ACCESSIBILITY EVALUATION MODEL TO SUPPORT DECISION-MAKING IN URBAN INVESTMENTS: THE CASE OF SANTARÉM-BRAZIL

RUI António Rodrigues RAMOS
University of Minho
School of Engineering
Department of Civil Engineering
Campus de Gualtar
4710-057 Braga
Portugal
Tel: (+351) 253604726
E-mail: rui.ramos@civil.uminho.pt

DANIEL Souto RODRIGUES
University of Minho
School of Engineering
Department of Civil Engineering
Campus de Gualtar
4710-057 Braga
Portugal
Tel: (+351) 253604726
E-mail: dsr@civil.uminho.pt

MAISA Sales Gama TOBIAS
University of Amazonia,
and Federal University of Pará
Brazil
E-mail: tapajos@amazon.com.br
E-mail: maisa@ufpa.br

Abstract: The main goal of the paper is to present an accessibility evaluation model for the urban area of Santarém, in Brazil. Located midway between the larger cities of Belém and Manaus, Santarém plays a crucial role in the region of Lower Amazonia. The paper describes the research instruments, sampling method and data analysis proposed for mapping urban accessibility. Basic activities (education, health, services, leisure and commerce) provided by the city were used to identify the main key-destinations. The model was implemented within a Geographic Information System (GIS). It estimates an accessibility index for each point of the network aggregating weighted sub-indexes referring to each group of key-destinations. GIS database components are the urban transport network, the location of key-destinations and their relative importance. The model also integrates the individual's perspective, through the definition of each key destination weight, reflecting their significance for daily activities in the urban area. The city of Santarém was divided into homogeneous groups of districts, according to geographical continuity, socioeconomic features and infrastructures locations. Questionnaires were used to characterize socioeconomics issues, inhabitants' daily activities, maximum distance travelled to perform those activities and main urban accesses. The map of Santarém showing the spatial distribution of the accessibility index highlights the areas with lower levels of accessibility to the most important key-destinations. The map exposes the actual inequity level of accessibility to main infrastructures of education, health services, leisure and commerce. Hence, the results of this model application can support city administration decision-making for new investments in order to improve urban quality of live. In addition, the model can simulate and analyze several planning proposal for the city, e.g., expansion of the transport network, the construction of new education and health services, helping to understand which will be the consequences of those actions.

Keywords: Geographic Information Systems, Planning Support Systems, Accessibility Evaluation, Brazil

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1. INTRODUCTION

City planning processes are often supported by decision-making methods that involve selection, evaluation and combination of several factors. Also, nowadays, the accessibility is one important issue for the development of cities. So, factors closely related to the accessibility are very relevant to identify and assess the location of urban facilities, which stresses the interest of evaluating accessibility methods.

The concept and evaluation of accessibility have been discussed for almost two hundred years. In urban context, that analysis is crucial to conduct a sustainable development process because it is linked with the opportunity of citizens to reach urban facilities and, at the same time, it can promote the reduction of urban traffic or support the improvement of urban transport systems. In one of the most interesting texts about accessibility, Hoggart (1973) sustains that accessibility is associated with the interpretation, implicit or explicit, of the easiness of reaching spatially distributed opportunities. This means that accessibility depends not only on the location of opportunities but also on the easiness of overcoming the spatial separation between individuals and specific places.

In the same line, Ingram (1971) defines accessibility of a place as its characteristic (or advantage) regarding the overcoming of any form of resistance to the movement. This author distinguishes between relative accessibility, which regards the degree of connection between two points on a surface (or network), and integral (or global) accessibility, which regards the degree of connection between a point and all the other points on a surface (or network). The second proposal, global accessibility, is a very important issue in urban planning process because most of urban investments are capitalized as general investments and not as specific investments. In urban context, the planning processes promote strategic and integrated decision-making in order to strength connectivity and reduce trips.

The way accessibility is evaluated depends on the purpose or objective to be achieved. Morris *et al.* (1979) present an extensive classification and formulation of measures for relative and integral accessibility. As referred before, the focus in this paper is the global or integral accessibility. For this reason it is important that the model includes: measures of separation between all the points; measures of separation incorporating the effect of distance; measures of separation incorporating network capacity restrictions; and complex measures of separation and supply/demand.

Several other contributions (Allen *et al.*, 1993; Geertman et al., 1995; Love and Lindquist, 1995; Mackiewicz *et al.*, 1996; Mendes *et al.,* 2005) proposed accessibility measures that somehow can be framed in the classification of Morris *et al.* (1979).

2. METHODOLOGY

The methodology is described in two steps. The first one identifies the theoretical issues of the multicriteria accessibility evaluation model focus in the dominion of an accessibility index (Mendes *et al.,* 2005). The second one explains how the model can be implemented within a Geographical Information System (GIS) in order to map the spatial variation of the accessibility index. Hence, the two steps methodology illustrates a simple process for mapping spatial variation of accessibility to city basic destinations in a global point of view.

2.1 Multicriteria accessibility model

The multicriteria accessibility evaluation model proposed in this research stands on a measure of separation incorporating the effect of distance. The principal theoretical points and assumptions in this model regarding envisioning accessibility include:

i) Accessibility evaluation is related to a certain objective/purpose; in this case we are concerned with accessibility evaluation for basic activities purposes in a city (education, health services, leisure and commerce).

ii) The accessibility index is a result of the combination of distances to a set of key-destinations, which can be particular points (e.g. facilities), lines (e.g. roads), or areas (e.g. neighborhoods or city blocks);

iii) Key-destinations are related to different objectives/purposes and can have different priorities (weights) in urban activities;

iv) In urban context key-destinations can be reached through streets/roads, each one can have different resistance to movement (friction) depending on its characteristics;

v) Cost-distances to a key-destination are a result of the combination of actual distances with the friction surface;

vi) Cost-distances to key-destinations can be normalized through fuzzy set functions that, after weighting, represent their contribution to the accessibility index.

The multicriteria accessibility index of a location Ai assessment given by equation (1) denote the fuzzy set membership function applied to cost-distances by $f(c_{ij})$, and the weight of the key-destination j by w_j.

$$A_i = \sum_j f(c_{ij}).w_j \qquad (1)$$

Points i, for which accessibility is measured, depend on the way space is modeled. For a network, the node points are considered; for a continuous space (surface), grid points are considered. In particular, when a raster model of the space is used, considered points are pixels of the raster image and depend on the adopted grid resolution.

Equation (1) is essentially a Weighted Linear Combination, one of the aggregation procedures available in the context of multicriteria evaluation (Voogd, 1983). In this multicriteria accessibility index, the assessment of the criteria c_{ij} represents the cost-distances to a key-destination j from a point i. Both, key-destination j and point i are location within urban area in evaluation.

A very important component of a multicriteria evaluation model concerns the priorities attached to the various criteria, i.e. the values of the weights w_j in equation (1). The objective of developing weights is to quantify the relative importance of key-destinations to one another, in terms of their contribution to an overall accessibility index. Among many methods to derive weights established and used by different authors, two are most commonly used Mendes (2000): the n-points scale (originally seven-points scale, as introduced by Osgood *et al.*); and a more complex method called Pairwise Comparisons, which was developed by Saaty (1977) in the context of a decision making process known as Analytical Hierarchy Process (AHP). Both methods are valid and the adoption of one of them depends on the possibility to implement a simple or complex survey.

Because of different scales upon which criteria are measured, it is necessary to standardize them before aggregation. The process of standardization is essentially identical to that of fuzzification in fuzzy sets (Jiang and Eastman, 2000). Depending on the nature of the criterion being fuzzified, different fuzzy functions can be selected. Among the most used are: Sigmoidal (S-shaped), J-shaped, Linear and Complex (Mendes, 2000).

In this model, the objective is to transform any scale to a comparable one measured according to a standardized range (e.g. 0-1). In our case, the result expresses a membership grade that ranges from 0.0 to 1.0, indicating a continuous variation from non-membership (no accessibility) to complete membership (maximum accessibility), on the basis of the criterion (distance) being fuzzified (figure 1).

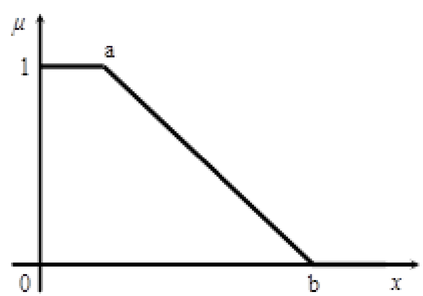

Figure 1 Linear fuzzy set membership function

When fuzzifying distance variables, the linear monotonically decreasing function (Figure 1) is one of the most used, for which membership grade μ (i.e., standardized value) is given by equation (2). Control points a and b are critical points that should be set for each particular situation, considering their inherent meaning.

$$\mu = (x - x_b)/(x_b - x_a) \quad (2)$$

When $x > x_b$, $\mu = 0$; $x < x_a$, $\mu = 1$

When evaluating the accessibility to urban facilities, the point *a* is often not adopted, as the assessment reduces immediately from the point where the facility is located.

However, a value for x_a can be adopted to characterize the effect of near-by (for instance, between the car stop and the facility entrance). In this case, x_a can be between 100m and 400m.

The value of x_b differs from facility to facility and from city to city. The value of x_b represents the maximum distance that can be considered until the accessibility to the facility becomes unavailable. Points witch distances are higher than x_b to the facility location are outside the hinterland of that facility. So, the accessibility to that facility does not contribute to the global accessibility index.

2.2 A vector GIS-based implementation

The formal model presented before can be implemented within a GIS environment, making use of toolbox set. The implementation depends on the specific characteristics of the software adopted. The following paragraphs explain the several stages to be taken on to implement the methodology within a vector GIS-based environment. The detailed information presented for the implementation of each stage implies that the reader is familiarized with GIS environment and toolbox set.

The flowchart of Figure 2 shows the geographical database needs (GIS layers) and the sequence of operations required to complement the attribute table to assess the accessibility index for the network points. The first step of the model is to calculate the cost-distance for each point of the network to each of the key-destinations. This step consists in calculating the OD Matrix from all network points to each key-destination and storing the values as new columns in the attributes table. At the end, the attribute table of the evaluated point's layer must have a number of cost-distances columns equal to the number of key-destinations used in the study undertaken.

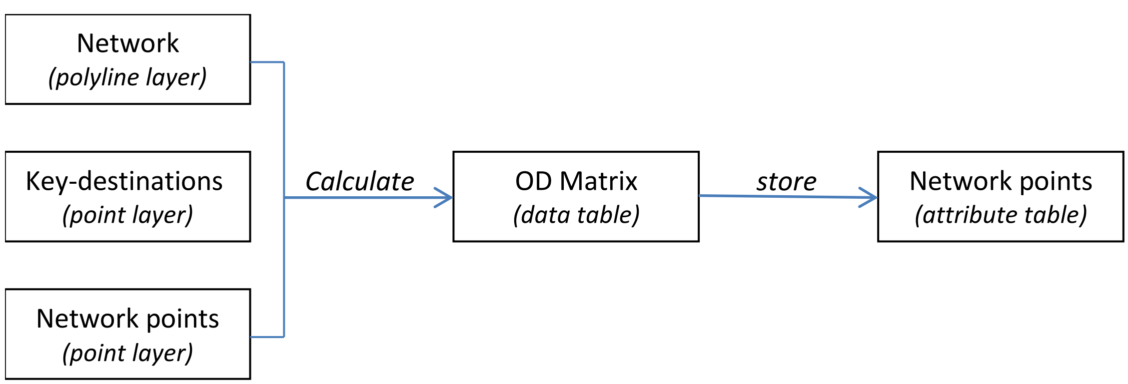

Figure 2 Vector GIS model to calculate cost-distances

Having the cost-distance from network points to all key-destination, the multicriteria procedure is implemented following the flowchart of Figure 3. The sequence of operations starts with the standardization (i.e., the application of the selected fuzzy set functions) followed by the weighting. Afterwards, the accessibility index is obtained by the aggregation of the several weighted standardized cost-distance. This procedure is applied at the attributes level. Once again, new columns must be added to the table: 2 columns for each key-destination (standardization results and weighting results). One last column is added to the attribute table to store the accessibility index.

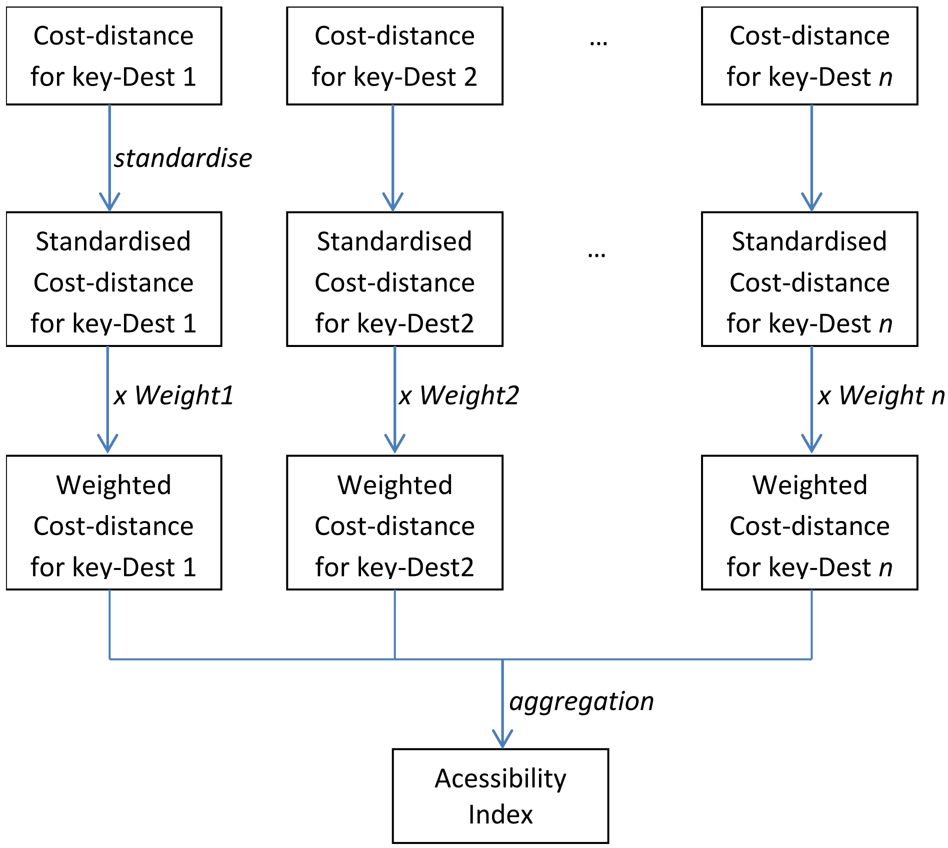

Figure 3 Accessibility index calculation process

With all the calculations concluded, it is possible to generate the accessibility map. The method adopted is building a triangulated irregular network (TIN) that will represent a surface covering the study area. Using as inputs the network points and applying their accessibility index as Z values, the resulting surface will show how accessibility values are distributed along the area by interpolating the obtained values of the network points. The same process can be implemented to create a map to show the accessibility to a specific key destination or a partial group of key-destinations. In this case, the TIN will represent as Z-values the weighted cost-distance for a specific key-destination or a partial group.

In order to use the accessibility evaluation model established in this paper, the model must be "customized" to the particular context under study. This means: (i) to identify the set of key-destinations; (ii) to establish the weights for each key-destination; (iii) to identify the fuzzy set functions to be used; (iv) and to set the control points a and b for the fuzzy set functions.

The proposed methodology can be implemented for any city to show accessibility evaluation in urban area. The evaluation can be put into practice by two different perspectives: as global index for the city area or as a partial index for facilities represented by a key-destination or a partial group. That allows a comparison between the several maps and an analysis of the relevance of partial facilities. Other possibility is to evaluate future scenarios in order assess the impact of future investments: (i) increasing accessibility network to improve better connectivity (new roads or streets) or urban transport systems; (ii) building new facilities to improve the spatial attendance or to redefine a location.

3. CASE STUDY: SANTARÉM, PA - BRAZIL

The city of Santarém is located in the Amazon floodplain, in the Brazilian State of Pará. The town is placed on the right side of the Amazon River at the confluence with the Tapajos River and was founded in 1661. Nowadays, Santarém is municipality with 294,774 inhabitants and occupies a territory of 22,887 km2 (IBGE, 2010). Most of the population is concentrated in the restricted urban area of the city of Santarém. The accelerated urban growth occurred from the 1940s (Figure 4) and, by the mid-1970s, the urban population of the municipality became the majority, until the present day (Figure 5).

Figure 4 Boundary evolution of the city of Santarém (1940-2002)

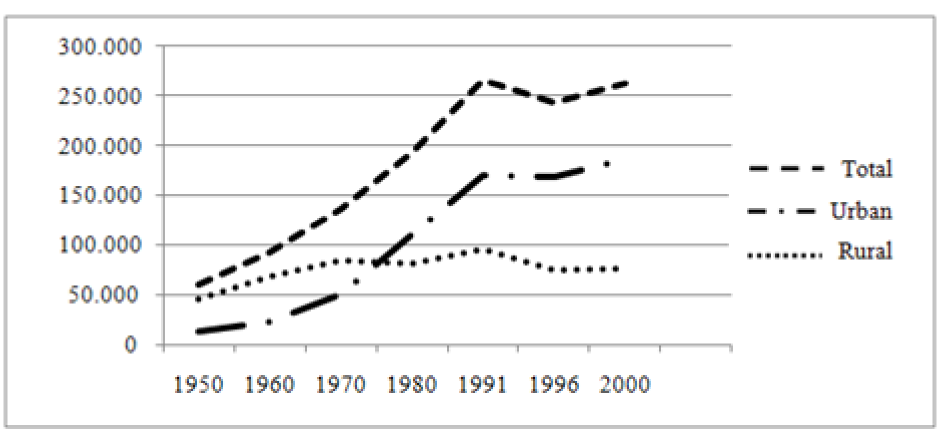

Figure 5 Population growth of the municipality of Santarém - 1950 to 2000 (IBGE)

Santarém is an important regional city in Lower Amazonia Region, located midway between to North Brazilian larger cities, Belém (capital of the state of Pará) and Manaus (capital of the state of Amazonas). The city economy is based on tourism activities, trade and services. Outside urban area, farming and fishing are the predominant activities. Like other riverside or coastal cities, the urban morphology is radial and the central business district is located in the old town area along the riverside. The most important access is by boat, with direct links to other cities in the region. By land, the Transamazonica road is the major motorway infrastructure of the region. There is also a connection by air (commercial flights and private) to Belém.

Nowadays, the mobility and quality of live become important issues in the developing process of the city. However, the location of the most important facilities in Santarém reflects previous public infrastructures policies or isolated private initiatives. Also, the central area of the old town preserves the importance for commerce and leisure activities. Hence, the accessibility evaluation is an important issue in the definition of future facilities buildings locations or to the definition of improvements in the transport infrastructures. The spatial assessment of accessibility to the city most representative facilities in inhabitants' daily activities (education, health, services, leisure and commerce) will be an important contribution to identify the urban areas with lower level of accessibility. The results can contribute for future land-use policies and planning decisions that can overcome the actual inequity level of accessibility of the peripheral neighborhoods.

3.1 Network and key-destinations in Santarém

In the case under study, the information needed to carry out the methodology was obtained by a survey. The survey was undertaken, as a pilot test, through a structured questionnaire from the reasons and destinations related previously by specialists, with the possibility to the interviewed add new destinations with-in the urban area. The pilot test was carry out only in two districts of the city: one in the center and another at the periphery.

After the conclusion of the pilot test, the survey was implemented for a panel of specialists, technicians, professionals and a large random group of residents. The survey had two phases: the first one to identify the location of the relevant key-destinations in the city of Santarém and to identify the modes of transportation in the city; the second one to obtain the data needed to the aggregation process.

Also, several issues about transports in Santarém, not directly relevant for the accessibility evaluation method, have been analyzed in the survey undertaken. Some figures from that part of the survey are the following:

- 80% of urban trips are related to work, education, commerce, services and entertainment;

- Over 70% of trips are made by individual motorized transport (car or motorcycle).

In a GIS environment, the first step was to generate the map of the streets/roads network and to extract the network points to be evaluated (figure 6).

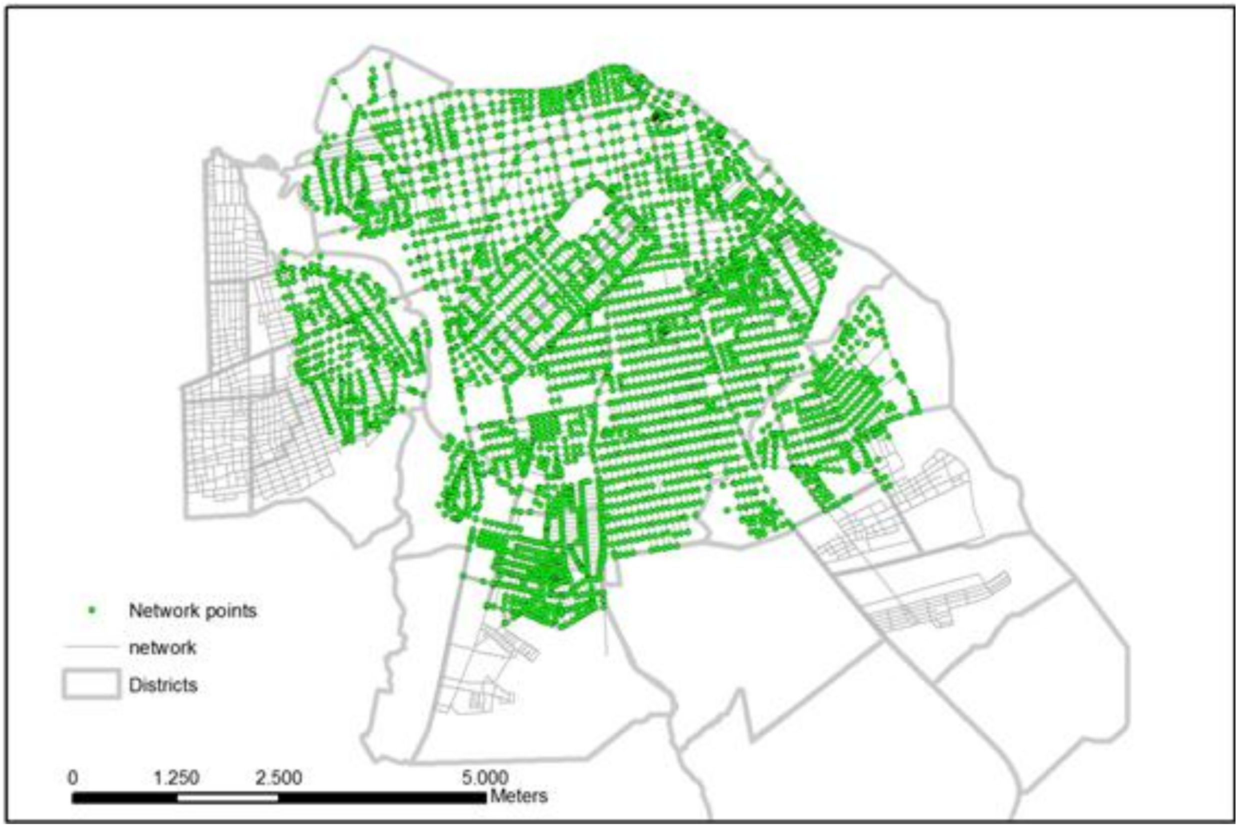

Figure 6 Network points map for Santarém

From the results of the survey, the key-destinations within the city were grouped into functionalities, namely the homogeneous set of key-destinations to perform certain activities: education, health, services, leisure and commerce. Thus, all functionalities were populated by the most relevant key-destinations in the urban area, i.e. schools, hospitals, services buildings, public recreational facilities and shopping areas. The figure 7 shows the maps with the functionalities location adopted in the study. The Table 1 list and make a short description of the key-destinations.

Figure 7 Key-destination maps for Santarém

Table 1: List of the key-destination for the city of Santarém

Funcionalities	Key-destination – short description
education	*Frei Ambrósio* School IESPES College Integrated Colleges of Tapajós and Tapajós High School
health	*Aldeia/Fátima* Health Center *Livramento/S. José* Health Center *Imaculada Conceição* Hospital Municipal Hospital Regional Hospital of West Pará Unimed Hospital
services	Bank of Brasil Itaú Bank Bradesco Bank Caixa Econômica Bank Bookkeeper of Rui Barbosa street Central Post Office
leisure	Shopping Centre of Santarém Municipal Market CR Supermarket *Candilha* Fair *Mercadão 2000* Fair
commerce	Santarém waterfront Church of the Peace Assemblies of God Church *Mariscada* Bar *Mascote* Restaurant

3.2 Fuzzy set functions and weights

In the case under study, the data needed to the aggregation process was obtained by a survey. The information needed to define fuzzy set functions and weights for the several key-destinations was not directly available and, for that reason, an empirical approach was implemented.

The second phase of the survey, as referred in the previous section, estimates the key-destinations relevance (weights) and the maximum distance that interviewed were willing to travel to each one (value of x_b, as define in the section 2.2). This phase of the survey was taken in 24 districts of Santarém, which represented 50% of city districts and 84% of the number of households, equivalent to 46,239 households. The research was household based, assuming one person per household. A binomial probability sample was used, with 95% confidence level error estimated at 10%, with, 400 households interviewed.

The relevance of functionality and key-destinations were evaluated by all the interviewed in a scale of 0 to 100 points. The relevance identified by the interviewees represents the importance of the key-destination for the realization of their activities. The average of the results was converted in weights for the key-destinations and for the functionalities groups.

For all key-destinations the interviewed also identified the maximum distance that can be considered valid to be in the respective spatial area of influence.

The questionnaire for the second phase of the survey had the following fields:

- Identification of the basic socioeconomic interviewed;

- A column with the funcionalities: a study, health services, leisure and commerce;

- Weights of functionalities;

- A column with the key-destinations;

- Weight of the key-destinations;

- Maximum distance to be traveled for each available key-destination.

The table 2 shows the relevant data need to the aggregation process.

3.3 Accessibility mapping

Applying the proposed model to calculate accessibility indexes for all points within a GIS platform is possible when taking advantages of database management. All key-destinations data must be stored in a table in order to perform further calculations that require standardization and weighting. Control points (minimum and maximum distances) must be assigned to each key-destination to allow the standardization of distance values through the fuzzy function. In this study the minimum distance has been considered null.

Then, the shortest distance to each key-destination must be identified and stored in the attribute table of the point layer. This step is performed using a tool for network analysis that generates OD Matrices. Network points (refer to section 3.1) are designated as origins and all the key-destinations (points) as destinations. The results are the shortest path over the network from each origin to each destination. To transpose those values into the attributes table of the network points layer, new columns were added and unique column identifier assigned in order to keep the relationship with the key-destinations. The existent one to one relationship between network points identifiers and key-destinations identifiers is used to ensure that the values transfer is applied successfully.

As the next calculation steps are associated to the standardization of values and the index calculation, once again, new columns were added to the network points attribute table: one column for each key-destination to store the standardized values and one extra column to store the final accessibility indexes values. The standardization was performed applying the chosen fuzzy function formula to each distance value using the "Field Calculator" tool. With all distances standardized, the accessibility indexes were finally calculated using the same tool to apply the aggregation formula from the proposed model.

Table 2: Weights and Max. Distance for Functionalities and Key-destination for the city of Santarém

Functionalities	Weights	Key-destinations	Weights	Max. Distance (m)
Education	0.14	*Frei Ambrósio* School	0.38	2,770
		IESPES College	0.15	3,794
		Integrated Colleges of Tapajós and Tapajós High School	0.47	3,764
Health	0.2	*Aldeia/Fátima* Health Center	0.08	1,460
		Livramento/S. José Health Center	0.06	4,579
		Imaculada Conceição Hospital	0.08	3,362
		Municipal Hospital	0.46	3,629
		Regional Hospital of West Pará	0.07	2,695
		Unimed Hospital	0.25	3,697
Services	0.23	Bank of Brasil	0.18	3,511
		Itaú Bank	0.38	3,656
		Bradesco Bank	0.18	3,528
		Caixa Econômica Bank	0.11	4,764
		Central Post Office	0.07	2,370
		Bookkeeper of Rui Barbosa street	0.08	4,416
Commerce	0.26	Shopping Centre of Santarém	0.62	3,804
		Municipal Market	0.07	1,792
		CR Supermarket	0.14	3,821
		Candilha Fair	0.08	4,060
		Mercadão 2000 Fair	0.09	2,959
Leisure	0.17	Santarém waterfront	0.57	3,942
		Church of the Peace	0.25	3,106
		Assemblies of God Church	0.08	2,472
		Mariscada Bar	0.06	2,517
		Mascote Restaurant	0.04	2,382

With the conclusion of the calculation process, the map production started. To generate a continuous surface that can illustrate how the accessibility to key-destinations varies over the study area, a triangulated irregular network (TIN) was created. The network points were used as mass points, covering the study area, and the accessibly index values was designated as Z values. Using those parameters, the resulting TIN “filled” the study area with accessibility indexes values. Figure 8 shows the accessibility index map obtained by changing the TIN symbology to a graduated color ramp that varies from red (lowest values) to green (higher values).

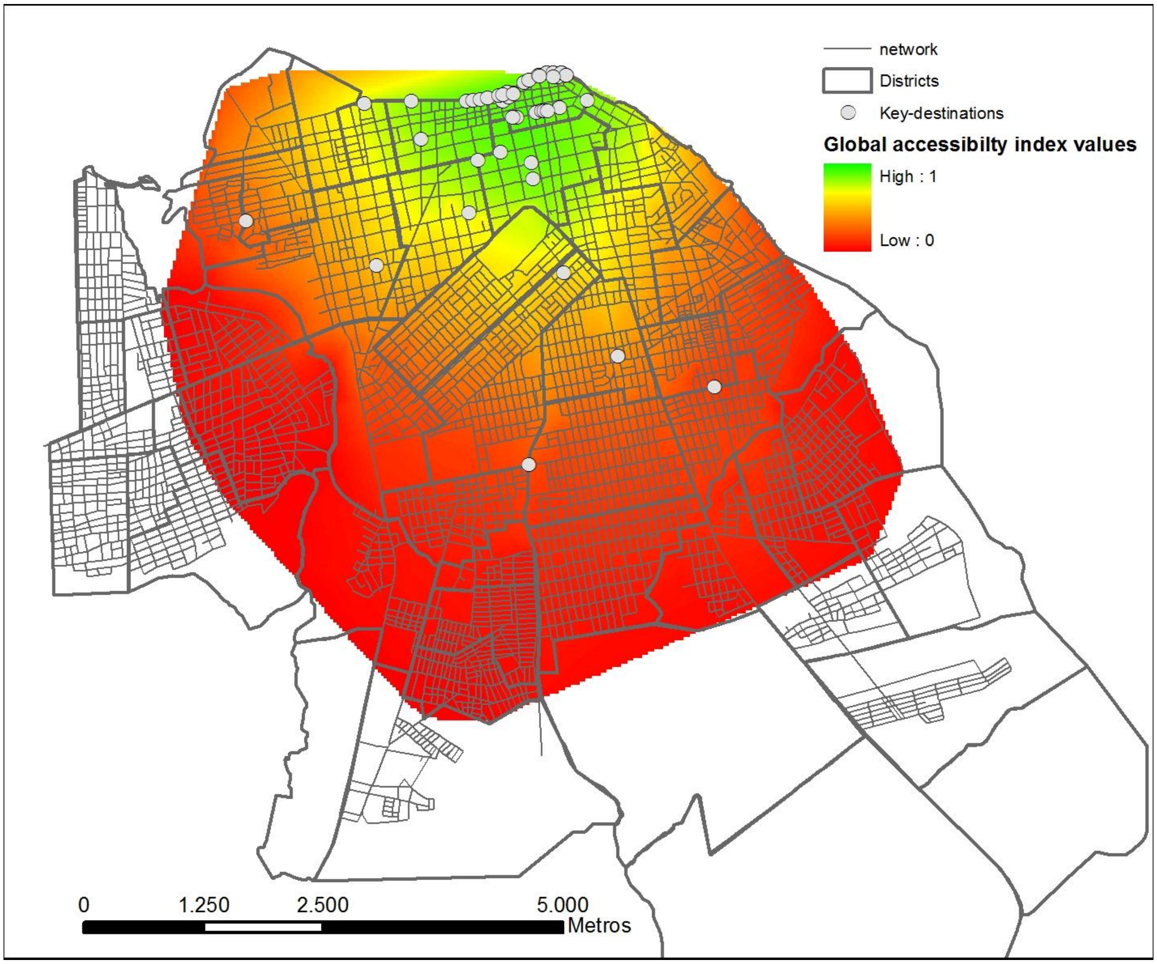

Figure 8 Map of Accessibility Index for Santarém

3.4 Case Study conclusions

The implementation of the methodology in Santarém indicates that a reasonable number of key-destinations could be easily adopted to evaluate the accessibility index. Moreover, the GIS environment and the representation of the index in a map give the opportunity to analyze the spatial distribution and to identify the city areas with and without accessibility to the key-destinations under evaluation.

A detailed analysis of the map show in figure 8 highlights the following aspects of the case studied:

- The concentration of key-destination for several functionalities in the central area of the city gives high level of accessibility for that part of city;
- Outside the central area, about 2km, we found some facilities distributed along a peripheral arc;
- In the outside peripheral area, between 2.5km and the limit of the city, there are none relevant facilities for the city;

- The accessibility values found in the central area and in the area inside the arc of 2 km are relevant and identifies good access to the most important facilities in the city;
- However, outside the 2.5km peripheral arc the accessibility to the facilities is very low;
- The spatial distribution of the accessibility index highlights the maintenance of the importance of downtown area (the old town) and the necessity of long trip for the inhabitants' daily activities.

4. CONCLUSIONS

In this paper a multicriteria accessibility evaluation model was developed within a GIS environment. The proposed model calculates an accessibility index given by the weighted summation of cost-distances to a number of key-destinations. Relevant elements in this model include:

- The calculation of cost-distances making use of a road network with friction that represents the resistance to movement.
- The standardization of cost-distances using fuzzy set membership functions that, when calibrated, represent much better the effect of distance in the evaluation.
- The combination of cost-distances taking into account the relative weight of key-destinations in the evaluation.
- The implementation in a GIS environment, taking advantage of the map algebra and visualization toolbox.

In that context, the methodology proposed for the accessibility index evaluation within a GIS framework forms a tool for an easy and ample assessment of urban spatial distribution of the most relevant facilities access. Moreover, it helps to identify the relationships between street patterns and urban morphology related to big traffic generators/attractors, i.e. hospitals, schools, services, leisure or shopping areas. In such way, the method can be used for monitoring and supporting transport policies and facilities location.

Hence, the results of this model application can support city administration decision-making for new investments in order to improve urban quality of live. In addition, the model can simulate and analyze several planning proposal for the city, e.g., expansion of the transport network, the construction of new education and health services, helping to understand which will be the consequences of those actions.

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