Development of a methodology to establish the parameters for the relationship between transport infrastructure and the dynamics of land occupation in Bogotá and the region

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RESUMEN
La Universidad de los Andes y la Secretaria Distrital de Planeación de Bogotá, se encuentran desarrollando un modelo de dinámica de ocupación del suelo, basado en autómatas celulares, el cual tiene la capacidad de simular y evaluar los efectos integrados de políticas territoriales, normativas y de infraestructuras de transporte. Esta herramienta utiliza funciones de transición simples para apoyar la toma de decisiones, de acuerdo a distintos escenarios, usando el software "Metronamica".

Este artículo busca determinar una metodología para establecer los parámetros de accesibilidad del modelo. Esta accesibilidad relaciona las dinámicas de ocupación del suelo con la infraestructura de transporte disponible. La metodología busca determinar si los cambios en los usos del suelo se relacionan con su proximidad a las diferentes infraestructuras de transporte, para lo cual se construyeron gráficas de subestimación y sobreestimación. Estas gráficas comparan la densidad de determinados usos, alrededor de cierto tipo de infraestructura, con la esperada en toda el área de estudio. A partir de estos resultados, se investigó la forma en estimar los factores de peso y función de decaimiento necesarios para alimentar Metronamica. Finalmente, estos parámetros se calibraron iterativamente simulando la región entre 2007 y 2016.

A partir de esto, se estableció un procedimiento detallado para determinar los parámetros de accesibilidad para el contexto local. También se definieron los parámetros de peso y función de decaimiento para cada tipo de infraestructura de transporte disponible y los usos de suelo aledaños.

Palabras clave: Metronamica, usos de suelo, accesibilidad.

ABSTRACT
The Universidad de los Andes and the Bogotá Urban Planning Department are developing a model of the dynamics of land occupation based on cellular automata, which has the ability to simulate and evaluate the impact of several territorial, regulatory and transport infrastructure policies. Using the software Metronamica, this tool uses simple transition functions to support decision making according to different scenarios.

This paper seeks to determine a methodology to establish the accessibility parameters of the model. Accessibility, in this study, relates the dynamics of land occupation with the availability of transport infrastructure and the methodology seeks to determine if changes in land uses are related to the proximity to different transport infrastructures. Overrepresentation graphs were constructed to compare the density of given land uses around a particular type of infrastructure with that expected in the entire study area. A way to estimate the decay distance and relative weight for the Metronamica model was determined from these graphs and calibrated iteratively, simulating the region between 2007 and 2016.

A detailed procedure was established from this to determine the accessibility parameters for the local context in Colombia. The parameters of relative weight and distance decay were defined for each type of transport infrastructure available and neighboring land uses.

Keywords: Metronamica, land use, accessibility.

INTRODUCTION

There is known to exist a strong relationship between land use and transport infrastructure, however, empirical evidence is lacking. Researches have sought to define this relationship by introducing intermediate variables such as economic productivity or accessibility (Zondag, 2007).

Because of the considerable influence of transport infrastructure on development, accessibility has taken an important role in the investigation of land use. Accessibility can be defined as “the extent to which land use and transport systems allow an individual or group of individuals to reach a determined activity or destination through the use a single mode or combination of various modes of transport” (Geurs et al., 2004).

Much of the existing research, in terms of the relation between land use and transportation, has focused on the effects of land use patterns derived from transport (Wegener & Fürst, 1999). This research seeks to determine the influence that land use has on the tendency of transport infrastructure to be dispersed and has come to various conclusions (Polzin, 1999). As stated before, there is a need for more empirical evidence to identify these bidirectional relationships. An effective way of determining these influences could be evaluating the changes in land use and infrastructure over time and identifying these relationships according to their dynamics over time. Existing software packages, like Metronamica, study the dynamics of land use and take into account transport infrastructure (Kim & Batty, 2011; Van Delden et al., 2005; White et al., 1997).

Metronamica is a modeling software developed by the Research Institute for Knowledge Systems (RIKS) that allows the simulation of land use models that uses a technic based on cellular automata (Furtado, 2009). The software development consists of a dynamic and spatial land use change model that can optionally include a regional migration model and a transport model for congestion and traffic pressure in the transport network. (Fertner et al., 2012; Gómez et al., 2014). The simulation of land use is driven by four focuses – neighborhood relationships, environmental zoning, land suitability, and accessibility. The last of which refers to the influence of transport infrastructure in the different categories of land use dynamics (RIKS, 2012).

Although this software seeks to determine the relationship between the dynamics of land use and transport infrastructure, there is currently very little empirical evidence for the parameters to feed the accessibility model in order to establish the relationship between transport infrastructure and development (Polzin, 1999). Therefore, the question arises of whether there is some manner of relating the dynamics of land use with transport infrastructure in a given region and if these methodologies can make the land use simulation models of Metronamica more efficient.

The general objective of this research is to answer this question by establishing a clear methodology for the definition of local accessibility parameters that feed the Metronamica model. Based on the land use changes observed between 2007 and 2016, the weight and decay distance parameters for local accessibility are calculated for the Bogotá Metronamica model. These results are then used to recalibrate the model and analyze the results to generate a proposal of the methodologies and parameters to be used in cities similar to Bogotá.

CONCEPTUAL FRAMEWORK

Metronamica is a software that allows the simulation of regional occupation in accordance with the definition of land use (RIKS, 2012; Van Delden et al., 2005). To determine the change of land occupation during a period of time, it is necessary to construct the layers of land use at two different times. Additionally, knowledge of zoning regulations, physical aptitude of the area, and accessibility is required. In this case, physical aptitude refers to risk variables and the physical conditions of the surroundings and accessibility refers to the relationship between transport infrastructure and land use.

Accessibility in Metronamica makes reference to the ease with which an activity or determined use can satisfy their transport needs and mobility in a cell (Meijers, 2012) and is composed of four elements as follows:

- Zonal accessibility: is a measure of potential accessibility expressed in the number of activities in a range, corrected for the cost of transport to these activities.
- Local accessibility: represents the distance between a cell and the closest transport infrastructure. Each different land use type has a clear preference in distance from the transportation network, local accessibility is a measure of how this preference is fulfilled and depends in the sub-parameters of relative weight and distance decay of the infrastructure with respect to each land use.
- Implicit accessibility: represents the accessibility given to cells that are already developed compared to those that are not.
- Explicit accessibility: explains that some types of land use cannot be crossed for activities generated by other types of uses.

Of these four components, the second is the one investigated in the present study, in order to determine for each transport infrastructure and each active land use the relative weight and distance decay on the basis of the infrastructure information and land use utilized in the Metronamica model for Bogotá and the region.

REQUIRED INFORMATION

The construction of the Metronamica model and development of the present study uses information on land uses for the years 2007 and 2016 developed by the Universidad de los Andes and the Bogotá Urban Planning Department. Additionally, the model depends on the transport infrastructure for the years 2007 and 2016 utilized in the simulation of the scenarios for the SDP project. For this model, the transport infrastructure consists of the following:

- Transmilenio in Phases I, II and III.
- Transmilenio Terminals
- Regional Main Roads
- SITP as the Public Transit Integrated System.

METHODOLOGY

The general methodology developed in this study follows the steps demonstrated in Figure 1. First, overrepresentation curves were developed demonstrating the variation in the enrichment factor to determine the neighborhood characteristics that relate transport infrastructure with the different land uses studied (Verburg et al., 2004). Subsequently, and based on the results obtained in the overrepresentation curves for each type of infrastructure, parameters like distance decay and relative weight were translated to be utilized in the Metronamica model (Meijers, 2012; RIKS, 2012). After this, the model was calibrated so that the simulated map was as similar as possible to the observed map for the final year (2016). This verification was made in an iterative manner and followed both visual parameters and graphical comparison indicators (Silva et al., 2015).

After the development of this procedure, conclusions and recommendations were obtained to estimate the parameters of accessibility for models utilized in other sites.

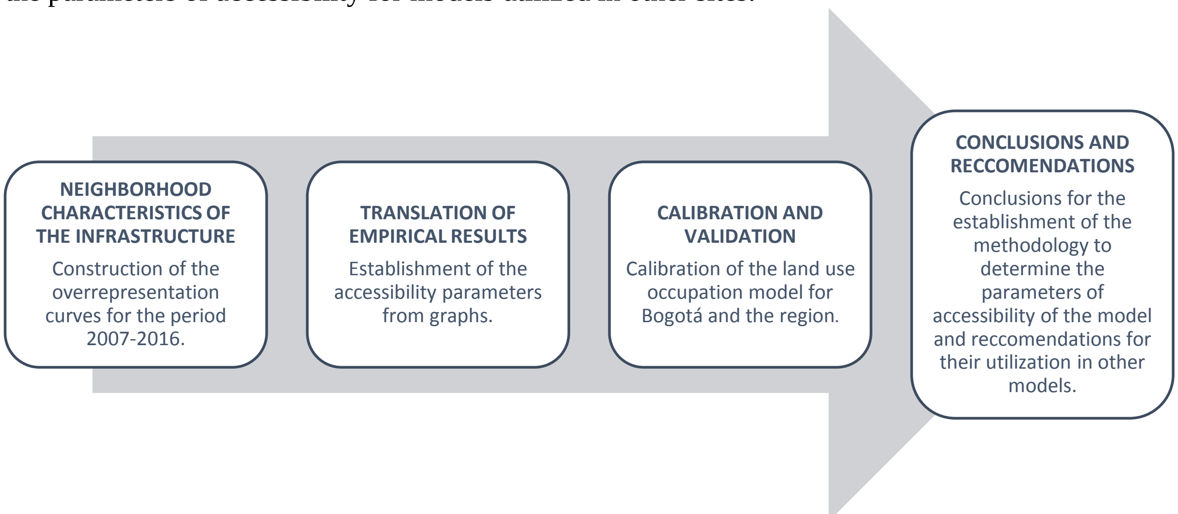


Figure 1. Methodology.

Neighborhood characteristics of the infrastructure

Neighborhood relations need to be calculated when the relationships between different locations are analyzed (Verburg, et al, 2004); in this case, the relation presented by the transport infrastructures with respect to the different land uses studied in the model is sought . For analyses developed in raster and cellular automata environments, neighborhood relations are used to determine the new values that a certain cell can adopt in a certain time. These characteristics can be utilized to design TOD (Transportation Oriented Development) type policies as the infrastructure may influence the development of land use in different locations in accordance with its setup. Different procedures can be carried out to determine these neighborhood parameters such as: convolution, spatial filtering, or focal functions (Bonham-Carter, 2014; Burrough et al., 2015).

This study utilizes the methodology developed by Verburg et al. (2004). Although Verberg's methodology was used to relate the land uses to each other, it can also be used to evaluate proximity characteristics to transport infrastructure. A measure of the proportion of land uses in the vicinity of a certain linear or point element of the transport infrastructure is used to estimate the relationships. This measure, called the enrichment factor (F), is defined by the presence of a certain type of land use related to a certain location with respect to the transport infrastructure and the presence of the same land use in the study area as demonstrated by the following:

$$F_{t,s,d} = {}^{n_{t,s,d}}/_{n_{d,t}} - {}^{N_s}/_{N} \qquad [1]$$

- $F_{t,s,d}$ represents the level of development of a certain land use "s" with respect to a transport infrastructure "t", to a determined distance "d" from the transport infrastructure

- $n_{t,s,d}$ represents the number of cells of use "s" present in the area of influence in a distance "d" from the transportation infrastructure "t"
- $n_{d,t}$ represents the total of cells or area in a distance "d" from the transport infrastructure "t"
- N_s/N represents the proportion of determined land use "s" in the total study area

So if an area of radius 200 meters from a Transmilenio station contains 50% of commercial cells and only 15% of the total study area, it would have an enrichment factor of 35%. Enrichment factors were calculated for distinct distance intervals for each transport infrastructure (every 100 m) according to the type of infrastructure. With these factors at different distance intervals, overrepresentation curves were constructed.

It is important to emphasize that in this analysis, the areas for each distance interval are independent for each infrastructure and distance. This means, the same distance with respect to a particular type of infrastructure is recorded as the same area since it represents the area of influence in a distance "d" from that type of infrastructure. Therefore, the number of cells of given land use with respect to particular transport infrastructure was calculated for each distance interval of the study area.

This methodology then results in series of graphs for each transport infrastructure which demonstrates their relationship with a combination of land uses. An example can be seen in Figure 2, in which the x axis represents the distance from transport infrastructure and on the y axis the enrichment factor or the overrepresentation of the different uses at distinct distances.

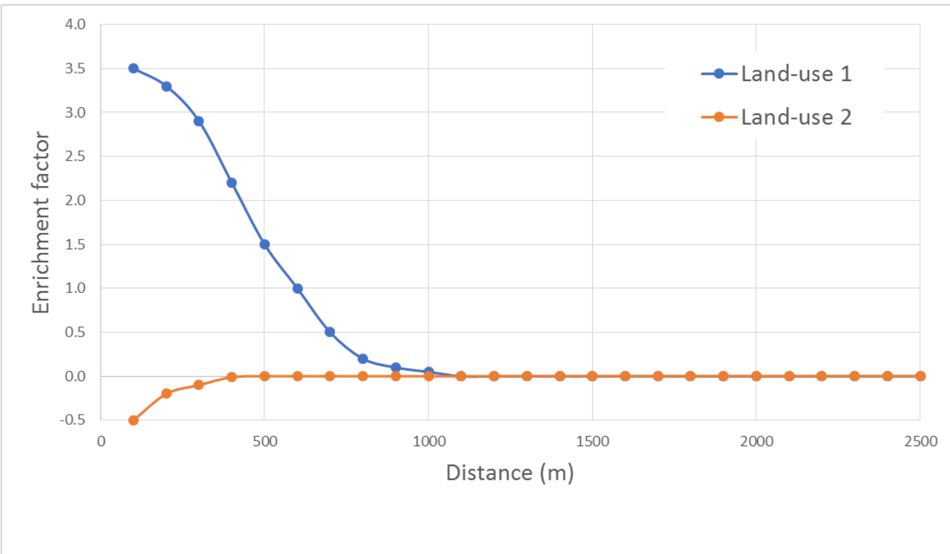


Figure 2. Example of land use overrepresentation curves

The purpose of the overrepresentation graphs are to obtain the proportion of determined land uses in the vicinity of transport infrastructure compared to the expected proportion for the same land use in the total study area.

Translation of Empirical Results

The local accessibility in Metronamica was determined from two parameters: the relative weight and the distance decay that try to maintain the idea that a certain type of land use is attracted by the elements of transport. Some authors suggest that the direct distance to the transport infrastructure can have an even greater impact on the changes of land uses than some of the complex accessibility variables (Silva et al., 2015) like does local accessibility in Metronamica. The overrepresentation graphs could be seen as a function of decay distance with respect to the infrastructure representing attraction or repulsion between the land use and transport infrastructure. The parameters to be entered into the Metronamica model were determined from these graphs.

Evaluating the existing literature related to the topic reveals that little work has been done on translation of the overrepresentation curves into directly usable parameters in Metronamica (Verburg et al., 2004). Therefore, an iterative process was carried out in order to determine which values for the distance decay and relative weight parameters improved the calibration of the model in terms of the established calibration indicators (Meijers, 2012). The parameter estimates are based purely on results obtained from the curves, and indicate which land uses have a greater relative weight with respect to a given infrastructure. The graphs demonstrate the decay distances of each land use with respect to the different transport infrastructures studied.

Model Calibration and Validation

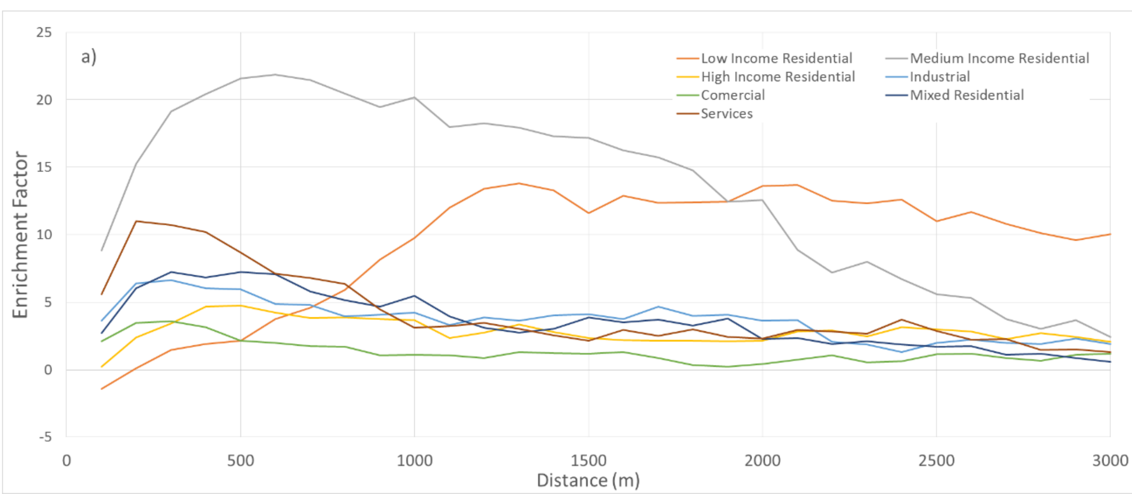
The calibration of the accessibility parameters is an iterative process in which a series of indicators were maximized. Two simulations were compared for validation: a first in which accessibility parameters were not taken into account, and a second which considered the accessibility parameters of transport infrastructure. These two simulations were compared both visually (White et al., 1997) and through a group of indicators that compare the modeled years cell by cell (Visser & De Nijs, 2006) .

Results and Conclusions

Once the local accessibility parameters for the Bogota model have been obtained, the recommendations and conclusions that allow developing the procedure for other models with cities similar to those presented here will be stipulated.

RESULTS

With the results obtained in the overestimation graphs of the transport infrastructure with which the model was simulated in the first instance, it is possible to have a first notion of the values with which the accessibility in Metronamica will be fed in terms of relative weight and distance of decay. For example, as seen in the first image (Figure 3a), the medium income residential uses and services are more important than the other uses with respect to the Transmilenio stations in the first 500 meters of influence.



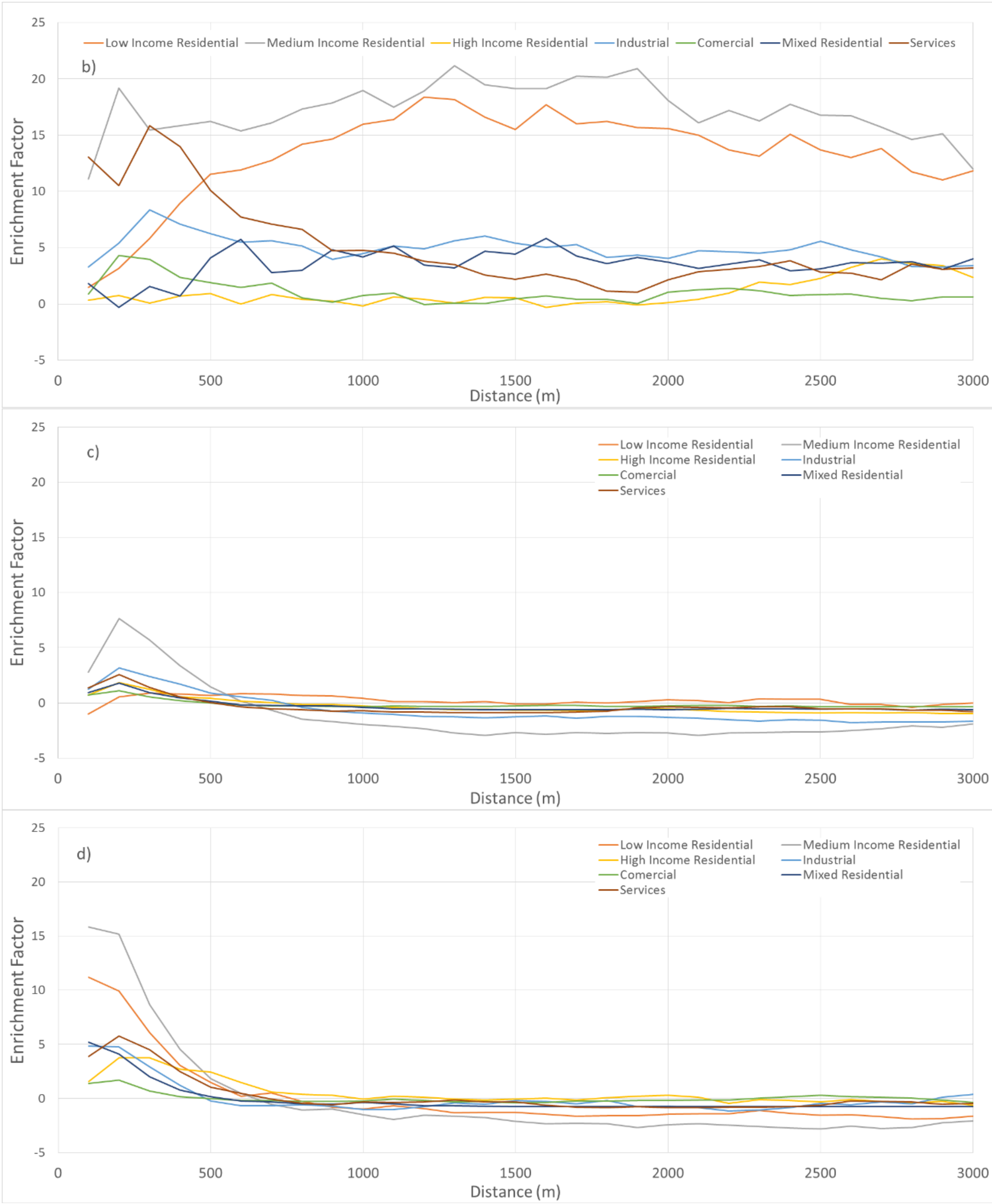


Figure 3. Graphs of land use overrepresentation with respect to transport infrastructure for: a) Transmilenio Stations, b) Transmilenio Terminals, c) Roads, d) SITP Network

In general, it can be observed that the infrastructure that is arranged in the form of lines such as the SITP and roads network tend to have lower overestimation values, a fact that may be due to the fact that they are infrastructures that are distributed through all the territory in a homogeneous way, allowing that its difference with the expected density of certain land use is not very high.

With these graphs and understanding the importance that the different available infrastructures with respect to land uses can have, the first accessibility parameters are established and from an iterative process of changing these parameters, it sought to maximize the *kappa* and *fuzzy kappa simulation* indicators looking to calibrate the model. This process goes hand in hand with an arduous work of visual interpretation by means of which spatial correlation patterns are identified between the parameters of accessibility and the development of land uses for 2016.

Table 1 shows the parameters established in this procedure for each of the land uses and transport infrastructures. With these results and verifying that they are coherent with the nature of the infrastructure and its correlation with the adjacent land uses, the model in Metronamica is run.

Table 1. Accessibility parameters for the model of Bogotá

	Low Density Residential		**Medium Density Residential**		**High Density Residential**		**Industrial**	
	Decay Dist.	**Weight**	**Decay Dist.**	**Weight**	**Decay Dist.**	**Weight**	**Decay Dist.**	**Weight**
Main Highways	8.33	0.10	8.33	1.00	8.33	0.50	8.33	0.80
TM Terminals	60.00	1.00	60.00	1.00	41.67	0.30	50.00	0.80
TM Stations	25.00	0.70	50.00	1.00	25.00	0.40	25.00	0.50
SITP	16.67	0.90	16.67	1.00	16.67	0.20	16.67	0.50
Bike Paths	41.67	0.80	25.00	1.00	25.00	0.40	25.00	0.40

	Commercial		**Mixed**		**Services**	
	Decay Dist.	**Weight**	**Decay Dist.**	**Weight**	**Decay Dist.**	**Weight**
Main Highways	8..33	0..40	8..33	0..50	8..33	0..75
TM Terminals	16.67	0.70	50.00	0.30	16.67	0.95
TM Stations	25..00	0.50	25.00	0.50	16.67	0.80
SITP	16.67	0.20	16.67	0.50	16.67	0.50
Bike Paths	25.00	0.20	25.00	0.40	25.00	0.80

To be able to verify the goodness of the adjustment that the accessibility parameters to the Metronamica model can present, the Kappa indexes are compared with a simulated model without accessibility parameters yielding the results shown in Table 2. As you can see all the indices taken into account, improve for the two simulations developed, demonstrating how with the accessibility parameters the similitude of the simulated model is being improved with the map of real land uses for 2016.

Table 2.Calibration results of the model

	Simulation I Without Accessibility	**Simulation II With Accessibility**
Kappa	0.793	0.797
Kappa Simulation	0.793	0.797
Fuzzy Kappa	0.851	0.853
Fuzzy Kappa Simulation	0.256	0.271

Bearing in mind some references regarding the level of acceptance of the indices, it can be said that Kappa and Fuzzy Kappa have a fairly good level of acceptance since it is very close to 0.8 (Silva et al., 2015) and that the values of Kappa simulation and Fuzzy Kappa simulation are valid according to practical experiences developed by Meijers (2012).

CONCLUSIONES

The main results of the research were the parameters of distance decay and relative weight of the transport infrastructure with respect to the different land uses modeled. To calibrate the model Kappa indices were compared for simulations before and after the addition of accessibility parameters to verify that the accessibility parameters improved the accuracy of the simulation (Meijers, 2012). These factors were accepted after calibrating the model in the simulation software in which some Kappa indices were evaluated with which it is verified that the simulated model represents with a degree of acceptance the real occupation of the territory

Observing the parameters shown in Table 1, the influence that certain infrastructures can have on the development of land uses in their vicinity can be verified. For example, for Transmilenio stations, the use of greater relative importance is the medium income residential, this being equal to what is lived in the reality of the territory. Similarly, there are uses such as commercial and services that have greater importance to the Transmilenio Terminal and stations.

The results of this study establish that the defined parameters for transport infrastructure have a positive impact on the accuracy of simulations of territorial occupation developed with Metronamica. The following steps were established to determine the accessibility parameters:

1. Calculate the enrichment factor and construct the overrepresentation curves for land use with respect to the available transport infrastructure.
2. Translate the overrepresentation curves into parameters of relative weight and distance decay of infrastructure with respect to the dynamic land use.
3. Calibrate the territorial simulation with consideration of the established parameters.

With this established procedure, the accessibility parameters of the Metronamica model can be determined for any region that has to be evaluated. It is important to note that the procedure is similar, however, it can change according to the relation presented by the infrastructure with the land occupation in other cities; each case must be evaluated in detail and verify that the results are valid.

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