ANALYSIS OF THE CAPACITY AND LEVEL OF SERVICE IN VEHICULAR TRAFFIC: THE CASE OF AVENUE GAITAN CORTES IN THE CITY OF BOGOTA

Janneth Pardo-Pinzón[1], Rubby Stella Pardo-Pinzón[1] and Wilson Gordillo-Thiriat[2]
[1]Facultad del Medio Ambiente y Recursos Naturales, Universidad Distrital Francisco José de Caldas, Bogotá, D. C., Colombia
[2]Facultad de Ciencias Matemáticas y Naturales, Universidad Distrital Francisco José de Caldas, Bogotá, D. C., Colombia
E-Mail: jpardop@udistrital.edu.co

ABSTRACT

One of the major objectives indicated in the Local and District Development Plans is the projects related to the adequacy of the road network, which directly influences the use of urban land, this document presents a spatial analysis model where the level of service of a road is determined, This paper presents a spatial analysis model to determine the level of service of a road, based on data collected in the field to identify the state of traffic on the roads, calculate traffic volumes, average traffic, and characterize the level of service of the roads, in order to determine the setbacks and changes in land use that they imply for the surrounding area. Then, using spatial autocorrelation methods, the degrees of association or dispersion of the service and commercial areas impacted by the road setbacks are shown.

Keywords: vehicular traffic, carrying capacity, level of service, spatial patterns.

1. INTRODUCTION

The main roads in Bogota were designed before the consolidation of the urban area and today they constitute a structure for the main economic activities; they are also considered social, economic, and even cultural elements.

The multi-functionality of the roads has generated a change in land use; commercial activity has grown around them, generating an attractive flow dynamic both in terms of occupation of public space, movement of cargo vehicles, a greater volume of vehicular and motorized traffic, which saturate the capacity of the roads and are also mixed with pedestrian and bicycle movements, which makes the roads of a city dysfunctional and inefficient.

To mitigate this problem, government entities are called upon to develop strategies to recover the harmony and proper structure of cities. Land use plans, development plans, mobility policies, and, in general terms, all processes related to urban planning and road network infrastructure need to be reviewed, updated, and implemented (Plan de Ordenamiento Territorial, POT, 2004).

In this sense, several authors have proposed spatial analysis studies for territorial planning, where they describe and contrast information related to local planning, traffic conditions, geometric design and distribution of road infrastructure; as well as those who present research on statistical and geospatial analysis, developing methodologies such as: K Ripley function which is used to analyze spatial patterns or trends of data that are distributed along a network as pointed out by Moreno(2017), and random spatial distribution analyses applicable to traffic accidents exposed by Alvarez *et al.* (2012) and Yamaha (2004); Buzai (2015) and Páez (2005), make a review about the evolution and geoinformatics trends for spatial analysis that can be applied to the field of geography, to the context of urban systems and transportation planning, they highlight the importance of using geographic information systems as a tool for planning; Yan-jia (2011), develops a matrix of correlation coefficients for quantitative analysis of the interrelation between urban area and certain parameters of the technical design of roads; Siabato and Manrique (2019), Zou *et al.* (2010), analyze the characteristics of population distribution through spatial correlation and geostatistical estimation methods, they argue that spatial autocorrelation methods provide indicators through which the spatial behaviors of variables or the degree of association presented by a phenomenon in a geographical framework can be inferred.

The present work seeks to relate spatial analysis methodologies and vehicular traffic analysis to establish a methodological scheme from field data collection to obtain the spatial patterns of land use. For this purpose, factors that indicate road adequacy were parameterized, the land uses present in the study area were established, and the behavior patterns were analyzed using spatial analysis methods. This document is organized as follows: a study of the transportation system vs. urban planning, characterization of the area under study, analysis of the urban spatial organization, the study of spatial patterns, and conclusions and proposals for future research.

2. BACKGROUND

Matizclarifies that there is a "mutual dependence between transportation and urban structure with causal relationships directed in both directions, which is rarely contemplated in the analysis of both urban development and the development of the transportation system" (2005); however, today most major cities continue to present a diffuse, disorderly development with processes of expansion and location of commercial activities in a disjointed manner from the transportation system.

It is understood from public policy that the purpose of road infrastructure design is focused on facilitating the movement of both people and goods and

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given that most commercial activities are located along the main road network, it is necessary to adapt the road network parallel to urban developments. Otherwise, the accelerated dynamics of change in urban development saturate the existing road network, causing mobility problems, environmental pollution, and causing discomfort in people's quality of life (Flechas, 2006).

Article 163 of the Land Use Plan (POT) states that the objective of the mobility system is to develop strategies for an efficient system, associated with a hierarchical road network on which a multimodal transportation system can be designed and articulated to meet the travel needs of individuals and the degree of connectivity throughout the network; an objective that is not met when government entities neglect the monitoring of urban development (Plan de Ordenamiento Territorial, POT, 2004).

Mangones (2007), points out the importance of road hierarchization as a sub-process of urban planning, given that this subsystem should allow adequate movement of people, avoiding congestion and pollution problems. Therefore, one of the main studies to be generated is the definition of the functionality of the types of roads; that is, to identify the types of movements to be performed on them, type of connections, traffic levels, and local access, among others.

Within the Mobility Master Plan (PMM), road hierarchization is a by-product of the urban planning process as mentioned above, which, based on design criteria, allows defining, among other aspects, the cross-section of the road; the PMM divides the system into four hierarchical grids, a Main Arterial Road Grid, which is the basis of mobility, allowing metropolitan and regional accessibility; A Complementary Arterial Road Network that connects the subsystems of the Main Arterial Road Network and facilitates mobility on an urban scale; an Intermediate Road Network composed of road sections that connect the Main and Complementary Arterial Networks, allowing access on a zonal scale; and a Local Road Network that allows access to housing. For this study, a section of the local road network was selected to parameterize and perform the respective analysis.

3. THEORETICAL FRAMEWORK

A. Study Area

One of the road projects contemplated in the District Development Plan 2016-2020, in Agreement 527 of 2013 of the Council of Bogotá and, in Agreement 645 of 2016, was selected as the area under study; it is the Jorge Gaitán Cortes Avenue road project, which through Resolution 0291 of March 2015 issued by the Mayor's Office of Bogotá defined the road reserve zone for the extension of this Avenue located between Boyacá Avenue and Eucharistic Congress Avenue (Planning, 2015). The reserve zone indicated in Resolution 0291 is related to the geographic spaces required for the adequate dimensioning of the new cross-section, as well as the zone for the urban treatments of the pedestrian space, the areas destined for vehicular roadways, and cycle routes among others. However, today the road project has not been built causing countless in conformities to the inhabitants of the sector (Planning, 2015).

Jorge Gaitán Cortes Avenue is in the locality of Tunjuelito and is one of the main roads that make up the road system of this sector along with Boyacá Avenue, 68th Avenue, and highway south, thus allowing connectivity for the distribution of goods and services and the movement of own and external people.

B. General Information about the Study Area

The study area is located in the surroundings of the cadastral sector of San Vicente Ferrer and Fátima, zoning planning unit (UPZ) Venezia locality of Tunjuelito city of Bogota; the sector under study has an expansion of 1444458 m2, of which 100% is urban land, with approximately 282 blocks belonging to stratum 2 (Low), according to the District Planning Secretariat (SDP). Residential land use is predominant in the area at 38.4%, followed by commercial land use at 37.1%, services at 9.4%, commercial at 9.0%, industrial at 5.8%, and others at 0.2% as shown in Figure-1.

Figure-1. Housing typology of the sector.

The type of housing in the area is self-construction; the properties do not have a unified structure in terms of shape and size; the owners produce and shape their environment; generally, the houses were built in stages in a progressive manner, the spaces were built and developed dynamically according to the economic possibilities of the owners.

The area has approximately 38900 lane meters of roads of different typologies, being the V-8 type the most representative of the area and that according to the PMM corresponds to the local road network; based on fieldwork 85% are paved in good condition, 10% are paved in poor condition and 5% are unpaved.

According to the Quality-of-Life survey in 2017, the population density in the area was 180 inhabitants/ha(National Quality of Life Survey, 2017), which represents a considerably populated area if compared to the figures issued by DANE in the 2018 census that show a population density of 44 habitants/ha in Bogota.

4. METHODOLOGY

To determine the capacity and level of service of Avenue Gaitán Cortes, the volume of traffic was studied in terms of demand and time, and gauging was carried out during both off-peak and peak hours to establish traffic

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volumes and determine the capacity and level of service of the avenue. Gauging was carried out at strategic points on the avenue once the points of greatest vehicular congestion were identified: the first at Carrera 33 with 51b south, the second at transversal 30 with diagonal 50a south, the third at transversal 30 with street 55 south and the last at transversal 30 with avenue Boyacá, as shown in Figure-2.

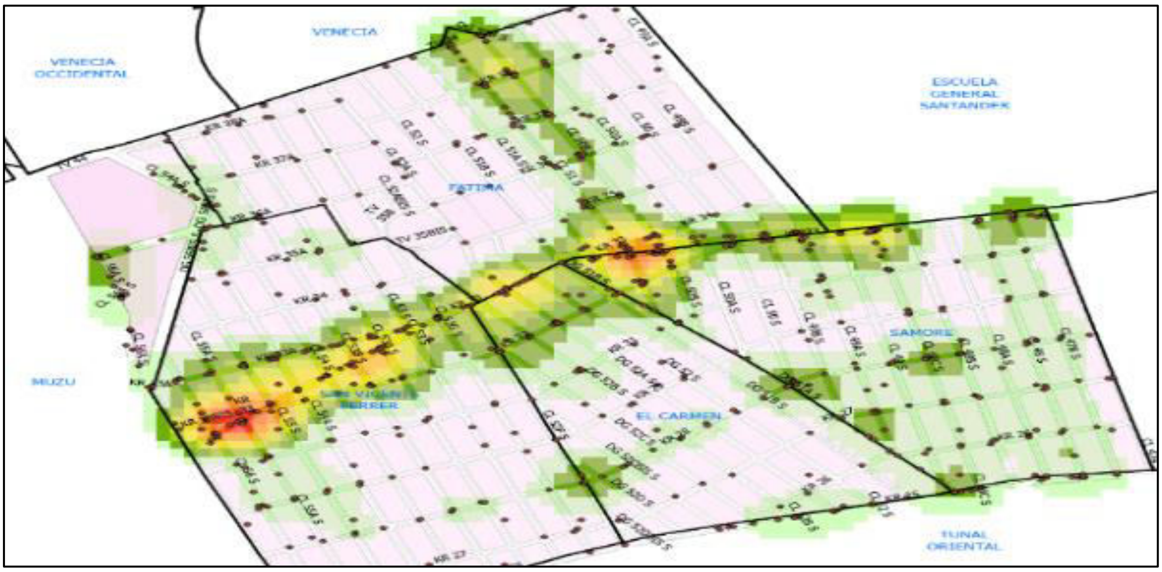

Figure-2. Map of the points of greatest vehicular congestion.

Sampling times were established at 15-minute intervals; at each gauging point, movements were identified and classified based on the traffic engineering studies manual. Vehicle flow behavior was considered for both typical and atypical days in the morning, afternoon, and evening, to determine vehicle flow rates at each gauging point.

In the first point, it was observed that the North access shows higher vehicle flow on typical days at night, in the South access the highest values are found on typical days in the morning, and in the East access the highest flow is found on typical days at night and in the West access there is saturation on typical and atypical days in the morning as shown in Figure-3.

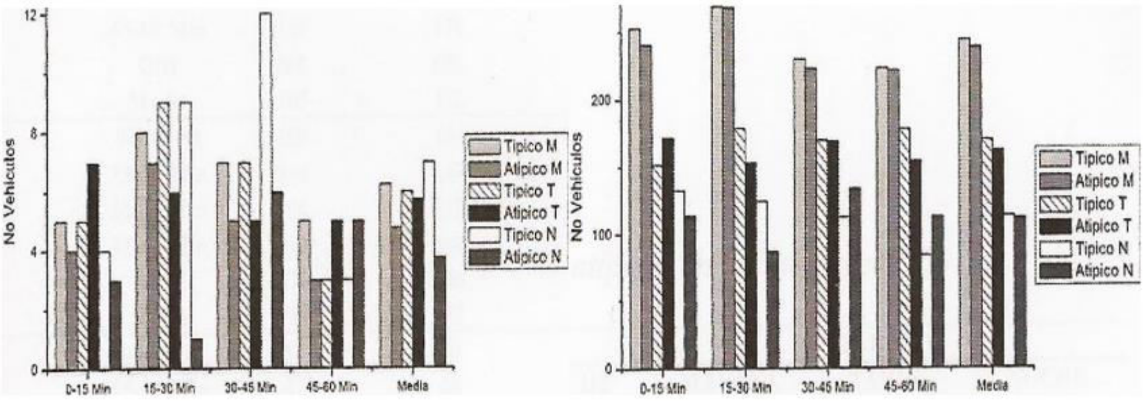

Figure-3. East access and south access of the first gauging point.

The second point for the North and South access showed constant discrepancy values on typical days in the evening hours and atypical days in the morning hours. The rate of behavior for the East access showed saturation in the morning hours, the West access showed different values of vehicular behavior. At the third gauging point, the North access shows high values on typical days in the evening hours, as well as on the East access, while the South access shows high values on typical and atypical days in the morning.

In terms of vehicle composition, movements 1 and 2 show an average volume of 42% of light vehicles, while movements 3 and 4 show 43% and 52% of light vehicles. Motorcycles are an important means of transportation in the area, with percentages of 40% and 42% in movements 1 and 2, and 34% and 21% in movements 3 and 4.

The maximum demand volume and vehicular composition were calculated for the gauging points as shown in Table 1, in order to determine the average traffic

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volume, the capacity level and finally the level of service of Gaitán Cortes Avenue; that is, the operational conditions of vehicular traffic were identified in relation to variables such as speed, travel time, freedom to maneuver and road safety (INVIAS, 2018).

Avenue Gaitán Cortes has a high level of vehicular saturation given that the average traffic volume exceeds the road's capacity. Currently, the level of service of the roadway is type F; that is, an intermittent forced flow with unpredictable characteristics; Table-2 shows the measures for calculating the current level of service.

Once the level of service and the Average Daily Traffic were obtained, a linear regression was calculated to determine the future volumes for the next 25 years; this type of regression was adopted since the projected volumes increase proportionally over time and not exponentially.

Table-1. Data to determine the Service Level.

VOLUMEN HORARIO MAXIMA DEMANDA		
ACCESO NORTE	5134	Veh/4h
ACCESO SUR	4980	Veh/4h
VEHICULOS EN AMBOS SENTIDOS	10114	veh/4h
ANCHO CARRIL	3	m
VELOCIDAD A FLUJO LIBRE	35	km/h
FACTOR DE HORA PICO	198 1.52	
VELOCIDAD MEDIA (vm)	14.48	km/h
TASA DE FLUJO DURANTE EL PERIODO EN QUE FUE MEDIDA LA VELOCIDAD	845	
PROMEDIO DE Q 15 (3-4pm)	198	veh/15min
COMPOSICION VEHICULAR %		
CAMIONES	4.14	
BUSES	30.74	
VEHICULOS LIVIANOS	61.12	
VELOCIDAD BASE DE FLUJO LIBRE (BVFL)	34.3	
Fhv	0.97	
Et (FACTOR DE EQUIVALENCIA A VEHICULOS DE CAMIONES) TABLA	1.1	
Er (FACTOR DE EQUIVALENCIA A VEHIC RECREACIONALES) TABLA	1	
Pt(PORCENTAJE DE CAMIONES Y BUSES)	0.35	

Table-2. Current service level calculation.

VFL (VELOCIDAD FLUJO LIBRE)	Vm	14.48	25.37
	Vf	845	
	fhv	0.97	
VFL	BVFL (Veloc a flujo libre)	34.30	23.80
	Fcb (factor ajuste ancho de carril) tabla	8.5	
	Fa (factor ajuste ptos de acceso) tabla	2	
VP (TASA DE FLUJO)	V (volumen horario ambos sentidos)	2529	1719.35
	FHP (factor hora pico)	1.52	
	Fg (factor de ajuste por pendiente)	1	
	Fhv (factor de ajuste vehiculos pesados)	0.97	
VMV (VELOCIDAD MEDIA DE VIAJE)		25.37	
		1719.35	
		0.8	14.48
PD (PORCENTAJE DE DEMORA)	PBD	77.94	
	f d/na (ajuste por distribuccion direc y zonas sin adelant)	2.40	80.34
PBD (% BASE DE DEMORA)	Vp (tasa de flujo)	1719.35	77.94
	(1-e^(-0.000879*Vp))	0.78	
VP (TASA MAXIMA DE FLUJO DIRECCIONAL)	Vp (tasa de flujo)	1719.35	
	factor	0.6	1031.61
LA DEMANDA EXCEDE A LA CAPACIDAD		1031.61	> 1700 Veh livianos/h/sentido
		1719.35	> 3200 Veh livianos/h/sentido
NIVEL DE SERVICIO (F)	Circulación forzada.		
	Demoras cercanas al 100% (99.995)		
	Velocidad variable 14.4		

The results showed that by the year 2022 in the north access, and south access an average vehicle flow of 1194 vehicles is expected and by the year 2037 an average vehicle flow of 2051 is expected; with these results and according to the classification table of urban roads based on functionality and design criteria (Board, 2010), Avenida Gaitán Cortes is classified as a minor arterial road because it has multiple accesses, connects with main roads such as Av. Boyacá and Avenue del Congress Eucharistic have an average speed of 35km/h with high vehicular and pedestrian density.

Thus, the Avenue is assigned a design category of type IV with three lanes in each direction and a level of service type D, which according to Annex No. 8_Cross Sections of the POT, goes from being a local road network road type V-8 with a minimum width of 10 meters to a complementary arterial road network road type V3-A with a minimum width of 22 meters according to Decree 323 of

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1992 and a total width of 31 meters according to Annex 8- Cross Sections of the POT.

Once the level of services and the projected cross-section were defined based on Annex 8, the current design of the road was determined, identifying the width of the roadway for each section that makes up the road, the width of the sidewalks, and the road separators, among others, as shown in Figures 4 and 5.

Figure-4. Typical section 1 present Boyacá Av. and Diagonal 50ª South.

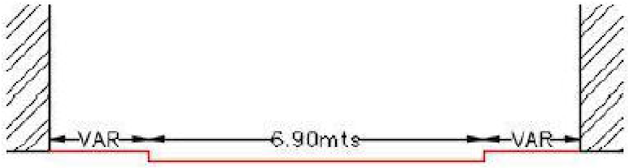

Figure-5. Typical section 2 present Boyacá Av. and Diagonal 50ª South.

Calculations were performed and a new geometric design was proposed based on the projection of vehicular flow, the design was developed using Civil 3D software and contemplates the cross-section of 35.6 m wide including two roadways for three lanes each, a lane for bicycle paths, road separator and sidewalks on the sides of the road. The proposed design and the respective calculations of the cross sections, the designs of circular and vertical curves can be consulted in the development of the degree work "Proposed Cross-Section the Avenue Jorge Gaitán Cortes between careers51ª south and the Avenue Boyacá, barrio Fátima"; the width of the proposed section is shown in Figure-6.

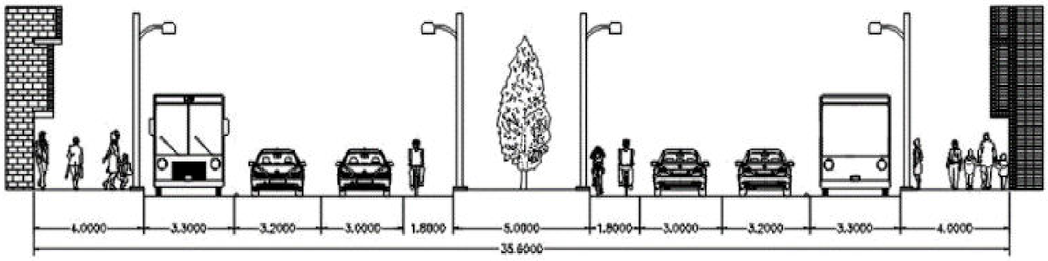

Figure-6. Proposed cross-section.

The change from a cross-section of 6.9 meters and 10 meters in the widest part of the road, to a proposed cross-section of 35.6 meters, implies setbacks and the purchase of land adjacent to the road; therefore, it would generate a high impact on the dynamics of land use in the sector.

5. RESULTS AND DISCUSSIONS

Today the territory has been conceived not as a strictly spatial framework but as a space where diverse social interactions converge, this vision implies that each territory has its own identity based on its urban dynamics. This vision implies that each territory has its own identity based on its urban dynamics; seen from this approach a territory is built from citizen participation and the prioritization of actions in the territories. However, it has been observed that urban dynamics are based on urban activities rather than on the efficiency of space occupation. While it is true that the administration has made progress in its efforts to link both land use planning and transportation system planning, for which different land use regulation mechanisms such as POTs have been implemented, as well as the formulation of infrastructure projects; however, full integration has not been achieved, the expansion of the road network continues to greatly impact the occupation of land use. Phenomena such as road setbacks due to the expansion of the road network generate changes in the economic use of land, in the creation and displacement of urban centers, and in business opportunities.

To determine the impact on land use caused by road setbacks, a multitemporal study was conducted in the area under study to verify the urban dynamics, for which aerial photographs from 1951 and 1985 were obtained and after georeferencing and digitizing, the areas destined for urban land use were obtained as shown in Figure-7.

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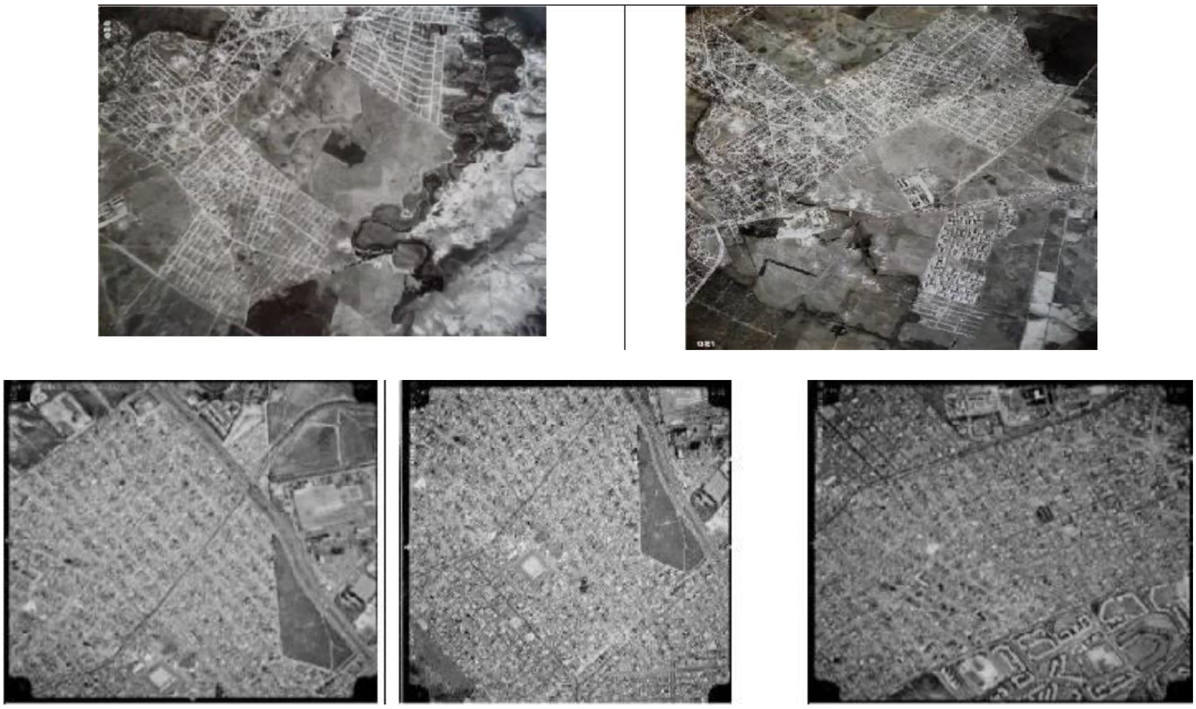

Figure-7. Multitemporal study 1951-1985.

A comparative table of areas by blocks was obtained and is shown in Table-3. It should be noted that for the current period, we worked with information from IDECA, as an official consultation of geographic data.

Table-3. Comparative data by apple for three seasons.

Period	Total, Apples	Area (Ha)
Year 1951	467	72.69
Year 1985	486	243
Year 2019	1184	700.92

It is observed that the use of urban land increased considerably, the change was mainly due to the fact that the area under study was in a preliminary stage of development and today is a transition zone between two business centers. Based on the information gathered through field visits, the current land uses in the area under study are shown in Figure-7, where it can be seen that there is not an adequate distribution of land use, but rather there is a cluster of multiple nuclei, as indicated by Harris and Ullman.

To determine land use trends, the land use change dynamics analysis method was used, which relates the speed of change and land use trends. In the formula, land use change (LUC) is characterized by: ATi1 is the area of land use type I in the initial stage (1) that is transformed; ATi2 is the area of change that is increased; CD is the dynamic degree of land use change and, n is the number of land use types.

$$CUS = \sum_{i=1}^{n} \frac{((ATi1 + ATi2)/CD}{(t2 - t1)} * 100\%$$

To determine the compaction index (CI) of land use, Ying Li's proposal was used, which is expressed by Aj and Pj, which refer to the area and perimeter of a polygon of some type of land use. The Area/Perimeter ratio is then used to indicate the land use compaction index (Li, 2010).

$$IC = \sqrt{\sum_{i=1}^{N} Ai} \ / \sum_{i=1}^{n} Pi$$

The entropy index (EI) can also be quantified to determine the phenomenon of dispersion or centrality of land uses in the geographic space as pointed out by Li (2010).

$$IE = \sum_{i=1}^{n} Pi \log\left(\frac{1}{Pi}\right) / LOG(n)$$

Where $Pi = \frac{Xi}{\sum_{i=1}^{n} Xi}$ where Xi is the value of the variable for each land use and n is the total number of uses.

The coefficients reveal that the degree of compactness of the area is relatively high, which shows that the development of the area has had a growth tending to the formation of decentralized business clusters, the study area shows a segmented territory because the

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economic needs of the owners vary. Land uses such as those destined for commerce show a greater degree of compactness and functional dependence not only because of road accessibility but also because of spatial location; thus, showing that these activities that occupy a larger surface area have had a greater probability of distribution in space, contrary to sectors such as institutional and recreational areas.

The coefficients reveal that the degree of compactness of the area is relatively high, which shows that the development of the area has had a growth tending to the formation of decentralized business clusters, the study area shows a segmented territory because the economic needs of the owners vary. Land uses such as those destined for commerce show a greater degree of compactness and functional dependence not only due to road accessibility but also due to spatial location; thus, showing that these activities that occupy a larger surface area have had a greater probability of distribution in space, contrary to sectors such as institutional and recreational areas. Geographic space is composed of a diversity of elements that are distributed randomly or in the form of agglomerations generating spatial patterns. The study of the variability of these elements in space has generated the development of techniques and methodologies to determine the behavior of spatial patterns. Generally, the techniques applied are cartographic, geometric, matrix elaboration, and digital procedures. It should be noted that a pattern can be the result of different processes, but in turn, a process can give rise to different patterns (Camero, 2006). The objective of spatial analysis is the description of a spatial behavior to deduce which processes give rise to a given pattern.

A spatial pattern related to land use is constituted by the location of each of the elements that compose it, but also by a characterization according to its shape, use, area, and economic destination, among others (Camero, 2006). However, spatial patterns change in terms of time and distance. Thus, the proximity between spatial elements can enhance and favor the environment or generate spatial impacts that deteriorate people's quality of life.

The spatial analysis of patterns as well as their spatial dependence is performed with traditional statistical methods but is also analyzed using spatial statistics with sample data. The application of spatial statistics is carried out because it is assumed that there is a spatial dependence between the selected sample data so that the values of a variable that are measured in different geographical locations have a degree of variability as a function of distance or time; that is, the closer the geographical location, the greater the similarity in the values obtained. Thus, spatial dependence is a function of the value of the same variable in neighboring units. In this order of ideas, distance will be one of the most important indicators to reflect the spatial correlation between spatial objects.

A. Spatial Autocorrelation I Global Morale

Zou *et al.* (2010), present two analysis techniques that allow for establishing spatial patterns: spatial autocorrelation and surface trend analysis. The former makes it possible to determine the spatial dependence between variables, i.e., how the value of a variable in a specific site influences the values of variables in adjacent locations. For this, it proposes to use the global Moran I statistic, because it measures the spatial autocorrelation from a set of elements and an attribute that must be associated to generate a specific analysis, it also evaluates whether the pattern obtained is grouped, dispersed, or random (Zou *et al.* 2010) (Smith, Goodchild, & Longley, 2004). Figure-8 shows the degree of correlation of the variates.

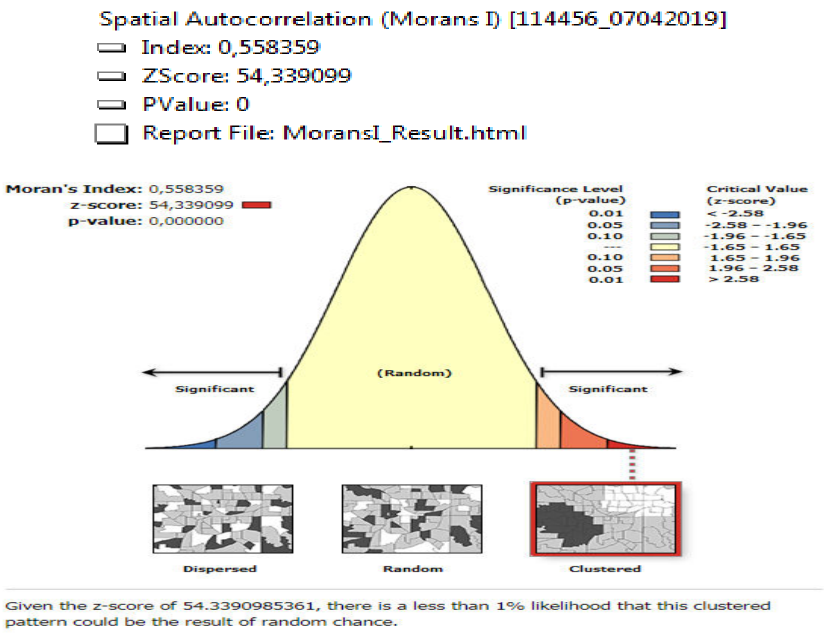

Figure-8. I Moral.

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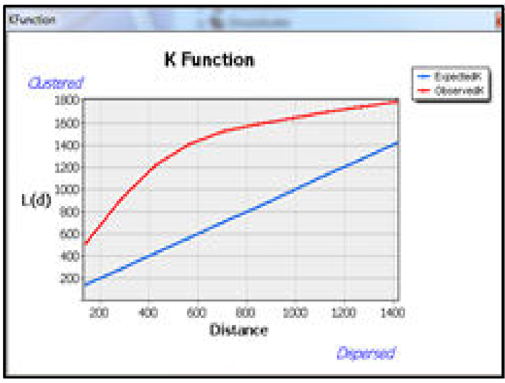
B. Ripley's K-Function

This toolkit generates the spatial autocorrelation but summarizes the spatial dependence over a range of distances. It is given by L(d):

$$L(d) = \frac{\sum_i^n \sum_{j=1}^n Wij(Xi - \overline{x})\,(Xj - \overline{X})}{S^2 \sum_i^n \sum_{j\neq 1}^n Wij}$$

Where n is the total number of features, A is the total area and $K\,i,j$ is the weight. In Figure-9 it is observed that in all cases the observed K is greater than the expected K then the distribution of the business centralities is more clustered than the random distribution; furthermore, since the observed K value is greater than the Diffk value the spatial clustering is statistically relevant for the assumed distance in weights.



OBJECTID *	ExpectedK	ObservedK	DiffK
1	141,251664	518,367708	377,116044
2	282,503327	906,319646	623,816319
3	423,754991	1213,081799	789,326808
4	565,006654	1409,757294	844,75064
5	706,258318	1520,577619	814,319302
6	847,509981	1589,448489	741,938508
7	988,761645	1642,624254	653,86261
8	1130,013308	1693,057854	563,044546
9	1271,264972	1739,572325	468,307353
10	1412,516635	1786,13164	373,615005

Figure-9. Function K Ripley.

C. Kernel Distance

For the second technique, Zou proposes to calculate the kernel density estimate (KSD) as a continuous function that allows analyzing the distribution characteristics of spatial data, because it calculates a value per unit area starting from a point or a polyline, adapting a surface to each point or polyline; where f(s) is the density in the sites s, and r is the radius of investigation or search. Illustration 36 shows some of the results obtained in this case for two of the most representative entities obtained in the field, which are educational centers, chain stores, and health centers. (ArcGis, 2018) (Zou, *et al*. 2010).

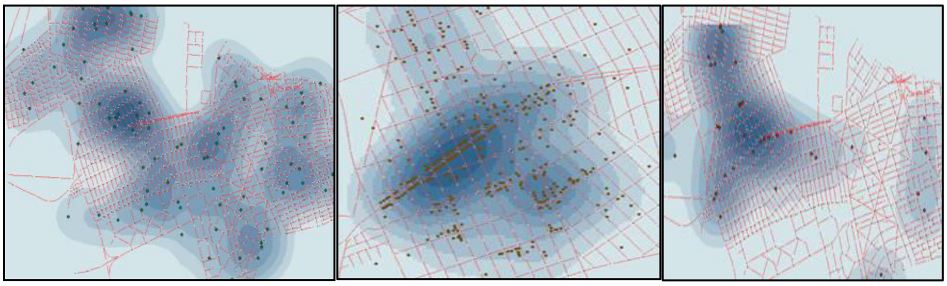


Figure-10. Kernel Distance to Educational Centers, Chain Stores and Health Centers.

6. CONCLUSIONS

The mix of different land uses in the area under study is a clear indicator of the functional nature of the zone; the occupation of urban space is not completely random, but rather presents defined patterns along the most relevant road axes in the sector; most of the uses are dedicated to services and commerce, which are concentrated in a radius of approximately 300 meters around the road axes. However, there are some isolated secondary clusters that denote the zonal change from concentric land use to multicore ecliptic land use.

The application of spatial statistics shows that there is a spatial dependence between the selected sample data; since the values of the same variable measured in different locations close to each other tend to be similar. Therefore, the distance factor is one of the most important factors to reflect the spatial correlation between spatial objects.

To identify spatial patterns in heterogeneous areas it is not possible to use a single estimation method that reflects the spatial behavior, a hybrid methodology must be used both with the use of computer tools and statistical tools that allow referencing the elements and assigning weight factors that reflect true results in the dynamics of the behavior of the variables.

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