Kurdish Studies
December 2022
Volume: 10, No: 2, pp.280-289
ISSN: 2051-4883 (Print) | ISSN 2051-4891 (Online)
www.KurdishStudies.net

DOI: https://doi.org/ 10.53555/ks.v10i2.2900

Evolution And Analysis With An Accessibility Approach Of The Public Bus Transportation System Network In The City Of San Juan De Pasto Using Graph Theory.

Jorge Luis Argoty[1*], Ciro. Jaramillo Molina[2]

[1]Universidad de Nariño, Programa de Ingeniería Civil, San Juan de Pasto, jlargoty@udenar.edu.co
[2]Universidad del Valle, Facultad de Ingeniería, Cali, Colombia, ciro.jaramillo@correounivalle.edu.co

Abstract
The evolution of the public bus transportation road network in the city of San Juan de Pasto, capital of the department of Nariño in Colombia, is analyzed. The structures of the road networks of the bus system are analyzed at different moments in the history of the city of Pasto. Four time scenarios are studied, ranging from the date of creation in 1948 to the present year 2021, and their topological relationships and operating conditions in terms of accessibility are evaluated by means of graph theory. The analysis periods considered for the bus transportation system network are the years 1948, 1965, 2006 and 2021. Each of the networks is evaluated by means of status and network shape indicators to later analyze each indicator individually and between variables, by means of a correlation matrix, obtaining the evolution of the network development, the level of connection, the degree of cohesion, density and coverage of the San Juan de Pasto public bus transportation system network, from its creation to the present.

Keywords: *San Juan de Pasto, Accessibility, Graph theory, Public transportation system.*

1. Introduction

Public transport problems occur at a regional and urban scale and are evident in small, intermediate and large cities, the latter two being more complex. The importance of transport on an urban scale is associated with the efficiency and impact that public transport systems have on the inhabitants of a city; Knowing its evolution over time can become an important element for the analysis of current problems, which are linked to the conformation of the territory and the transport networks that have been implemented over the years in the urban area of cities.

Public transportation is one of the fundamental services in all cities, and especially in Latin America, where it facilitates the accessibility of inhabitants to work, academic, recreational opportunities and social exchange, among others. An efficient transport system contributes to the reduction of territorial problems, economic differences, social inequality, air pollution and territorial inequality; It is an axis for the development of existing areas and for the future expansion of the urban centre of the city. These reasons have made public transport systems hubs of investment and development in Colombia's cities, which at the same time generate strategies whose objective is to improve the quality of life of their inhabitants.

Colombia is a benchmark in Latin America in terms of public policies for urban mobility, through the Integrated Mass Transport Systems (SITM) and the Strategic Public Transport Systems (SETP), as organized and formal models of urban public transport (1). The development of these systems has required investments in infrastructure close to $15 billion pesos (2) between the contributions of the nation and the territorial entities, which translates into the reduction of travel time between 5 and 51 minutes (3). These results have been achieved through interaction and articulation between public and private actors to meet the objectives of the national public transport policy.

The city of San Juan de Pasto, as the capital of the department of Nariño, is categorized as a first category municipality (4), due to its urban population, which is 349,352 inhabitants for the year 2018 (5), and is between one hundred thousand one (100,001) and five hundred thousand (500,000) inhabitants, in addition to its current income of free destination. Comments (4)

In the city of Pasto, the SETP was implemented in 2009, after the National Planning Department identified that transportation was inefficient, since there was an oversupply and this generated that the system did not leave any type of profit, making the quality of this service poor, being unsafe and more expensive. Comments (6)

The Strategic Public Transport System (SETP) for passengers for the city of Pasto, seeks to provide citizens with a better and faster journey, with the modernization of the system and through the implementation of a Fleet Management and Control System. The entity in charge of planning, coordinating, managing, developing and

implementing the system is AVANTE and the operation of the SETP is executed by the Temporary Union Ciudad Sorpresa, thus contributing to a more modern and friendly city and generating intelligent mobility, which improves the quality of life of its inhabitants. Comments (6)

The analysis of the evolution of the network of public bus transport systems in the city of San Juan de Pasto, using graph theory, requires as a first step, to know and analyze the structure of the road networks in different temporal scenarios, corresponding to the development of the public bus transport system network from its creation to the present. For this analysis, tools are used to study the structure of this public transport system, according to the network developed in the city in each era, allowing a subsequent comparison of the same road network at different moments in history. For this purpose, four temporal scenarios are studied, ranging from the inauguration date in 1948 to 2021, where their topological relationships and operating conditions are evaluated in terms of accessibility through graph theory.

The four periods of analysis considered for the bus transport system network are:

- The first scenario corresponds to the year 1948, which corresponds to the year in which the system was inaugurated and according to the existing records, this occurred on October 29, 1948. For this period there were 3 bus routes. Comments (7)
- The second period corresponds to the year 1965, with the operation of the Pasto public transport system in charge of 3 companies. For this period, the Mayor's Office decided to distribute eight routes. Comments (7)
- The third period corresponds to the year 2006, in which the characterization of mobility in Pasto was carried out and was the scenario prior to the implementation of the Strategic Public Transport System (SETP).
- The fourth scenario corresponds to the year 2021, from which the routes of the SETP that is currently operating have been implemented.

For the analysis of the evolution of the network of public bus transport systems in the city of San Juan de Pasto, accessibility measures are used, based on the infrastructure and on the public transport networks that existed and that currently exist, so that when evaluating each of the networks through indicators of the state and shape of the network, Each indicator can be analyzed individually and between variables, through a correlation matrix, obtaining the evolution of the development of the network, the level of connection, the degree of cohesion, the density and the coverage of the network of the public bus transport system of San Juan de Pasto, from its creation to the present.

2. Methodology

This study was developed through the compilation of existing information in the Transit Secretariat of the municipality of Pasto and studies associated with the evolution of the Public Transport System of the municipality. The research approach was quantitative and had as connection measures the indicators associated with the state of the network alpha (α), beta (β) and gamma (φ) and the indices associated with the shape of the network, an index that measures the Degree of Cohesion (Cst), Network Density (ND) and the coverage indicator (S). Variable correlation was performed.

2.1 Collecting information from public transport networks

The starting point was the compilation of information on the transport networks for each of the four proposed scenarios and the plans for each period were obtained.

- **The first scenario, 1948.** It corresponds to the year in which the system was inaugurated, on October 29, 1948, which had 3 bus routes, organized as follows:

- First line: part of the San Pedro hospital, with 15 stops.
- Second line: part of the "El Ejido" wood market sector, with 13 stalls.
- Third line: part of "Chapal" south, with 14 stops.

Figure 1 shows the route of the routes in Pasto. Comments (7)

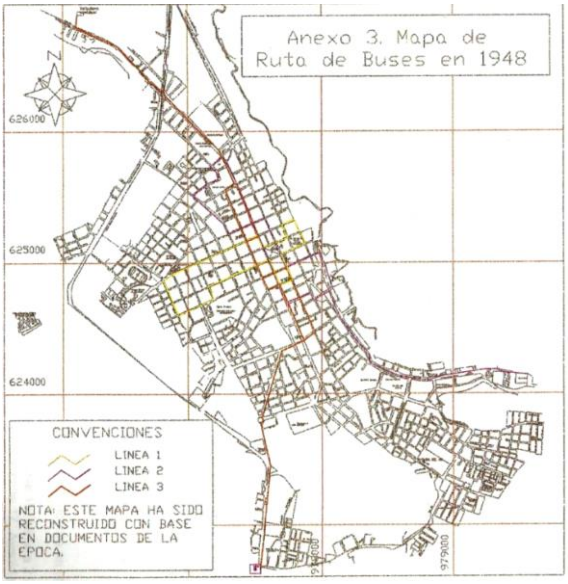

Figure 1. *Bus routes map 1948*

- **The second scenario, 1965.** There is a shortage of vehicles and the coverage of the system is expanded. The operation of the system is in charge of three companies and the mayor's office distributes it in 8 routes, as follows(7):

- Route No. 1: Barrio Laureano Gómez-Barrio San Rafael: Empresa Transportadora Kennedy.
- Route No. 2: Barrio Lorenzo de Aldana-Reten Cano Airport: Empresas Colectivos Ciudad de Pasto.
- Route No. 3: Barrio Santa Bárbara- Barrio San Vicente: Empresa Autobuses del Sur.
- Route No. 4: Barrio Santa Clara-Matadero Municipal: Empresa Transportadora Kennedy.
- Route No. 5: Barrio Mijitayo - Barrio Estrella del Oriente: Empresa Transportadora Kennedy.
- Route No. 6: Reten del Norte-Barrio Obrero: Kennedy Transport Company and Collective Companies City of Pasto. First line: part of St. Peter's Hospital, with 15 stops
- Route No. 7: Barrio el Carmen (Cemetery)-Barrio San Felipe: Empresa Autobuses del Sur.
- Route No. 8: Barrio Lorenzo de Aldana-Villa Lola (intersection of Calle 16 with Carrera Panamericana): Empresas Colectivos Ciudad de Pasto.

Figure 2 shows the route system for this second period.

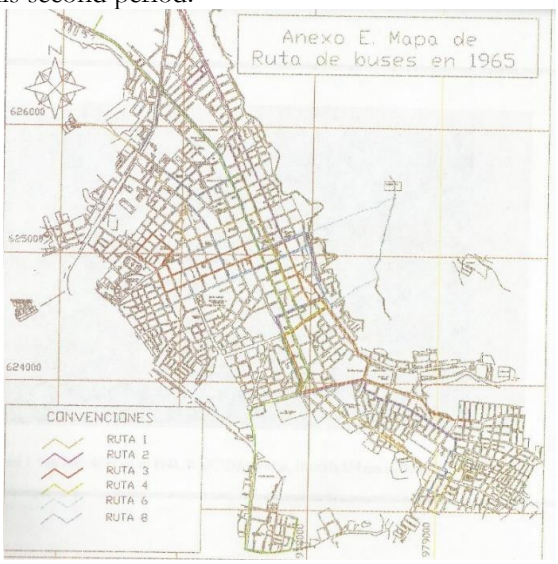

Figure 2. *Bus routes map 1965*

- **The third scenario, 2006.** Between the previous period and during the 70's, 80's and 90's, the municipality of Pasto and the transport companies presented great transformations, due to natural calamities such as floods at the beginning of the 70s, generating relocations of the population over the territory, the growth of the city in the 80s, In the 1990s, the city's growth towards the peripheral areas continued, influenced by fearful experiments in land

use, planning and modernization of the urban perimeter. In the year 2000, the document CONPES 3167: POLICY TO IMPROVE THE URBAN PUBLIC PASSENGER TRANSPORT SERVICE WAS IMPLEMENTED. This policy "consists of improving the urban public passenger transport service through the application of innovative technical and financial tools, with the purpose of strengthening the processes of decentralization, increased productivity, organization and consolidation of cities" [20]. and for the year 2006, the period prior to the implementation of the Strategic Public Transport System (SETP) is presented.
From the report to DNP of the firm Duarte & Gutermán (2006), the 26 routes of the system that were operating for the year 2006 are obtained. These routes were plotted on an updated map of the city of San Juan de Pasto (see Figure 3).

Figure 3. *Bus Route Map 2006*

- **The fourth scenario, year 2021.** It corresponds to the moment from which the SETP routes were implemented, which are currently operating. There are seven strategic routes and sixteen complementary routes. The information of each of the routes was provided by the AVANTE executing unit and verified through the Ruti mobile application

Figure 4. *Mobile application where the routes for the year 2021 are presented*

2.2 Determination of Calculation Variables

The routes were digitized in Autocad for the four scenarios and in each of them, the arcs and nodes for each scenario were identified. Figures 5, 6, 7 and 8 show the plans obtained for each period studied.

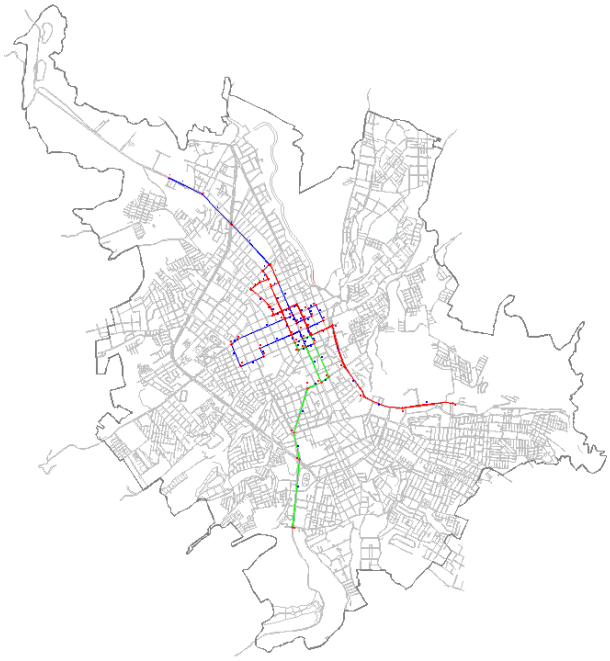

Figure 5. *Public transport network year 1948*

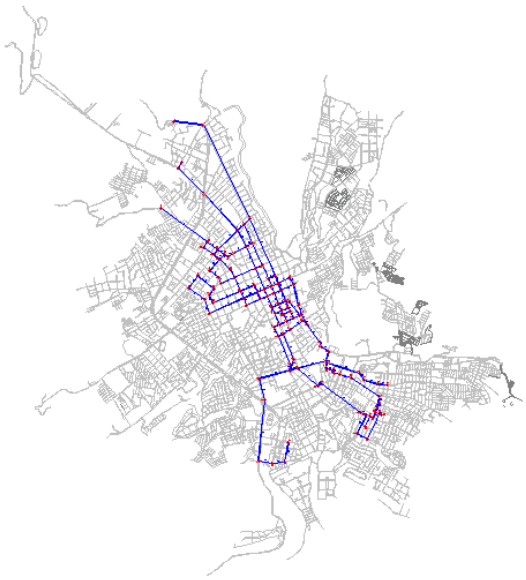

Figure 6. *Public transport network year 1965*

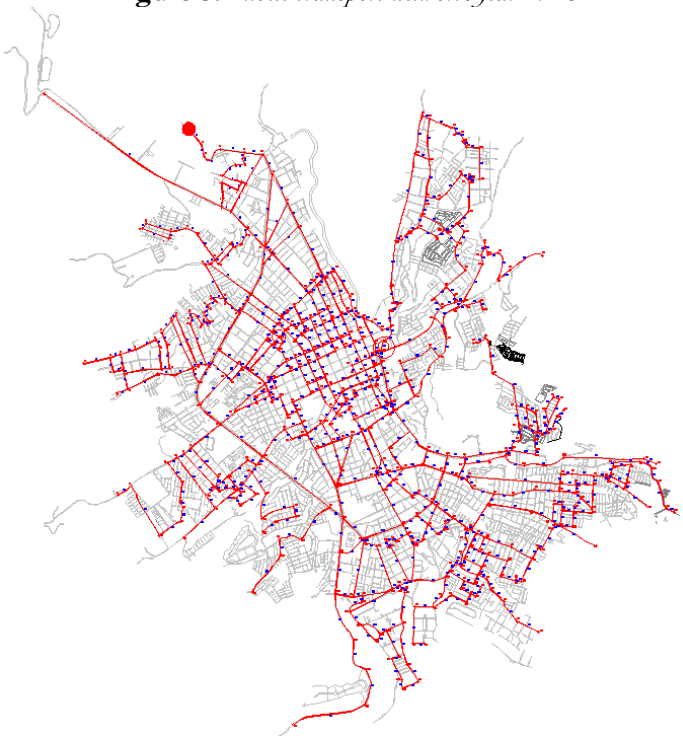

Figure 7. *Public transport network year 2006*

Figure 8. *Public transport network year 2021*

Then, the variables that will allow the establishment of the indicators of the state and shape of the network were determined. These variables are: the urban area in square kilometers, the urban population, the length of the network in kilometers, the number of nodes (e) and the number of arcs (v), for each period of analysis considered, obtaining the values presented in Table 1.

***Table 1**. Study Variables*

Año	Area Urbana (km2)	Población Urbana	Longitud red (km)	e (número de arcos)	v (numero de nodos)
1948	2.30	31.808 (1955)	13.71	54	48
1965	3.87	62.562 (1967)	26.83	139	110
2006	21.02	312.277(2005)	119.81	652	508
2021	24.00	391.242 (2005)	127.66	615	455

2.3 Calculation of network status and shape indicators

The research approach was quantitative and had as connection measures the indicators associated with the state of the network alpha (α), beta (β) and gamma (φ) and the indices associated with the shape of the network, an index that measures the Degree of Cohesion (Cst), Network Density (ND) and the coverage indicator (S). Variable correlation was performed.

The indicators used to analyze the structures of the network are measures of connection, such as the indicators associated with the state of the alpha network (α), which shows the percentage of circuits that the network has out of the total possible:

$$\propto = \frac{e-(v-1)}{(0.5v(v-1))-(v-1)}$$

The beta index (β), which shows the complexity of the network:

$$\beta = \frac{e}{v}$$

The fi index (φ), which represents the percentage of arcs in the network, of all possible arcs:

$$\phi = \frac{e}{3(v-2)}$$

In relation to the indices associated with the shape of the network, the following were analyzed:
The index that measures the Degree of Cohesion (Cst):

$$Cst = \frac{v(v-1)}{2e}$$

Network Density (ND):

$$ND = \frac{L}{s}$$

Coverage Indicator (S):

$$S = \frac{L}{Ns}$$

***Table 2**. Calculation of network status and shape indicators*

Año	Población Urbana	β	α	ϕ	C_{st}	ND	S
1948	31808	1.13	0.0065	39.13%	21	5.96	0.286
1965	62562	1.26	0.0051	42.90%	43	6.93	0.244
2006	312277	1.28	0.0011	42.95%	198	5.70	0.236
2021	391242	1.35	0.0016	45.25%	168	5.32	0.281

3. Results and discussion

To carry out the analysis of the evolution of the network of public bus transport systems in the city of San Juan de Pasto, it was based on the following topics, making use of graph theory:

3.1 Regarding the state of the network

Three indicators are analyzed in relation to the state of the network, the first is associated with the complexity of the network. Using the Beta index, this characteristic of the network is shown based on the connection level, if it takes a value of 1, the network would form a single circuit; whereas if it is less than unity, the networks are disjointed, and if it is greater than unity, the networks are complex. The results obtained for this index are presented in Table 3.

***Table 3**. Calculation of the β Index*

Año	Población Urbana	β
1948	31808	1.13
1965	62562	1.26
2006	312277	1.28
2021	391242	1.35

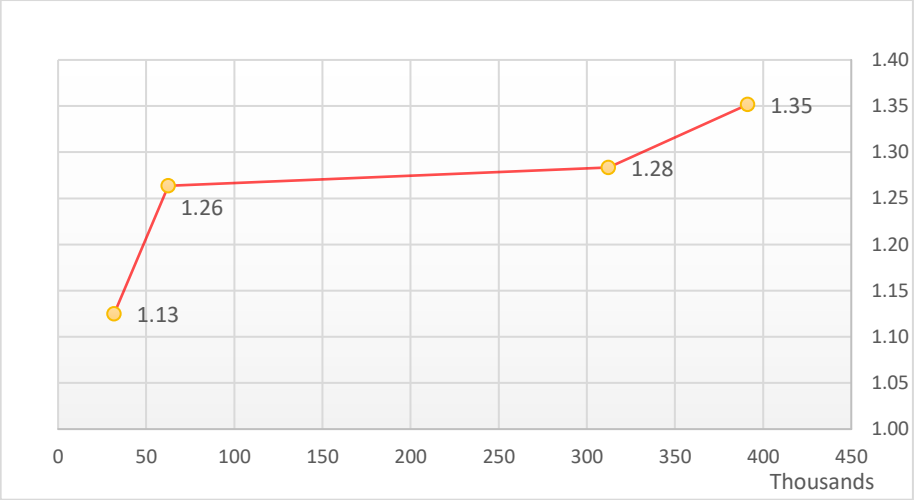

***Figure 9.** Variation of β with population*

According to the results graphed for the periods analyzed, the development of the network in terms of its complexity is observed, from 1948 to 2021. 73 years later, all the networks analysed are defined as complex networks (b>1), given their low levels of connection and development. There is a development of the network in 1965 compared to 1948. On the other hand, there was a low level of development between 1965 and 2006. In addition, there is a greater degree of complexity of the current network compared to previous networks. For the alpha index, which shows the percentage of circuits that networks have, out of the total possible, Figure 10 was obtained.

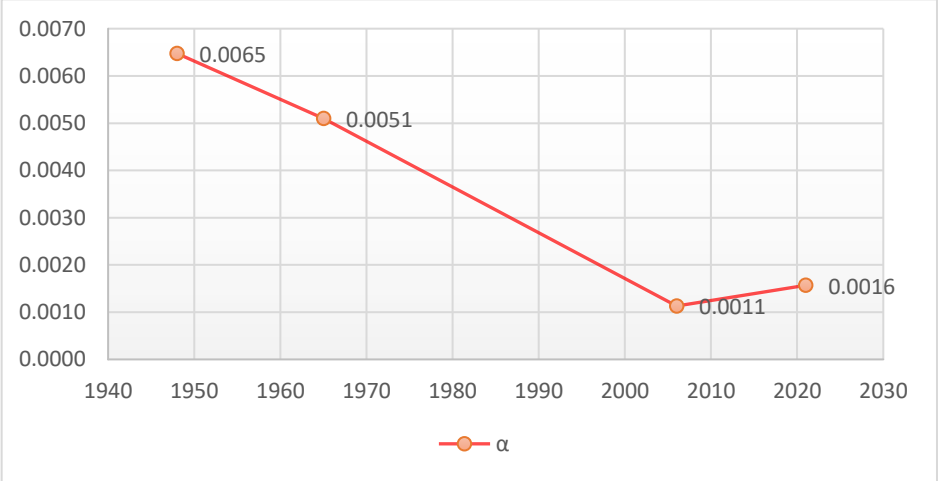

***Figure 10.** Variation of a over time*

In 1948, there was a α≈ 0.65%, the highest value of the 4 periods analyzed; in 1965, it was α≈ 0.51%; in 2006, it was α≈ 0.11% and in 2021, it was α≈ 0.16%, the lowest value of the 4 periods analyzed. In accordance with the above, it can be said that the evaluated networks have a very low percentage of circuits with respect to the maximum possible, indicating that from this perspective they are underdeveloped networks (García, 1979). In the periods analyzed, it is observed that the networks corresponding to each temporal moment have less than 1% of the maximum possible circuits and it is considered that in all the periods analyzed there are networks with a low level of development.

In relation to the index (fi), which relates the percentage of arcs that a network has, with respect to the maximums, the results presented in Figure 11 were obtained:

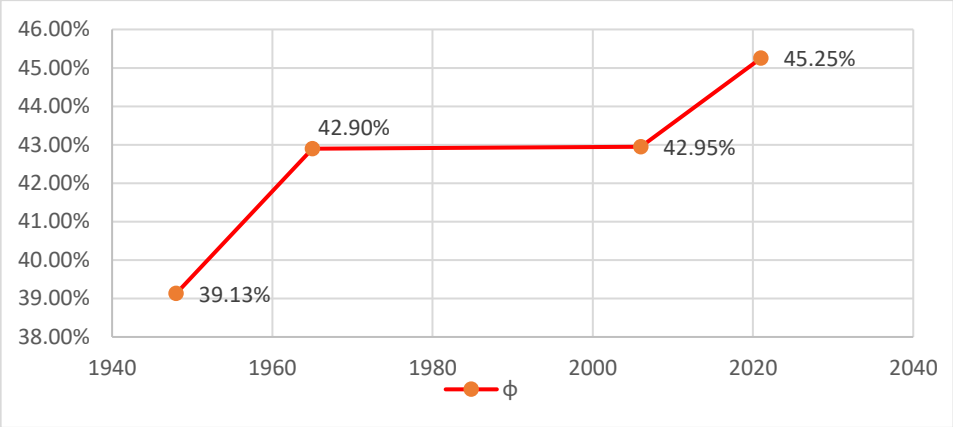

Figure 11. *Variation of φ over time*

The 1948 network has 39.13% of all possible arcs; To be 100% connected, it should have 138, i.e. it is missing 84 arcs (60.87%). The 1965 network has 42.90% of all possible arches; To be 100% connected, it should have 324, i.e. it is missing 185 arcs (57.1%). The 2006 network has 42.95% of all possible arcs; To be 100% connected, it should have 1518, that is, it is missing 866 arcs (57.05%) and the network of the year 2021, has 45.95% of all possible arcs; To be 100% connected, it should have 1359, i.e. it is missing 744 arcs (54.05%). It should be noted that in the networks analyzed, low levels of connection (less than 50% in all the systems studied) are observed.

3.2 Inrelation to the shape of the network

Three indicators are analyzed, the first corresponds to the Index that measures Degree of Cohesion, which allows to identify the cost of the network or the total length of it, making a relationship between the nodes, the links and the greatest number of connections (Potrykowski and Taylor, 1984), the minimum limit is determined as n/2. When the degree of cohesion is closer to zero, it means greater cohesion When the degree of cohesion is closer to one, it means minimum cohesion. Figure 12 shows the results obtained for this indicator.

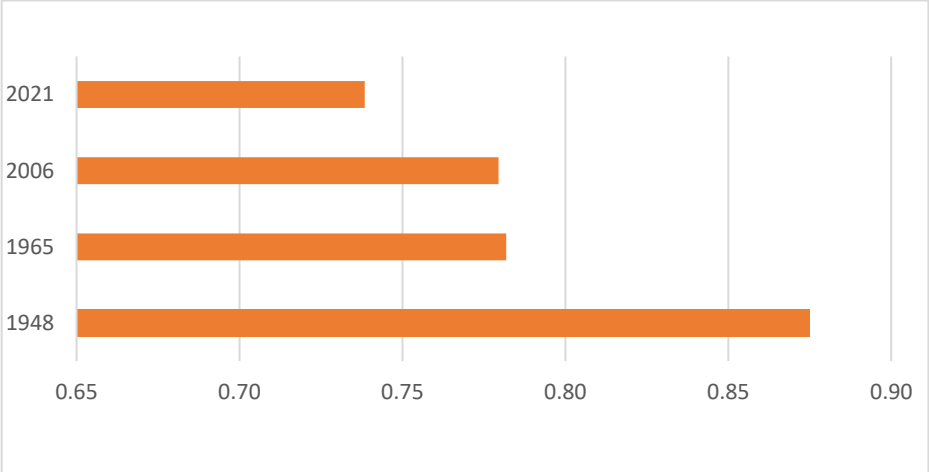

Figure 12. *Variation of Cst over time*

For all the periods analysed, the degree of cohesion is closest to the limit, when it indicates minimum cohesion. The network of the year 2021 is the most connected, cohesive or coherent network, offering more alternatives to its users. The 1948 network is the least connected and least coherent of all, with few travel alternatives for users, due to the lack of corridors in the public bus transport system.

Network density measures the amount of space occupied by a network, taking into account the length of the links and the surface area (Rodrigue, et al, 2013) and the coverage indicator, which allows the total coverage of the network to be calculated, taking into account the length, number of stations and the distance between them. The lower this value, the greater the local coverage of the network (Derrible and Kennedy, 2010). Figure 13 shows the density and coverage results obtained.

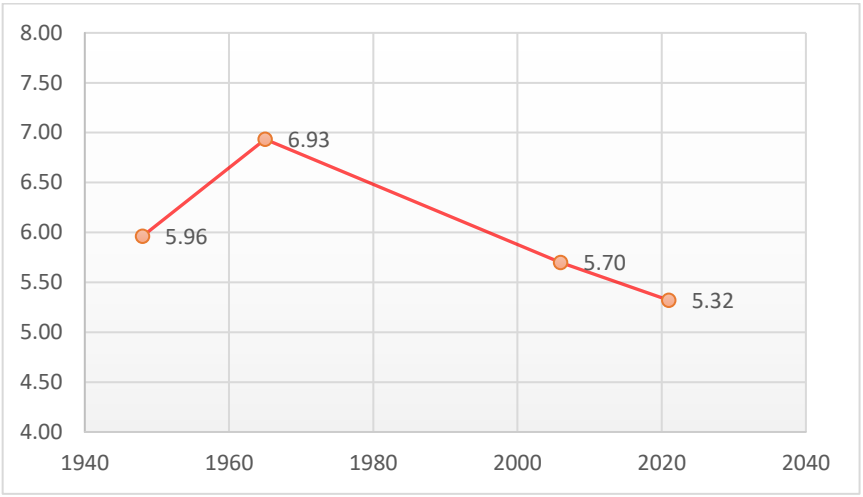

Figure 13. *Density Variation Over Time*

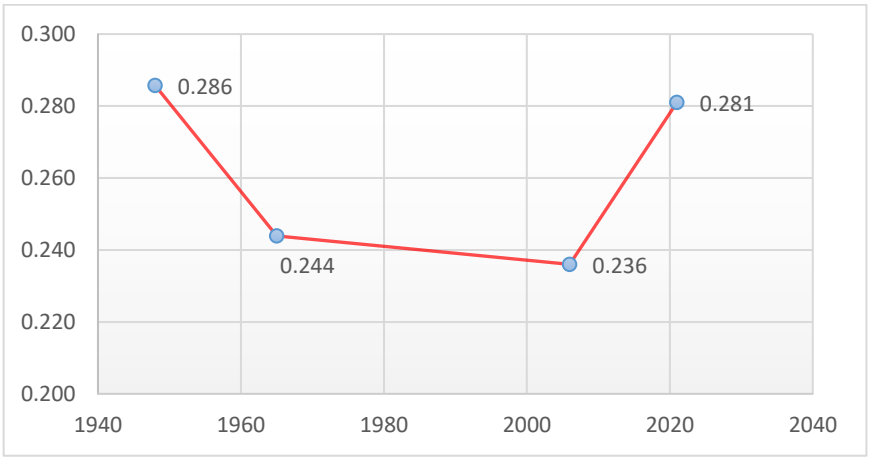

Figure 14. *Variation in coverage over time*

3.3 Calculating the Correlation Matrix

A correlation matrix is developed and for its interpretation, Pearson's correlation coefficient p is used, obtaining the results shown in Table 4.

Table 4. *Calculating the Correlation Matrix*

	β	**α**	**ϕ**	**Grado de Cohesión**	**ND**	**S**
β	1					
α	-0.837	1.000				
ϕ	0.996	-0.790	1.000			
Grado de Cohesión	-0.997	0.798	-0.995	1.000		
ND	-0.312	0.628	-0.287	0.232	1.000	
S	-0.296	0.334	-0.241	0.333	-0.437	1.000

From the above, it can be obtained that the development of the network (α) is related to the network in terms of complexity (β). The connection level (φ) is directly related to the development of the network, in terms of complexity (β) and, to a lesser extent, to the development of the network (α). The degree of cohesion is directly related to the development of the network, in terms of complexity (β) and the level of connection (φ) and, to a lesser extent, to the development of the network (α). Density (ND) is related to network development with (α) and coverage (S) is slightly related to density (ND).

4. Conclusions

In the period of time between the inauguration of the public transport system of San Juan de Pasto, until the present, a greater degree of complexity of the current network is observed, compared to the previous networks, identifying the development of the network in 1965 compared to 1948 and a period of low development of the network between 1965 and 2006. It was possible to determine that in all the periods analyzed, there are networks

with a low level of development, since they have less than 1% of the maximum possible circuits. In the networks analyzed, low connection levels were observed (less than 50% in all the systems studied).
The current network, from 2021, is the most connected, cohesive or coherent network, offering more alternatives to its users The 1948 network is the least connected and least coherent network of all, with few travel alternatives for users due to the lack of corridors in the public bus transport system.

5. References

(1) Urbano, Camilo; Pardo, Carlosfelipe; Olivares Medina, Claudio; Iguavita, Laura. Ed, Colombia's Public Transport Systems, Challenges, Opportunities and Financing Strategies. Ministry of Finance and Public Credit. National Development Finance. (2019).
(2) Ministry of Transport, Executive Report 2010-2018. Sustainable Urban Mobility Unit, (2018).
(3) Fedevelopment. The integration of urban transport systems in Colombia: a reform in transition. (2013)
(4) Decree - Law 2106 of 2019
(5) National Administrative Department of Statistics (DANE). National Population and Housing Census (2018)
(6) Hidalgo Ruiz M. Evolution and diagnosis of the public transport system in Pasto (SETP) [Undergraduate thesis on the internet]. Bogotá: Universidad Santo Tomás. [Cited 2021 May 08].
(7) Rosero Ortega L. History of national transport and its links with regional transport, particularly with urban transport in the city of Pasto between 1948 and 1965. Pasto, 2003. Bachelor's thesis. University of Nariño. Faculty of Human Sciences. Social Sciences Program