Bulletin of Geography. Socio-economic Series, No. 51 (2021): 95–108
http://doi.org/10.2478/bog-2021-0008

ISSN 1732–4254 quarterly

BULLETIN OF GEOGRAPHY. SOCIO–ECONOMIC SERIES

journal homepages:
https://content.sciendo.com/view/journals/bog/bog-overview.xml
http://apcz.umk.pl/czasopisma/index.php/BGSS/index

The impact on urban accessibility conditions of a proposed cableway line in the city of Manizales, Colombia

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How to cite:
Montoya, J.A. Aguilera, J.C. and Escobar D.A. (2021). The impact on urban accessibility conditions of a proposed cableway line in the city of Manizales, Colombia. *Bulletin of Geography. Socio-economic Series*, 51(51): 95-108. DOI: http://doi.org/10.2478/bog-2021-0008

Abstract. Due to the increased tendency to use private transport in urban areas of Manizales and Villamaría municipalities, it is intended to include alternative modes of transport that are more time-efficient and environmentally sustainable to improve the inhabitants' quality of life. This article aims to analyse the inclusion impact of a sustainable public transport system, such as a new cableway line in the city connecting the Central Business District (CBD) with Ciudadela del Norte district, measuring overall average accessibility for the current and future scenario. This establishes the average travel time and the savings in terms of time shown as a percentage that these modes of transport would create in the population displacement and also which inhabitants are the most likely to benefit.

Article details:
Received: 19 August 2020
Revised: 15 October 2020
Accepted: 22 December 2020

Key words:
Geographic accessibility,
cableway,
geostatistics,
travel time,
coverage

Contents:

1. Introduction

In recent years, the significant increase in number of vehicles worldwide has become more important, as delays in people's regular travel become apparent. Colombia, a country of just under 50 million inhabitants, with 14,137,795 vehicles according to the statistics of the National Registry of Transit (RUNT) up to August 2018, is not oblivious to the problem caused by excessive motorisation. Manizales, an intermediate city in Colombia, had a population of approximately 400,000 inhabitants in 2018 (Departamento Administrativo Nacional de Estadística [DANE], 2018) and it is bordered by Villamaría, which has a population of approximately 60,000. Due to their proximity, both municipalities daily exchange a large part of their population in the development of different activities. They are also located in the central mountain range – a fact that is reflected in the steep topography (Robledo, 1996). Manizales is divided into 12 districts, which are clusters of neighbourhoods with similar characteristics, among which is the Ciudadela del Norte district that is the region intended to carry the route of the cableway and that therefore will be the centre of study. Villamaría will also be taken, as a district with 13 neighbourhoods.

La Ciudadela Norte district has the largest population in the city, with 63,625 inhabitants as at 2018 (DANE, 2018), representing 16% of the Manizales population. Furthermore, it has, at the socio-economic level, strata between one and three, with stratum two prevailing. Strata are socio-economic classifications ranging from one to six, being the 1st and the 6th the highest according to purchasing power of the population, the characteristics of housing, and the quality of public services (Perilla et al., 2018), where strata one to three are the subsidised strata in the latter area and strata 5 and 6 are responsible for providing these subsidies.

Due to these characteristics of the population, which depends mostly on public transport and where the cable transport system is intended to be included, the aim is to determine the time savings in terms of the displacement of the studied population and identify which area or population will benefit most from the project. So, will the new cableway

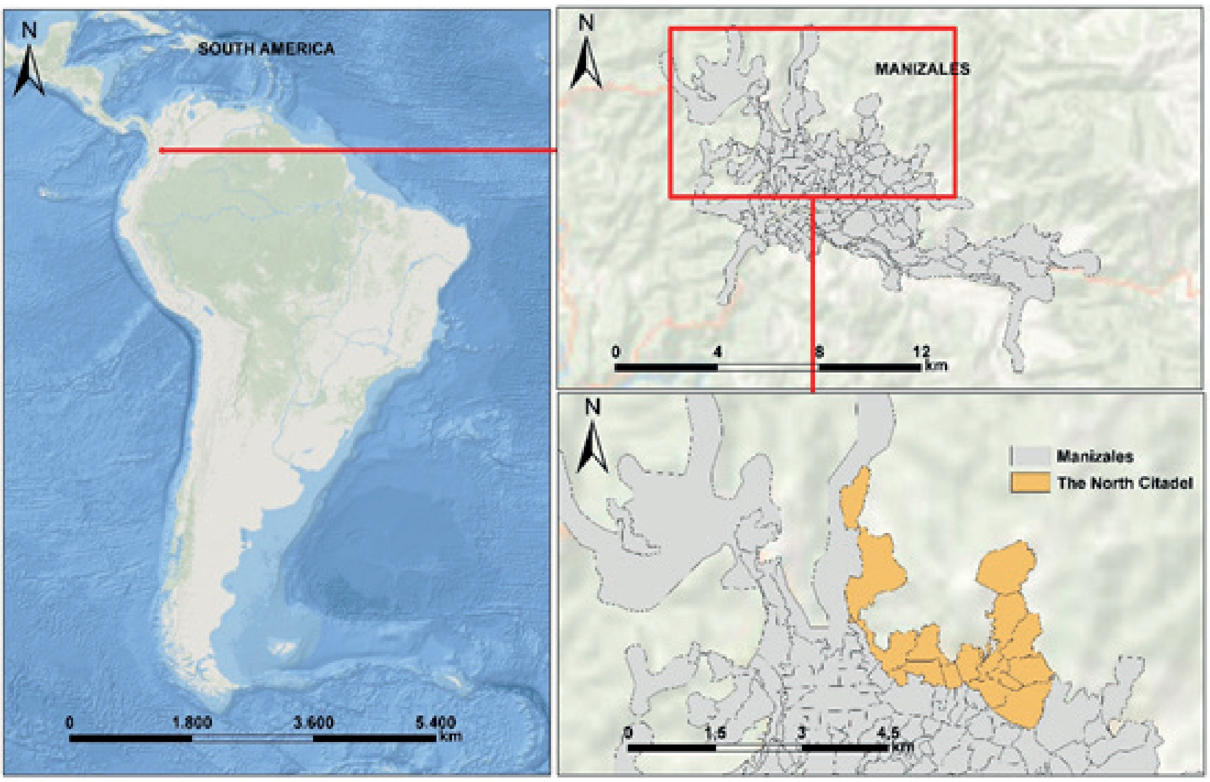

Fig. 1. Geographic information. Source: own elaboration based on ArcGis Online tools

line improve travel times and, if so, what percentage of the studied population will benefit?

2. Vehicle fleet

Over the past decade, the rate of population and vehicle-fleet growth has made a big difference. Manizales' population has grown at a rate of less than 0.4%, while the number of cars has experienced growth with an average rate of about 11% (Fig. 2). This evidences the number of vehicles per 1,000 inhabitants in the years 2009 to 2017, showing an increase of 202 to 425 vehicles, representing an increase of more than 110% in just eight years (Manizales Como Vamos [MCV], 2018).

Due to the high number of motor vehicles each year in Colombia, alternative means of transport have been implemented that are environmentally friendly, such as cable transport systems. This system was traditionally implemented for tourist purposes around the world until the first cable transport system was launched in the city of Medellin (Colombia) in 2004 (Leiber and Brand, 2012). From that moment on, thanks to the success achieved in Medellin, there has been interest in other cities to replicate the insertion of this type of infrastructure to improve mobility.

Manizales, a city with similar topographical characteristics to Medellin, implemented its first cableway line five years later (2009), building line 1 with an extension of 2.1 kilometres between the city centre and the transport terminal – a line consisting of three stations. The Line 1 project was not very successful due to the low flow of passengers, which triggered a financial crisis in the entity responsible for managing the system as it was operating at a loss. This was until 2014, when line 2 of the Manizales air tram was opened with an extension of 720 metres (Manizales air cable, 2018). This line extended the route of Line 1 to the municipality of Villamaría, ostensibly increasing the flow of passengers, so that the system went from operating at a loss to generating profits (El Tiempo, 2015), in addition to improving the mobility of both municipalities.

Taking into account the above, the administration decided to construct and implement more cableway line systems, one of which is the line foreseen in the land-use plan for the route between the city centre and the Ciudadela del Norte district (Manizales City Hall, 2017) (Fig. 3). Despite the existence of other modes of transport with greater capacity, such as light rail (De Bruijn and Veeneman, 2009), this selection considers the topographical conditions, as well as the distance between the areas of direct intervention by the overhead cable (Ciudadela del Norte – City centre), which would make a railway system connecting them non-viable. Thus, the evaluation of the selected cableway line will be the subject of this article, where its evaluation and analysis will be carried out to determine how beneficial this infrastructure can be.

On the other hand, the studied cities have a public transport system composed of seven companies and 66 routes distributed in the urban area of Manizales and Villamaría. This transport system also op-

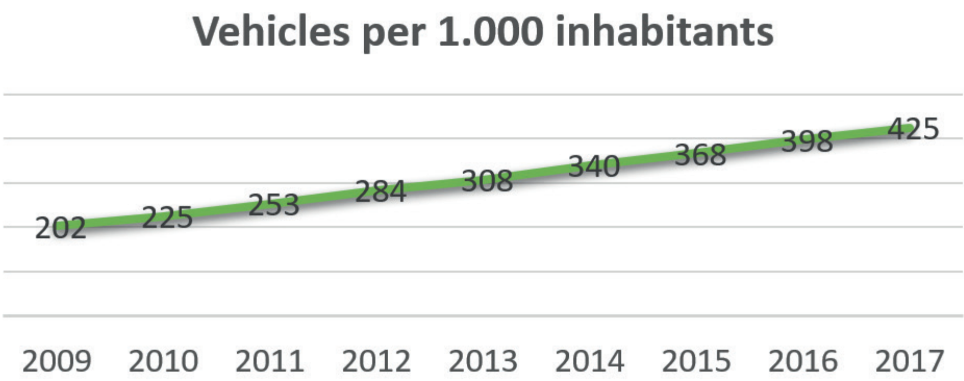

Fig. 2. Number of vehicles per 1000 inhabitants in the city of Manizales. Source: self-made. Data obtained from the Quality of life report Manizales 2018

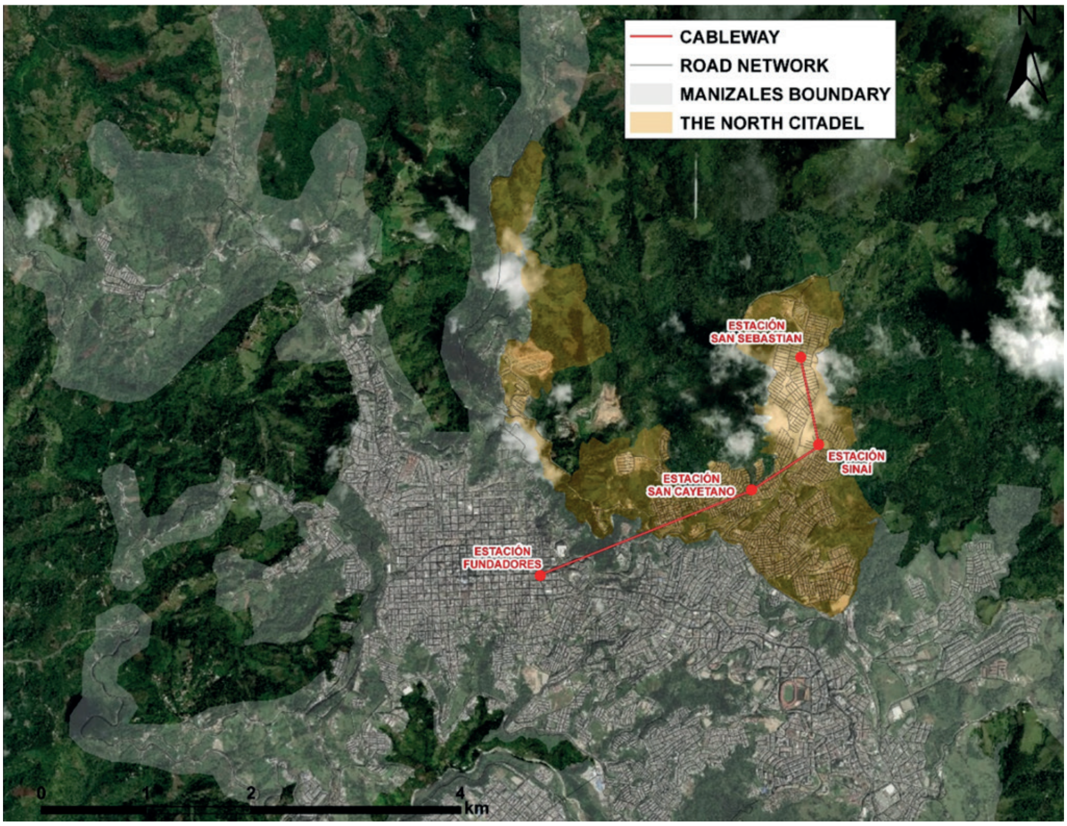

Fig. 3. Cable transport system layout. Source: Self-made

erates in the form of affiliates, which creates strong impacts on the quality of service and the cost of use, resulting in a low perception of citizen satisfaction (MCV, 2018). This could trigger the same trend in the cities of Colombia where there are strategic transport systems (SETP) that show a clear decrease in passengers transported, due to the failures of policies to promote public transport making the population migrate to private transport (Escobar et al., 2017).

3. Accessibility

Accessibility is one of those concepts with as many definitions as authors who have studied it. As Gould said, "Accessibility is an elusive notion, one of those common terms that everyone uses until they face the problem of defining and measuring it" (Gould, 1969). Therefore, the concept has changed over the years, and the perspectives that the authors have given it according to their approach. One of the first influential authors in the study of accessibility stated that accessibility was the "potential of opportunities for interaction" (Hansen, 1959). Since then, other authors have described accessibility as "the ease of reaching any area of activity using a given transport system" (Dalvi and Martin, 1976) and "the benefits provided by a transport system" (Ben-Akiva and Lerman, 1985; Hawthorne et al., 2015)

Accessibility will be considered as a measure of the ease of communication offered by a network, with a certain mode of transport, on foot or by car (Escobar and García, 2012; Vilcea and Avram, 2019). Therefore, it is closely related to the existing infrastructure and the intrinsic characteristics of it, taking into account that greater infrastructure is not always accompanied by greater accessibility (Nogales et al., 2002). It is also related to land uses and how the facilities are distributed in the network studied (Geurs and Ritsema, 2001). Accessibility is classified according to Ingram as Relative, Integral and Global. Relative accessibility refers to the degree of connection between a pair of nodes located on the same surface (Ingram, 1971). Integral accessibility is defined as the degree of interconnection between a given node with a series of nodes located on the same surface (Ingram, 1971). Finally, Global accessibility refers to the degree of interconnection between all existing nodes in an area among them (Izquierdo de Bartolomé and Aymerich, 2001).

In practice, when accessibility is evaluated, depending on the approach to measurement, there are four basic perspectives (Geurs and Van Wee, 2004): infrastructure-based measure, location-based measure, person-based measure and utility-based measure. This research will focus on global accessibility, as a transport supply model, based on the infrastructure that primarily analyses the level of service offered by certain transport infrastructures, as it is intended to determine what the change in the intensity of the accessibility measure of a given network is, given a current scenario and a scenario in which the network is modified with the insertion of a new transport infrastructure. However, as Geurs and Van Wee point out, measurement using this approach does not meet some theoretical criteria such as land-use and individual characteristics (Geurs and Van Wee, 2004).

4. Methodology

The methodology begins with data entry and consists of six subsequent stages, each of which has a series of steps described below and shown in Fig. 4.

Georeferencing, updating and achieving the road network

As a first step, Manizales road network was georeferenced through previous research carried out in the city (Escobar and García, 2012b), which consists of vehicle corridors composed of nodes and arches (Horňák et al., 2015) that, for the purposes of the project, must be complemented, since it is intended to make an analysis of the state of public transport. Therefore, pedestrian corridors such as stairs, pedestrian bridges, and narrow paved roads are included, as, through them, people access public transport routes on foot. The network complement was made for both the current and future scenario network, which included links belonging to the pro-

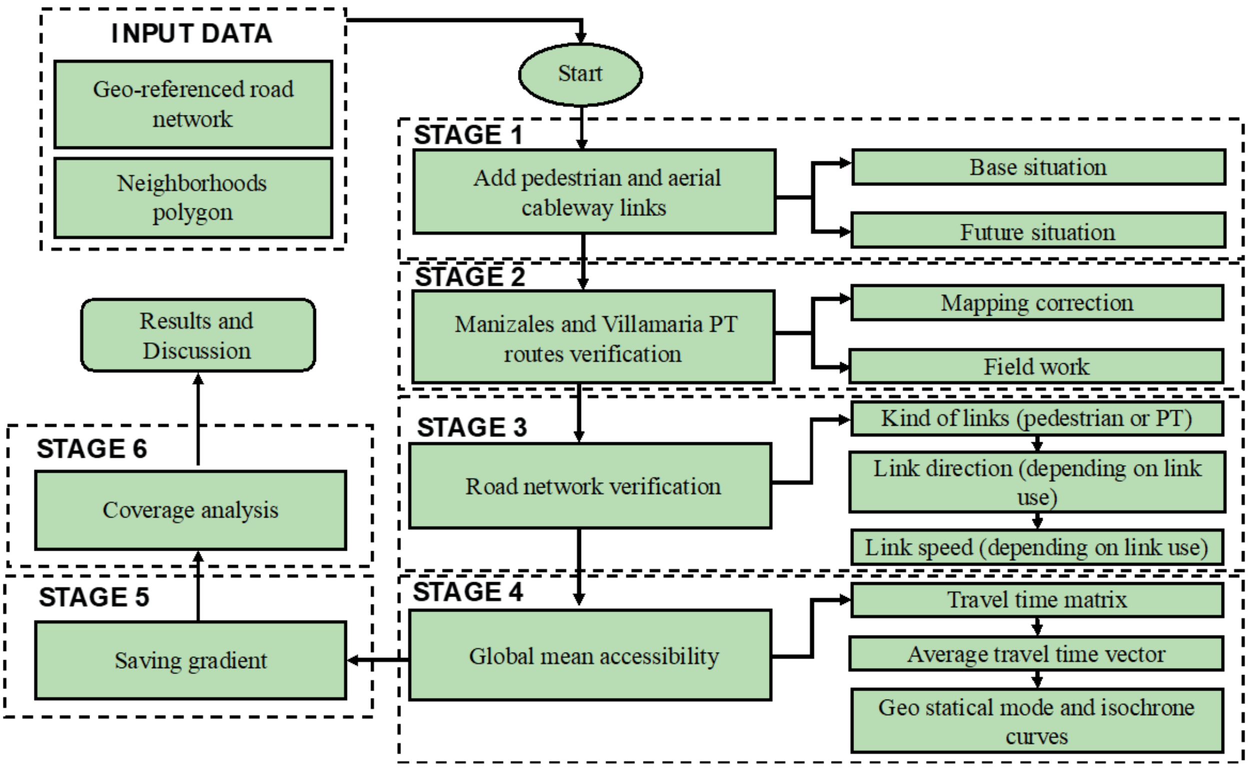

Fig. 4. Research methodology. Source: self-made

posed air cable infrastructure between the city centre and Ciudadela del Norte.

Update Public Urban Collective Transportation Routes

Information was requested from the Secretaría de Transito y Transporte de Manizales (STTM) to update the urban public transport routes in the study area. This government entity regulates mobility in the city of Manizales, where all the resolutions that empower private companies to provide the public transport service were obtained by indicating the line number, name, route and frequency, and type of vehicle to be used. Besides, the STTM has a georeferenced file with the public transport routes that were outdated. Therefore, with the creation of a checklist based on the route resolutions, it proceeded to review the routes that were missing from georeferencing or that had errors in their path. Through fieldwork, some public transport routes were updated using Global Positioning Systems (GPS), allowing GIS software to capture all public transport routes the city has.

Road Network Validation

With up-to-date information on public transport routes, it was determined which road network arches were used exclusively by public transport vehicles (including air cable). The other arches were classified as pedestrian, as it is understood that users must walk through the remaining arches to approach the transit network. On the other hand, they are characterised by the sense of the road, where, if it is pedestrian, it retains the double designation. Otherwise, the direction of movement of the Transport System is preserved (Escobar and García, 2012).

Subsequently, operational speeds are ascribed to the links according to the determined use: 4.32 km/h for the pedestrian links, given by previous research carried out in Manizales (Zuluaga et al., 2018) and 17.5 km/h for the links that are used by the transit network (Muñoz et al., 2016), adjusting the values given by other research for the steep topography presented by the two municipalities. These studies were carried out by fieldwork within the framework of the Sustainable Mobility Research Group of Universidad Nacional de Colombia, Manizales. On the other hand, the current cableway line has a speed of 3.8 m/s (13.68 km/h), according to official data from the company in charge of its operation (Cable Aéreo Manizales, 2018), which was also verified over the cableway's entire route. It is assumed that the operating speed of the cable car in the future scenario will remain the same (13.68 km/h) since the technology of the cableway will have no changes. Likewise, the use of public transport speed is kept constant to exclusively assess the impact caused by the implementation of the new cable line.

Global average accessibility

The average travel time used as an accessibility measure is obtained by dividing the speed and length of each existing link in the infrastructure network. The shortest path is then defined using The Dijkstra algorithm, which considers the existence of multiple paths between an origin and a destination (Equation 1), based on the existing road network, subject to any road restrictions that may exist (Brandes, 2001). In this sense, the intersection set of the network is linked as calculation nodes, and the arches are subdivided into sections of less than 80 metres, considering the length of the urban roads of the city. The Dijkstra algorithm use is contained within the TRANSCAD tool in the "multi-paths" extension. In the calculation of travel times, penalties for right or left turns have not been taken into account due to the high degree of the complexity required to add values per turn to public transport links and others to pedestrian links. The experience of other research was also taken, showing that the use of turn penalties is an issue that can be omitted since if one area is accessible, it will continue to be so whether or not modelling penalties are used (Yiannakoulias et al., 2013). On the other hand, taking into account that the cable transport system does not operate as a mode integrated into the bus system, the transfer time between modes is defined by the running time in the arches between the two modes of transport. Once the travel time matrix is calculated between all the source and destination nodes in the road network, the average travel time vector for each node in the network (Equation 2) is calculated, which is an average of the routes from node i to the rest of the j nodes, where n is the number of existing nodes in the network (Cardona et al., 2018).

$$Tv_{ij} = min\{Tv_{ij_1}, Tv_{ij_2}, \dots, Tv_{ij_m}\}, m = Roads \quad (1)$$

Where Tv_{ij} is the shortest of the travel times from node i to node j, within the set of values Tv_{ij} of the multiple available paths.

$$\overline{Tv_i} = \frac{\sum_{j=1}^{n} tv_{ij}}{n-1} \qquad i = 1, 2, 3, \dots, n \qquad j = 1, 2, 3, \dots, n \quad (2)$$

By having the average travel time's vector with the coordinates of each of the nodes, a geostatistical calculation is performed to obtain the isochronous coverage curves for global mean accessibility using the ArcMap tool in the extension of the Geostatistic Wizard, which will be the proxy and therefore the visible face of the previous calculations. This geostatistic calculation will be made by spatial interpolation with Kriging's ordinary method, as it takes less calculation time and allows accurate results (Kameshwara and Narayana, 2015). This ordinary Kriging uses semilinear variogram, which takes the shortest distances between existing data (nodes) achieving better predictions over short distances (Giraldo, 2002; Wakernagel, 2003). The method was selected based on previous research in predicting demand for the public transport system (Prasetiyowaiti, 2016).

Savings gradient between the future scenario and the current one

After calculating the isochronous curves in each of the scenarios (current scenario and scenario with the inclusion of the cable type system), the savings gradient between the two scenarios is calculated (Equation 3). The saving gradient (SG) percentage is related to the resulting global accessibility between the current situation (CS) and the future situation (FS) (Perilla et al., 2018). This calculation is derived from subtracting the average travel time vectors and is shown as a time saved percentage, which implies better global average accessibility if it is positive and deterioration if it is negative.

$$SG\ (\%) = \frac{CS - FS}{CS} * 100 \quad (3)$$

Coverage analysis

Coverage analysis considers the different average travel times of the isochronous curves for both scenarios, the savings gradient and the neighbourhood polygon with sociodemographic information such as population, area, socio-economic strata, and several dwellings.

5. Results and discussion

Global average accessibility in the current and future scenario

The isochronous curves of the global average accessibility for the current scenario, calculated every two minutes, are shown in Fig. 5, where it is evident that the network average travel times are between 17.4 and 114 minutes. In the centre and in Avenida Santander area, which is the main avenue of Manizales, less than 20 minutes average travel time values are shown. In the south of Villamaría, the whole area is covered in less than 45 minutes, which reveals the lack of corridors connecting Villamaría and Manizales. The highest values are found in the eastern and western sectors, where values of up to 114 minutes are presented. These values are mainly due to the distance of the sectors from the urban centre and the low level of road development. In the northern area, where the cable transport system is to be introduced, values of between 20 and 35 minutes are shown, with the lowest values in this sector being those closest to the urban centre.

Figure 6 shows the isochronous curves of the future scenario, in which the collective public transport network such as the pedestrian network is evident, and highlights the overhead cableway lines, with lines 1 and 2 and line 3 proposed to improve the Ciudadela del Norte district accessibility. An

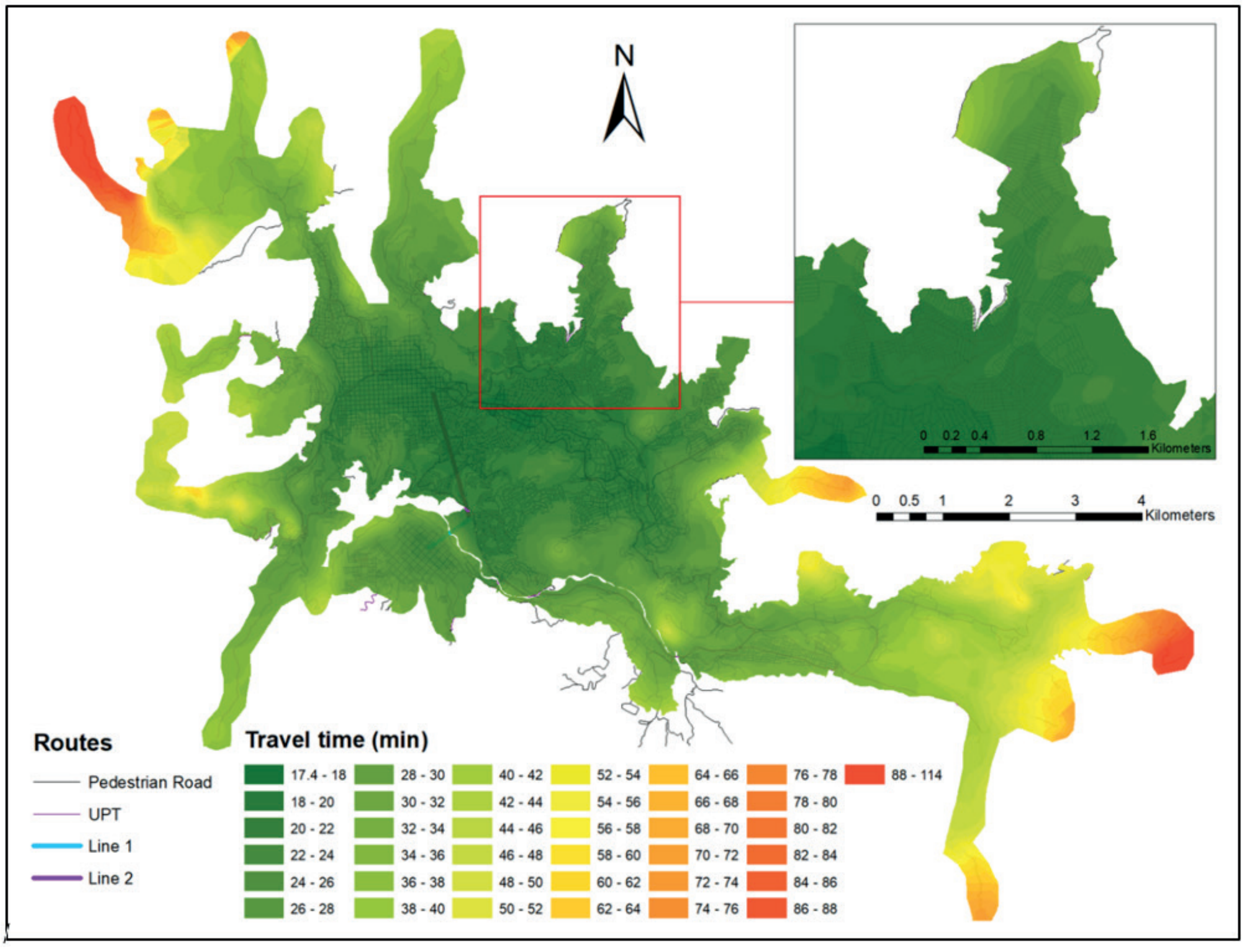

Fig. 5. Isochronous curves in the current scenario. Source: self-made

isocratic curves analysis shows that the city has not changed much in its overall outlook. This fact that is evident in the range of average journey times, which is from 17.4 to 113 minutes, except for the location to which it is intended to improve its conditions, which offers an improvement that will be more easily identifiable in the savings gradient.

Figure 7 shows the figure of the savings gradient comparing the current and future scenarios, where the above is reinforced since the overall perspective does not reflect the new infrastructure, since most of the figure is in values of zero or close to it. Moreover, it is evident in the Ciudadela del Norte, where there is an average saving of between 5% and 7%, but where there is also an 11% savings around the San Cayetano station, becoming a significant saving in the area.

Coverage analysis

As already mentioned, the project of line 3 of the cable transport system aims to extend from the centre of the city to the Ciudadela del Norte that, among its characteristics show a stratum between 1 and 3, with stratum 2 being the predominant one in that area. Figure 8 shows which strata are the most benefited in the two municipalities (Manizales and Villamaría) with the current project infrastructure, which identifies that more than 20% of the city's stratum 2 has a time saving of 6% and more than 10% savings of up to 7% compared to the current scenario. This is extremely beneficial due to the high impact that the project under study means to the target population.

As a final debate, despite the assessment obtained in terms of global accessibility, it would be interesting to assess the impact generated concerning existing services nearby, as has been done in other

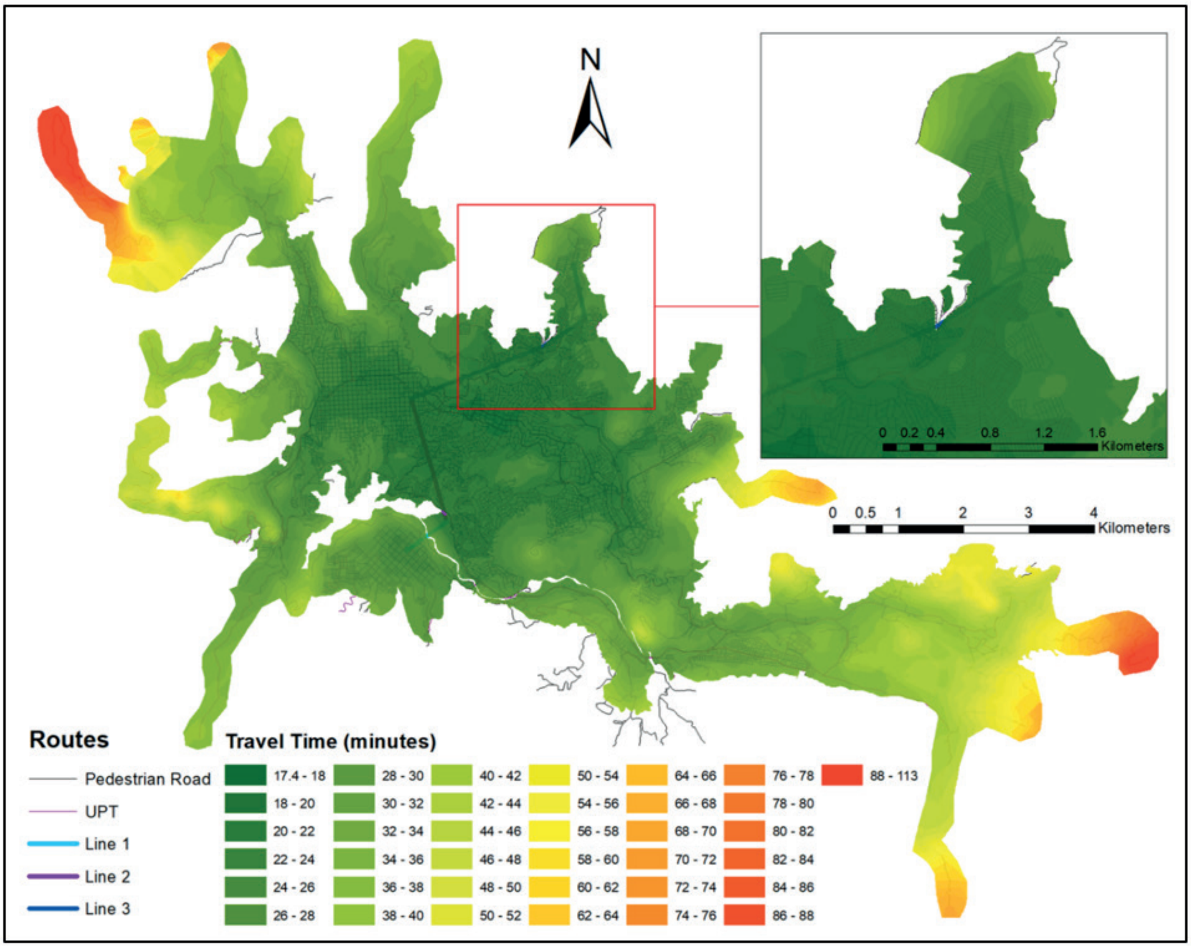

Fig. 6. Isochronous curves in the future scenario. Source: self-made

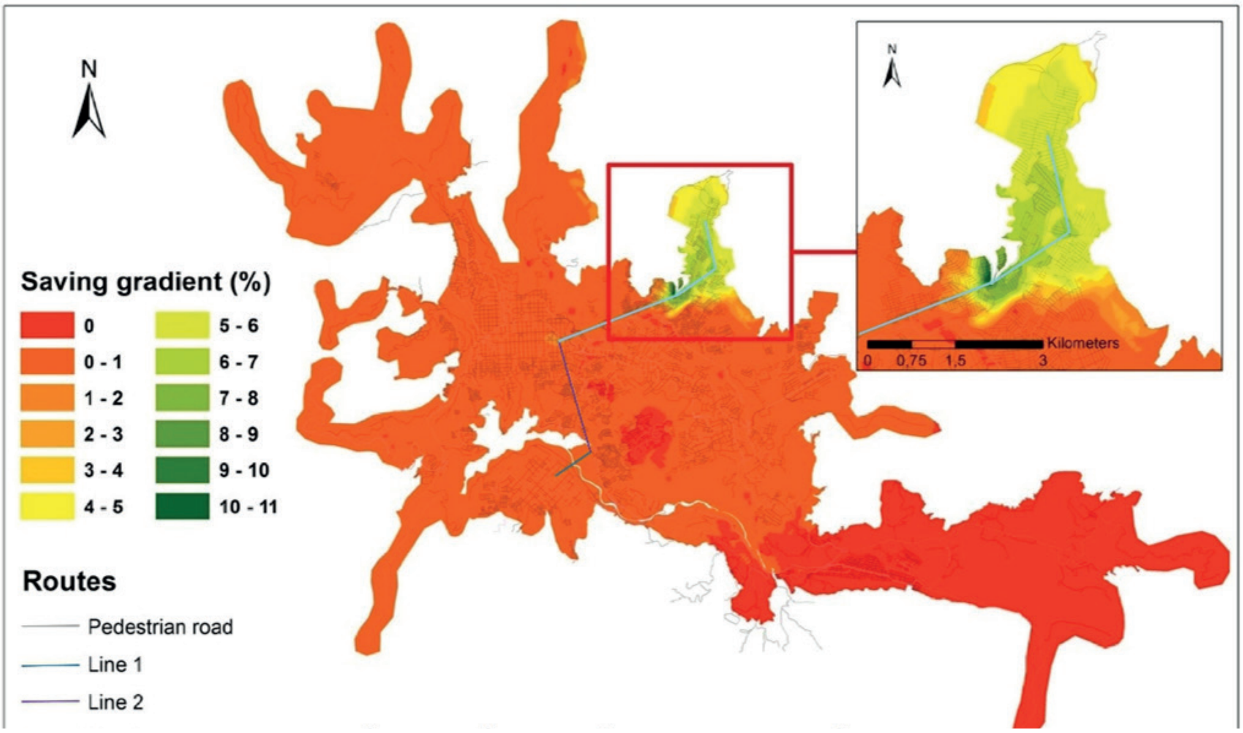

Fig. 7. Savings gradient. Source: self-made

research (Escobar et al., 2015; Goliszek, 2019). Besides, the implementation of more sustainable transport systems to minimise the impact generated by private vehicles should be associated with the possibility of evaluating different alternatives (Edwars and Mackett, 1996) and not a single option such as that presented by the municipal administration.

6. Conclusions

Given the results obtained from global average accessibility for the current and future scenario, it is determined that the project of the cable transport system between Manizales city centre and the Ciudadela del Norte is highly beneficial for the inhabitants of this commune, given the savings in average travel time, which reach 11% in certain areas. Its inhabitants, being between strata 1 and 3, rely heavily on public transport or walking to get around the city; thus, offering them alternatives that provide better quality and comfort of service as well as savings in travel time will be reflected in a greater appropriation of the city. Besides, there will be an increase in the inhabitants quality of life by being able to more quickly access the different activities and opportunities offered in the city such as employment, education, health, recreation and others. Globally, as can be identified in Fig. 9, most of the

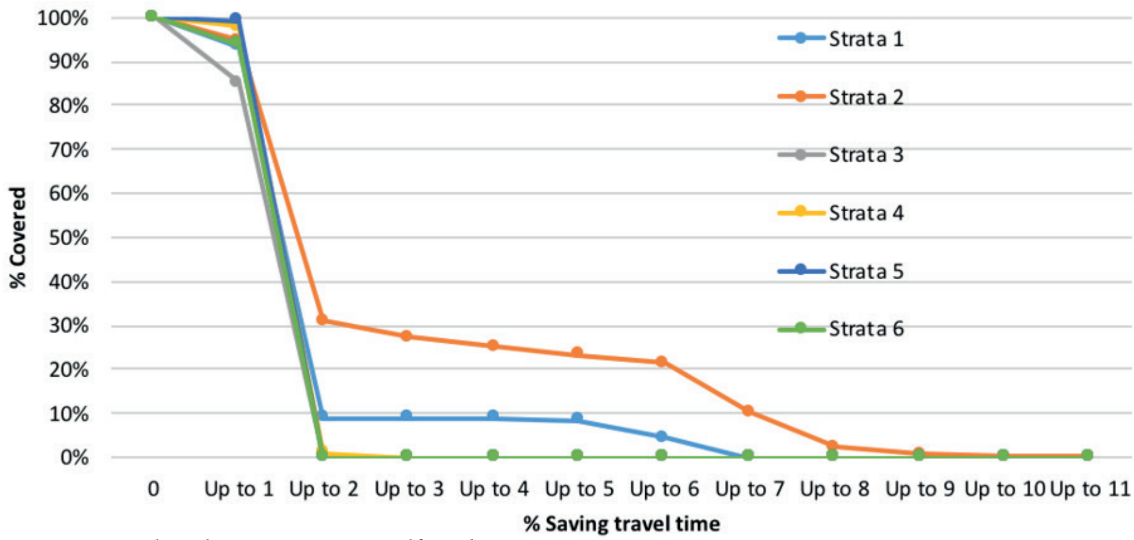

Fig. 8. Coverage analysis by strata. Source: self-made

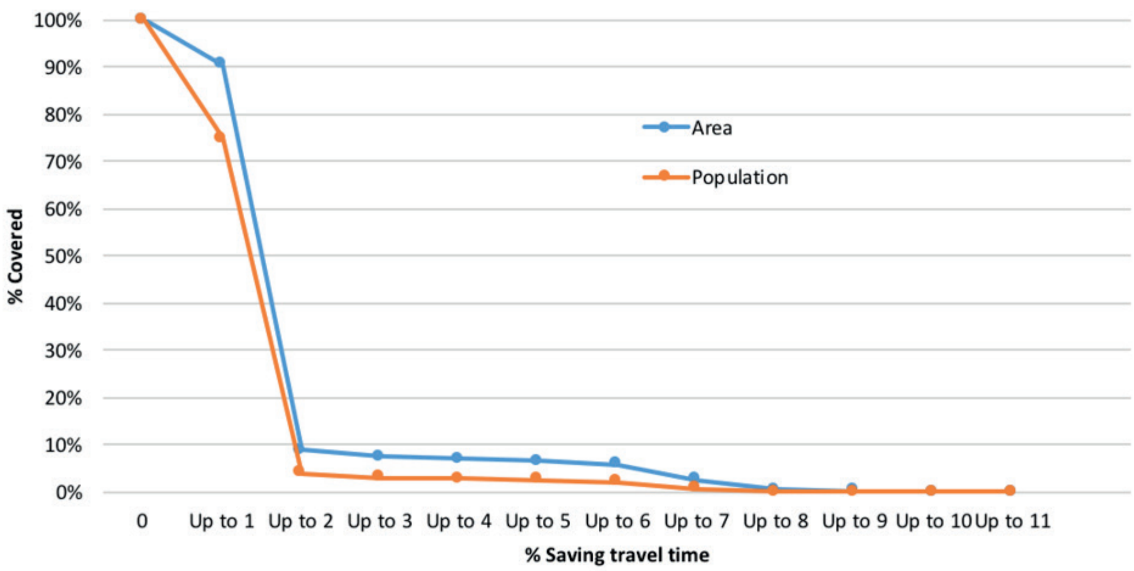

Fig. 9. Analysis of global coverage

area and population have time savings of up to 1% due to the new infrastructure.

Thanks to the fieldwork carried out to know the layout of the different transport routes, it was possible to identify some deficiencies that must be treated with thorough control of the companies that provide the service. Among the deficiencies, the fact is that they do not have a route number, which makes it difficult to recognise exactly which route code belongs to a specific vehicle since they only have the place names that cross the route. It has also been possible to verify that drivers stop to pick up new passengers on any section of the route, so that the stops stipulated by the municipalities are not used correctly, and even vehicles providing public transport service stop in areas expressly prohibited, which means a reduction in operating speeds.

In addition, it can be expressed that the use of accessibility as an impact measure reveals the benefit of the supply of a new transport system. However, since the model used is strictly a model of transport supply, it should be complemented by the analysis of demand, in which it is possible to quantify the actual volume of users, as well as the infrastructure needed for service satisfaction.

Acknowledgments

The authors express their gratitude to Juan Camilo Aguilera for his important contribution to the development of this research within the framework of the Master's Degree in Engineering – Infrastructure and Transport Systems; the Research Group on Sustainable Mobility – GIMS of Universidad Nacional de Colombia (Manizales), supported it. This full article has been subjected to an academic peer-review process.

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Ministry of Science and Higher Education
Republic of Poland

The proofreading of articles, positively reviewed and approved for publishing in the 'Bulletin of Geography. Socio-economic Series', was financed from the funds of the Ministry of Science and Higher Education earmarked for activities popularizing science, in line with Agreement No 695/P-DUN/2018.