procedure of region growth in the segmentation process was due to the fact that in an object-based approach the goal is the use of geometric features, texture, context, and topological relations in order to achieve better performance in identifying the intended targets (in this case the companies). The polygons generated by the segmentation by region growth were converted to vector format. That way, they can be used as training samples for digital image classification and/or visual image classification, through the assignment of classes to the polygons.

The parameters adopted to perform the segmentation by region growth in the software SPRING were: similarity equal to 30 and area (pixels) to 50. The measure of similarity is based on the Euclidian distance between the mean values of gray level of each region. Thus, two regions are considered distinct if the distance between their means is higher than the similarity threshold chosen. The parameter area refers to the minimum size of area, in number of pixels, which represents a segmented region. Regions with an area less than the minimum chosen are absorbed by the more similar adjacent regions to these.

The next stage of work was the classification procedure. First, it was made a preliminary classification in the software SPRING, using the algorithm Isoseg, that classifies regions of a segmented image. It is a clustering algorithm, non-supervised, that is applied on the set of regions (objects), which in turn are characterized by their statistical attributes (mean and covariance matrix), and also by their area. The figure 3 shows the preliminary classification in a part of the study area.

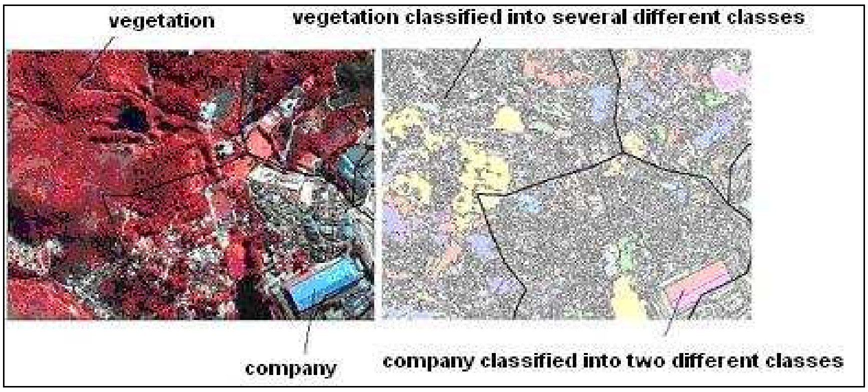

Figure 3 – Detail of the Isoseg classification of the study area

The preliminary classification (Isoseg) generated 55 classes, which have been mapped in order to transform the classified image into a thematic map in raster format. This thematic map was converted to vector format and exported to a GIS environment. Then, it was performed the image reclassification based on objects. To accomplish the reclassification of classes, some information about shape and context was introduced in the analysis, with the objective of creating classification rules. This phase was carried out in the GIS software ArcGIS – ESRI. As the focus of the study was the geographical localization of the companies, there was not concern about the other classes (vegetation, water, shade, roads, bare soil, residences, etc.). For instance, there were a lot of sub-classes within the class vegetation (many different types of vegetation). But, the purpose was not to describe or classify the vegetation, so, all the classes mapped as vegetation were grouped in a general vegetation class and put aside. They were eliminated of the process of companies' detection. The same criterion was adopted for the other classes. As a result, it was obtained two groups of information (classes): companies (object of interest), and all the rest (all other classes). The result of the object-based classification is shown in figure 4.

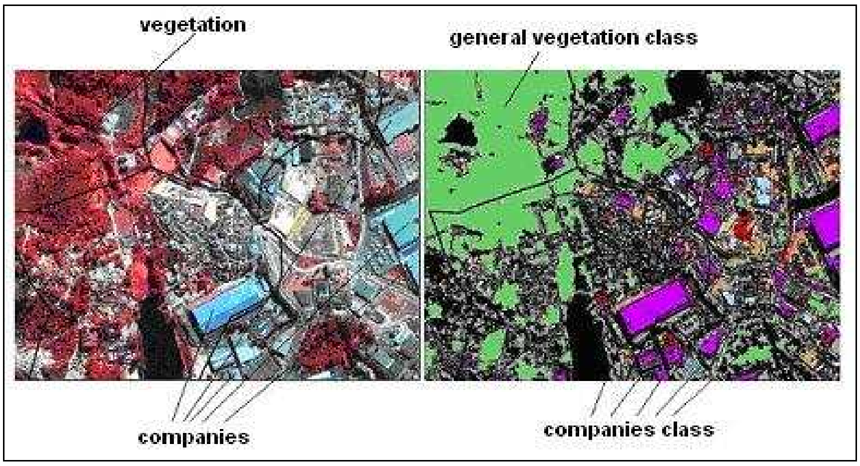

Figure 4 – Detail of the object-based classification of the study area

After the object-based classification, it was obtained the spatial location of the medium and large size companies in Osasco. It means that the result was polygons classified as companies. However, to calculate the accessibility index it is necessary points, not polygons. Then, it was calculated the centroid of each polygon, also in the software ArcGIS. The result is shown in figure 5.

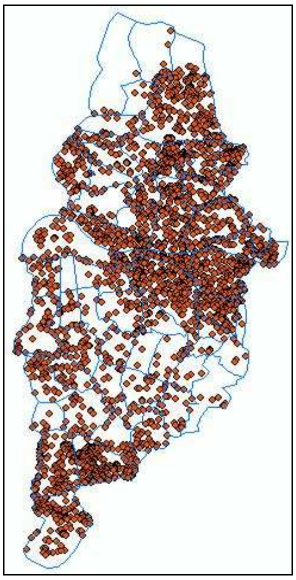

Figure 5 – Centroids of the polygons – Companies - Osasco

The last step was to calculate the accessibility index. It was adopted a spatial separation accessibility index, as described previously. With a GIS software specific to transportation analysis – TransCAD – Caliper, which combines the ability of a GIS with transportation modeling procedures, on a single platform, each point (centroid), was allocated on the highway network (logistic network), at the intersection (node) closest to it (figure 6).

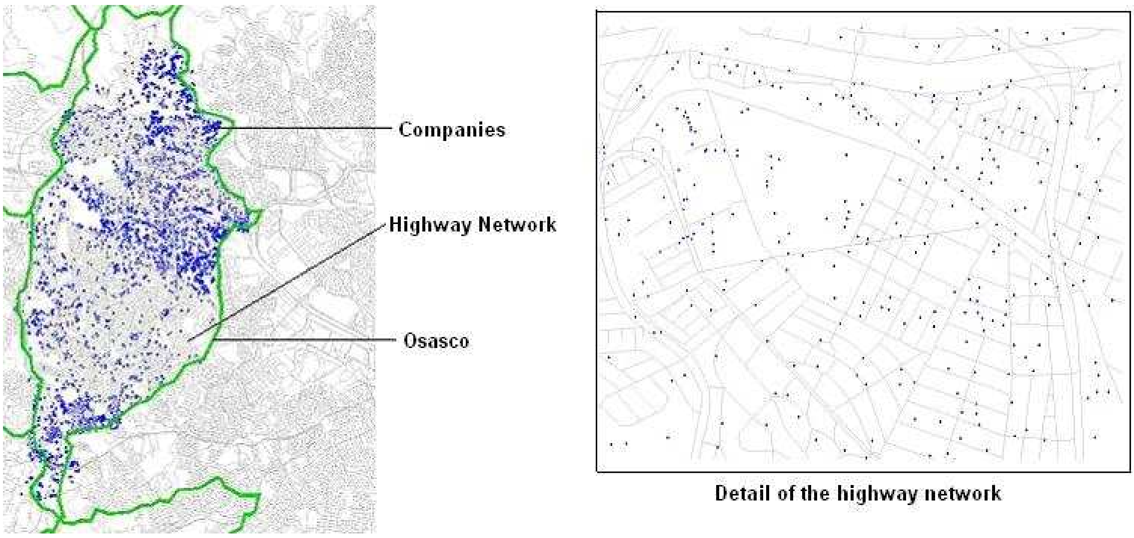

Figure 6 – Highway network and Osasco's companies

It was determined a matrix with the distances between the company i to all companies j through the highway network. With the companies (points) allocated in the network nodes (intersections), were performed the calculation of the total accessibility as described in the item 3 as follows:

- Overall accessibility index to the business sector in Osasco: $E_{companies}$
- Overall general accessibility index of Osasco: $E_{general}$.

To validate the proposed methodology, the overall accessibility index to the Osasco's business sector was calculated through the recorded data for 2003 ($E_{recorded}$). The results are presented as follows:

Overall Accessibility Index (E)
$E_{companies}$ = 6.54
$E_{general}$= 5.47
$E_{recorded}$ = 4.21

6. CONCLUSIONS

The results obtained in this study validate the methodological proposal presented, because they prove that is possible to build a database to determine levels of accessibility of a study area directly from remote sensing images.

The indices that were calculated, $E_{companies}$, $E_{general}$, and $E_{recorded}$, are similar, with the same order of magnitude, indicating that the method can be applied and also improved. More than that, the method proved that is possible to use the remote sensing products for extract the database for urban and transportation planning and analysis. This approach is particularly useful to places where there isn't recorded data (obtained from field work), or they are outdated. This encourages that more researches and studies are conducted, in order to improve the method and make it more accurate, for example, using specific softwares for O-O image classification (for instance, Definiens eCognition or ENVI's feature extraction module). Also, the results can be improved by the use of images with higher spatial resolution, such as the images from the satellites QuickBird and GeoEye.

The scientific advances in remote sensing technology occur very quickly. This is an area of knowledge that is in full development. The trend is that in short term its application area is expanded and its results show a marked improvement.

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