ACCESSIBILITY TO NODES OF INTEREST: A PRACTICAL APPLICATION OF THE VARIOUS FORMS OF THE IMPEDANCE CURVES

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ABSTRACT - Impedance is, in territorial statistics, the greater or lesser difficulty of a territory to be served/provided with adequate infrastructure and related services, useful for the improvement of the resident's quality of life. In the opposite, a greater impedance implies a low attractiveness of the territory for the establishment of new productive activities. The purpose of this research is to provide a picture as comprehensive as possible of the existing methodology for the elaboration of impedance, providing practical applications in relation to the Tuscan territory. The methodology used in this paper is part of the category of models called "gravitational", which are characterized by the denominator of the equation (index) that expresses the impediment in relation to accessibility between points in geographic space. In this case, the calculations have been made considering the cost of travel, which depends on the distance or travel time between points located on the transportation network that represent the points of departure and arrival. The processing affect the function of impedance by elaborating linear, exponential and logistic forms for the infrastructures related to hospitals with emergency rooms, upper secondary schools, airports, and railway stations. Processing separately covered the metropolitan municipality of Florence. The research highlights the main existing methodologies in relation to determining accessibility (attractiveness) of the territories, according to their infrastructural facilities and services. The analysis reveals the strengths and weaknesses, as well as the salient features of the equation used. In this sense, the research has produced a real benchmark between different approaches, using from time to time the variation of the impedance function.

Keywords: accessibility, regional development, impedance curves, territorial statistics, infrastructures, logistic form, exponential form

INTRODUCTION

The measures of accessibility can be summarized in three broad categories:

- measures based on cumulative opportunities;
- gravitational measures;
- measures based on "utilitarian" choice.

The measures based on cumulative opportunities are the simplest and are based on counting the number of opportunities within a range of distances expressed in terms of time (or space). All potential destinations within a certain period of time are equally weighted, so the choice falls on the points that have a greater number of destinations, in relation to the cut chosen in terms of the distance interval.

Measures based on gravity are characterized by the denominator of the equation (index) that expresses the impediment in relation to accessibility between points in geographic space. The

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The authors share the results of research and are jointly and severally liable for the content of the report. Specifically, Raffaella Chiocchini be attributed the section "GIS impedance analysis to calculate distances" and the matrix of the distances between municipalities and infrastructure. Gioacchino de Candia has conducted the research by developing the equations, introduction, analysis and conclusions.

impedance is represented by a function expressed in terms of travel times or travel cost. The synthetic form is the following:

$$A_i = \sum_j a_j f(t_{ij})$$

where a_j is the activity/service/infrastructure in the area *j*, t_{ij} is the distance in terms of travel time (or cost of the trip) between zones *i* and *j*, $f(t_{ij})$ is the impedance function. The shape of this function is often exponential or logistic (Andy, Niemeier, 2004).

Measures based on the utilitarian choice are the result of choosing an individual based utility on the choice of a specific opportunity/service/infrastructure compared to the total possible choices. If it is assumed that an individual's utility checks to each destination chosen from a set of possible choices (C) and the choice falls on the one that maximizes its utility, accessibility can be defined by means of a multidimensional logit model. The accessibility A_n for an individual *n* is then measured by the following equation:

$$A_n = \ln\left[\sum_{\forall \in C_n} \exp(V_{n(c)})\right]$$

where $V_{n(c)}$ is the matrix of spatial and temporal components observed in relation to the choice *c* for the individual *n* and C_n is the set of choices for the individual *n*. The logit model serves to summarize the measures of desirability of a group of choices (Ben Akiva et al., 2004). The specific utility function includes variables representing the attributes for each choice and reflects the attractiveness and the impedance of a destination, which must be the best for the same destination, while reflecting the tastes and preferences of the individual.

The research focuses mainly on the shape and its application of the impedance function, identifying the methodology for the case of Italy with an experiment developed in respect of the municipalities of Tuscany and its metropolitan municipality (Florence). The application concerns the hospitals, schools of secondary grade, airports and railway stations, up to the final conclusions and the future possibilities of further development of the model and its applications on a municipal scale.

MATERIALS AND METHODS

The methodology used in this paper is part of the category of models called "gravitational", which are characterized by the denominator of the equation (index) that expresses the impediment in relation to accessibility between points in geographic space. The calculations have been made considering the cost of travel, which depends on the distance or travel time between certain points located on the transportation network that represent the points of departure and arrival. The formula that represents a generalized way in this class of accessibility indicators is:

$$A_i = \sum_{j \in D} W_j^{\beta} f(c_{i,j}, \alpha)$$

where A_i is the accessibility of a resident of the area *i* with respect to the node *j* in the region *D*, W_j^{β} is a measure of the activities or services (mass of opportunity) located in zone *j*, β is a calibration parameter (used to account for the effects agglomeration) and $f(c_{i,j})$ is a function of impedance generally decreasing with the cost (or with the distance or travel time).

The function of impedance, which focuses on the analysis, assumes different expressions depending on the authors. In elaborations, from time to time and to test the ability of the impedance function of representing the attractiveness of a city, the logistic curve, the exponential curve and the linear curve are chosen as functions. Therefore, the different expressions of the impedance function take the following forms:

$$f(c_{i,j}) = \left(\frac{1}{1 + \exp - k(c_{i,j} - c_0)}\right) \qquad \text{(logistic)}$$

with

$c_0 = \frac{1}{2}(c_{min} + c_{max})$, where $c_{\min}$ is the minimum cost and $c_{\max}$ the maximum cost observed and

$k = 2\ln\left(\frac{1}{\gamma} - 1\right) \Big/ (c_{\max} - c_{\min}) \qquad \gamma > 0$

$$f(c_{i,j}) = \exp(\gamma c_{i,j}) \qquad \text{(exponential)}$$

with $\gamma > 0$

$$f(c_{i,j}) = \gamma c_{i,j} \qquad \text{(linear)}$$

with $\gamma > 0$

To get the most appreciable, γ must have a value greater than zero, but very small. In the calculations the value γ has always been set equal to 0.05.

The methodology, referred to in the preceding paragraph, was applied at municipal level for all municipalities in Tuscany under study. In the case of the metropolitan municipality of Florence, part processing was performed, as these types of joint are distinct in constituencies, in order to measure the attractiveness of each of them on the basis of their infrastructure. As stated in the introductory paragraph, the infrastructure considered for experimentation on a municipal basis was as follows:

- hospitals (public and private);
- upper secondary schools;
- railway stations (platinum, gold, and silver);
- airports.

One last point should be made in relation to the construction method of the list of municipalities to summarize their impedance functions: the methodology used includes the "arithmetic mean" and the statistics called MPI (Mazziotta Pareto Index). This indicator represents a novelty in the field of statistics and is proposed in the following form:

$$MPI = \mu(1 - CV^2)$$

where

μ is the simple arithmetic mean and CV is the coefficient of variation. Where CV is greater than 1, the statistic is negative, defining the low (very low attractiveness) of the municipality.

Finally, the distances between the towns and their infrastructure have been calculated using the ArcGis software based on the TomTom 2012 road graph.

GIS ANALYSIS TO CALCULATE IMPEDANCE DISTANCES

The calculations of travel times were made by using the ArcGIS Network Analyst module of the GIS software. For the calculation we used the TomTom Multinet road graph, where the data on road conditions were updated at the end of 2012. As points data, to find the driving distance, the centroids of the municipalities of Tuscany (Istat 2012) and the centroid of the sub - municipal areas (Istat 2010) were used as source data only for the city of Florence, while all the considered infrastructures (hospitals, railway stations, secondary schools, and airports) were used as destination points.

The infrastructure used is derived from georeferencing public administrative archives, integrated with the Point of Interest that are included in the graph road datasets. The facilities that we used are:

- railway stations (platinum, gold, and silver) from the 2012 RFI (Railway Italian Infrastructures) source;
- airports from the 2010 ENAC (Italian Civil Aviation Authority) source;
- public and private hospitals with first aid from the 2007 Health and Care Ministry source;
- secondary schools from the 2011 Ministry of Education source.

The output OD cost matrix, that is the result of the GIS processes, consists of all drive time and kilometric distances from origins to destinations. The calculations were performed in ideal conditions and in the absence of traffic and using a travelling speed that is set on the road graph.

The travelling speed used is referred to the highway code speed and to road signs contained in the updated road graph. The tool used is ArcGIS "find closest facilities" contained in the Network Analyst package; this tool allows the calculation of all driving distances starting from the closest to the farthest.

RESULTS AND DISCUSSION FOR MUNICIPALITIES

The Tuscan territory is divided administratively into ten provinces: Arezzo, Florence, Grosseto, Livorno, Lucca, Massa - Carrara, Pisa, Pistoia, Prato, and Siena. There are in total 278 municipalities and 3,672,202 inhabitants, according to the latest Census of Population and Housing (2011).

In developing the model, as explained above, we proceeded to isolate the metropolitan area of Florence, for which data on districts were available, resulting in a matrix of impedance functions for the remaining 277 municipalities.

The elaboration of the impedance function was processed for each type of infrastructure, in the logistic, exponential, and linear forms; thus, a series of lists was obtained, where each time sorting is based on the arithmetic average (of the functions of impedance) and MPI on statistics.

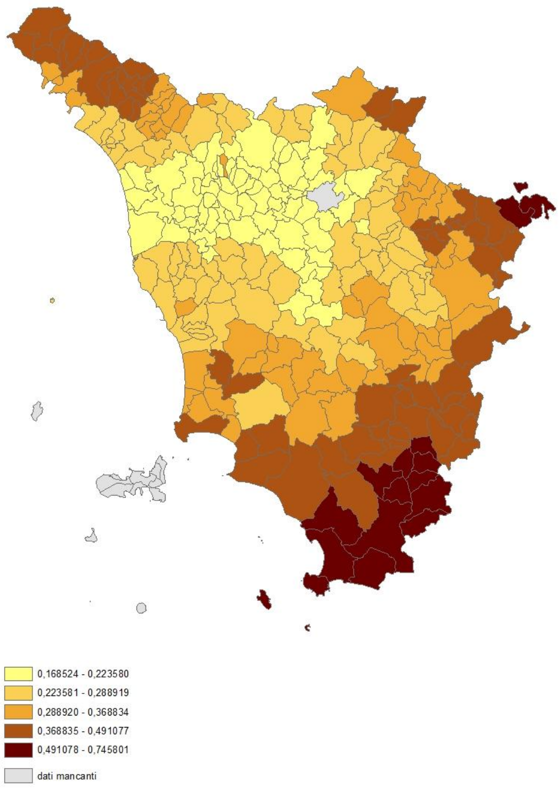

Figure 1. *Synthesis of the impedance function in the logistic form, through arithmetic average*

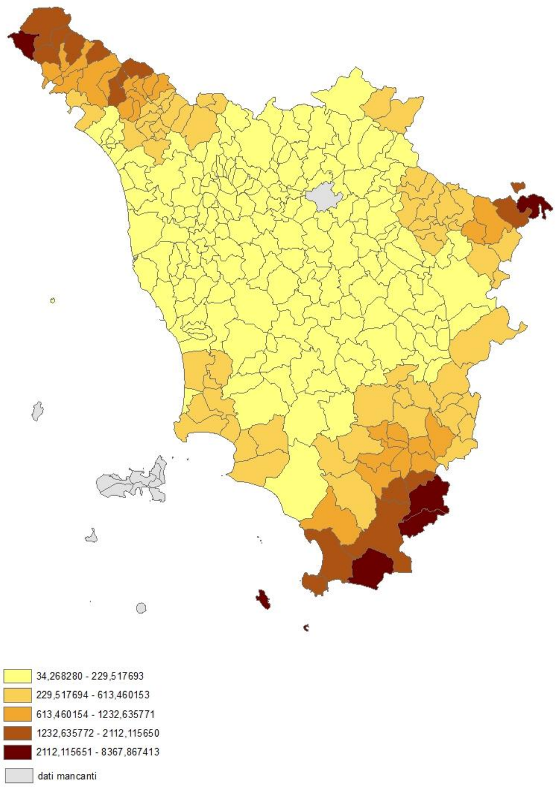

Figure 2. *Synthesis of the impedance function in the exponential form, through arithmetic average*

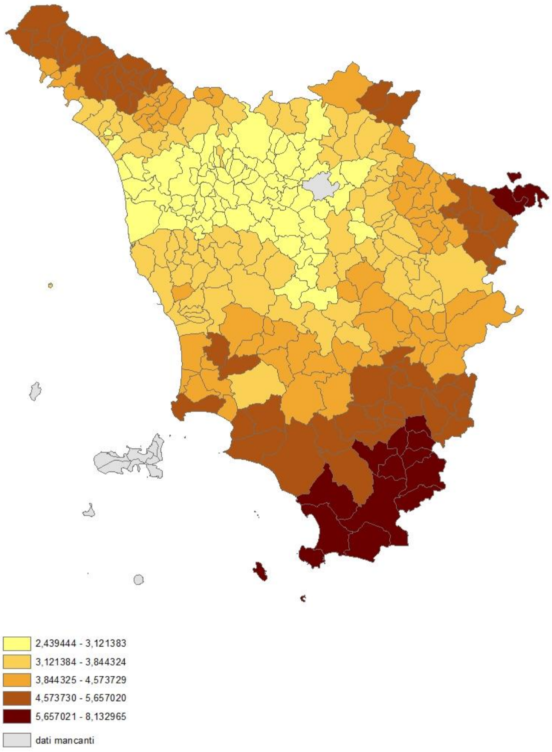

Figure 3. *Synthesis of the impedance function in the linear form, through arithmetic average*

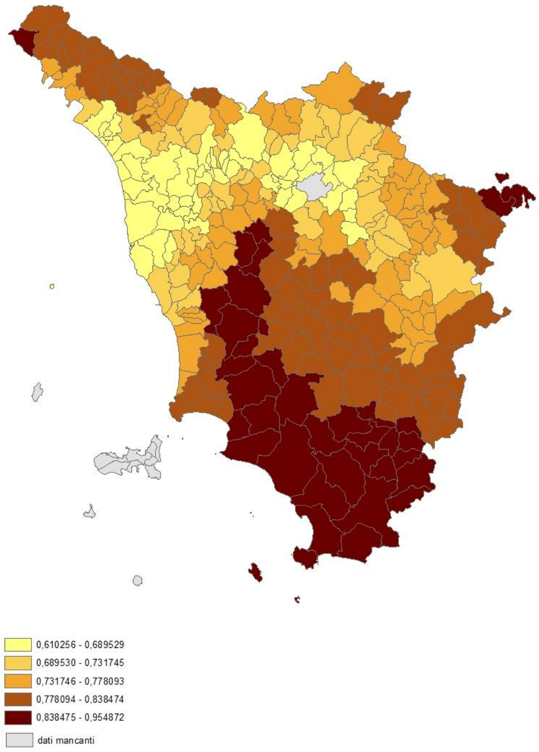

Figure 4. *Synthesis of impedance function in the logistic form, using MPI*

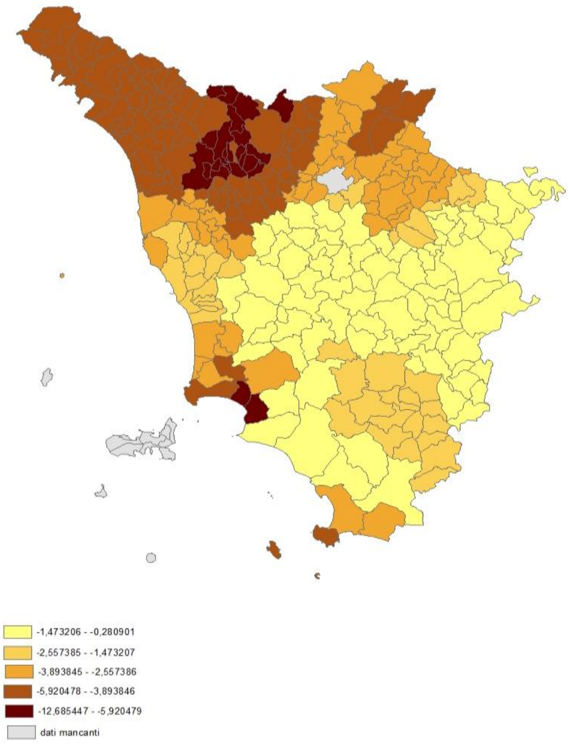

Figure 5. *Synthesis of impedance function in exponential form, using MPI*

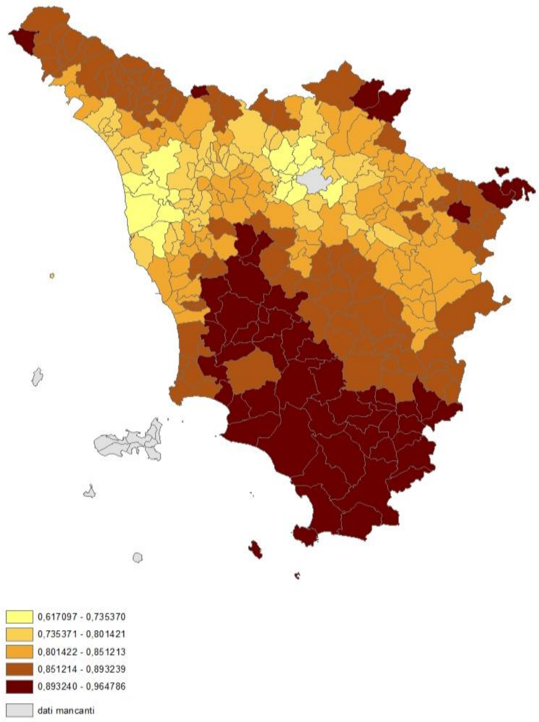

Figure 6. *Synthesis of impedance function in the linear form, using MPI*

The analysis of the impedances and related Figures demonstrates how the distributions synthesized by logistic curve and linear (by arithmetic average) result similar to each other, while the use of the exponential function tends to even out the distribution of the impedance in relation to the four types of infrastructure.

Considering the characteristic of the Tuscan territory and the distribution of hospitals, secondary schools, toll highways, and airports, the summary produced by the arithmetic mean of the logistic curves is more relevant to reality. In fact, in the Florence - Prato - Lucca - Pistoia - Pisa area focus a good number of these infrastructures, as shown in Figure 1.

The exponential function (Figure 2) produces results that are too homogeneous within the territory, flattening excessively the processing. Finally, we used the linear curve, which produces similar results to the logistic function, since the distances between the common and related infrastructures tend to resemble each other, producing graphics analogues.

As regards the use of MPI statistics for the synthesis of the functions of impedance, this indicator is too sensitive to the variability of the distributions. Indeed, in all cases it produced results that were totally different from each other and misleading when compared to the real distribution of infrastructure on the territory. However, the use of the impedance function in the logistic form (Figure 4) produced less distorted results compared to the other two approaches.

Further confirmation of the appropriateness of synthesis through arithmetic mean, as well as the exclusion of the exponential curve as a function of impedance, comes from the application of the Gini correlation coefficient in the synthesis of the lists, both in distribution and in alphabetical order of the municipalities.

Table 1 clearly shows that the highest correlation is realized between the functions of logistic and linear impedance, summarized by arithmetic average. The use of the synthesis via MPI, presenting negative values, demonstrates high discordance.

Table 1. *Gini index of correlation between the rankings*

Arithmetic mean			
Curves	**Log**	**Exp**	**Lin**
Logistic	-		
Exponential	0,802	-	
Linear	0,998	0,785	-
MPI			
Curves	**Log**	**Exp**	**Lin**
Logistic	-		
Exponential	-0,983	-	
Linear	-0,918	-0,918	-

The same processing was performed by comparing the distributions by alphabetical order of the municipalities. The results are shown in Table 2, which confirms the analysis by rankings, increasing the synthesis of impedance functions.

Table 2. *Gini index of correlation between the rankings (by alphabetical order)*

Arithmetic mean			
Curves	**Log**	**Exp**	**Lin**
Logistic	-		
Exponential	0,744	-	
Linear	0,997	0,741	-
MPI			
Curves	**Log**	**Exp**	**Lin**
Logistic	-		
Exponential	0,392	-	
Linear	0,938	0,351	-

As a conclusion, it is good to point out that the choice of the synthesis by arithmetic average tends to leave unchanged the distances between the various infrastructure and municipalities, respecting its range of variation; this is especially true selecting the logistic curve for the processing of impedances.

THE CASE OF FLORENCE

As specified in the preceding paragraphs, the metropolitan municipality of Florence[3] was the subject of separate analysis.

We therefore proceeded to elaborate the impedance function in the three known forms, in order to summarize the results by using the arithmetic mean and the MPI.

For the main city, the elaborations were produced only for hospitals, as the small number of constituencies[4] makes it less useful to extend the model to the other infrastructure.

Table 3 contains the rankings related to the synthesis by arithmetic average, compared to the functions of logistic, exponential and linear impedance.

Table 3. *Rankings of the synthesis of impedance functions for the district through arithmetic mean*

Constituencies	Logistic	Constituencies	Exponential	Constituencies	Linear
Isolotto Legnaia	0,42005	Gavinana Galluzzo	50,80	Isolotto Legnaia	2,81090
Centro Storico	0,42307	Isolotto Legnaia	51,47	Centro Storico	2,81781
Rifredi	0,42998	Centro Storico	53,50	Gavinana Galluzzo	2,86433
Gavinana Galluzzo	0,43072	Rifredi	60,05	Rifredi	2,87042
Campo di Marte	0,44870	Campo di Marte	64,19	Campo di Marte	2,98307

Table 4 contains the rankings for the synthesis using the MPI, compared to the logistic, exponential, and linear impedance functions.

[3] Florence is the capital of the region of Tuscany and is among the most famous cities in the world. According to the 2011 Census, it had a population of 358,079 inhabitants.

[4] The municipality of Florence is divised by constituencies. They are 5: Centro storico, Campo di Marte, Gavinana - Galluzzo, Isolotto – Legnaia, and Rifredi.

Table 4. *Rankings of the synthesis of impedance functions by district through MPI*

Constituencies	Logistic	Constituencies	Exponential	Constituencies	Linear
Centro Storico	0,60529	Gavinana Galluzzo	-2,15777	Centro Storico	0,70161
IsolottoLegnaia	0,60824	Centro Storico	-2,51265	Rifredi	0,70443
Rifredi	0,61066	IsolottoLegnaia	-2,55124	IsolottoLegnaia	0,71580
Gavinana Galluzzo	0,63440	Campo di Marte	-2,67327	Gavinana Galluzzo	0,73399
Campo di Marte	0,64416	Rifredi	-2,99956	Campo di Marte	0,73418

By analyzing the distributions summarized by arithmetic average, the differences between the rankings are identified: Gavinana - Galluzzo is the first (lower impedance) when using the exponential curve; however, it becomes the fourth when using the logistic curve and the third when using the linear curve. In all cases, Campo di Marte is last (maximum impedance). It must be noted that even in this case there is the extreme similarity between the rankings constructed when using the logistic and the linear functions.

Regarding the distributions synthesized by MPI, several differences are recorded compared to the previous classifications. The few similarities concern Gavinana - Galluzzo, which is first in the list by using the exponential function and Campo di Marte, almost always the last.

The analysis of Florence shows that in each case, the constituency of Campo di Marte appears to be the area with higher impedance (lower attractiveness) in terms of hospitals, while for the other constituencies situations are decidedly more complex and varied. However, the analysis shows that the differences between the areas of the city, in terms of the value of the indices synthesized, appear to be minimal, so a small movement of the index can reflect a reversal of rankings.

This is due to three factors: the low impedance, however, within and between the districts, the low number of districts in which the city is divided, and the use of a single infrastructure.

Therefore, the methodology used, especially the synthesis using the arithmetic mean, is useful to represent the local area, but needs further study not only on the possibility of having more extensive and comprehensive information in relation to infrastructure, but also to extend the analysis to those municipalities that have a greater number of constituencies.

CONCLUSIONS

The research has highlighted the main existing methodologies in relation to determining accessibility (attractiveness) of the territories, according to their infrastructural facilities and services.

Focusing on gravity models, the “cost of travel” being considered in terms of travel time, the report noted the strengths and weaknesses, as well as the salient features of the equation for different forms of impedance function. In this respect, the research has produced a real benchmark between the different approaches by using the logistic, the exponential, and the linear curve as a function of impedance. Moreover, another important comparison was produced by selecting the final values through arithmetic mean and MPI statistics.

In addition, the study has shown the importance of capillarity of the processing on the territory, which produced results up to the municipal level, as well as for the metropolitan area of Florence.

In general, it can be stated that the choice of logistic function to represent the impedance is found to be convincing, while the synthesis of elaborations produced via MPI is sometimes difficult to interpret and it is heavily constrained to the variability of the observed phenomenon.

It is important to remember the necessity of deepening and detail the information found at the local level (municipal), of finding the variables now missing and adding new information about infrastructure up to now not included in the calculations, including the commercial distribution (large and medium). They are all extremely important in mapping the socio-economic attractiveness of the territory.

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