AN ACCESSIBILITY APPROACH FOR TRANSPORTATION PLANNING ASSISTED BY A GEOGRAPHIC INFORMATION SYSTEM

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ABSTRACT

This paper presents an alternative methodology for transportation planning at the urban context. The methodology is based on the analysis of the harmony between the transportation system and the urban development policies defended by the structure plan of a city. The planning areas are characterized by their land-use and by a refined measure of their accessibility indexes, and the transportation system, by the level of service and capacity of each transportation mode. Both can be actual (analyzed at the first stage of the proposed methodology) or idealized (defined from the guidelines established by the structure plan, analyzed at the second stage). It is also proposed an integrated use of a geographic information system in order to provide tools for spatial analysis and network simulations, besides to allow a better management of the data consulting and updating process. The methodology is tested by means of a case study, and the results demonstrate that it is reliable and provides application simplicity, once compared to the traditional methods. It turns out to be more appropriated to the economic reality of small cities or to those ones with restricted financial resources.

Keywords: transportation planning, accessibility, land-use, geographic information system

INTRODUCTION

The increase of the traffic jams, traffic accidents, excessive consumption of fuel and another natural resources, and environmental impacts, with reflexes on the population quality of life and local economy, are the negative effects of the cities sprawling. Some radical strategies, like the traffic restrictions in central areas (i.e., London and São Paulo cities), have been adopted around the world in order to minimize these problems, but, with badly results. Thus, alternative methodologies that use the transportation system to induce, or to attend, an urban occupation compatible with the cities development guidelines, seems to be more appropriated.

In this context, the urban transportation systems represent a complex and potential tool in order to promote the orderly and balanced growth of the cities. But, the economic reality of the majority of the Brazilian cities, and the high costs of application of the traditional methods, indicates the need for alternative methodologies more simple and direct.

Therefore, this paper intends to contribute presenting a methodology to transportation systems planning, at the urban context, assisted by a geographic information system. It is based on the analysis of the harmony between the transportation systems and the land-use or development policies defended by the cites development or structure plans, once these represent a guideline with technical and political back-up, also reflecting the society interests.

The methodology seeks after to help during the analysis of the harmony between the network connections, measured by the capacity and level of service of each transportation mode, and the accessibility, land-use and development indexes of each planning area of the city. Both can be actual (existing, analyzed at the first stage of the methodology) or idealized (designed, direct or indirectly established by the guidelines of the cities structure plans, analyzed at the second stage).

It is also proposed the integrated use of a geographic information system in order to allow the management of the whole process of data consulting and updating, besides to provide several tools for spatial analysis, advanced cartographic production and network simulations, which makes more efficient the application of the proposed methodology.

A review, in section 2, presents three streams of research: the transportation planning; the accessibility metrics; and, the use of geographic information systems on transportation. In section 3 the proposed methodology is presented with the detailed description of its steps. In section 4, case study, the methodology is tested by means of its application to Petrópolis city (Rio de Janeiro, Brazil). The section 5 presents the conclusions with a critical analysis of the obtained results and some propositions to improve the proposed methodology.

REVIEW

The transportation system planning is a very complex and non-trivial problem to solve due to the dynamics of the several issues involved, such as relevant society data (population, basic economy sectors, energy, public health, education, etc.), natural and built environment perspectives (biology, ecology and sustainability), equations, models and laws (Booth, 1998; Nadakavukaren, 2000; Kress and Barrett, 2001).

The city transportation network traditionally has been treated as a technical activity with the goal of optimizing the circulation of people and goods. Therefore, the development of each location in an urban system is not only the result of physical interventions in the transportation system, but it is also the result of a complex and interconnected interacting of several factors, related to nature, society and technology (Knox and Marston, 2003; Amekudzi and Meyer. 2005).

To reach that wider concept of transportation planning, the methodology proposed in this paper searches to integrate that physicist-mathematical analysis to the political, social, urban and institutional factors of the planning areas of the city, obtained from the city structure plan. The relevance of the city structure plan, in this process, is because it is a city development guideline that includes not only those factors, but also because it guarantees, by law (Brazil, 1988), popular participation in its elaboration.

Over the last forty years the transportation planning has evolved, but with no clear theoretical foundation, and directed to a practical, usually quantitative, output (Banister, 2002). A research developed by Silva (1996), revealed that the majority of the Brazilian cities have been developed its transportation planning, only based on planners intuition and expertise. In other words, that analysis has been empirical and positivist in its approach.

In 1960s, the transportation planning process was evolved as a systematic method for solving the urban transportation problem. It was intend to be comprehensive with the collections, analysis and interpretation of data concerned with existing conditions and historical growth (Banister, 2002). According to Bruton (1992), the transportation planning is based on several principles and hypotheses, such as: travel standards are tangible, stable and predictable; demand for moves is directly related to the distribution and land-use intensity. In addition to these fundamental hypotheses, it is important to take over that:

- there are relationships between all the transportation modes;
- the locations are influenced by, just as they influence, the transportation system;
- a wide regional operational analysis of the transportation system is required by the areas with continuous urbanization;
- the transportation studies are part of the planning process, which is continuous, and requires a constant improvement and update.

Giuliano (1988) revised theories about the relationship between transportation and land-use, which were tested by an empirical research, and the results were explained by the changes in urban structure. Meyer (1993) defined multimodal transportation planning as the process of defining problems, identifying alternatives, evaluating potential solutions and selecting actions that meet community goals in a manner that includes all feasible transportation modes. Meyer and Miller (2001) defined urban transportation planning as the process of:

- establishing a vision of what a community wants to be and how the transportation system fits into this vision;
- understanding the types of decisions that need to achieve this vision;
- assessing opportunities and limitations of the future in relationship to goals and desired system performance measures;
- identifying the near- and long-term consequences to the community and to transportation system users of alternative choices designed to take advantage of these opportunities or respond to these limitations;
- relating alternative decisions to the goals, objectives, or system performance measures established for an urban area, agency, or firm;

- presenting this information to decision makers;
- helping decision makers establish priorities and develop an investment program.

A new approach to transportation planning, developed by Lowry and Balling (2009), which is based on a concept called district land-use scenarios (DLS), casts the land-use and transportation planning as multiobjective design problems and solved using an optimization algorithm. The cities utilize a form of multiobjective design to create a handful of candidate designs (or plans) on the basis of public input and the expertise of the planners. The plans are formulated mathematically and executed automatically with the aid of a computer in order to be evaluated, with respect to particular criteria, and selected. In the DLS approach, the land-use and transportation design problems are optimized simultaneously using a genetic algorithm.

In urban transportation planning many approaches utilize paradigms that consider the verticality and transversality of the planning process, and that kind of studies involved three levels of planning: strategic level; tactical level; and, operational level (Anthony, 1988; Hellriegel, 1992). The strategic level is involved in the formulation of general aims and policies, driven and works at an aggregated level of analysis, in order to reach the balance of transportation and land-use, and the balance of private and public transportation. At the tactical level, based on the general aims established on the strategic level, the transportation system is studied at a much greater level of detail than at the strategic level, and are making the decisions to reach the general aims, and how to do this most efficiently (i.e., design patterns configuration and traffic signal settings). The operational level analyzes the dynamics of urban traffic management, such as travellers, vehicles and control systems, to carried out the tactical level decisions, and in an efficient way.

Another important issue related to the transportation planning is the accessibility. According to Koenig (1980) for evaluating the distributional or equity effects of transportation system and urban land-use policies and plans, the accessibility is particularly an appropriated tool. Researches developed by Teixeira (1975), Pereira (1985) and Caliari *et al* (1996), used the accessibility concepts to analyze highway systems and the structure of transportation networks. Sanches (1996) applied the accessibility concept to the evaluation of a city transportation system.

The accessibility indexes presented in the literature typically weight the planning areas according to their sizes measured with respect to quantities such as population, floor area, sales, etc. (Stewart and Warntz, 1958, Hansen, 1959). Sales Filho (1996) developed a research to investigate the several methodologies of accessibility observation by means of a review of the urban accessibility conceptions and its several definition possibilities. One of these possibilities defines accessibility as the ease with which land-use activities can be reached from a location by using a transportation system.

Allen *et al* (1993) developed a research that constructed an accessibility index to capture the overall transportation access level of an area, and can be calculated accurately without incurring very high costs. According to Kwan (1999), the measurements of accessibility consist of three fundamental approaches: a reference location; a set of destination; and, the effect of physical separation. Another distinction considers the person accessibility, the place accessibility and the topological or graph-theoretic measures based on network properties (Pirie, 1979).

All those spatial analysis can be assisted by a geographic information system (GIS). The first GIS was developed in the seventies decade as the reflex of the need to storage, to analysis and to report geographical information (Paredes, 1994). GIS were being modernized with the evolution of the computer science and, at the same time, became more popular. At the beginning of the nineties decade there was an intensification of the GIS use, and Belo Horizonte city, in Brazil, for example, have since 1995 a GIS organizing a wide range of digital geographical information, such as: urban cadastre, traffic lights, bus stations and routes (Zuppo, 1996).

Nowadays GIS are recognized as a potential tool in the database and maps integration process, and its application practices are very wide, since any kind of registers (phone, networks, light, water, etc.) until the transportation planning, providing a permanent up-to-date database, forecasts and simulation models generation, and many other spatial analysis tools. In this paper the GIS provides a fundamental support to the proposed procedures application.

Among the GIS application examples in the transportation research area, a highlight can be given to the following works: Raia and Silva (2001) used a GIS integrated to artificial neural networks for the urban and the transportation strategic planning; Odoki *et al* (2001) developed a model to measure the accessibility benefits in developing countries, supported by a GIS; Johnston and De La Barra (2000) worked with accessibility indexes integrated to a GIS in order to analyze the evaluation of the land-use and the transportation policies; Li *et al* (1999) uses the resources of a GIS to analyze the highway system impacts on the urban environment and to optimizing the highway design.

PROPOSED METHODOLOGY

This section presents a methodology for transportation system planning that integrates urban development policies, defended by the structure plan of a city, and decision making in long-term (i.e., ten years) and metropolitan-level application. The proposed methodology is shown in Figure 1 that illustrates where the development policies, like the land-use, are incorporated.

The first step is the definition and characterization of the planning areas (districts, traffic zones, etc.) and the transportation system. The transportation planning, done in tune with the structure plan guidelines for the land-use and development of the planning areas, needs not only the knowledge of the existing situation, but also the knowledge of the historic context of its growth. Otherwise, this step is also comprised by the identification of the planning areas centroids, or the transportation network nodes.

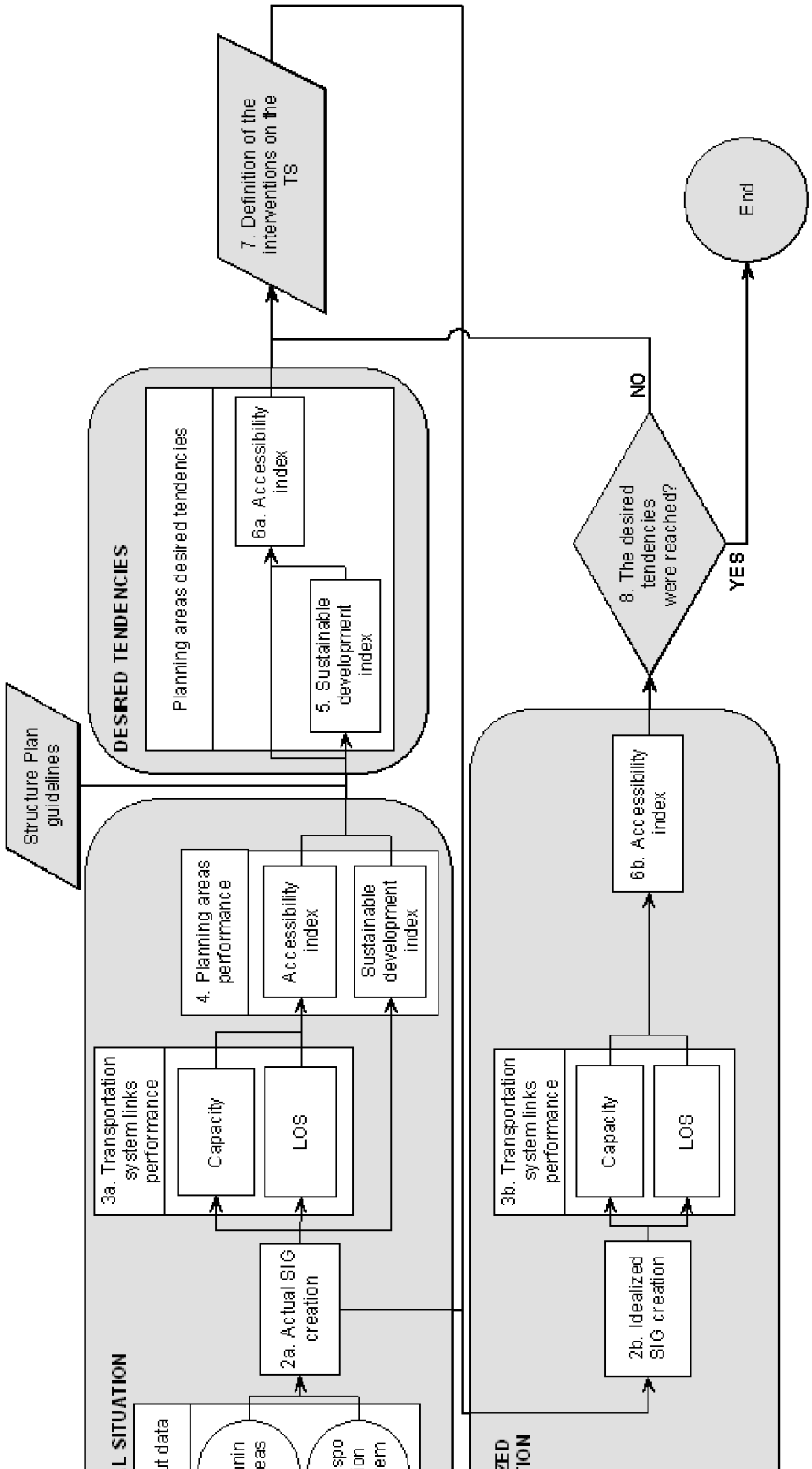

Figure 1 – Flow chart with the steps of the proposed methodology

The creation of the geographic information system (GIS) of the city is the second-a step, and intents to develop and to evaluate the transportation systems plans. GIS is a sophisticated tool for characterization and analysis of planning areas and transportation networks, monitoring of changing environmental characteristics and land-use, for example, through satellite imagery.

This tool is used to allow the development of databases that include spatially located information about the major transit stations and route networks, representing the transportation system. This database also include the land-use, parcel-based (tax lot) property data, boundaries, census background boundaries, local economy, natural resources, environment, and development indexes of the planning areas, and to analyze its effects on the transportation system, by means of the following procedures:

1. Map creation – the map intents to present the planning areas and its geographic database with all relevant information;
2. Identification of the planning areas' centroids (nodes), and creation of each transportation mode network – these networks intent to store information about its nodes and links, and provides conditions to measure and update the capacity and traffic or transit demand, automatically.

In the third-a step is determined the capacity and, as an optional information, the level of service (LOS) of each link of the actual transportation system, in order to measure its general performance. This information are obtained based on the Highway Capacity Manual (TRB, 2000) because it presents methods for analyzing capacity and LOS for a broad range of transportation facilities, and are determined for each transportation mode. In this proposed methodology, the Highway Capacity Manual (HCM) is used at the planning (strategic) level of analysis.

The planning level of analysis was adopted because it directs towards strategic issues, and the time frame usually is long-term. Those studies, for example, address the possible configuration of a highway system; a set of bus routes; the expected effectiveness of a new rail service; a lane-use control for heavy vehicles; the likely impact of a proposed planning areas development.

The next step, fourth, is comprised by two parts. The first one aim to measure the accessibility index of each planning area, which can be global or derived from a specific transportation mode. Accessibility refers to the ease with which land-use activities can be reached from a location by using a transportation system (Allen *et al*, 1993). Thus, it derives from the characteristics of locations and/or from the transportation system.

This methodology focus on the transportation system and measures accessibility in terms of a measure based on the travel distance-time between the network nodes (centroids and subcentroids of the city) rather than in terms of distance, travel cost or other impedance variables. The travel distance-time is obtained from the distance and average speed between the origin and destination planning areas, and is based on the HCM (TRB, 2000) methods to determine capacity of the transportation networks links, for each transportation mode. The following Equations 1 and 2 can express the actual accessibility index:

$$A_i = \sum_{k=1}^{x} w_k A_{i,k} \tag{1}$$

$$A_{i,k} = \sum_{\substack{j=1 \\ j \neq i}}^{n} C_{ij} \times d_{ij}^{-\gamma} \tag{2}$$

Where: A_i is the actual (existing) accessibility index of the planning area *i*; *i* is the origin planning area; *j* is the destination planning area; *k* is transportation mode; *x* is the number of transportation modes; w_k is the weight of the accessibility index of the transportation mode *k*, standardized by the passengers daily volume; $A_{i,k}$ is the actual accessibility index of the planning area *i*, for transportation mode *k*; d_{ij} is the actual travel time between *i* and *j* (impedance); γ is the impedance parameter; C_{ij} is the actual capacity between *i* and *j*.

Also in this fourth step is determined the performance of environmental factors. The metrics here adopted is an index called sustainable development index, which identifies the ecological environmental and socioeconomic/community characteristics of the planning areas. This index is intent on providing a measure of the impacts of these planning areas characteristics on the environmental and transportation facilities, and verifies if the land-use is in tune with the structure plan's policies. The following method is used to determine this index:

1. Selection of the indicators of evaluation on sustainable development;
2. Standardization of the selected indicators (Equations 3 – 5);

$$x'_I = \frac{x_I - \bar{x}}{\delta} \tag{3}$$

$$\bar{x} = \frac{1}{n} \sum_{I=1}^{n} x_I \tag{4}$$

$$\delta = \sqrt{\frac{1}{n-1} \sum_{I=1}^{n} \left(x_I - \bar{x} \right)^2} \tag{5}$$

Where x_I is the original value of indicator *I*; x'_I is the standardized indicator; $\bar{x}$ is the average of sample data; δ is the standard deviation of sample data; n is the number of indicators of subsystems.

According to Zhang *et al* (2003), these indicators are related to the following subsystems:

- population (total population, natural growth rate of population, population density, total enrolment of vocational senior schools, total enrolment of specialized secondary schools, total enrolment of secondary schools and total enrolment of primary schools);
- economy (gross domestic product - GDP, GDP per capita, total investment in fixed asset, gross output value of industry, per capita gross output value of industry, etc.);
- society (number of doctors per person, level of urbanization, per capita floor space of residential building, etc.);
- resources (water consumption per unit GDP, energy consumption per unit GDP, forest coverage rate, etc.);
- environment (volume of industrial wastewater discharged, volume of industrial waste gas emission, volume of industrial solid waste produced, etc.).

Thus, the model expressed by the Equation 6 calculates the sustainable development indexes:

$$F = F_P \times W_P + F_{EC} \times W_{EC} + F_S \times W_S + F_R \times W_R + F_{EN} \times W_{EN} \qquad (6)$$

Where: F is the sustainable development index; F_P, F_{EC}, F_S, F_R and F_{EN}, are the sustainable development indexes related, respectively, to the Population, Economy, Society, Resources and Environmental subsystems; W_P, W_{EC}, W_S, W_R and W_{EN}, are the weight of each kind of indicators, obtained from the component score coefficient matrices of the subsystems (Bastianoni *et al*, 2008).

Depending on the city characteristics, other indicators can be selected for the analysis. Zoning practices generally divide the community into different use districts by appropriating areas for industrial, residential, commercial, institutional, and public uses, among other specified uses.

Economic development impacts are a very general discussion with linkages between improvements to accessibility and subsequent enhancement of the economic activity. Therefore, the fifth step is to study the desired tendencies for the development indexes based on the analysis of the city’s structure plan guidelines.

These desired tendencies do not represent values, but symbols indicating the desired strategies for the planning areas development indexes, as shown in the Table 1, in order to orientate the decisions.

Table 1 – Symbology representing the desired tendencies for the development indexes

Desired tendency for the development index	Symbol
Increase	↑
Increase moderately	↗
Remain the same	=
Decrease moderately	↘
Decrease	↓

In the sixth-a step, according to these tendencies desired for the planning areas development indexes, are determined the desired tendencies for their accessibility indexes, expressed also by means of symbols indicating the chosen strategies (Table 2).

Table 2 – Symbology representing the desired tendencies for the accessibility indexes

Desired tendency for the accessibility index	Symbol
Increase	↑
Increase moderately	↗
Remain the same	=
Decrease moderately	↘
Decrease	↓

Than, in the seventieth step, is analyzed potential interventions on the transportation system in order to provide the desired tendencies for the transportation networks performances. This important step is heavily dependent on data collection and interpretation, in order to understand how changing the characteristics of the transportation system links might affect system performance.

From these proposed interventions, in the second-b step (Figure 1), a new geographic information system, now called idealized, is created. In the third-b step, from this new network configuration, is determined the new capacity of the idealized transportation network links, of each transportation mode, and intents to provide an accessibility more appropriated for each planning area. Service flows rate at a determined LOS for the local conditions (for example, C or D), also can be used to ensure an acceptable operating service for facility users in according to the desired tendencies for the development index.

This strategy can be reached by means of interventions on the transportation mode infrastructure or operation parameters (for example, the speed limits), or on the planning areas of the city. From these new values, derives, in the sixth b step, the idealized accessibility indexes, expressed by the Equations 7 and 8:

$$A_i^{'} = \sum_{k=1}^{x} w_k \, A_{i,k}^{'} \tag{7}$$

$$A_{i,k}^{'} = \sum_{\substack{j=1 \\ j \neq i}}^{n} C_{ij}^{'} \times d_{ij}^{'-\gamma} \tag{8}$$

Where: $A_i^{'}$ is the idealized accessibility index of the planning area *i*; $A_{i,k}^{'}$ is the idealized accessibility index of the planning area *i*, for transportation mode *k*; $d_{ij}^{'}$ is the idealized travel distance-time between *i* and *j* (impedance); $C_{ij}^{'}$ is the idealized capacity between *i* and *j*.

In the eightieth step, in order to analyze the effects of these changes on the transportation network, these idealized accessibility indexes are compared with the desired tendencies for the actual accessibility indexes. If they are compatible, the adopted strategies goals were reached and the planning process is finished. Otherwise, the process returns to the seventieth step, new interventions are studied, and this process is repeated until to reach the desired tendencies for the actual accessibility indexes.

A measure (T_i) proposed to analyze the interventions effects on the accessibility indexes, is shown on the Equation 9, and theoretically can be: 0, when the planning areas *i* and *j* loss connection; 1, when no change occurred; <1, when the accessibility index decreases; >1, when the accessibility index increases.

$$T_i = \frac{A_i^{'}}{A_i} \qquad (9)$$

Thus, this approach allows deciosionmakers to mitigate priorities from the perspective of minimizing differences between actual and desired accessibility and development indexes of the planning areas, and so, minimizing potential problems on its transportation system, environmental and land-use.

CASE STUDY

This section presents the results of the case study to illustrate how the planning areas of cities have incorporated the development policies considerations into each step of the proposed methodology. The selected study area was Petrópolis city, located in Rio de Janeiro, Brazil. Petrópolis has in 2005 an estimated population of 312,766 habitants in its five districts (Brazil, 2007). These districts are Petrópolis, Cascatinha, Itaipava, Pedro do Rio and Posse, and were selected as the planning areas.

As shown in Figure 2, the central business district (Petrópolis) concentrates most of the city population distributed in a valley with an approximated radius of 9 km, surrounded by mountains, at an elevation of 845 m above sea level. The population of the other districts lives along a narrow strip of land roughly 2 km wide that is squeezed between mountains.

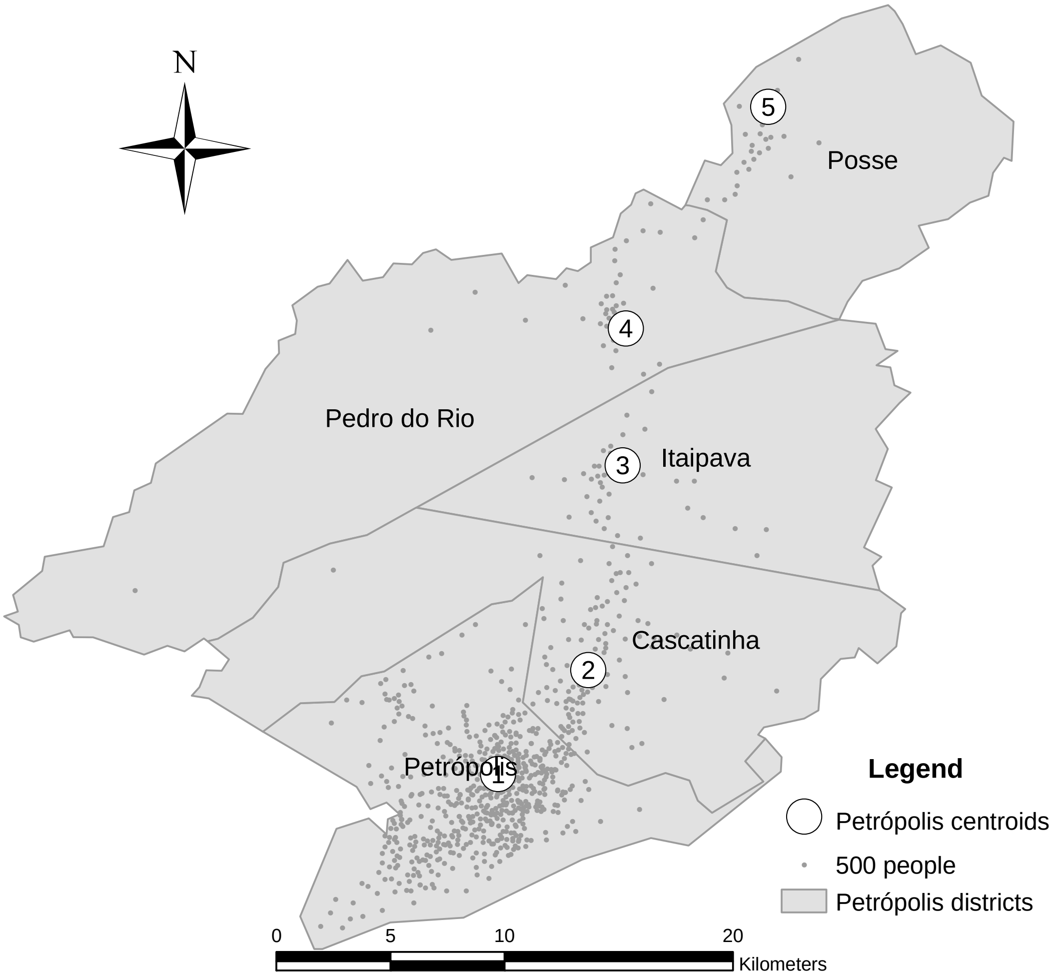

Figure 2 – Petrópolis city districts and population density

The transportation system consists of 22 nodes (5 centroids and 17 subcentroids) and 27 links (a main corridor connecting the districts and the road network of the central areas). The focus of this study is on the regional roads and highway network at the five districts, thus the links representing the residential roads were omitted on this network (Figure 3).

At the second step of the methodology, was created the GIS of the planning areas where have been mapped all the critical informations, like the transportation network, the capacity of each link, the land-use, population, main economic activities and quality of life. In this process, first is created a network dataset in a geodatabase workspace, in order to model a multimodal transportation network (suports multiple links and nodes sources).

Nevertheless, as in Petrópolis has only the road transportation mode, here was created only one network dataset. So, was identified the node sources as the Petrópolis district centroids and some more relevant crossing roads as the subcentroids (Figure 3), and the role they will play on the network.

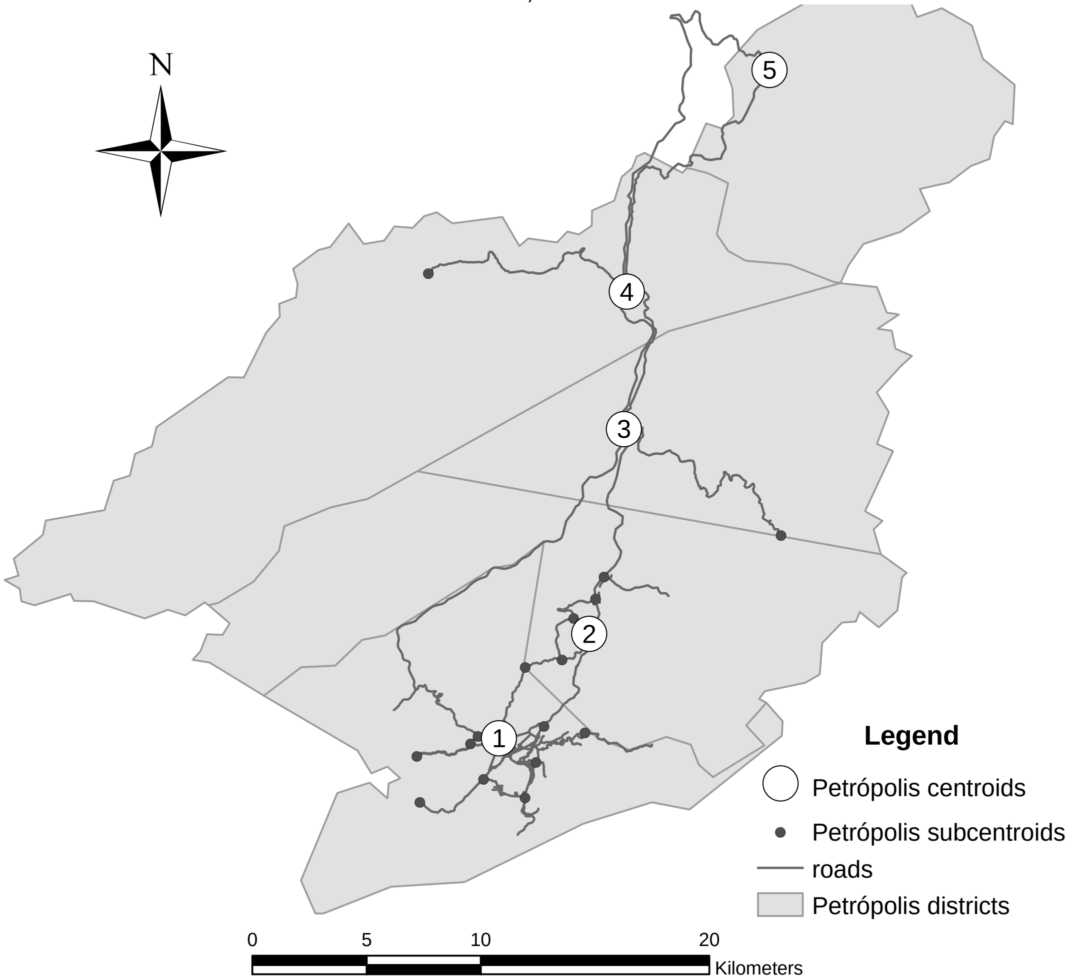

Figure 3 – Road network

In this methodology, link attributes include road geometry (number of lanes), speeds and capacity, for each selected segment of the roads. Thus, at the third-a step, first was estimated the free-flow speed (FFS) field-measured, the geometric data and the segment lengths, for the existing roadway network links. From this data was evaluated the travel time, d_{ij}, between the centroids and subcentroids. A impedance parameter, γ = 1, was used based in Silva's (1996) study of the accessibilities in Petrópolis. Then was determined the links capacity.

The transportation network of Petrópolis city is composed mainly by urban streets, but also has one highway and some rural streets. So, each kind of road was analyzed from their respective methodologies presented in HCM. As described at the previous section, in the fourth step was estimated the accessibility index, A_i, for the travel time unit, d_{ij}, and the links capacity, C_{ij}, expressed by the Equations 1 and 2.

In order to use this index as a comparative measure it was normalized by the sum of the planning areas, as shown in Equation 10. In Figure 4, the normalized accessibility indexes, representing the actual (existing) situation, is mapped by planning area.

$$A^*_{i,k} = A_{i,k} \div \sum_{i=1}^{y} A_{i,k} \qquad (10)$$

Where: $A^*_{i,k}$ is the normalized accessibility index of the planning area *i*; for transportation mode k; $A_{i,k}$ is the actual accessibility index of the planning area *i*, for transportation mode *k*; y is the number of planning areas (centroids).

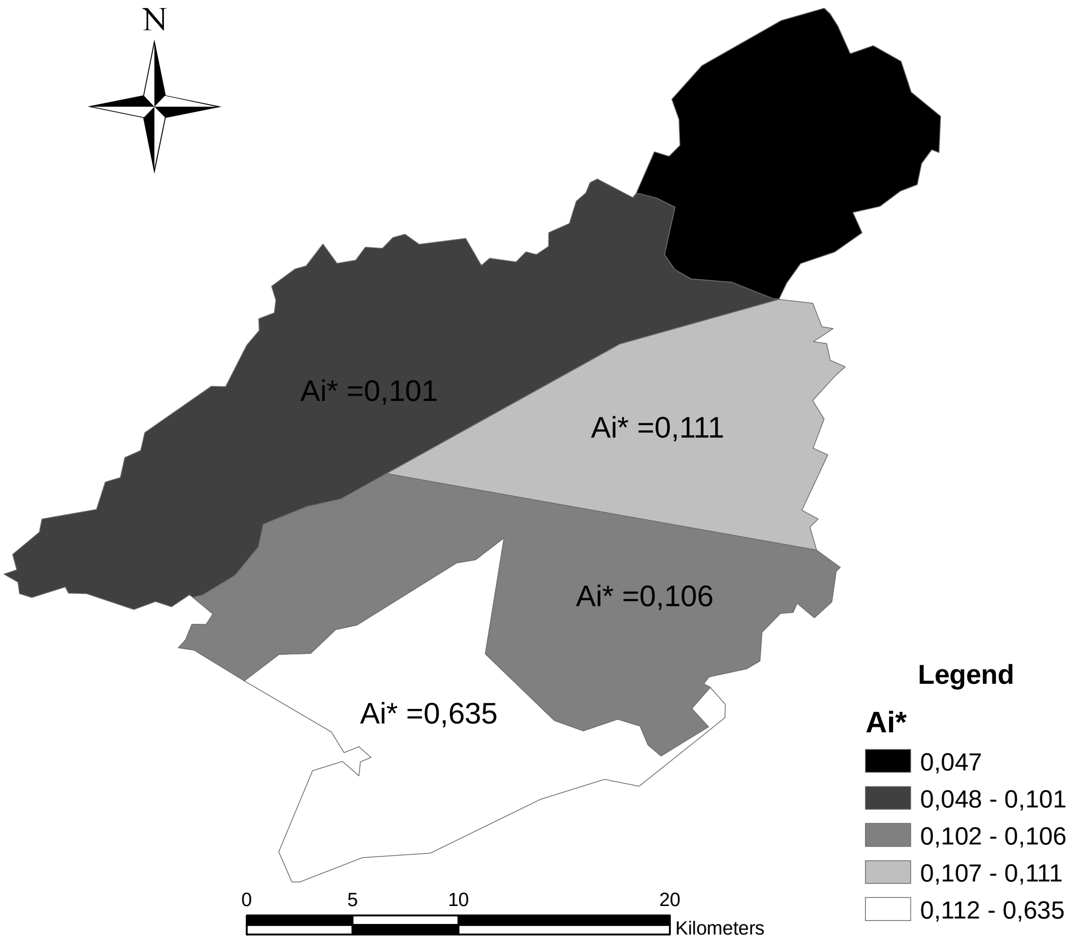

Figure 4 – Actual situation accessibility index by planning area

Also in the fourth step is determined the performance of environmental factors. The sustainable development indexes, F, of the planning areas was estimated by means of the Equations 3, 4, 5 and 6, in order to analyze if the land-use is in tune with the structure plan's policies. The Petrópolis city development process was directly influenced by its mountainous topography and historical context, where physical barriers (mountains) delineated over time their occupation.

With regard to historical context, the city grew from a starting investment of the Portuguese royal family, which moved there in 1848, and the time it was the official summer residence of Presidents, after the Proclamation of the Republic in 1889, until changing the federal capital to Brasília in 1960.

As described in the previous section, the sustainable development index was estimated from a list of indicators. However, some of these indicators have not been found and they were replaced by similar data available. Thus, the following indicators were selected:

- population;
- gross domestic product (GDP) per capita in 2005 (Brazil, 2007b);
- number of households served by public water per capita (replacing the water consumption per capita);
- number of households served by public energy per capita (replacing the energy consumption per capita);
- number of industrial establishments (replacing the volumes of industrial wastewater discharged and waste gas emission);
- number of commercial establishments;
- number of services establishments.

Table 3 – Petrópolis population in 2005

District	Population
First - Petrópolis	200787
Second - Cascatinha	68469
Third - Itaipava	20871
Fourth - Pedro do Rio	16083
Fifth - Posse	10556

Table 4 – Development indicators in 2005

District	Indicators (2005)					
	GDP (US$1000)	Public Water	Public Energy	Industrial Establishment	Commercial Establishment	Services Establishment
First - Petrópolis	1406374,75	32095	63242	660	3217	1614
Second - Cascatinha	152435,30	6137	18074	100	339	156
Third - Itaipava	139661,60	5746	7986	59	392	94
Fourth - Pedro do Rio	21949,19	3999	6286	3	59	24
Fifth - Posse	16779,72	2092	3751	1	48	16

Table 5 – Development indicators per capita in 2005

District	Indicators per capita (2007)					
	GDP (US$)	Public Water	Public Energy	Industrial Establish.	Commercial Establish.	Services Establish.
First - Petrópolis	7004,31	0,1598	0,3150	0,0033	0,0160	0,0080
Second - Cascatinha	2226,34	0,0896	0,2640	0,0015	0,0050	0,0023
Third - Itaipava	6691,66	0,2753	0,3826	0,0028	0,0188	0,0045
Fourth - Pedro do Rio	1364,74	0,2486	0,3909	0,0002	0,0037	0,0015
Fifth - Posse	1589,59	0,1981	0,3553	0,0001	0,0046	0,0015

First, the indicators of each subsystem were standadized by the Equations 3, 4 and 5, in order to satisfy the basic requirements of statistic analysis method. The components which rate of variance are equal or greater than 85%, were selected. Then, the indicators were normalized and the development index of each planning area was calculated by the Equation 6, which provides the indexes shown in Table 6. The weights of population, economy, resources and environment subsystems were estimated as 0.154, 0.169, 0.237, and 0.271 respectively, based on the research developed by Chunmiao and Jincheng (2009).

Table 6 – Development indicators per capita in 2005

District	Normalized Indicators (2005)							Fi
	Population	GDP	Public Water	Public Energy	Industrial Establish.	Commerc. Establish.	Services Establish.	
First - Petrópolis	0,634	0,810	0,641	0,637	0,802	0,793	0,848	0,607
Second - Cascatinha	0,216	0,088	0,123	0,182	0,122	0,084	0,082	0,110
Third - Itaipava	0,066	0,080	0,115	0,080	0,072	0,097	0,049	0,067
Fourth - Pedro do Rio	0,051	0,013	0,080	0,063	0,004	0,015	0,013	0,030
Fifth - Posse	0,033	0,010	0,042	0,038	0,001	0,012	0,008	0,018

In Figure 5, the sustainable development indexes, representing the actual situation, is mapped by planning area.

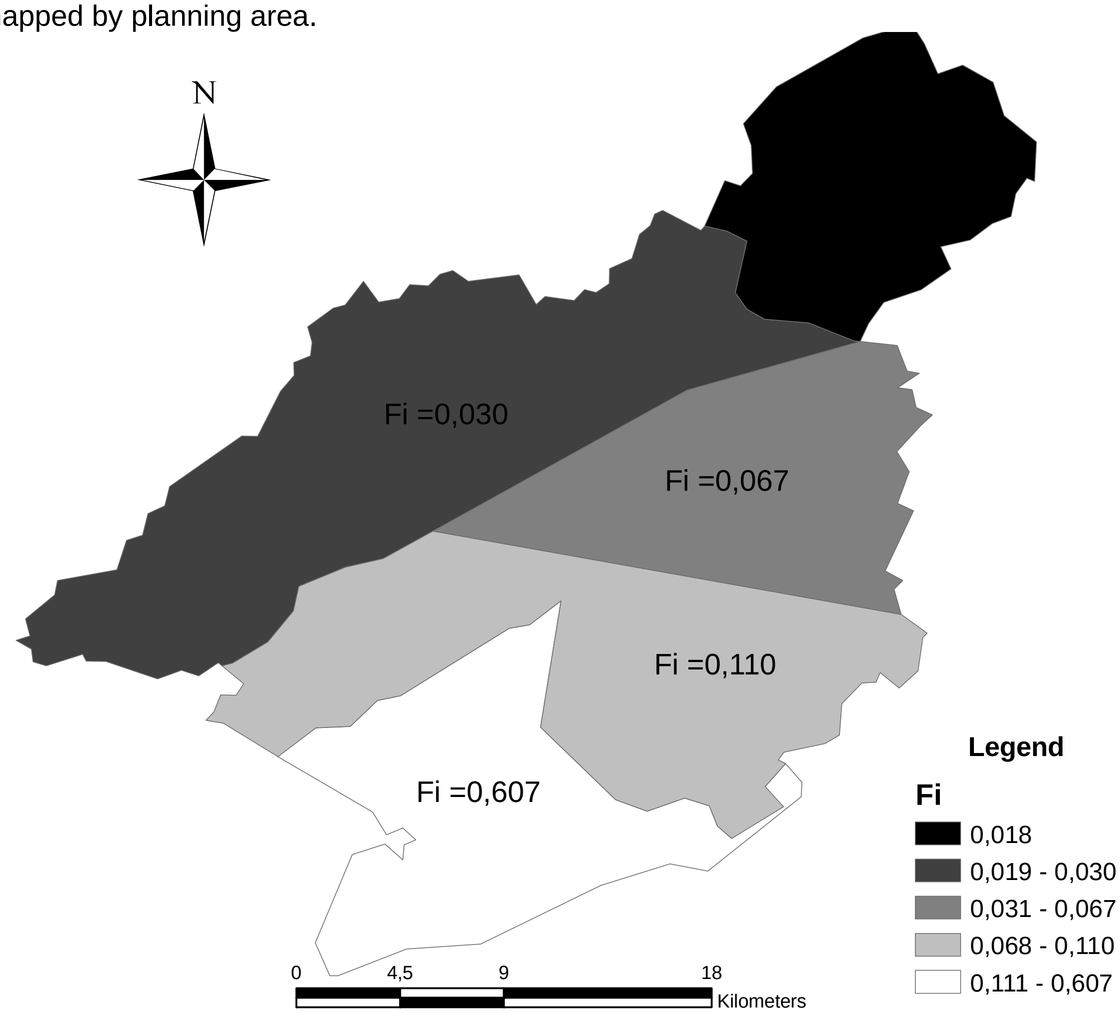

Figure 5 – Actual sustainable development index by planning area

Note that the first district (Petrópolis) has the highest accessibility index (63.5 % of total), and the fifth district (Posse) has the lowest (4,7 % of total), while the others are flat in the range of 10 to 11 % of total. The first district concentrates the majority of the commercial activities and has a population of 200787 habitants (63,4 % of total population). The other districts have the following populations: Cascatinha – 68469 (21,9 %); Itaipava – 20871 (6,7 %); Pedro do Rio – 16083 (5,1 %); Posse – 10556 (3,4 %).

As shown in Figure 6, the first district has also the better sustainable development index, following by Cascatinha, Itaipava, Pedro do Rio and Posse. It was expected due to its status as the metropolis. The second district has obtained an index more closer to the third district than the first, and can be seen as a reflex of the first district expansion which absorbed and concentrated the activities. Itaipava presented a development index below average, but for its natural beauty, topography, accessibility among other favorable characteristics, represents the district with the greatest growth potencial. Pedro do Rio and Posse have the worst sustainable development indexes, which can be explained by their rural characteristics and several infrastructure issues observed, such as few paved roads, water shortages, etc. In the specific case of Posse, there is still the problem of low accessibility.

The next step, fifth, is to analyze the guidelines of structure plan for the city development, and, regarding to the results obtained until now, to define de desired tendencies to the sustainable development indexes of the planning areas. The first district presents the area with the highest occupancy rate, with a consolidated roadway transportation system, operating in poor LOS at peak hours, and with little scope for expansion.

Regarding to the structure plan, in general terms, the activities descentralization is one of the main guidelines to the city development. How the first district has already the better sustainable development index, it is important to stimulate the investiments on the other districts' activities, mainly on the fourth and the fifth districts. Although the second district presents a low development index, compared to the first district, the barriers imposed by its topography indicate that its current development index should be the same. So, the Table 7 presents this desired tendencies to de sustainable development indexes.

Table 7 – Desired tendencies to the development indexes

District	Desired tendencies
First - Petrópolis	=
Second - Cascatinha	=
Third – Itaipava	↗
Fourth - Pedro do Rio	↗
Fifth – Posse	↑

Based on these desired tendencies, in sixth-a step is determined de desired tendencies to the accessibility indexes, which will be used as a reference to the definition of the interventions on the transportation system. From the analysis done with the GIS resources, that allowed to execute a series of spatial analysis, and spatial autocorrelations, highlighting the flat areas, which indicated the tendencies presented in Table 8.

It was found that the third district presents the best options for expansions, that includes accessibility, geographical features favorable to development. The worst accessibility observed on the fifth district represents considerable impedance to its development. The first district has an acceptable accessibility having in mind that the structure plan's guidelines indicate that its development, in relation to the other districts, is good.

Table 8 – Desired tendencies to the accessibility indexes

District	Desired tendencies
First - Petrópolis	=
Second - Cascatinha	=
Third – Itaipava	↗
Fourth - Pedro do Rio	↗
Fifth – Posse	↑

In the seventieth step, potential interventions on the transportation system, in order to provide the desired tendencies for these accessibility indexes, were identified, highlighting that, as described in the previous section, this step is heavily dependent on data collection and interpretation.

In terms of accessibility, no intervention is proposed for the first district, but some general recommendations, to minimizing the traffic flow problems at the peak hour, should be presented, such as the creation of new parking areas, improvements in the urban traffic control, and to define traffic assignment policies. The same policies are proposed for the second district.

For the third district, with respect to the main roads that cross this district, to the highway BR-040 that already has a good capacity (2120 veh/h), it is proposed that its geometrical features should be maintained, and to the road União e Indústria are proposed the construction of one new lane in each direction by making its capacity to increase from 1110 veh/h to 2120 veh/h.

This intervention proposed to the road União e Indústria is both in the segment between the second and the third districts, as in the segment between the third and the fourth districts. Thus, this intervention also has impact in the accessibility of the fourth district.

For the fifth district, are proposed to increase its internal connectivity, by means of building new routes and improving the geometry and/or paving of existing roads. Also is proposed the the construction of one new lane in each direction on the road União e Indústria, in the segment between the fourth and the fifth districts.

From these proposed interventions, in the second-b step, a new geographic information system, now called idealized, was created. In the third-b step, from this new network configuration, was determined the new capacities and operational strategies of the idealized transportation network, of each transportation mode.

The Table 9 shows the interventions effects on the accessibility indexes, estimated by the Equation 9, described in the previous section.

Table 9 – Percentage variation of the accessibility indexes

District	Accessibiliy index		Δ (%)
	Ai (actual)	Ai' (idealized)	
First - Petrópolis	220743	220743	0
Second - Cascatinha	36815	36815	0
Third - Itaipava	38728	53333	38
Fourth - Pedro do Rio	34960	45373	30
Fifth - Posse	16469	31454	91

The strategic interventions proposed in the transportation system planning of Petrópolis city, fully responded to the desired tendencies for the accessibility indexes of the planning areas. Thus, the planning process proposed here is finished, once it has reached the desired effects.

CONCLUSIONS

This research contributes with an alternative methodology that provides tools, for planners and decionmakers, able to assist them during the transportation system planning process. But, it is important to highlight that this methodology considers the strategic level of planning, and the knowledge and expertise of the planners has fundamental participation, having in mind the several factors involved and the complexity of the whole process. We should also stress that the methodology in theory is logical and its applying is less hard than the traditional methods, but requires a political control in the long-term.

The methodology, based on an accessibility approach for the analysis of the transportation network structure, seeks after to establish an explicit equity between the transportation system and the land-use patterns and developing guidelines established by the city structure plan. So, this methodology highlights the importance of to respect the city's standard regulations that define the permitted uses, density of population and buildings, lot sizes, off-street parking, etc.

For example, according to Petrópolis development policies, services such as shops, stores, services, daycare centers, bank offices, restaurants, gyms and coffee shops must be located within or near residential neighborhoods. Thus, this planning guidelines mixing land-uses supports facilitate a more economical arrangement of land-uses, encourages pedestrian and bicycle travel.

The GIS capabilities was used with great results when the transportation system planning was being developed, providing the development policies of the planning areas established by the structure plan of the city, and the general information about such areas.

The proposed interventions impacts on the accessibility indexes, are based on the assumption that the links' traffic volumes remain the same between the actual and idealized situations. But, travelers can change their routes in response to the changes on, for example, the links' LOS. So, in order to refine this methodology, here is proposed, for future researches, the development of a transportation model to simulate and to analyze the proposed interventions impacts to the trip assignment.

Another proposition is to develop a research to establish a statistical correlation between the accessibility and the development indexes of each planning area, in order to serve as a new parameter during the planning process.

Finally, it should be noted that, although this methodology has been focused on the transportation system planning, which is seen as a tool driving the development of the cities, in a broader context, this planning must also consider the overall infrastructure, including for example, the water supply, sewer, etc.

REFERENCES

Allen, W. B., D. Liu and S. Singer (1993). Accessibility measures of US metropolitan areas. Transportation Research. B 27, pp. 439-449.

Amekudzi, A. and M. Meyer (2005). Consideration of environmental factors in transportation system planning. Transportation Research Board, NCHRP Report 541. Washington, D.C., US.

Anthony, R. N. (1988). The management control function. Havard Business School, Boston, US.

Banister, D. (2002). Transport Planning. Spon Press. New York, US.

Bastianoni, S., F.M. Pulselli and S. Focardi (2008). Correlations and complementarities in data and methods through principal components analysis (PCA) applied to the results of the SPIn-Eco Project. Journal of Environmental Management, 86, pp. 419-426.

Booth, D. (1998). The environmental consequences of growth. Routledge. London, UK.

Brazil (1988). Brazilian Constitution. Brazil.

Brazil (2007) Mesh of urban census tracts in 2007. IBGE - Brazilian Institute of Geography and Statistics.

Brazil (2007b) Coordination of National Accounts in 2005. IBGE - Brazilian Institute of Geography and Statistics.

Bruton, M. J. (1992). Introduction to transportation planning, UCL press, London, UK.

Caliari, C. C. L., A. A. Araújo and F. A. A. Gomes (1996). Graph attributes identification in images of highway maps (for the routing problem). Proceedings II Congress for Geographic Information System' Users, GISBRASIL 96, pp. 388-391, Curitiba, Brazil.

Chunmiao, C. and S. Jincheng (2009). Comprehensive Evaluation on Urban Sustainable Development of Harbin City in Northeast China. Chin. Geogra. Sci., 19(2), pp. 144-150.

Giuliano, G. (1988). New directions for understanding transportation and land use. Institute of Transportation Studies, University of California, California, US.

Hansen, W.G. (1959). How accessibility shapes land use. Journal of the American Institute of Planners, Vol. 25, pp. 73-76.

Hellriegel, D. and J. W. Slocum Jr. (1992). Management. Addison-Wesley. Reading, MA.

Johnston, R. A. and T. De La Barra (2000). Comprehensive regional modeling for long-range planning: linking integrated urban models and geographic information systems. Transportation Research. Vol. 34(A), No. 2, pp. 125-136.

Knox, P. and S. Marston (2003). Places and regions in global context. Human Geography. 2nd edition, Upper Saddle River. Prentice Hall, NJ, US.

Koenig, J. G. (1980). Indicators of urban accessibility: theory and applications. Transportation, Vol. 9, pp. 145-172.

Kress, J. and G. Barrett (2001). A new century of biology. Smithsonian Press, Washington, D.C., US.

Kwan, M. P. (1999). Gender and individual access to urban opportunities: a study using space-time measures. The Professional Geographer. Vol. 51(2), pp. 210-227.

Li, X., W. Wang, F. Li and X. Deng (1999). GIS based map overlay method for comprehensive assessment of road environmental impact. Transportation Research. Vol. 4(D), No. 3, pp. 147-158.

Lowry, M. B. and R. J. Balling (2009). An approach to land-use and transportation planning that facilitates city and regional cooperation. Environment and Planning B: Planning and Design 2009, Vol. 36, pp. 487-504.

Meyer, M.D. (1993). Jumpstarting the move toward multimodal planning. Transportation Research Circular, 406.

Meyer, M.D. and E. Miller (2001). Urban transportation planning: A decision oriented approach. McGraw-Hill. New York, US.

Nadakavukaren, A. (2000). Our global environment, a health perspective. 5th edition. Prospect Heights. Waveland Press, IL, US.

Odoki, J. B., H. R. Kerali and F. Santorini (2001). An integrated model for quantifying accessibility-benefits in developing countries. Transportation Research. Vol. 35A, No. 7, pp. 601-623.

Paredes, E. A. (1994). Geographic Information System – Principles and Applications. Ed. Érica. São Paulo.

Pereira, L. R. S. S. (1985). Transportation and cities networks: A measure of its association – case study for the State of Rio de Janeiro. Ph.D. thesis submitted to the Transportation Engineering Program / COPPE/UFRJ, Rio de Janeiro, Brazil.

Pirie, G. H. (1979). Measuring accessibility: a review and proposal. Environment and Planning A. Vol. 11, pp. 299-312.

Raia Jr., A. A. and Silva, A. N. R. (2001). Travels potential index to urban transportation strategic planning using GIS and artificial neural networks. Proceedings of GISBRASIL 2001. Curitiba, Brazil.

Sales Filho, L. H. (1996). The use of accessibility indicators for the evaluation of the urban transportation structured networks. Ph.D. thesis submitted to the Transportation Engineering Program / COPPE/UFRJ, Rio de Janeiro, Brazil.

Sanches, S. P. (1996). Accessibility: A indicator of the cities transportation systems performance. Proceedings of X National Congress of Transportation’s Research and Teaching – ANPET. Brasília, Brazil.

Silva, W. P. (1996). Methodological contribution to a highway system planning. Master's thesis submitted to Transportation Engineering Program / COPPE/UFRJ, Rio de Janeiro, Brazil.

Stewart, J.Q. and W. Warntz (1958). Physics of population distribution. J. Reg. Sci., Vol. 1, pp. 99-123.

Teixeira, M. P. V. (1975). Connection standards and urban system – An analysis applied to the State of Guanabara and Rio de Janeiro. Master's thesis submitted to the Geography Pos-Graduation Program / UFRJ, Rio de Janeiro, Brazil.

TRB (2000). Highway Capacity Manual 2002. Transportation Research Board. National Research Council. Washington, DC, US.

Zhang, K., Z. Wen and B. Du (2003). Evaluation on Ecologic City and Indicators System. Beijing. Chemical Industrial Press. Pp. 6-17, 334-369.

Zuppo, C. A., C. A. Davis Jr. and A. A. C. Meirelles (1996). GIS in the transportation and transit system of Belo Horizonte. Proceedings of GISBRASIL 96. Curitiba, Brazil.