# MANAGEMENT AND MONITORING OF THE RELATION BETWEEN TRANSPORT AND URBAN LAND USE – APPLICATION FOR THE CITY OF RIO DE JANEIRO

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**ABSTRACT**

In the scope of the urban politics directed toward the management of the demand it is of great interest to study how the transport demand can be influenced in its roots, through spatial organization. The integrated planning of the Transport and the Land Use, aiming at the sustainable transport, configures an alternative approach in this aspect.

The present research develops a methodology to analyse the relation between transport and urban land use, aiming to contribute in the process of formulation of public policies and decision making as for the planning and to the operation of the transport systems and their impacts on land use pattern. This methodology is based on the combination of the Geoprocessing techniques and the concepts of Urbanism for Networks, for the identification of the space-time relation's in the territory and the regulation of these by means of the development of prospectives studies, based in GIS. We look to go deep in the study of the formation of the spatial processes in the city, which supply the conceptual base toward a better understanding of the transport and land use relation.

The method was tested, maps of the factors that represent the attributes of the network and of the territory had been created and combined by means of techniques of geoprocessing (GIS) and evaluation for multiple criteria (MCE). Were constructed fuzzy membership functions, aiming at mapping the degree of membership of these factors for the occurrence of the spatial process of urban segregation, in the city of Rio de Janeiro. Finally, urban areas differentiated by space-time relations, configured for the functioning of the bus transit had been identified how important, in the peak of the morning. Extensive areas with greater potential for the formation of the spatial process of urban segregation had been also identified, in direction of West Zone and part of the North Zone of the city.

## INTRODUCTION

Considering the disorganized and not planned growth of third world cities, the high levels of segregation observed in their urban structure, as well as, the high levels of production, extension and concentration of urban travels, the effective management of the relation set between urban transport and land use is extremely important to the territorial arrangement and sustainable development.

The relation between transport and land use is obviously spatial, and it has cyclic behaviour which we describe: 1) Transport network, which functioning configures space-time relations; 2) An specific space-time configuration produces decisions that affect individuals localization and urban activities; 3) The changes in individuals localization and activities, in the other hand, produce changes in the spatial organization patterns and land use; 4) The changes in the spatial patterns and land use produce changes in the spatial links; 5) The changes in the spatial links modify the existing transport patterns, repeating the whole process all over.

The demand for transport might be influenced in its origin, through the integrated planning of the Transport and Land Use, promoting the sustainable transport, as well as, favourable changes in the spatial organization. Everything this implies, preliminarily, having a good knowledge of spatial processes that configures the city.

Although widely to be known in the spatial analysis for geoprocessing the raster processing is not used with all its potential in the study of the transport networks. We consider that this technique could establish great contributions for one better understanding and representation of the attributes and performance of the networks and, therefore of its impacts in the environment, or either, a new perception of the network in the GIS studies.

The present research develops a methodology to analyse the relation between transport and urban land use, aiming at to contribute in the process of formulation of public politics and decision making as for the planning and to the operation of the transport systems and their impacts on land use pattern. We present in this article a case study evidencing the areas with potential greater for the formation of the spatial process of urban segregation, in the city of Rio de Janeiro.

## METHODOLOGY

The combination of the Urbanism of the Networks and the Geoprocessing constitutes the methodological base of our proposal, in which the conceptual aspects of both the theories establish mechanisms for the joint management of Transport and Land Use relation. Therefore, we look for identify to the relations space-time in the territory and regulate these relations by means of the accomplishment of prospectives studies, based in GIS.

### Bases of the methodology

The Urbanism of the Networks, offers a global approach of the networks in its relation with the territory, supporting that all the networks possess common an essential and structural characteristic: the territoriality. Although all sectoral particularity of each network *(Dupuy, G. 1991)*. The Space appears as the product of the dialectic established between the territory and its transport networks. The essential properties of the territory are the autonomy, the coherence, the permanence and the organization, in analogous way; the networks in general, possess the reticular properties of conexion, connectivity, homogeneity, isotropy and nodality.

The space determines the transport networks, but these also produce its proper space, by means of the particular combination of its reticular properties. On this if it bases the power to discipline and regulator of the networks for the circulation and the urban activities pattern *(Moreno, J. P. 2000)*.

For example, the organization of the urban territorial system integrate all the reticular properties: the connexion it is a basis property and in it will allow them to observe the distribution and concentration of the network of transport in the space; the connectivity will make possible to observe the density of the offered circuits and the existing alternatives of linking; the homogeneity will show the use of the network, or either, the space-time meaning of its functioning; the isotropy will delimit, in the case of low homogeneity, the limits differentiated of the space-time correlation; finally, the nodality, will allow to know the poles or the localizations of privilege in the space in function of the topological and kinetic links.

The geoprocessing treats the environmental problems, considering the localization, the extension and the spatial relations of the analysed phenomena, aiming at to contribute for its explication and attend its future evolution. In this context the procedures of diagnosis and prognostic of the Environmental Management for Geoprocessing, can be integrated in the context of a study of the territory for geoprocessing *(Bonham-Carter, 1994)*, organized in 3 steps: a) Building spatial data base, b) Data processing, and c) Integration modelling.

The process will supply to 3 types of synthesis maps: 1) derived maps, result of operations/transformations effected in the database georeferenced, aiming at to extract important aspects that represent the attributes of the network and the territory; 2) intermediate maps, result of the combination of the previous maps using diverse techniques of aggregation based in inferences or theoretical knowledge of the phenomenon in study. For example, areas with potential of occurrence of a spatial process specific; e, 3) prediction maps, result of new combinations considering new premises in the networks or territory, in the present time or the future.

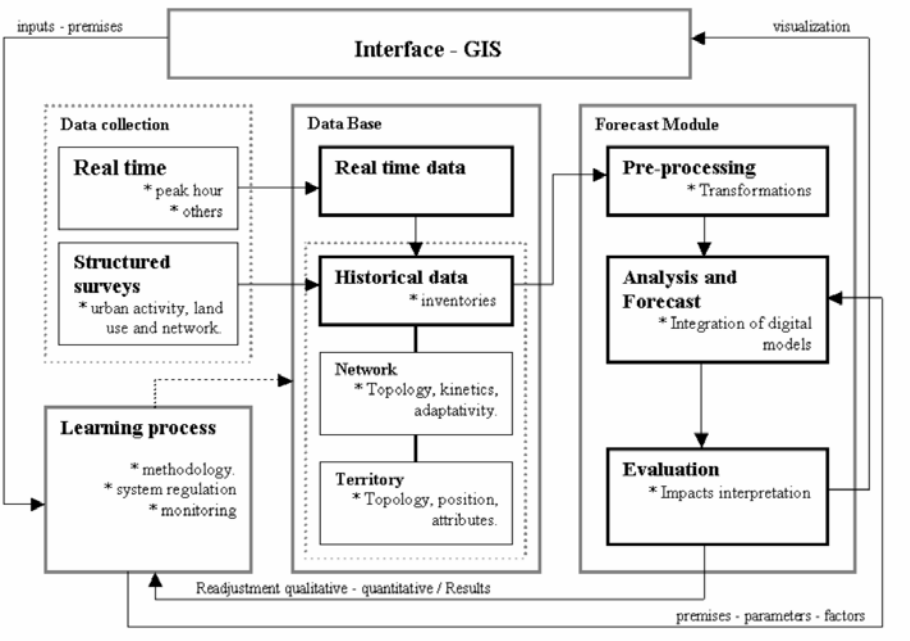


*Figure 1: Management and Monitoring / Structure of the Process.*

## Structure of the process

The use of the geoprocessing in the management and monitoring of the attributes of the Network and the Territory, can offer contributions for the study and formulation of politics of Transport - Land Use at medium and long term. The process is composed for 5 modules: a) interface, b) data collection, c) database, d) forecast module, and e) learning process *(Moreno, 2002)* (see figure 1).

In relation to data collection, it is necessary to implement a system of structured surveys, within of the supplier's institutions of data of the city, looking for information with regard to the urban activities and operational data of the public transport corridors. The construction of the database is a permanent task in the process, directed to the update and maintenance of the historical data georeferenced.

The final results of the forecast module, as well as, the eventual necessity to establish readjustments in the factors (maps) or premises (quantitative and qualitative), will be able to lead a learning process, or either, for successive approaches we can adjust the digital models. Changes in the kinetic and topology of the networks (transport politics) and changes in the attributes of the territory (relative politics to the land use) also could be modelling by means of maps of forecast, in this way we effect the regulation of the urban system.

### STUDY OF CASE FOR THE CITY OF RIO DE JANEIRO

In the city of Rio de Janeiro a historical and unequal accumulation of functions, economic activities and infrastructures occurred, originating valorisation of the CBD areas and the noble zones of the city. Therefore, the population of lesser income was dislocated for the peripheral zones and suffer the raise of price of services of public transport. 1.500.000 dwellings in the city exist, of which 14% are located in slum or similar areas. In the period of 1970 the 1990, the population diminished 3.5% in the Centre, Tijuca and in the South Zone of the city, however, in the immediate periphery (north zone) it increased 31% e, in the intermediate periphery, 74% (west zone). Therefore, we can affirm that the city grew without ratio in the periphery, developing the length and the duration of the urban trips, what it establishes an great spatial un-balance when we consider that, in the centre and the south zone of the city if it concentrates 60% of the work market, while the periphery alone represents 40% of this market.

The process of creation of the database, to be used in this application, configure 3 stages: 1) construction of the mathematical network that better can represent the route of the main lines of the bus transit system in the city (transport corridors); 2) survey of the existing information concerning to the transport network and the territory; and 3) edition of the data and, when necessary, pre-processing and edition.

All the data of the corridors correspond the structural lines of transport and had been survey considering the periphery-centre direction in the peak of the morning, in order to represent the daily displacements of mass transit, correspondents to the first stage of the commuter's movement residence-work, residence-study or residence-other. The basic data of transport correspond the 1997. As result of such operation, we have 383 links (lines) and 327 nodes (points). The available operational information is relative to the peak of the morning, in an interval of 3 hours.

The forecast module is the main one in the Structure of the Process and is organized in 3 sub modules: a) pre-processing, b) analyses and forecast and c) evaluation. To follow we will present the followed steps to identify the areas with potential greater for the urban segregation, in the city.

**The Pre-processing**

The majority of the data relative to the links and nodes could have been edited directly, however some factors was made a pre-processing until the definitive configuration of the database. With this purpose we effect operations of spatial transformation in the data. For the case of the network, the transformations follow the logical line - point - area (link - node - areas of influence).

The first transformation (link - node) is mathematical, for which we construct to matrices with origin-destination data of the links of the network in study (travel time, distance, headway, transport capacity, etc.). The information of the links are placed its respective node, making use of specific algorithms. Later, we effect the second transformation for geoprocessing in the network, making the interpolation of these values, corresponding to the nodes of the network and constructing raster maps with them.

**a) Mathematical operations**

From the information of distance in km and travel time in hours, for each link, the calculation of the isoacessibility index or speed of circulation in the network was effected, which is a isotropy index *(Dupuy, 1985)*. Therefore, a program for the development of the matrices was created. The values of the vector solution later had been assign to 327 nodes of the network. The isoacessibility is equivalent to the division of the sums of two matrices:

$$\mathbf{V_i} = \frac{\sum_j \mathbf{d_{ij}}}{\sum_j \mathbf{t_{ij}}}$$

$v_i$ = speed of circulation in i
$d_{ij}$ = distance in km of i up to j
$t_{ij}$ = time in hours of i up to j

For the calculation of the frequency equivalent or availability of transport, we leave of the principle of that, knowing the travel time in a link during the peak of the morning, as well as, the headway of the buses in the same link and period of the day, will be able to get, for division, the number of available vehicles or the potential of occurrence of some vehicle for this link. The frequency equivalent index calculates the availability of bus for a moment given (the peak of the morning) in the nodes of the network, or either, for example, a node or intersection of two links will be able to have available 5 buses (3 of link x and 2 of link y) however, simultaneously, in another place of the city, another node will be able to have offers very lesser:

$$\mathbf{isoF}_i = \sum_j \left( \frac{\mathbf{t}_{ij}}{\mathbf{hway}_{ij}} \right)$$

$isoF_i$ = frequency equivalent in i
$t_{ij}$ = travel time of i up to j
$hway_{ij}$ = headway of i up to j

Similar procedures had been effected for calculate the bus transit capacity and highway hierarchy. As result of these operations we have vectorial maps with the distribution of nodes and its respective values, in the space.

**b) Transformations for geoprocessing**

In this stage we effect the interpolation of the values concerning to the nodes of the network, calculated in the previous stage. Therefore, we use the data of the coordinates and numerical attributes supplied by the set of nodes, being the surface delimited for the coordinates of a raster map of reference. The used procedure was distance-weighted average.

Thus raster maps had been developed towards isoacessibility, frequency equivalent, bus transit capacity, highway capacity, traffic volume and highway hierarchy. In synthesis, the transport network diverse attributes: the diffusion of the urban movement and the impacts of the performance of the transport network.

To get a map that represents the total accessibility, we use two previous maps: isoacessibility and frequency equivalent. Which also express the accessibility attribute. To effect the aggregation, we need weighted these maps for some criterion, based on the state of the art. According to empirical studies *(Bruzelius, 1979)*, the value of the wait time attributed by trip maker is between two and three times greater that the value of the travel time, which supplies an subsidy in relation to the perception of the total accessibility for the users of the bus transit.

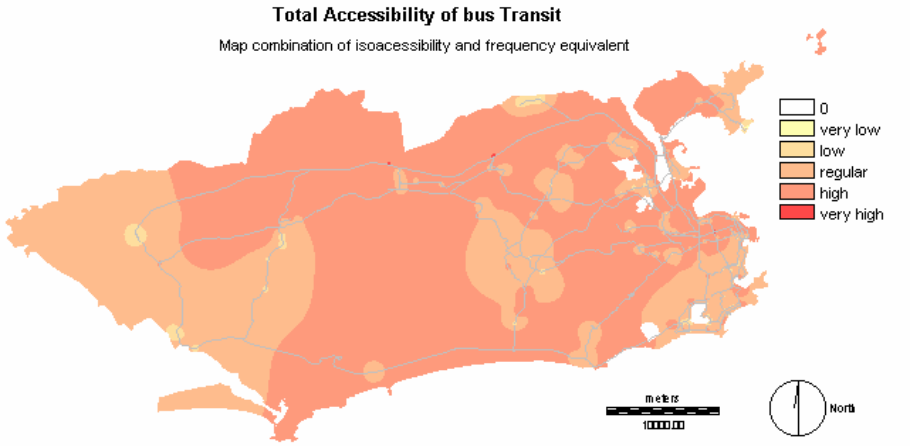


*Figure 2: Total Accessibility of the Bus Transit System.*

The wait time is related with the availability of vehicles, or either, the offer of bus and the travel time is related with the speed of these buses in the network. Waiting that the unit represents the total accessibility, it would correspond to the frequency equivalent one weight of (2/3) 66.6% and to the isoacessibility one weight of 33.3% (1/3). The biggest value of frequency equivalent (isofrq) was 13,124 and of isoacessibility (isoace) 81,448, based in this, we standardized the factors:

$$\mathbf{acetot = (isoace)(1 / 8.1448 \times 3) + (isofrq)(2 / 1.3124 \times 3)}$$

By means of map algebra tool, we effect the integration. In theory, the point where it has simultaneous occurrence of best (isoace) and of best (isofrq), will have a value of 10. We can see in figure 2 the map of the total accessibility of the bus transist, classified and the network of corridors.

**Analysis and forecast**

In this stage we effect the crossing of the attributes of the Network and the Territory, represented in raster maps (factors), combining qualitative and quantitative techniques of forecast. The factors are decision criteria that define some degree of membership for a process or specific phenomenon (in this case the urban segregation) in the study area. The criteria can be of two types: absolute barriers (maps that represents restrictions) and factors or relative limitations (maps that represent factors).

In the evaluation for multiple criteria (MCE) we use the weighed linear combination (WLC), which makes possible the compensation of factors ones to the others, by means of a set of weights attributed to the maps. Factors (maps) with high favourability in a place can compensate factors (maps) with low favourability in this exactly local.

| Factor | Map | %: Specialist | Weights |
|---|---|---|---|
| Total accessibility | acetot | 100 | 0.12 |
| Bus transit capacity | cstma | 63 | 0.07 |
| Highway capacity: service level | cvns | 63 | 0.07 |
| Traffic volume in the intersections | vtim | 75 | 0.09 |
| Highway hierarchy | hvia | 75 | 0.09 |
| Network configuration | trmvia | 75 | 0.09 |
| Liquid density | denliq | 88 | 0.10 |
| Number of commercial establishments | nestcom | 88 | 0.10 |
| Land value index | ivsolo | 63 | 0.07 |
| Income for inhabitant | rendah | 75 | 0.09 |
| Car ownership index | taxmot | 75 | 0.09 |
| Traffic control index | isemaf | 25 | 0.03 |

*Table 1: Weights of the Factors in the Transport Land Use Relation.*

**a) Weighted and classification of the factors**

The 12 main factors of the Transport and land use relation had been identified (table 1). In the aggregation process we grant different relative weights for each one of the factors (maps). The weight indicates the relative importance of each factor in relation to others for a specific process. The identification and weighted of the factors based in *Palhares (1994)* was achieved making use of qualitative techniques of forecast, with city planners. A preliminary classification for each map was effected also, defining a hierarchy of 5 expressions for unify the data represented in other scales. We use intervals of classification based in an ordinal scale: very low, low, regular, high and very high.

**b) Fuzzy Classification**

The classification intervals had helped to define the degree of membership in the interior of a factor (map) for the occurrence of the spatial process in analysis, considering fuzzy decision rules. Therefore, fuzzy membership functions or fuzzification had been constructed with the module fuzzy of Idrisi 32, aiming at to associate this operation with the evaluation for multiple criteria and thus to deal with the uncertainty, gradually. The maps had been standardized for a continuous scale of membership of 0 (less favourable) to 255 (more favourable).

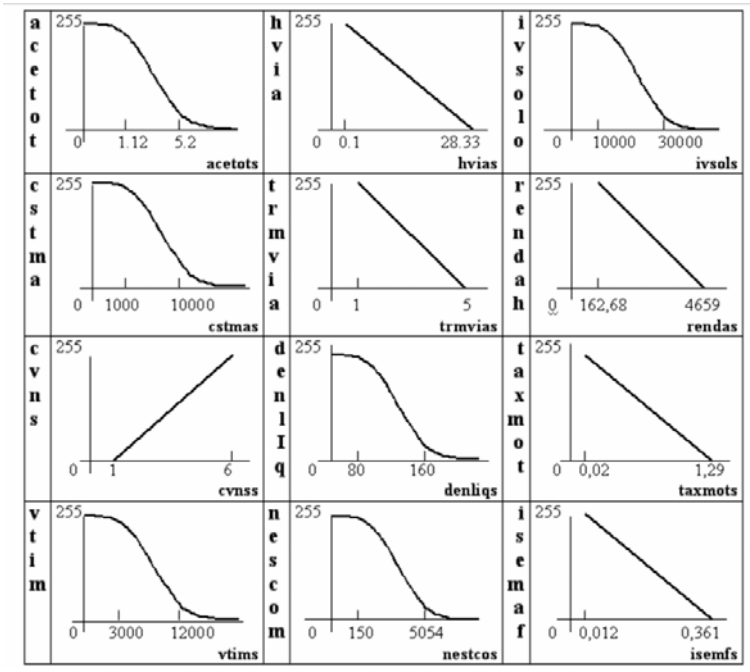


*Figure 3: Membership Functions of the Factors for the Spatial Process of Segregation.*

The reasoning that had given origin to these functions had been elaborated using the specific state of the art to the spatial process of urban segregation, as well as, the experience of the specialists, that is, knowledge based approach. Therefore, the spatial process of urban segregation will have potential greater of occurrence in the areas where if they verify the characteristics of the functions of membership of the set of the 12 factors, described in figure 3. To follow we explain the formulation of some of the membership functions used.

In case of total accessibility factor, membership for segregation will be very high in areas where accessibility was classified as low or very low, why these areas configure a greater scenario of limitations in relation to the performance of the transport networks. Beyond this value, the membership it decreases with the increase of the index and reaches a minimum close to where total accessibility was classified as very good, because areas with very good total accessibility hardly will be segregated. Such function is better described for a decreasing sigmoidal curve (figure 4).

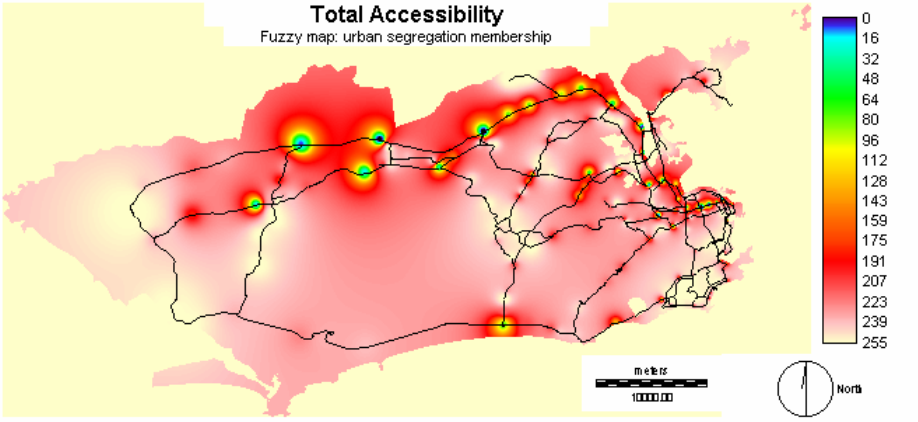


*Figure 4: Fuzzy Map of Total Accessibility.*

The bus transit capacity factor describes a high aptitude for the urban segregation in areas where the capacity is classified as very low. Beyond this value, the aptitude decreases with the increase of the capacity and reaches a minimum close to where the capacities are classified as high or very high. Evidently, such index would correspond to the dense central areas and which concentrate the flows of the transit. This function is described, also, for a decreasing sigmoidal curve. The number of commercial establishments and services factor describes a high aptitude for the urban segregation in areas where it was classified as very low. Beyond this value, the membership decreases with the increase of the number of establishments and reaches the minimum close to the value of Copacabana (5,054 establishments), that it is the sub-centre with greater number of establishments after the metropolitan centre of Rio de Janeiro (29,345 establishments), or either, after this value the total lack of membership if keeps constant.

For the case of the land value index, the membership for the segregation will be very high in areas where the index is classified as low or very low, why the segregated areas do not possess high land values or activity of investors. Beyond this value, the membership decreases with the increase of the index and reaches a minimum close to where the value was classified as good or very good, or either, the index who would correspond to the valued areas or CBD of the city. This function is better described for a decreasing sigmoidal curve. The car ownership factor, will evidence a proportionally decreasing membership for the urban segregation to the measure that increases the value of the index, or either, a linear function simple. The lesser indices will correspond to the segregated areas, because of the income of these social groups, which conditions the auto ownership in the family and mobility when compared with other sectors of the city.

### c) Integration of the digital models

In module MCE of Idrisi 32, we select procedure WLC, introducing the weights data of the factors and select the 12 fuzzy maps that they will respectively represent the membership function of each factor in the space. The weighed linear combination multiplies each standardized factor (fuzzy) for its corresponding weight, adding, to follow, all the factors. After to effect the sum, the last step is to extract those features out of area of study (lagoons, sea, limits etc.).

Thus, we achieve the final raster map of the areas with greater potential of urban segregation in the city. Looking for to visualize these areas we make a classification, in order to select the areas with potential greater (figure 5), establishing 3 intervals: a first class with 95%-99% of membership, in a dark color; one second class with 90%-95% of membership an intermediate color and finally, a clear color for the interval of 85%-90% of membership. The areas out of the selection are in white color.

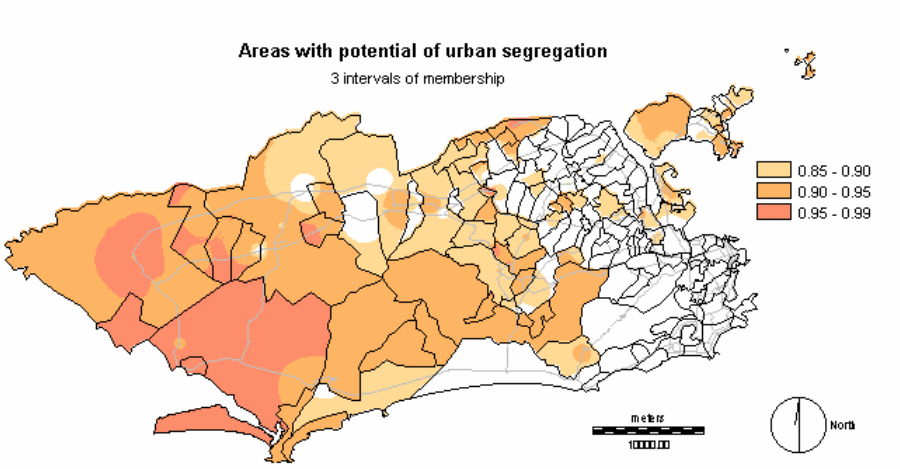


*Figure 5: Potential for the Formation of the Spatial Process of Urban Segregation.*

### Evaluation

The areas with greater potential of urban segregation predominantly extend for the West Zone and in some points of the North Zone of the city. In the West Zone the quarters of Santa Cruz, Sepetiba, Guaratiba, Paciencia and the Cosmos are affected, as well as, partially the quarters of Jacarepaguá and Tanque. The quarters of Deodoro and Pavuna had been affected in the North Zone. In these places and the neighborhoods the index minors of accessibility and performance of the bus transit had been found, in the peak of the morning, as well as, predominantly low indices of network configuration, car ownership, income, number of commercial establishments and land value. It is important to show that in some places of the West Zone, as well as, in many quarters of the North Zone linked for the Brazil avenue, good index of total accessibility and performance of the transport system, they had been identified, which could have influenced that some sectors of these quarters, did not present high potential of segregation. This fact was evaluated through occurrence of indices of traffic volume,

commercial establishments and car ownership (see figure 6), above of the average in these areas

In synthesis, evaluating topological and kinetic aspects the relations established for the transport network are not homogeneous. The space-time created by functioning of the transport network impacts the territory. The segregated spaces reflect social and spatial fragmentation, for the case of the urban transport, if express in mobility forms also segregated: the origin of the informal transport modes as alternative of the disfavored social groups.

The presented method also made possible to foresee the results of the espacialization of public policies by means of new combinations in the factors, as well as, also was applied to identify to the areas with potential for the formation of the spatial processes of auto-segregation and urban decentralization in the city of Rio de Janeiro *(Moreno, 2002)*.

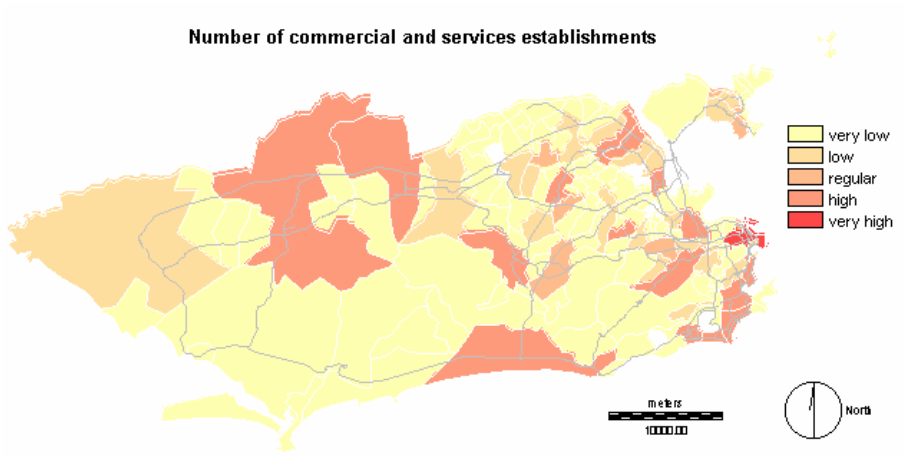


*Figure 6: Number of Commercial and Services Establishments.*

## CONCLUSIONS

The method made possible to evidence the areas with potential for the formation of the spatial process of segregation in the city of Rio de Janeiro, being disclosed a social and spatial fragmentation. Also it was identified to the existing polarization between the West Zone and the South Zone in the city, or either, a clear social and spatial duality.

The index's minors of accessibility and performance of the bus transit system, in the peak of the morning, had been found predominantly in the places where if reproduces the spatial process of urban segregation, or either, the West Zone and part of the North Zone of the city. These places configure an extensive and distant area of the metropolitan centre, which will make it difficult the future implementation of policies to promote the sustainable transport, without reducing the demand of transport in its origin. For example, by means of a spatial organization decentralized of the city, mixing land uses, integrated planning of the transport and the land use, etc.

The sped up development of the technologies of information and the telecommunications will establish gradual changes in the paradigms and relative conventional spatial patterns to the localization of the industry, services and attractors in the urban areas. The appearance of new productive activities, the growth of the services sector, the loss of the efficiency of the transit systems, the growth of the urban insecurity, the growth of the car ownership, etc. will be able to be reflected in new urban spatial patterns, still in the cities of the developing countries, extending the existing social and spatial polarization. Such scenario will also originate changes in the mobility patterns, analyzed by direction, distance or the existing connections (transport modes). In this context, the monitoring of the dynamics of the spatial processes that will occur will have strategical importance, aiming at the sustainable development and the understanding of a new urban reality.

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