Transport Costs and the Main Modes of Transportation in the Location Preferences of the Metropolitan Region of Bogotá

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1 Introduction

Metropolization can be understood as a phase in the evolution of the interurban spatial structure of a set of cities that occurs around a main urban agglomeration or nucleus. It is a process characterized, among other things, by the rearrangement of the population tending to the formation of a new geographic unit of socio-spatial organization, which surpasses the jurisdictional limits of the main nucleus (Ruiz, 2015). This expansion of the concentration space unit implies the "disconnection between the place of residence and that of productive activities" (Jiménez, 2009) of the metropolitan inhabitants, and thus an increase in daily interurban commuting or intercity passenger. A disconnection of spaces largely induced "by the growing preponderance of the private vehicle" (Jiménez, 2009). Therefore, a phenomenon of metropolization implies the existence of a permanent mobility derived from the change of residence of the core city to the set of surrounding cities or agglomerations (or vice versa), where daily transportation tends to condition the location decisions because it allows to maintain the functional relations between migrants and the city.

Although in the last decades, Colombian cities have implemented different instruments for the planning and development of the local territory, metropolization in the Colombian urban system has emerged spontaneously, as a result of the evolutionary dynamics of the national spatial structure, oriented mainly by the logic of the real estate market and not by regional planning instruments. In these cases commuting on a metropolitan scale will be conditioned by the particularities of the resulting metropolitan occupation patterns and their structuring elements, such as the transport infrastructure.

In the particular case of the city of Bogotá, the process of metropolitanization with the nearest cities (agglomerations) has not obeyed an articulated planning regarding the land occupation. In spite of the two-way functional relations that favor socioeconomically both Bogotá and neighboring agglomerations, public interventions in each jurisdiction are not conceived from a regional perspective, but rather local, and therefore fail to respond to the needs demanded by the metropolitan population, much less manage to order land occupation in the region. From the perspective of transport, for example, the intensification and consolidation of the process of metropolization in recent years has brought a significant increase in interurban travel. This, coupled with the absence of an integrated urban public passenger transport system, and the configuration of the territory of Bogotá and the region around local structuring elements, has increased pressures on the regional road infrastructure of the city and surrounding agglomerations. A fact that translates into higher transportation costs, resulting from the predominance of certain modes and transport infrastructures in the agglomerations and, therefore, in the region.
Therefore, it is necessary to inquire about: **What has been the role of the main urban and interurban modes of transport of daily passenger trips in the spatial structure and forms of land occupation in the metropolitan region of Bogotá in the period 1993 - 2014?**

With this question and reference studies, this paper focuses on identifying and characterizing the role of the main urban and interurban modes of transport used in daily commuting, on the processes of spatial structuring and land occupation of The metropolitan region of Bogota between 1991 and 2014. This is the basis for further research that allows the dimensioning of transport potential as a planning and territorial management mechanism.

To this end, the document proposes a first part about the "Spatial interaction and commuting between Bogota and the surrounding agglomerations", in order to recognize the dynamics of mobility as an expression of the dynamics of the processes of metropolization. Beyond the presentation of figures and data on transport supply and demand at the metropolitan scale, the relationship between the metropolitan spatial structure and the demand for the main modes of transport used in the region is investigated. In the absence of a public integrated public transport system at the metropolitan scale, prepared to attend to the growing commuting between Bogotá and the surrounding agglomerations, local urban transport modes such as Bogotá BRT (Transmilenio) and the private vehicle have been attending the Greater proportion of this travel demand.

The second part of the document, "Interdependence between Transport and Metropolitan Spatial Structuring", focuses on reviewing the trends and possible changes that have occurred between the main modes of transportation used in commuting of the metropolitan region of Bogota and the Trends in Land use in the region; As well as its relation with the metropolitan spatial structure. Given the scarce availability of historical information on trips on a metropolitan scale in the Region, it is theoretically explained how transport costs and the predominance of modes such as the urban BRT and the private vehicle seem to affect the land occupation of the region. This is based on the postulates about the localization theories and the contributions of Von Thünen on the relationship between spatial structure and transport costs.

Finally, a "Conclusions" is presented, which includes a synthesis of the evidences found on the evolution of the metropolitan spatial structure of Bogota, interurban commuting in the main modes of transportation, territorial occupation in the region and the relationship between these parts. The dissertation presented in this document leads to the conclusion that the transportation costs related to the population's trip time through the predominant modes and transport networks have influenced the spatial structure and territorial occupation of the Metropolitan Region of Bogota: In the processes of metropolitan location, housing and economic activities, the search for the optimization of the transport costs associated to the different transport networks arranged to satisfy the metropolitan commuting, have contributed in the reconfiguration of the spatial structure of the region.
2 Spatial interaction and commuting between Bogota and surrounding agglomerations

In territorial perspective, the expansion of the spatial concentration unit implies a territorial rearrangement of the population and a relocation of economic activity to the peripheral sectors of the city (Jiménez, 2009). In the dynamics of these processes of metropolitan spatial structuring, there is simultaneously an increase in permanent mobility (migrations) and in daily inter-urban transportation, as a result of the "disconnection between the place of residence and the place of work" of the inhabitants metropolitan areas (Jiménez, 2009). In a spatial structure, in this case a metropolitan region, commuting is a form of spatial interaction.

As presented in Silva (2017) from the application of the range-size function to the urban subsystem of the Metropolitan Region of Bogotá, it does not express a spatial balance between the core city and the surrounding agglomerations. Thus, in terms of Zipf’s postulates, it can be inferred that there is also no balance between economies of scale and transport costs. This suggests that the search for the reduction of transportation costs of economic actors (companies and inhabitants) has changed over the years. This simplified perspective of the Central Place Theory shows that transport costs have been determinant in the spatial structuring of the region.

Being associated with distance, understood as an impedance factor and determinant of accessibility in spatial interaction, transport costs also allow to explain the location decisions within an agglomeration. Decisions that by cumulative effect are affecting the structuring of space (Camagni, 2005). As will be seen below, the transportation costs reflected by the different modes of transport, and represented in this chapter from a transport network logic, affect the location rents with respect to a central market. For this reason, the rearrangement and the great changes of the spatial structure of the metropolitan region of Bogota can be explained theoretically from the Theory of Location proposed by Von Thünen.

This numeral seeks to recognize the commuting as an expression of the dynamics of the processes of metropolization, starting from a general characterization of the demand and the offer of interurban transport (that is of the trips realized between jurisdictions in the different modes and transport networks Available), as well as the trip time assumed by the inhabitants of the Metropolitan Region of Bogota, associated in this study to transport costs. Subsequent to this, and taking into account the scarce information available on trip times at metropolitan scale for different periods of time, a theoretical dissertation is presented on the changes that have occurred in the transport costs of the study area, also contemplating its Variation between different modes of transport. This emphasizes the way in which the spatial configuration of certain transport networks determines the use of the different media in the metropolitan trips, and in turn condition the transport costs represented by the trip time of the users. This analysis of transport costs is the starting point for identifying the relationship...
between transport networks, accessibility, preferences of residential location in the region and its cumulative effects reflected in the metropolitan spatial structure, starting from the postulates of the Von Thünen's Localization Theory.

2.1 The demand for interurban commutes
The demand for travel in a given area is usually estimated through Travel Surveys or Mobility Surveys, based on different methodologies. The most commonly used is the household survey, which consists of the definition of a sample size to be collected from surveys and forms that record, among other things, trips made by each of the People who make up a home on a typical day. The information collected is used for the elaboration of transport models, such as the traditional Four-Stage Model, for the expansion of the sample and projection of demand; Useful tools for the definition, planning and evaluation of transportation policies (Santana, 2009) and urban growth.

According to the aforementioned survey, it is estimated that for that year, on average, about 12,576,600 total trips were carried out in Bogota and 825,700 total interurban trips. 86% (about 710,100 trips) were made between Bogotá and the surrounding agglomerations, and the remaining 14% (about 115,600 trips) were made between these agglomerations (District Secretariat for Planning, 2014, p.230). In terms of metropolitan dynamics, these results show the primacy of Bogotá and its role as a metropolitan nucleus, because it concentrates the largest population and the greatest economic activity, and also the greater number of daily trips made in the region. From the agglomeration perspective, although the greater proportion of the interurban trips has as origin or destination to Bogotá, the surrounding agglomerations also have established functional relations between them, outside the city.

According to the trends described, the magnitude of the daily trips to the interior of Bogota, and between Bogota and the surrounding agglomerations, suggests the manifestation of a monocentric metropolitan model, where Bogota is the main center of generation and attraction of trips in the region. Although the surrounding agglomerations have established functional relationships with each other, as shown by the participation of interurban commuting, in this case the magnitude of these trips does not represent a significant flow of daily trips that can resemble a polycentric metropolitan model. This shows that despite the attempts to induce a regional growth model tending to deconcentration of population and economic activities, monocentric metropolitan relations based in Bogota predominate as the central nucleus of the region.

Map 1 shows, as lines of desire, the total of the trips made between Bogota and the surrounding agglomerations. These lines of desire form a network of bi-directional relations developed by the central nucleus as a result of their spatial interaction with the environment (Camagni, 2005), i.e. the surrounding agglomerations. There reaffirms the presence of a more intense spatial interaction of Bogota with the closest agglomerations, regarding the
interaction of Bogota with the more distant agglomerations. As already mentioned from the territorial distribution of interurban travel, agglomerations such as Soacha, Mosquera and Chia, identified as the most dynamic in the process of metropolitan spatial structuring, currently tend to participate in greater proportion in mobility with the city; While less dynamic of cities in the metropolitan spatial structure tend to manifest a smaller participation in the daily commuting with Bogota. It is important to bear in mind that although the agglomeration of Madrid seems to have a more intense spatial interaction with Bogotá, with respect to agglomerations closer to the city, this trend could be overestimated because of the different analyzes made to the survey data base, Different inconsistencies were found associated to the process of information gathering, particularly in the case of Madrid (Secretaría Distrital de Planeación, 2014).

Map 1. Lines of desire of the trips made between Bogota and the surrounding agglomerations, year 2010.

*Es probable que algunas tendencias expresadas por los indicadores de movilidad presentados en el análisis se encuentren subestimadas o sobreestimadas, en especial en el caso de Madrid, por lo tanto para efectos del presente análisis es necesario hacer una lectura cuidadosa de los resultados asociados a estos indicadores.

Source: (Bogotá Planning Secretary, 2014)
2.2 Modal split, networks and transport structure

In spite of the evident functional relations between Bogota and its metropolitan cities, the Metropolitan Region does not currently have a metropolitan public transport system where different modes of transport are integrated to attend to the growing daily demand of interurban trips. However, spatial interaction does not recognize political-administrative boundaries in a given geographic space. Therefore, the structure of transport that supports the interurban commuting is more due to a set of transport networks existing in the area of study, most of which have been conceived under a local approach. One of the main elements that characterizes the networks are the modes of transport. A review of modal distribution trends in the region provides an idea of the modes of transportation that predominate in interurban commuting between Bogotá and metropolitan cities.

In this study, the main modes of transportation used to cover the longest distance of a trip is called the main modes, which in many cases involves the use of other complementary or auxiliary modes to cover the total distance of the trip from the origin to the destination. Consequently, the main modes does not correspond to a single mode of transport used from the origin to the destination of the trips, since their use depends as much on the preferences of the users as on the available supply, that is to say, the networks.

Figure 1 presents as a summary the modal split of the interurban trips of the study area of the year 2011, result of the Survey. This graph shows that 75% of commuting in the urban area of the Metropolitan Region of Bogota was done in motorized modes, while the remaining 25% was made in non-motorized modes. The most used motor vehicles in the region, according to their participation in the modal split, are Urban and Interurban Public Transport (34%), private vehicle (11%), Bogota Mass Transportation (15%), informal transportation (3%), and school transport (4%).

Figure 1. Modal split of interurban trips in the Metropolitan Region of Bogota according to the Survey of Mobility of 2011.

Source: (Bogotá Planning Secretary, 2014)
Each of these modes of transportation has its own capacity limits and operating conditions within a transport network, thus significantly affecting transport costs (Rodrigue, Comtois, & Slack, 2006). Although all the modes employed in the interurban trips of the study area are associated with the same mode of transport, the road operator, it is possible to distinguish several types of network, depending on the infrastructure and the mobile equipment (modes of transport). Two factors that, according to the production function of the Transport Industry, are determinant in the efficiency and capacity of transport (De Rus, Campos, & Nombela, 2003), and thus in the behavior of transport costs.

A transport network can be defined as a set of points (or nodes) and connecting lines (arcs) organized in order to allow the transit of passengers from one point to another (De Rus, Campos, & Nombela, 2003), to through different modes of transport. This organization of arcs and nodes arranged to meet a specific demand, allows to coordinate the resources arranged for the transportation of passengers, such as infrastructures and modes of transportation, in order to reduce transport costs represented mainly by the times of Users' travel (De Rus, Campos, & Nombela, 2003).

In the planning of transport networks from a local perspective, efficient coordination (technical and economic) between the infrastructures and the modes that make them up, which has a direct impact on the transport costs assumed mainly by the Users (trip times). Therefore, efficient coordination depends not only on transport production factors, such as infrastructure and mobile equipment, but also on exogenous factors, such as in this case, local planning decisions (De Rus, Campos, & Nombela, 2003).

There are different types of networks defined according to the interaction between the elements that comprise them. According to the easiness with which the infrastructure and the mobile equipment can be modified, the transport networks can be fixed or flexible, and can be based on direct connections or connections with transfers (De Rus, Campos, & Nombela, 2003). The difference between the types of networks and the type of connections is in the transport costs incurred by the users and the producers for the realization of the trips. For example, a network of connections with transshipment implies higher opportunity costs for users, when compared to a network of direct connections, since each trans-shipment represents a rupture between the origin and the destination where the costs for the users increase.

A fixed transport network is characterized by the use of infrastructures and rigid modes of transport with less possibilities of being modified (De Rus, Campos, & Nombela, 2003). This is due to the magnitude of the unrecoverable costs that must be incurred for the provision of the service, as they require specialized infrastructure for the circulation of mobile equipment. In this case, the infrastructure can not be shared between different modes of transport, so the exclusive use of the infrastructure by a single modes of transportation offers operational advantages such as higher traffic speeds, shorter trip times and lower cost sensitivity such as
congestion. Contrary to this, a flexible network is characterized by the use of easily modifiable infrastructures and modes of transport, since fixed costs are relatively low (De Rus, Campos, & Nombela, 2003). Unlike a fixed network, the infrastructure of a flexible network can be used by different modes of transport (mixed use) with different operating specifications, which tends to decrease its long term performance due to congestion.

Taking into account this general classification of transport networks, for the study area it is possible to identify 3 types of networks according to the available transport infrastructure and the modal split: a flexible network, a semi-fixed network and a fixed network. Next, each of these networks is characterized, in order to recognize the metropolitan transport structure (Map 3) that supports interurban commuting, and the implications of its configuration and spatial scope in transportation costs Figure 2, understood as the trip time of users.

### 2.2.1 Flexible network

Conformed by the local, departmental and national road infrastructure (represented by yellow lines in Map 3 and in the other maps and graphs related to the transport networks presented in this document from this point), and modes such as urban and interurban public transport, school transport, informal transport, taxi, particular vehicle and motorcycles. Taking into account modal split, it is estimated that 80% of motorized interurban commuting, which in turn accounts for 60% of total interurban travel between Bogota and the surrounding agglomerations, is estimated through this network. By sharing the same road infrastructure, the increase in interurban transport costs has increased in the flexible network, due to the increase in the number of vehicles and congestion (decreasing yields law).

However, the modal split show that the growth of the region has mainly depended on road infrastructure as it has been the predominant mode in the region.

According to the Plan of Territorial Planning of Bogotá, the city has 11 roads of regional and national integration, through which it connects from North to South and from East to West with the region and with the rest of the country. Of these roads of integration, five stand out because of their direct connection with national and regional routes, representing the main accesses to the city:

- **Calle 13 Avenue**: connects to the west with Mosquera, Funza, Madrid and Facatativá.
- **Calle 80 Avenue (Medellín Avenue)**: it connects directly to the north-west with Cota, and through variants it connects with agglomerations of the west and north of the city.
- **Avenida del Sur NQS**: connects with Soacha and Sibaté.
- **Paseo de Los Libertadores Avenue**: Connects directly to Chia, and from two branches connects on the one hand with Cajicá and Zipaquirá, and on the other hand with Sopó, Gachancipá and Tocancipá.
- **Via La Calera**: It connects to the east with the agglomeration of La Calera.
For this reason, the geographic scope of this network covers the entire study area, since it connects Bogotá with metropolitan agglomerations through a series of "arcs" that favor direct access between jurisdictions. However, the connections depend on the modes of transport that make use of this network, for which only the most used modes will be mentioned according to the modal split: urban public transport (TPC), interurban transport and private vehicle. The modes of private use as the vehicle directly connect the origin and the destination, according to the needs and preferences of the user. Contrary to this, modes of public transport (urban and interurban) require transhipments or connections to cover the entire journey from the origin to the destination, because the operation of these modes depends on the routes offered by operating companies that increase trip time (access and waiting) (Figure 2).

The Metropolitan Region of Bogotá is not legally constituted as an administrative entity nor as Metropolitan Government, therefore there are different restrictions on the circulation of vehicles that provide the public transport service in the region. An example of this is traditional public transport. This refers to the public transport that is provided within each jurisdiction, regulated by the respective local authority, and therefore is not allowed to operate in another jurisdiction, unless there is an agreement between the respective local authorities as it happens between Bogota And Soacha. This modes that its use in interurban travel implies the use of other complementary modes that increase the trip time of the users, in terms of waiting and transhipments.

2.2.2 Semi-fixed network
Conformed by Bogotá’s Bus Rapid Transit (BRT) System (represented by red lines in Map 3 and in the other maps and graphs related to the transport networks presented in this document from this point), called Transmilenio. It was implemented by the year 2000 to attend only the demand for trips to the interior of the city, which is why its infrastructure and operation do not exceed the jurisdictional limits of Bogota. This means that it depends on other modes of transport of the flexible network for the realization of interurban commuting. In spite of that, it is one of the most used modes in the commuting between the city and the surrounding agglomerations. This is favored mainly by a condition of the infrastructure of the bedside stations (or portals) located to the north and north-west of the city where the entrance of interurban routes that operate as an auxiliary modes of the trips between Bogota and the surrounding agglomerations is allowed that this implies a tariff, operational or institutional integration), as shown in Map 2.

As can be seen in this map, from the portals of the system it is not possible to reach all the agglomerations in the region. This is the case of agglomerations such as Mosquera, Bojacá, Zipacón, Soacha, Sibaté and La Calera, which is why their daily trips depends exclusively on
the Flexible Network; That is, they are highly sensitive to the increase in transportation costs. In the particular case of Soacha, in 2011, an extension of the NQS-South trunk of the system entered into operation in the agglomerations, which undoubtedly introduced a decrease in transportation costs. However, it is not possible to determine the changes in the demand for travel to this agglomeration as a result of the Transmilenio operation, as previously mentioned, the information analyzed in this study corresponds to the mobility survey published in 2011, and Whose information was collected in 2010.

For the purposes of this study, the Transmilenio system has been termed as a semi-fixed transport network, although it has specialized infrastructure for its exclusive transit (favoring its speed of movement with respect to the modes of mixed transit), it depends on the modes of the flexible network for the realization of interurban trips. This implies a rupture in the spatial interaction, which although it has been covered by the modes of the flexible network, is an operating condition that significantly increases the trip times of users (Figure 2).

Map 2. Extension and scope of the Semifixed Network of the Metropolitan Region of Bogotá

2.2.3 Fixed network
Towards the end of the XIX century three railroad corridors were built in order to communicate the city with the rest of the country and to provide a regional service to the surrounding agglomerations near Bogota, which had a train station for the ascent and descent

Source: (Secretaría Distrital de Planeación, 2015)
of passengers: The Northern Railroad, which passed through Usaquén (town annexed to Bogotá in 1954), Chía, Cajicá and Zipaquirá until arriving at the department of Boyacá; The Western Railroad passing through Fontibón (town annexed to Bogotá in 1954), Mosquera, Funza and Facatativá until reaching Puerto Salgar; And the South Railroad that passed through Bosa (town annexed to Bogotá in 1954), Soacha and Sibaté until reaching the Salto de Tequendama. This mode of transport favored the expansion of the city, especially on the north axis (Montezuma, 2000). However, with the boom of vehicles and road transport and the improvements in speed brought with the technological advance, by the 1950s the railroad transport entered a process of decay throughout the country (Montezuma, 2000).

The Tren de la Sabana operated as a regional transportation system until the late 1950s, and was replaced by roads connecting Bogotá with the region and other cities in the country. Today, a significant part of the region’s railway infrastructure is conserved, with the exception of the Ferrocarril del Sur corridor, which has been withdrawn to allow the expansion of the highway and BRT infrastructure between Bogotá and Soacha. In spite of this, in recent years there have been several initiatives to reactivate the operation of the train (such as Public Private Partnerships), to deal with the road congestion that is daily experienced in the accesses north and west of the city where it has been perceived a greater increase of trip times. However, in spite of having a recent study called "SITUR Integrated Regional Urban Transport System" that supports the need to implement a suburban train system in the metropolitan area of Bogotá, these initiatives have not managed to coordinate or materialize between Bogotá and the agglomerations of the area of influence of the project.

**Figure 2.** Scope of modes and networks in metropolitan spatial interaction

Source: (Silva, 2017)
2.3 Trip time: the opportunity cost of spatial interaction

By understanding daily interurban commuting as a form of spatial interaction, it depends on the distance between the central city and the surrounding agglomerations. Covering a distance in spatial interaction requires costs of various kinds (Polèse, 1998). In the case of daily trips, these costs are called transport costs and vary according to the networks and modes of transportation available to cover the geographical distances (De Rus, Campos, & Nombela, 2003). A useful proxy variable to represent transport costs is trip time, which varies depending on the distance but also depending on the modes of transport (technology). Therefore, more than the distance, transport costs derived from each modes of transport contribute to explain the main characteristic of the evolution of the spatial structure of the...
region: increasing the dynamics of the nearest agglomerations to Bogota and the backwardness of the most distant agglomerations (subregional centers).

Although there is insufficient information to compare the trip time between Bogota and the surrounding agglomerations for different periods of time that may be comparable, there are previous exercises that can help to visualize trip times. For example, in Graph 1.3, an approximation of the trip time is shown in the form of isocronas that, according to the analysis carried out by Mesa de Planificación Regional (2005), implied commuting from each of the agglomeration of the region (called Cundinamarca) to the center of Bogota in 2005. According to this analysis, for that year the cost of transportation between the city and the surrounding agglomerations ranged from 60 to 90 minutes. Even at the time, the Mesa considered it necessary to provide improvements in the road infrastructure to ensure a greater connection between the agglomerations and thus motivate a deconcentration of the population outside the Savannah, where agglomerations such as Zipaquira and Facatativá acquired greater relevance for their articulating role as Subregional centers.

Although this exercise does not provide greater precision in the estimation of trip times between Bogota and surrounding agglomerations for 2005, it allows us to have an approximation of the maximum trip time that for that moment involved such trips: 90 minutes. Another exercise for the estimation of trip times in another period of time is the exercise made from the Bogota Mobility Survey of 2011 (Secretaría Distrital de Movilidad, 2012), whose results correspond to 2010. Based on this Information, Figure 4 shows trends in the behavior of interurban travel, associated to the main modes of transport, based on three variables and the combination between them: average distance between Bogota and each of the agglomerations, weighted average trip time interurban, and total inter-city travel. From this graph, several facts are identified that, based on the behavior of the demand for transport, show the relationship between the modes of transport and the metropolitan spatial structure.

From the point of view of the average distance of the trip or distance between urban agglomerations, it is found that the closest agglomerations to Bogota carry out more trips in TPC, TM and private vehicle; while in the more distant agglomerations, most of the trips are made in private vehicle and TM. The predominance of the use of TPC over other modes in the nearest agglomerations has its explanation in the case of Soacha, the only agglomeration completely conurbated with Bogota. The loss of jurisdictional limits suggests the establishment of more urban-local rather than interurban relations. Therefore, the conurbation is associated with a closer proximity to Bogotá and a greater demand for urban services such as TPC. However, in the year 2013 an extension of TM to Soacha began operating which directly connects the agglomeration with the city. A fact that will undoubtedly have changed the trends described here based on the Mobility Survey for Bogota 2011. Although in the year 2015 Secretaría Distrital de Movilidad conducted a Mobility Survey for the metropolitan area of Bogota, during the realization of this Study was not counted with
this information since the results of that survey were published time after the conclusion of the present study. For this reason it was not possible to make a comparison of commuting for the years 2010 and 2015.

**Figure 3.** Distance to Bogota based on estimated trip time for the Cities Network year 2005.

Source: (Mesa de Planificación Regional, 2005)

With respect to the average trip time of the most employed modes, it is found that for the nearest agglomerations as well as for the more distant agglomerations, the private vehicle tends to manifest a smaller average trip time with respect to the TM trip time. The difference in trip time of these two modes is between 30 minutes (in the nearest agglomerations) and 40 minutes (in the most distant agglomerations). A significant difference related to transshipment by medium change to which the use of TM in the interurban travel is subject. A modal change from which the private vehicle is exempt because, unlike TM, it allows to cover
the entire journey from the origin to the destination through direct connections, that is to say, without auxiliary modes (Figure 2).

Based on these evidences, the role of TM and of the private vehicle in the spatial structuring process of the metropolitan region is emphasized: the use of TM is predominant in the nearest agglomerations, despite being the medium with the longest trip time; while in the more distant agglomerations the use of the private vehicle predominates. Although there is no information available to characterize the evolution of interurban commuting trends in the region before 2011, the entry into operation of TM 15 years ago coincides with the period when the dynamics between Bogotá and the nearest agglomerations increased. Therefore, in recent years TM has managed to meet the need for interurban travels, despite the limitations in its coverage at regional level.

**Figure 4** Trends in the demand for travel between Bogota and the surrounding agglomerations for the main modes of transportation.

![Trends in the demand for travel between Bogota and the surrounding agglomerations for the main modes of transportation.](image)

Source: (Silva, 2017).

Due to the configuration of the transport networks, the absence of a formally constituted metropolitan transport system and the predominance of the modes of transport for interurban travel, the private vehicle is the only mode of transportation that offers a direct connection between Bogotá and surrounding agglomerations. Contrary to this, in the case of other predominant modes such as TM and TPC depend on other modes such as interurban to
complete an interurban trip, as seen in Figure 2. This scheme makes it possible to understand the types of connection between transport networks and modes of transport. The understanding of these connections, to a large extent, justifies the behavior of trip times in the predominant modes of transportation between Bogotá and the surrounding agglomerations: greater in TM despite the operational advantages offered by bus traffic in exclusive lanes; Compared to less time in a private vehicle, despite the disadvantages of mixed traffic and congestion. In this way, it is confirmed for the analyzed case that "the transshipment of one mode of transport to another implies costs, mainly the opportunity costs of lost time" (Polèse, 1998).

This cost of opportunity, understood as the cost of transport or the trip time of people varies significantly from one mode to another, due to the configuration of transport networks previously described. In general terms, the total trip time (T) can be disaggregated as follows (De Rus, Campos, & Nombela, 2003):

\[ T = t_a + t_e + t_v + t'_a + t'_e + t'_v + t''_a \]

Where \( t_a \) represents the access time from the point of origin of the trip to the point where the user must approach the chosen modes of transport, \( t_e \) the waiting time of the vehicle or route, \( t_v \) the time on board the vehicle, and the access time \( t''_a \) to the destination. In the event of a transshipment being required, the access time \( (t'_a) \), the waiting time \( (t'_e) \) and the time in the vehicle \( (t'_v) \) involving the trip break. Given this for the modes of transport prevailing in the trips between Bogotá and the surrounding agglomerations, that is to say for TM and the particular vehicle, there is a substantial difference in the disaggregation of its trip times. Since the transport networks operating in the region have been conceived from a local perspective, interurban travel is subject to connections that significantly increase trip time (TM and interurban), in relation to direct travel between origin and destination (Private vehicle).

\[ T_{TM} = t_a + t_e + t_v + t'_a + t'_e + t'_v + t''_a \]

\[ T_{VEH} = t_a + t_v + t''_a \]

2.4 Transportation costs in the location of activities

The Theories of Localization of the urban economy allow to give an explanation on the individual decisions of localization of economic agents such as people and economic activities, among others, in a geographic space with respect to economic and social centralities. In general, these centralities are usually represented in these theories by a large central urban district CBD (Central Business District), which in turn and in an aggregate way transcend in an order of intraurban structure. Behind these locational decisions a competition between agents arises for the most advantageous locations where a maximization of profits is obtained.
Located in the CBD implies the immediate availability of the demand factors in the different forms of spatial interaction.

Spatial interaction entails opportunity costs understood as transport costs (passenger and freight), which can increase for a variety of reasons, many of which are associated with geographic distance and technology of modes used (De Rus, Campos, & Nombela, 2003; Rodrigue, Comtois, & Slack, 2006); so it is reasonable to think that the economic agents will seek locations where these costs are lower with respect to the distances with the main centralities or the large urban center in the case that is represented by the CBD. Since geographic space can be considered as a good, it is clear that its availability is limited and therefore its occupation, between different economic and social activities, can be understood as a process that results from competition between economic agents by the locations closest to that center, that is, the most advantageous because they involve lower transportation costs.

In order to understand the way economic agents, and especially the population, are distributed in the territory, the Theories of Location start from the concept of accessibility, which as Camagni expresses, can be considered as a genetic principle of spatial organization (Camagni, 2005). Accessibility, understood as overcoming the restrictions imposed by distance (space) to spatial interaction (such as the movement of people from one point to another for the development of economic activities and access to urban services), is a factor determinant not only of the competition for the location but also of the metropolitan spatial order and structure. While accessibility depends primarily on distance, it also depends on the modes of transportation available and the costs associated with them.

In this way and from these theories, the competition for the localization not only obeys to a matter of closeness as a variable of the distance with respect to the CBD, but also to a search for the reduction of the opportunity costs incurred in the displacement toward said center. One of the most important deductions in localization theories is the incidence of transport costs in individual location choices (Polèse, 1998) for different urban uses, such as residential location: locations with greater accessibility to the center, that is, with lower transportation costs will offer greater advantages and therefore be more attractive with regard to locations with less accessibility or with higher transportation costs.

These advantages of localization used by the economic agents are usually expressed in the urban economy as rent of location, since these advantages derive in benefits obtained from the location, for example the CBD, and rather than the productive capacity or economic activity that develops. These benefits are derived, on the one hand, from the valuation that agents give to each location, and on the other hand, the savings in transport costs that implies locations that are closer to or accessible to the CBD. Therefore, in a geographic space where spatial interaction implies transportation costs (as a function of distance and available modes of transport) it will always be subject to the manifestation of location rents as a reflection of competition for space between producers and residents. The competition for space implies an
implicit or explicit assessment of the agents on the different locations in space, where accessibility and transportation costs are determinant in location choices. In this sense, both the rent of location and the costs of transport contribute to explain the processes of urban and metropolitan spatial structuring, as a function of distance (the main spatial variable used in localization theories) and even the modes of transport available in urban space as will be explored later.

The so-called Von Thünen model, proposed at the beginning of the 19th century, is one of the most important conceptual bases on which the theories of localization have been developed. The simplicity of the model is one of its greatest virtues because it managed to explain the dynamics of economic location, which can be applied to different geographical scales. For the case of the formation of cities, the result of the model finally manages to relate the rent of location, the costs of transport and the urban structure, reason why they make of this model a conceptual tool still in force to explain different urban phenomena. Although the model was originally conceived to explain the location of agricultural production in a homogeneous geographic space with respect to a central market, its conceptual basis has been replicated by different authors to the urban context and the spatial distribution of the different productive activities of an agglomeration. The model is based on a series of simplifying assumptions that make it possible to understand the genesis of location rents and their organizing nature of space in terms of the costs of opportunity (or transportation) of everyday movements (Camagni, 2005).

For Von Thünen, the central market (CBD) is a point in the space where all the agricultural products that arrive there from the different points of production distributed around the center on a homogeneous space or plain (that is lacking of geographical features) whose land has a uniform production capacity. The movement of the products from the points of production to the central market takes place through the available infrastructure which, theoretically, connects the center with all production points in all directions. According to Von Thünen, the income per unit space (Equation 1) arises as a residue obtained after subtracting the total income from production \((p \times x)\), costs incurred in production \((c \times x)\), and costs of opportunity for the transportation of the products to the central market \((\tau \times \delta \times x)\); Therefore, rent arises “from the savings on the transport costs that can be made by the producer located on the land closest to the central market” (Camagni, 2005).

\[
\begin{align*}
  r(\delta) &= (p - c - \tau \delta)x \\
\end{align*}
\]

Equation 1

Where:
\(P\) = price of the product defined exogenously and considered fixed in the model.
\(C\) = unit cost of production, considered fixed in the model.
\( T = \) Cost of unit transport, considered constant and defined exogenously. The total cost of transport increases depending on the volume of production and the distance traveled to the center. Even the cost of transportation can change from one good to another.

\( X = \) Yield or quantity of product obtainable per spatial unit.

The graphical representation of this economic phenomenon is shown in **Figure 5**, where the vertical axis represents the rent of location with respect to the CBD located in this axis, whereas the horizontal axis represents the distance to which an agent can be located with respect to this center. For a certain producer, the maximum benefit you will receive will be \((p - c) \times\), only if it is located in the CBD. As it moves away from the CBD (by increasing the location distance), the perceived benefit will decrease as a result of the increase in the opportunity costs incurred in transporting its production to the central market \((\tau \delta x)\), and it will find a point at which you will not receive benefits from the location due to the magnitude in these costs. The producer’s location income decreases as distance to the central market increases due to the increase in transportation costs and there will be a maximum distance where no benefits are perceived in the location due to the high opportunity costs.

If, for some reason, unit transport costs decrease, this implies a decrease in the slope of the straight line that defines the location rents, which is why there is an increase effect on location rents (**Figure 6**). By introducing an improvement in the accessibility to the central market, the unit transport costs decrease \((\tau_2 \delta x)\), and therefore the savings derived from them increase. This effect could be seen from two perspectives: on the one hand, the producer could be located at a greater distance from the center (from \(\delta_A\) to \(\delta_B\)), without this implying a decrease in the rents received \(((r_1)_{\delta_A})\); And on the other hand, the producer could perceive a higher income \(((r_2)_{\delta_A})\) without changing its location \((\delta_A)\).

There may also be a decline in accessibility (eg due to congestion), where unit transport costs increase. Given this scenario, if the producer maintains its location \((\delta_b)\), it will perceive a decrease in the location revenues; If, on the other hand, it decides to maintain its rent of location \(((r_1)_{\delta_A})\), it will seek to locate closer to the center (it would go from \(\delta_B\) to \(\delta_A\)).

However, assuming that 3 types of products are produced in a region, as shown in **Figure 7**, this conceptual model responds to the question of where each producer is located, as well as the location income of each point, understood as the Price that each producer is willing to pay for the floor according to its location with respect to the center. For this, it is assumed that each agricultural product has its own production function and its own transportation costs that depend on the volume transported and the distance traveled.

In **Figure 7**, the producer of good 1 perceives higher profits in the CBD because it incurs lower opportunity costs than the producer of the good 2, and this in turn perceives higher profits in the CBD because it incurs lower opportunity costs than the Producer of the good 3. For this reason, the producer of good 1 is willing to pay more for its location in the CBD than
what the producer would be willing to pay 2, and the producer is willing to pay more for its location in the CBD with respect to what the producer would be willing to pay. 3. Since the producer of good 1 is the only one that offers the greatest willingness to pay among the producers of the different goods, he gains the competition for the closest location to the CBD. However, because of the increase in transport costs as a function of distance, the producer of good 1 quickly loses the benefits of its location with respect to the center as it moves away from it, to the point at which costs are so high that they cancel out the benefits expected by the producer; A scenario in which any willingness to pay for such location is lost.

Figure 5. Geometric representation of location rent according to Von Thünen

Source: (Silva, 2017; Instituto de Desarrollo Urbano - Universidad Nacional de Colombia, 2015)

Figure 6. Effect of the change in unit transport costs on the location rent of the Von Thünen model

Source: (Silva, 2017; Instituto de Desarrollo Urbano - Universidad Nacional de Colombia, 2015)
In the case of producer 2, although his willingness to pay for the location closest to the CBD is not as high as that expressed by producer 1, there is a location in which his willingness to pay is greater than that of producer 1 and that of the producer 3. This is because their transport costs increase to a lesser extent when compared to the transport costs of the good 1. Therefore, the location where the greatest benefits the producer 2 perceives and for which he is willing to pay, it defines the limit of the optimal location of the producer 1. Finally, in the case of producer 3 whose willingness to pay for the CBD location is the lowest in this competition for the most advantageous location, Allow to locate the most distant to the center, where the producers 1 and 2 manifest their lower disposition to pay or even they do not manifest the intention to be located there; Thus defining the optimal location limit of the producer 2.

In this way, competition between 3 producers of different goods for the most advantageous location with respect to the CBD is solved through a process of maximization of benefits and minimization of opportunity costs (transportation). Thus, the resulting spatial structure consists of a series of rings concentric to the central market, where each ring represents the optimal location of each good, the result of the individual location decisions, as a function of the distance to the CBD. Although the model explains the location of agricultural products in space, the location of activities and urban uses occurs under the same logic. Both producers in different economic sectors and residents of a region are all in constant competition for the most advantageous locations according to the transport costs they are willing to take. However, given that the economic phenomena that occur around urban agglomeration are more complex, location rents in the urban context are not only defined by accessibility and transportation costs, but also by the size of the land unit or housing unit.

This means that the explanation of location rents can become more complex as different variables are included as determinants in the location decisions of a person or a company. Even factors unrelated to the decision-making process of individuals, such as the availability of land and the norms that govern the use and occupation of the land, can be determinant in the rents of localization. However, the simplifying assumption under which location is assumed to depend only on accessibility and transport costs, allows a valid explanation of individual location decisions and a particular spatial order without differentiation by agents or activities.
Figure 7. Von Thünen model applied to 3 agricultural products

Source: (Camagni, 2005; Polèse, 1998; Silva, 2017)

3 Interdependence between transport and metropolitan spatial structure

Considering the territorial occupation as a geographic expression of the metropolitan spatial structure, based on different geographic analyzes taken from the study Metropolitan Region
of Bogota (Secretaría Distrital de Planeación, 2014), it is found that the changes associated to
the hierarchy and population concentration of the Region have gone hand in hand with an
increase in land urbanization. Although the occupation of land, as an expression of the spatial
structure of the Bogota Metropolitan Region, has more obeyed the logic of the real estate
market, transportation costs derived from modes and transport networks have influenced the
consolidation of a pattern of occupation that came to be of a "dispersed linear" type around
the so-called Axes of Regional Integration, that is, the access routes between Bogota and the
region, consolidating in the last years more was a pattern of urban expansion.

Individual location decisions, which are seen as transcending in the dynamics that govern
spatial (urban, metropolitan, regional, inter-urban, etc.) structuring processes, finally
materialize in space by occupying the ground. Therefore, land use for urban uses, as well as
their resulting patterns and forms, can be seen as an expression of the location preferences of
the different urban actors against a CBD; Preferences heavily dominated by transport costs. In
order to review the trends and possible changes that have occurred between the main modes
of transportation used in the commuting of the metropolitan region of Bogotá and the trends
of land occupation in the region, as well as its relationship with The metropolitan spatial
structuring, this chapter presents in a theoretical way how the dynamics between location
rents and transportation costs associated with each medium explain the different forms of
land occupation in the Metropolitan Region of Bogotá. For this, first a description of the
resulting land occupation patterns in the study region, taken from the study "Metropolitan
Region of Bogota: a vision of land occupation" (Secretaría Distrital de Planeación, 2014) is
presented first. A proposed adjustment to the Von Thünen localization model, applied to a
monocentric metropolitan model, is presented and adapted to the dynamics between the core
and the periphery of the Region. Based on this model, a series of simulations are carried out to
explain the previously identified land occupation patterns from the perspective of transport
costs associated with different transport networks and their interaction with urban fertility,
As well as its transcendence in the metropolitan spatial structure.

Finally, an adjustment is proposed to the System Dynamics model formulated by Secretría
Distrital de Planeación (2014) in order to quantitatively simulate population growth and the
incidence of transport networks in the metropolitan spatial structuring of the Region . For
this, three scenarios are simulated to identify possible "consequences that the evolution of the
phenomenon of metropolization can have on the territory" (Gómez & Rodríguez, 2012) that
are: tendential without effect by transport networks; With a flexible network effect associated
with higher transportation costs; And trend with fixed network effect associated with lower
transport costs.

3.1 The resulting land occupation patterns in the región
The growth and urban expansion has been a result of the evolution of the spatial structure
given in the last 20 years in the region. This urban expansion has been characterized, on the
one hand, by local territorial planning decisions defined by each jurisdiction of the respective agglomerations, and by the logic of the real estate market of the region (Secretaría Distrital de Planeación, 2014). It has been observed how the changes in the concentration of population that have characterized the evolution of the spatial structure of the Metropolitan Region have tended to modify the land occupation patterns of the region. Given a relatively lax normative scenario with land use decisions in the surrounding agglomerations, especially in relation to the location of urban activities, the increase of the dynamics of the agglomerations closest to Bogota has gone hand in hand with an increase of Urbanization (understood as the occupation of land for urban uses).

In order to have an approximation about the trends and main characteristics of the land occupation in the region, here are some analyzes that are part of the book "Metropolitan Region of Bogotá: a vision of the occupation of the ground" (Secretaría Distrital de Planeación, 2014). These analyzes on the urbanization of the land and the patterns of occupation resulting from the urban growth and expansion of the surrounding agglomerations contribute to a theoretical explanation of how transport costs, linked to the rents of location, and the predominance of modes such as BRT Urban and private vehicle appear to affect the land occupation of the region. **Map 4** shows the rate of variation of urbanized land in the years 1990, 2000 and 2010, where it is found that the agglomerations closest to the city showed a significant increase in urbanization in the last 20 years, while more distant agglomerations the subregional centers showed less variation of the urbanized land.

However, this increase in urbanization of the land has not necessarily meant a consolidation of agglomeration urban areas. Despite having urban land and expansion available for occupation and development of urban activities, according to studies of Secretaría Distrital de Planeación (2014), agglomerations have prioritized the empowerment of rural land for occupation in high densities. An example of this is the high degree of "anthropization" or "impact of human activities on the territory" presented by the agglomerations closest to Bogotá and of greater expansive urbanization in the last 20 years (Secretaría Distrital de Planeación, 2014). Some of these agglomerations have even been enabling urban occupancy in environmental protection zones, which affects the environmental sustainability of the region in the long term (Secretaría Distrital de Planeación, 2014). Contrary to what has happened to the agglomerations closest to the city, more distant agglomerations such as the subregional centers have had less intensity and expansion in urbanization, as well as a lower "anthropization degree" and a lower rural land occupation for the development of urban activities.

**Map 4.** Rate of variation of the urbanized land by agglomeration of the metropolitan area 1990 - 2010.
The increase in the metropolitan dynamics of the nearest agglomerations and the backwardness of the more distant agglomerations, as a characteristic feature of the evolution of the metropolitan spatial structure of the Bogota Region, has not only been reflected in the dynamics of commuting but also in the dynamics and patterns of land occupation. The urban expansion carried out on rural land by the agglomerations closest to Bogota has not occurred in isolation in the territory. This urban expansion has obeyed a fundamental characteristic: the empowerment of rural land for urban use has been concentrated around the regional integration routes that connect Bogota with the Region (Secretaría Distrital de Planeación, 2014). This characteristic has fostered the consolidation of an occupation pattern, which began as a "linear dispersion", passing to an urban expansive pattern in rural land, in the agglomerations of the nearest border; oriented by the access roads to the city. In addition, as shown in Map 5, it can be observed that some of the more distant agglomerations (such as subregional centers) have a slightly more compact occupation pattern, associated with a lower occupation of rural land for urban use and, therefore, a lower "degree of anthropization" of rural areas.
3.2 Land occupation structures in the Metropolitan Region: a theoretical view from the interaction of location and modes of transport

These patterns of land occupation, as a result of the changes in the spatial structuring process of the region, can be theoretically explained from Von Thünen’s postulates and his theory of location. Although in this theory, costs contribute to explain the localization preferences of economic agents, it is important to take into account the available transport networks as well as their configuration, since they are determinant in the structure and form adopted by a metropolitan region (Anas, Arnott, & Small, 1997).

As previously reported, Von Thünen’s localization model as well as the later contributions of Alonso, Muth and Mills (Camagni, 2005) allow us to understand, with its conceptual simplicity, the relationship between location rents, transport costs and structure Urban This model of location, where abstractly represents a core and its periphery, not only incorporates the distance as a variable of the spatial location of urban activities in one or another agglomeration, but also recognizes the incidence of factors such as the costs of Transport and urban fertility in spatial location. Therefore the decisions of locating people in a geographic
space arise as an individual optimization process capable of transcending in a collective order, where it seeks to maximize the benefits derived from the residential location and at the same time to minimize transport costs.

The conceptual abstraction of Von Thünen proves to be an instrument of great utility to explain the spatial structuring processes derived from the locational decisions of the inhabitants of a region. Although the original model starts from a centrality and its relation with the surrounding territory, it is possible to introduce adaptations to this base model and thus to involve in the spatial structuring analyzes more of a centrality. Figure 8 presents a proposal of the Von Thünen localization model applied to two centralities, which could be similar to a monocentric metropolitan model.

This proposed model recognizes the relationship between a core city (centrality 1) and the peripheral agglomerations represented in an abstract way as a point in a second centrality (second vertical axis of Figure 8). The space between these axes corresponds to the distance that separates, in an abstract way, such centralities connected to each other through the different transport networks available. The metropolitan models of monocentric type are characterized by an important daily commuting between the core city (CBD) and the peripheral agglomerations, with respect to the reduced daily trips between the peripheral agglomerations (Ewing, Pendall, & Chen, 2003). Therefore, this proposed adaptation to Von Thünen’s model is only intended for monocentric metropolitan models, where the spatial interaction between the nucleus and the peripheral agglomerations is more dynamic with respect to the interaction between the peripheral agglomerations, as is the case in the Region Metropolitan of Bogota. Without a doubt the Von Thünen model could also be adapted to polycentric metropolitan models, where each peripheral centrality to the CBD would be represented by a vertical axis. However, the conceptual development of this polycentric adaptation is not part of the scope of the present study because it does not correspond to the metropolitan dynamics of the case study.

The proposed adaptation to Von Thünen’s localization model focuses his attention on two determinants of location rent: urban fertility and transportation costs. Urban fertility is associated with the dynamics of economic growth, population growth, density of buildings and other aspects related to the potential of an agglomeration and its attractiveness to other agglomerations. Transport costs, considered in the model as an endogenous factor, represent the networks and modes of transport available for trips between the two centralities, which tend to increase as urban fertility increases (for example, (Eg congestion resulting from an increase in urban density), and may be reduced by public intervention (eg road infrastructure construction or implementation of public transport systems). Taking into account the conceptual basis of the basic model of Von Thünen (Figure 5), Figure 8 shows for a hypothetical region the spatial structuring effects caused by changes in fertility and Transport within the respective location income equations of each centrality (Equation 2 and Equation 3): The increase in urban fertility induces an increase in the maximum income of location; The
increase in transport costs induces a reduction of the optimal location distance; And the reduction in transport costs induces an extension of the optimal location distance.

$$R_{C1}(\delta) = (B_{C1} - C_{C1} - \tau_{C1} \times \delta) x_{C1}$$  \hspace{1cm} \text{Equation 2}

$$R_{C2}(\delta) = (B_{C2} - C_{C2} - \tau_{C2} \times \delta) x_{C2}$$  \hspace{1cm} \text{Equation 3}

**Figure 8.** General shape of the Von Thünen localization model adapted to two centralities

The abstraction of this conceptual model, applied to the case of the Metropolitan Region of Bogotá, allows us to give an approximation on how the search for the reduction of transport costs of the inhabitants of the region has tended to reconfigure the metropolitan spatial structure in recent years, according to the modes of transport prevailing in the region. The modes of transportation, as well as the networks, are determinant in the accessibility between the core city and the peripheral agglomerations, and determine the opportunity cost of the daily displacements in metropolitan scale; Reason why "the metropolis extends as far as daily displacements are possible and not beyond" (Gómez & Rodríguez, 2012). This suggests that, as a result of the individual (and collective) optimization process, an optimal distance exists in which a metropolitan inhabitant would be willing to locate a trade off between the perceived benefits of the CBD (central city) and the periphery (surrounding agglomerations). It is important to take into account that this adaptation of the model represents only the residential location, since it is the urban activity where the demand for land increases the population of each agglomeration grows.

The following is an exercise of theoretical scenarios simulation on the proposed adaptation to the Von Thünen model, in order to demonstrate how the role of networks, as well as the main modes of transport, can be understood in the spatial structuring of the Metropolitan Region of Bogotá. Based on the evidence presented throughout the document on changes in the spatial...
structuring of the region, both demographically and economically, the simulation of von Thünen’s model starts from a series of assumptions that particularizes the abstraction of the model at. In the case of the Metropolitan Region of Bogotá, and focuses on two variables: transportation costs associated with transportation media and networks for metropolitan mobility and urban fertility, which expresses the attractiveness and potential benefits of a centrality (city). Not only to the residential location, but in general to the location of any activity. In this way, the simulation of different scenarios for the representation of the dynamics in the spatial structuring associated to different periods of time, allows to explain the dynamics of metropolization in the region as well as the role that have fulfilled the modes of Transport in this process of structuring, associated with networks and represented as transport costs in the model. Although it is an abstract and therefore theoretical model, both assumptions and conceptual simulation yield coherent and conclusive results on the form and spatial structure adopted over time by the region, according to the predominant networks and modes of transport.

The simulation based on the equation of the Von Thünen model was made in a spreadsheet of the tool Microsoft Excel (Silva, 2017). It presents different scenarios under a temporal sequence, where the conditions of each centrality vary in terms of transport costs and urban fertility. The definition of scenarios, the temporal sequence and the valuation of the variables in each scenario, takes into account the model of metropolitan spatial structuring, based on the concept of the U of metropolization, (Ruiz, 2015). This model presents the metropolization as an evolutionary process of an urban system, in which three major periods stand out: consolidation of urban concentration, phase of transition to metropolitanization and metropolitan consolidation (Ruiz, 2015).

In the case of the metropolization of Bogotá and its region, the occurrence of a metropolitan evolution on different periods initiated in the middle of the last century is identified. Specifically, this evolution of the spatial structure occurred as follows: Between 1918 and 1951 Consolidation of the urbanization where Bogotá slowly increased its pace of urbanization; A phase of transition between 1951 and 1964 where the city began to urbanize more quickly, and began to manifest its first process of metropolization with neighboring agglomerations that, by the end of this period, were annexed to the jurisdiction of the city; This fact gives rise to a new stage of consolidation of urban concentration, between 1964 and 1973, where the new territory of the jurisdiction is urbanized, and then enter a new phase of transition between 1973 and 1985 with the surrounding agglomerations, and Since 1985 enters a phase of consolidation of the metropolization where the agglomerations begin to grow at a considerable pace.

In this vein, the simulation of the adaptation of Von Thünen’s model starts from the culmination of the second consolidation process of urbanization, after the annexation of neighboring agglomerations to Bogotá, and the beginning of the second phase of transition to The metropolization. This in order to give an explanation, from the interaction between urban
fertility, transport costs and rent of location, to what is known as the second process of metropolization of the city. Table 1 presents as a summary the qualitative valuation given to transport costs and urban fertility in the equations of each centrality, for each period of analysis (delimited by decades). This summary also guides the assumptions assumed in each simulation, which will be explained below in the development of the same. This qualitative assessment has a quantitative support intuitively assumed for the development of the exercise, which can be consulted in Silva (2017).

Table 1: Summary of simulated scenarios with Von Thünen’s model proposal

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* Simulación tendencial – prospectiva

Source: (Silva, 2017)

3.2.1 Simulation 1: Period 1980 to 1990

Due to the difficulties of accessibility between centralities, the city of Bogotá as a metropolitan center is undergoing a process of consolidation of urbanization concentrated in its urban center, characterized by an increase in population and urban density (Figure 9); That is, it goes from a medium-low fertility to an average fertility. Assuming that the city grows at a faster pace and that public investments in urban and metropolitan infrastructure do not respond in a timely manner to this growth, the growth of the city manifested in an increase in urban fertility is accompanied by an increase in the costs of transport.

For this reason, it is necessary to intervene the transport infrastructure and in this way to induce a decrease in transport costs towards the core city. Taking into account that the centralities have only a flexible transport network, the way to reduce transport costs is through the construction of new roads or the expansion of existing roads. As a result of this decrease in transport costs in the centralities, there is a reconfiguration of the spatial structure since it increases the optimal distance of residential location (Figure 9). Thus a point of location indifference arises: a person may choose to be located in the CBD or in the centralities of the periphery, even in the most distant of the CBD, since in both places he can receive the same rent of location.

Once the urbanization consolidation is over, and as a result of its economic growth, manifested in a greater fertility, the process of metropolization begins where the city continues to grow but now the metropolitan agglomerations begin to acquire greater
importance in the spatial concentration of the population (Ruiz, 2015). The surrounding agglomerations increase their urban fertility, since with respect to the city, they begin to offer more advantages in the relocation processes characteristic of the metropolization (Figure 10).

**Figure 9.** Simulation of Von Thünen model adopted for two centralities, associated to the beginning of the metropolitan transition phase between 1980 and 1990.

**Figure 10.** Simulation of Von Thünen model adopted for two centralities, associated to the development of the metropolitan transition towards the year 1990.

**Source:** (Silva, 2017) based on Von Thünen’s model (Camagni, 2005)
3.2.2 Simulation 2: Period 1990 to 2000

The core city continues its growth path, consolidating itself as the great center of the region. The increase of its urban fertility affects the increase of transport costs at the metropolitan level. Given that commuting in the region depends only on the flexible network (i.e., modes such as the private vehicle and interurban transport), as a result of the law of diminishing returns (infrastructure with few variations in its capacity against a mobile equipment increasing), there is a progressive increase in transport costs towards the CBD. For this reason, there is a reconfiguration of the spatial structure defined by a decrease in the optimal location distance (Figure 11).

Although the location was more attractive at a greater distance from the center, the location indifference point moves towards the CBD due to the increase in the costs of commuting. This increase in costs will lead to a scenario in which the point of indifference is lost, and this is where location decisions must choose to be located in the CBD or in the nearest agglomerations without losing the benefits of localization. For this reason, with the passage of time the more distant agglomerations begin to be less attractive in the residential location compared to the agglomerations closest to the city. In this way, it is observed that the dependence on the flexible network and its sensitivity to the increase in transport costs tend to limit the metropolitan development of the agglomerations more distant to the city.

Figure 11. Simulation of Von Thünen model adopted for two centralities, associated to the development of the metropolitan transition between 1990 and 2000.

Source: (Silva, 2017) based on Von Thünen’s model (Camagni, 2005)

3.2.3 Simulation 3: Period 2000 to 2010

Despite the effects of increased transport costs on the spatial structure of the region, both the CBD and surrounding agglomerations continue to grow and increase their urban fertility. Within the CBD, congestion levels due to growth in the agglomeration economies show the
need to implement mass transportation systems to solve the growing urban mobility of the CBD. Towards the year 2000 Bogotá implements the BRT type public transport system, Transmilenio, where it combines the operation of trunk buses (exclusive traffic) and the use of feeder buses in mixed traffic routes. Although its implementation did not exceed the limits of the city, it offered the possibility of connection at metropolitan level, along with the use of interurban buses. This situation offered a new option of metropolitan accessibility in front of the predominance of the flexible network. However, the extension of the system strengthens the dependence of the flexible network on interurban trips (Figure 12).

**Figure 12.** Simulation of Von Thünen model adopted for two centralities, associated to the development of the metropolitan transition between 2000 and 2010.

These conditions of operation and dependence of the flexible network have led to a new state of reconfiguration of the metropolitan spatial structure. Although the BRT system helped to reduce trip time to the interior of the city, its use in commuting implies different transhipments and disconnected connections that transcend important increases in trip times. For this reason, the optimal location distance continues to approach the CBD: more distant agglomerations appear to be less attractive in residential location preferences, compared to the nearest agglomerations. Even if we compare the morphology of the networks present in this period, it is possible to affirm that the configuration of the semi-network favors linear growth around the access routes, while the flexible network favors a more expansive growth, since it allows Reach areas a little more distant from the main roads.

### 3.2.4 Simulation 4: Period 2010-2020

The region continues to grow and little by little the spatial structures defined by the optimal location distance induced by each network are consolidated. Assuming a prospective trend
scenario for the next years, the last simulation presented, entails the progressive increase of transportation costs without major public interventions aimed at improving mobility between centralities. If transportation costs were not cushioned by investments in mass transit systems of the metropolitan area, in the future there could be conurbation phenomena between centralities with strong accessibility problems. In this sense, the simulation shows how the location tends to be concentrated in the sectors closest to each centrality, similarly as it happened in the urban consolidation phase.

Assuming that a significant reduction in transport costs can be achieved with the implementation of a mass transit system of metropolitan scale, such as suburban train, a new change in spatial structure could be induced: the reduction in transport costs leads to an extension of the optimal location distance, and the emergence of the point of indifference in the location. This fact, together with the morphological configuration of the fixed network, would favor more concentrated occupation models around the centralities (surrounding agglomerations), with respect to the expansive and linear models induced by the flexible and semifixed networks, respectively.

**Figure 13.** Simulation of Von Thünen model adopted for two centralities, associated to the development of the metropolitan transition between the years 2010 and 2020.

Source: (Silva, 2017) based on Von Thünen’s model (Camagni, 2005)

### 3.3 Scenario modeling of the Spatial Structuration of the Region

The combination of future scenarios and simulation models constitutes an approach for the representation of spatial dynamics and the formulation of future scenarios on spatial structuring. In this regard, the study "Metropolitan Region of Bogotá: a vision of land use" (2014), proposes a prospective model based on the logic of Systems Dynamics, to evaluate future scenarios associated with Territorial order of the Region focusing on the most likely
occupation of land that could occur in the coming years (Secretaría Distrital de Planeación, 2014), as well as changes in demographic level. In this sense, the model proposed by the District Planning Secretariat starts from two major components: population and urban land demand.

**Figure 14** shows a representation of the System Dynamics model for the Metropolitan Region of Bogotá, which, under the logic of a series of causal relationships between different variables, annually feedback the behavior of population growth and the increase in the demand for land at a metropolitan scale, in a time horizon between 2005 (corresponding to the last Demographic Census of the country) and 2030.

According to this model, the evolution of the population that would occupy land in each agglomeration of the Region depends on demographic variables typical of population projection models, such as birth rate, mortality rate and migration rate. In addition to this, the model recognizes as a causal relation of population growth, an effect on the migration associated with daily commuting that affects the localization decisions of the residents: "Not only the limitation of the developable land in the agglomerations conditions its Level of occupation, but also the commuting relationships that tend to structure the metropolitan territorial order" (Secretaría Distrital de Planeación, 2014). A supposition based mainly on the localization theories of the Urban and Regional Economy, as well as the location model of Von Thünen.

This effect on migration results from an assessment of the friction in the spatial interaction between Bogota and the surrounding agglomerations. This evaluation is obtained from the application of the gravitational model, used to interpret territorial phenomena (Camagni, 2005), and commonly used in the travel distribution stage of the traditional four-stage model of Transport Engineering. Accordingly, the effect on migration is an estimate of the impedance factor of the gravitational model applied to the study area, based on the results of the 2011 Mobility Survey. This is how the proposal of Secretaría Distrital de Planeación (2014) incorporates a spatial variable into a quantitative model to determine how the location of the agglomerations with respect to Bogota can influence migration and hence the distribution of the population in the region.

According to the findings evidenced in the simulations of the proposed theoretical model based on Von Thünen’s localization concepts, the transportation costs associated with transport networks available for daily commuting at metropolitan scale also influence spatial structuring processes. Although the impedance allows to adjust the migration rate by the relative location of the agglomerations with respect to Bogota (as a friction that implies the overcoming of the distance), it ignores the effect of the transport networks in the spatial structuring.
For this reason, in this work we propose the incorporation into the System Dynamics model of the region a variable called "Effect by type of transport network predominant", as shown in Figure 15, this predominance is understood in the model as the networks and the respective modes of transport of greater use in the daily commuting at metropolitan scale (greater participation in the modal split). In this way, the combination of the effects on the migration by location of the agglomerations with respect to Bogota and by the concept of the available networks for the spatial interaction between the agglomerations and Bogota, allows to adjust the tendencies on the location decisions in the region, which transcends changes in the distribution of population on a metropolitan scale.
Figure 15. Incorporation of the effect of transport networks in the system Dynamics model on the spatial structuring of the región

Source: Based on (Secretaría Distrital de Planeación, 2014).

The incorporation of this factor in the Dynamics of Systems model allows the evaluation of future scenarios of spatial structuring, from a demographic perspective, based on future changes that could occur in transport networks for commuting between Bogota and agglomerations. For the simulation of these scenarios, only the demographic block of the model proposed by Secretaría Distrital de Planeación (2014) will be used because, on the one hand, the document has emphasized the demographic perspective of spatial structuring; And on the other hand, population growth can also be understood as a proxy type of the rents of location of agglomerations: the greater the agglomeration, the rents of location will tend to be higher when compared with the smaller agglomerations (Polèse, 1998).

Given this, the simulation exercise consists of the prospective estimate of the population, calculated on an annual basis for a time horizon of 25 years starting from 2005, the date on which the last population census was conducted. Therefore, the demographic adjustments for population projection are based on an official count of the population of the country and not on projections estimated using unknown statistical and probabilistic methods. It is also important to bear in mind that the exercise proposed here does not seek to speculate on population growth in the region. On the contrary, it seeks to evaluate the effects that could have over time the interventions in the transport networks of the study area on its spatial structure, understood in this case as the changes of population distribution, concentration and hierarchy Urban (Silva, 2017).
Although there are specialized tools for the simulation of systems dynamics models, the exercise presented here was performed in a spreadsheet of the Microsoft Excel tool. The estimation of population from year to year in the defined time horizon is the result of the application of the equations that represent the model variables (Figure 15): Population, population increase, birth rate, migratory balance and mortality (where \( i \) represents Year of projection).

\[
\text{Población}_i = \text{Población}_{i-1} + \text{Incremento de Población}_i
\]

\[
\text{Incremento de Población}_i = \text{Natalidad}_i + \text{Saldo Migratorio}_i - \text{Mortalidad}_i
\]

\[
\text{Natalidad}_i = \text{Población}_{i-1} \times \text{Tasa de Natalidad}_{i-1}
\]

\[
\text{Saldo Migratorio}_i = \text{Población}_{i-1} \times \text{Tasa Migratoria}_{i-1} \times \text{Efecto sobre la migración}_{i-1} \times \text{Efecto por red}_{i-1}
\]

\[
\text{Mortalidad}_i = \text{Población}_{i-1} \times \text{Tasa de Mortalidad}_{i-1}
\]

The birth rate, death rate and immigration rate are specific values for each jurisdiction obtained from a time series exercise, worked by the model of Secretaria Distrital de Planeación based on the historical information of the Departamento Administrativo Nacional de Estadística (DANE). These values as well as the results of the projections are presented in more detail in Silva (2017). The effect on migration is assumed to be constant annually according to the estimates made on the gravitational model based on the Mobility Survey Of 2011. In the case of net effect valuation, a variable incorporated into the reference model, it starts from an initial value that was adopted subjectively for the year 2005 and varies annually according to the type of network and the availability of the network In each jurisdiction. Although the estimation of these values can be done by econometric exercises for the calibration of the proposed model, the available information is not sufficient for this purpose.

Taking into account the above and given that it is sought to review possible changes in the spatial structure of the study area due to the effect of transport networks between 2005 and 2030, 3 scenarios are defined according to the predominant network: trend without Net effect, trend with flexible and trend network effect with fixed network effect. The assumptions of each scenario, as well as the results obtained are detailed below. It is important to bear in mind that in the scenarios mentioned, the semi-fixed network is excluded, although it has been determinant in the spatial structuring of the Region, the configuration of its specialized infrastructure does not exceed the limits of the city and depends on the Flexible network for interurban trips. Therefore, the implications in spatial structuring for the predominance of the semi-network in the coming years, are assumed similar to the results of the trend scenario with effect by flexible network.
3.3.1 Scenario 1: Trend without effect by transport network
The first scenario simulated in the System Dynamics model corresponds to a trend growth of the population without the incorporation of the effect by network. The results of this simulation, shown spatially in Map 6 for the years 2015, 2020 and 2030, result from population estimation under a constant rate of migration over time. The possible changes in the hierarchy that could result from this growth trend are shown in Table 2. Under certain trend growth conditions, a change in the hierarchy of the agglomerations in the study area could occur over the time horizon. This means that, as it has been happening in the last 20 years, the growth of the region does not occur homogeneously throughout the territory. According to the results of this scenario, agglomerations like Chia, Mosquera, Funza and Cota would carry out the main changes in the hierarchy of the subsystem.

This suggests that in the next 15 years the agglomerations of the urban border closest to the city would continue to reaffirm their predominance in the metropolitan dynamics, with respect to the agglomerations more distant to the city. As a consequence of this, the agglomerations considered as subregional poles (Zipaquirá and Facatativá) would be relegated to positions of lower hierarchy by the important growth of Chía and Mosquera, agglomerations located between the subregional poles and Bogota in the north corridor and the corridor of the west, respectively. The implications of this trend on land occupation patterns could result in the consolidation of a model of expansion over the agglomerations closest to the city and which began as a linear dispersed pattern around access corridors to Bogota. In these agglomerations of the border near the city would concentrate an important part of the metropolitan population, by the advantages that their location offers with respect to the great central nucleus.

3.3.2 Scenario 2: Trend with flexible network effect
The second simulated scenario corresponds to a trend growth of the population applying an effect by flexible transport network. The results of this simulation for the years 2015, 2020 and 2030 (Map 7), result from the application of a factor of 1 in the year of departure, which decreases at an annual rate of 0.02. This decrease is assumed to be an effect of the decreasing yields to which the flexible network is subject (Silva, 2017): even if there is an increase in the capacity of the roads connecting Bogotá with the agglomerations, factors such as the continuum Growth of the automotive park in the country as well as the dependence of the metropolitan commuting to modes of transport flexible, the trip time in this type of network will increase progressively. As possible changes in the hierarchy, resulting from the effect of the flexible network on the decisions of location of the population in the surrounding agglomerations, a behavior similar to the trend scenario without effect by networks is identified. That is, Chia, Mosquera, Funza, Cota and even Tocancipá would carry out the biggest changes in terms of their position in the hierarchy of the subsystem.
However, under this scenario the magnitude of growth would be lower than that presented in the previous scenario. While the agglomerations on the nearer edge of the city would concentrate a significant proportion of the metropolitan population, the progressive increase in the costs of transporting the flexible network tends to limit the preferences for being located outside the city, and even within the city. For this reason, given the possible preponderance of the flexible network in the spatial interaction of Bogota with nearest agglomerations, the result on land occupation would be the consolidation of an expansive occupation initiated under a linear dispersed pattern. An expansive occupation tending to conurbation between Bogota and the nearest agglomerations, mainly oriented by access corridors to Bogota.

3.3.3 Scenario 3: Trend with fixed network effect
The third simulated scenario corresponds to a trend growth of the population applying an effect by fixed network of transport, that could be representing a system of massive iron transport type of suburban train. The results of this simulation for the years 2015, 2020 and 2030 (Map 8), result from the application of a factor of 1 in the year of departure, which is increasing at an annual rate of 0.02. It is important to emphasize that the assessment of the fixed network factor varies according to the proximity between the agglomerations and the railway corridor. As was seen in the scheme of the transport structure of the region, agglomerations such as Chía, Sopó, Cota, Tabio, Tejo, Bojacá and La Calera are distant from the rail corridor, so the factor's valuation was assumed between 0 and 0.5, depending on the case. In the case of agglomerations with a factor of 0, that is to say without access to the fixed network, the respective projections of the flexible network were taken, since it is the predominant medium in its metropolitan spatial interaction. On the other hand, the increase of the factor in this scenario is understood as a progressive growth of the demand after the implementation of a massive transport system of metropolitan scale that would facilitate the spatial interaction between Bogota and the agglomerations. Unlike the flexible network, in the case of the fixed network, the annual adjustment applied to the network factor is assumed positive, since the configuration of the fixed network is not very sensitive to the decreasing returns.

The main change in the hierarchy, resulting from the effect of the fixed network on the decisions of localization of the population in the agglomerations, is identified in the positions occupied by Mosquera and Chia. Unlike the flexible network scenario where Chía was placed in the third place of the hierarchy of the urban subsystem, before the implementation of a fixed network Mosquera would occupy the third place while Chía would be relegated to a fifth place. Although the agglomerations on the next urban border would continue to concentrate a significant part of the metropolitan population, the reduction in transport costs associated with the fixed network could favor location decisions in the agglomerations most distant to the city. This in terms of land occupation would lead to more concentrated occupancy.
patterns around the train stations, thus mitigating the consolidation of a linear dispersed pattern induced by the flexible network.

**Table 2. Urban hierarchy resulting from the trend projection without net effect**

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**Source:** (Silva, 2017)

**Table 3. Urban hierarchy resulting from trend projection with flexible network effect**

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**Source:** (Silva, 2017)
Table 4. Urban hierarchy resulting from trend projection with fixed network effect

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Source: (Silva, 2017)
Map 6. Trend projection of population size of the study area

Source: (Silva, 2017)
Map 7. Projection of population size of the study area with flexible network effect

Source: (Silva, 2017)
Map 8. Projection of population size of the study area with fixed network effect

Source: (Silva, 2017)
3.3.1 Comparison of scenarios

When comparing the results obtained in each scenario proposed for the proposed projection period, and specifically for the three years of analysis, the effect of the networks in the concentration of the population is more clearly observed. Although the System Dynamics model does not explicitly address the spatial interaction between agglomerations, but instead focuses on estimating the individual migrations of each agglomeration, the results allow to identify a pattern of population concentration in the study area Result of the preponderance of the different transport networks. For the comparison of the results obtained in the different scenarios, we review on the one hand the percentage variations between the results of the scenarios and the size of the population in the year 2005, base year of the model.

Table 5 shows the percentage variation that could occur in the size of the population of each agglomeration in the years 2015, 2020 and 2030, with respect to the population estimated by the 2005 Census, for the three scenarios: no net effect (Trend), with flexible network effect, and with fixed network effect. These data suggest that the most dynamic agglomerations in the metropolitan spatial structure could be Mosquera, Chía, Facatativá and Funza by 2030, for both the trend scenario and the scenario with a flexible network effect, as they would double their size or more. The difference between these two scenarios lies in the magnitude of the change, because in the trend scenario the percentage variation tends to be greater with respect to the percentage variation of the scenario with flexible network effect. This is due to the manifestation of the decreasing returns to which the flexible network is subject: due to a limited road supply and a progressive growth of the automotive fleet, transport costs increase, which in turn discourage relocation tendencies in the region.

In the case of a fixed network in the region (metro type or suburban train), the most dynamic agglomerations in the metropolitan spatial structure will be those closest to the railway line. Assuming that the fixed network implemented corresponds to the current route of the railways of the region, the most dynamic agglomerations would be Mosquera, Facatativá, Chía and Tocancipá, Soacha, Gachancipá and Funza. In contrast to the previous case, the fixed network would favor location trends in more distant agglomerations, such as Facatativá, Tocancipá and Gachancipá, and not only to the agglomerations on the nearer edge, as suggested by scenarios with no net effect and effect of flexible network.

The percentage variation of the population size in the projected periods allows to identify the cities that could present major changes in their size, but not the changes or dynamics that could present the metropolitan subsystem as a whole. In general, the implementation of a fixed network could induce a repositioning of the subregional centers in the Metropolitan Region due to the reduction of the transport costs that this type of network would represent in the metropolitan daily commuting. In this sense, besides favoring the displacements to the agglomerations more distant from the city, the fixed network could induce new dynamics in the metropolitan spatial structuring as well as patterns of land occupation less dispersed. Contrary to this, a spatial interaction totally dependent on the flexible network would
reinforce the tendencies of concentration of the population on the agglomerations closest to the city and patterns of land occupation dispersed and expansive around the access roads.

Just as "the shape of the city over the territory, its extent, the location of its activities and, to a large extent, its intensity of production depend on the extent and form of its infrastructure networks" (Herce, 2009); The simulation exercises lead to the conclusion that the organization of the Bogotá Metropolitan Region over a 15-year time horizon, in addition to the form it adopts over the territory, will depend to a great extent on the extent and configuration of the available transport networks For mobility on a metropolitan scale in the coming years.

Table 5. Percentage variation of the population estimated for the years 2015, 2020 and 2030, applying the effects of networks, with respect to the population of 2005.

<table>
<thead>
<tr>
<th>Location</th>
<th>Sin Efecto de Red</th>
<th>Con Efecto de Red Flexible</th>
<th>Con Efecto de Red Fija</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bogotá</td>
<td>15%</td>
<td>22%</td>
<td>35%</td>
</tr>
<tr>
<td>Bojacá</td>
<td>7%</td>
<td>11%</td>
<td>20%</td>
</tr>
<tr>
<td>Cajicá</td>
<td>22%</td>
<td>35%</td>
<td>67%</td>
</tr>
<tr>
<td>Chía</td>
<td>64%</td>
<td>112%</td>
<td>258%</td>
</tr>
<tr>
<td>Cota</td>
<td>35%</td>
<td>58%</td>
<td>115%</td>
</tr>
<tr>
<td>Facatativá</td>
<td>51%</td>
<td>84%</td>
<td>169%</td>
</tr>
<tr>
<td>Funza</td>
<td>46%</td>
<td>74%</td>
<td>150%</td>
</tr>
<tr>
<td>Gachancipá</td>
<td>29%</td>
<td>47%</td>
<td>91%</td>
</tr>
<tr>
<td>La Calera</td>
<td>13%</td>
<td>21%</td>
<td>39%</td>
</tr>
<tr>
<td>Madrid</td>
<td>33%</td>
<td>53%</td>
<td>100%</td>
</tr>
<tr>
<td>Mosquera</td>
<td>94%</td>
<td>148%</td>
<td>352%</td>
</tr>
<tr>
<td>Sibaté</td>
<td>14%</td>
<td>22%</td>
<td>40%</td>
</tr>
<tr>
<td>Soacha</td>
<td>31%</td>
<td>50%</td>
<td>94%</td>
</tr>
<tr>
<td>Sopó</td>
<td>17%</td>
<td>25%</td>
<td>43%</td>
</tr>
<tr>
<td>Tabio</td>
<td>22%</td>
<td>34%</td>
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</tr>
<tr>
<td>Tenjo</td>
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<td>30%</td>
<td>52%</td>
</tr>
<tr>
<td>Tocancipá</td>
<td>32%</td>
<td>51%</td>
<td>100%</td>
</tr>
<tr>
<td>Zipaquirá</td>
<td>28%</td>
<td>40%</td>
<td>61%</td>
</tr>
</tbody>
</table>

Source: (Silva, 2017)

4 Conclusions

The present work has focused on the metropolitan dynamics of the last 20 years that has governed the formation of a particular region - Metropolitan Region of Bogota; Characterized by a process of spatial structuring that has represented important spatial and temporal changes from the demographic, economic and morphological perspective. Based on the concept of urban hierarchy, identified by Camagni (2005) as a genetic principle of city organization, analyzes about metropolization show that the major changes in the spatial structure of the region have been concentrated in the agglomerations closest to Bogota.

The cities closest to Bogota as nucleus had a greater concentration of the metropolitan population, compared to others of greater size but distant and that have had a tradition of
subregional poles. Although in different strategic planning scenarios elaborated by public entities did not recommend a concentrated growth in the edge closer to the city, the dynamics of population concentration evidences the consolidation of this unwanted scenario, which in turn has affected in a lag of the most distant agglomerations within the hierarchy of the urban subsystem.

A few decades ago, these subregional centers, as previously known, established important dynamics of spatial interaction with Bogotá, despite being the most distant agglomerations in the urban area of the region. Over time, the cities located closer to the city as well as improving their position in the urban hierarchy have presented a more dynamic spatial interaction with the city as opposed to the backwardness of the subregional centers. Theoretically the spatial interaction depends mainly on the distance. Therefore, considering the daily commuting as concrete forms of spatial interaction of the metropolitan type between Bogotá and the surrounding agglomerations, it is found that the distance seems to condition the metropolitan dynamics of the last decades.

In general it can be considered that the urban geographic structure of the region has had a transition of changes in its hierarchy. The relative backwardness of subregional centers in their hierarchical importance (economic, urban and population) can not therefore be considered as a result of a significant increase in distance from Bogotá; Rather, it is explained by a considerable increase in the relative costs of transport, which, although they are a function of distance, depend more on the modes of transport used in daily interurban trips.

In the absence of a metropolitan public transport system, conceived in a more integrated way, with segregated road infrastructure that guarantees a lower variation of transport costs over time, the real transport costs associated with the use of the main modes, grouped under The concept of flexible network and semi-network, have increased significantly in recent years. By sharing the same road infrastructure available between Bogotá and the agglomerations, the general increase in the transportation costs of the main modes of transportation due to congestion is more sensitive. This cost falls directly on the users, which is why these costs affect the residential location decisions of the inhabitants of the region: they tend to be located on the agglomerations that carry lower costs of transportation, that is, those closest to Bogotá.

In this way, the rearrangement in the hierarchy and therefore the adjustment in the spatial structure measured mainly in population terms, has an important explanation in the configuration of the networks that condition the times of the daily displacements between the agglomerations and Bogotá. Trip time, in addition to being a function of distance, is an expression of transport costs from the perspective of demand. With only two modes of transportation based on highways, such as the private vehicle and public transportation based on buses with no system focus, the increase in transport costs from the agglomerations to Bogotá persists and vice versa. This increase in transportation costs has contributed to
changes in the hierarchy of subregional centers (more distant agglomerations) to border agglomerations (closest agglomerations).

This change in hierarchy from the subregional centers to the bordering agglomerations has also characterized the transformations in the patterns of territorial occupation. In the last 20 years the border agglomerations presented the greatest variation of land urbanization. However, this increase in urbanized land was not concentrated in the urban centers of the agglomerations, but in the rural areas located around the roads connecting the region with Bogota; A fact also induced by the permissive local decisions of territorial planning and the logic of the real estate market.

Based on the postulates of the Von Thünen localization model applied to the case of the Region, it can be inferred that the expansive land occupation at the edge closest to Bogota occurred in the analysis period of the present study seems to be a consequence of the Predominance of the flexible network and semi-transport network (as well as of the respective modes of transport that operate them) and the increase in transport costs between the agglomerations and Bogota: the empowerment of urban expansion land and even rural areas as new zones Of urban occupation around the access roads to Bogotá of bordering agglomerations, facilitates access to Bogotá with shorter trip times compared to trip times to more distant agglomerations. A palpable trend in the prospective estimates made by a basic model of Systems Dynamics to a time horizon of 15 years, under the assumption of continuing daily commuting dependent on the flexible network.

The study suggests that the predominance of the flexible network (private vehicle, intercity buses) and semi-network (Transmilenio and intercity buses) has favored more expansive land occupation patterns, along the roads connecting the city with the agglomerations. Contrary to this, if a fixed network were implemented, the effect of the occupation on the ground would tend to be more concentrated around the network stations.

5 References


