Comité de selección, Departamento de Ingeniería Civil y Agrícola, Universidad Nacional de Colombia

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**Fecha:** 02-17-2026
**Objeto:** Estado tesis – Santiago Cardona Urrea

Estimados miembros Comité Concurso Profesoral, Perfil TC4

Mediante esta carta, me permito informar el estado de mi tesis escrita de doctorado titulada "Breaking barriers: Exploration of travel behaviour and transport challenges and innovations in Disadvantaged Communities in Colombian cities" la cual se compone de un compendio de cinco artículos. A continuación, se listan los artículos y su estado:

1. Aerial cable cars as a transit mode: a review of technological advances, service area characteristics, and societal impacts in Latin America and the Caribbean (2024). Publicado en la revista Transport Reviews.
2. Activity participation among disadvantaged communities and the impact of an aerial cable car: The case of TransMiCable, Bogotá (2026). Publicado en la revista Cities.
3. Breaking barriers: Evaluating the Aerial Cable Car's impact on Accessibility of discretionary activities: Case of TransMiCable, Bogotá. En proceso de revisión por pares en la revista Journal of Transport Geography.
4. THE ROLE OF TRANSPORT EXCLUSION AND AERIAL CABLE CARS IN SHAPING COMMUTING CHOICES IN STEEP CITIES. En proceso de revisión por pares en la revista Journal o Public Transportation
5. Differences in how transport-related social exclusion is perceived: A latent profile analysis. En proceso de finalización para someter para publicación.

Anexo los documentos publicados del articulo 1 y 2 y los documentos 3 y 4 inéditos que están en proceso de revisión por pares.

Atentamente,

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# Aerial cable cars as a transit mode: a review of technological advances, service area characteristics, and societal impacts in Latin America and the Caribbean

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# Aerial cable cars as a transit mode: a review of technological advances, service area characteristics, and societal impacts in Latin America and the Caribbean

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**ABSTRACT**
The success of the first Metrocable line in Medellín (2004) as a feeder for the Metro system served as a turning point in considering the use of aerial cable cars (ACC) as a mode of public transport in urban settlements. In the following years, 33 ACC transit lines were inaugurated in Latin America and the Caribbean (LAC), the majority after 2010. This review has several aims: (i) to understand the differences in aerial cableway transit (ACT) technologies; (ii) to describe the characteristics of the ACC service area for the most critical case studies in LAC and identify their role in the public transport system; and (iii) to find the essential societal benefits presented by ACC. We will follow two complementary approaches. First, the review concentrates on the most recent technological advances. Second, 24 reports were obtained from scientific databases, complemented by another 18 found using the "snowball" method. Our findings show that detachable gondolas, called aerial cable cars in the transport literature, are the most used technology as a transit mode. Furthermore, the ACC initially served as a feeder mode, serving low-income communities on hillside terrains. However, some cases are restructuring the public transport system and building a comprehensive network utilising the ACC. The empirical evidence shows that complementary projects are essential to impact less-frequent ACC users and people in the neighbourhood. Moreover, travel time and cost reductions increase accessibility and reduce inequalities, especially in the service area. Participatory budgeting may also prompt community engagement with the project, especially among low-income residents. Considering integration between transport modes (and within transit modes) in the project's early stages will also increase ridership and users' accessibility. Future research should focus on the travel behaviour and societal impacts of ACC integrated into the structure of the public transport systems.

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## 1. Introduction

Public transport provision is essential to fulfil the population's accessibility needs, especially for those low-income people who face inequity and spatial segregation (Bocarejo & Oviedo, 2012). Cities with unique morphology characteristics, such as geographical constraints (e.g. hilly terrains or rivers) or consolidated urban settlements, have created a need for specialised transit modes like aerial cableway transit (ACT) technology to supply necessary public transport services (Alshalalfah et al., 2012; Brand & Dávila, 2011; Flesser & Friedrich, 2022; Vuchic, 2007). ACT technology uses a cable to suspend and propel cabins along a fixed route to move passengers automatically with electric power (Alshalalfah et al., 2012). Argel (Algeria) in 1956 and New York (US) in 1976 deployed aerial tramways (AT) for public transport (Alshalalfah et al., 2014; Canon Rubiano et al., 2020). Several other air-based technologies have been developed as well, including detachable gondolas (aerial cable cars-ACC) (Alshalalfah et al., 2012, 2013). Medellin's *Metrocable* in 2004 was the first implementation of ACC as a transit mode, producing a turning point for considering the technology suitable to fulfil transport needs in urban settlements and broadening the range of alternatives for decision-makers and travellers. *Metrocable* utilised a well-established technology commonly used to reach ski resorts (detachable gondolas) in mountainous regions or as a tourist attraction in global north countries (Alshalalfah et al., 2012; 2013; Brand & Dávila, 2011).

Most authors have agreed on the transport planning advantages of using ACT as a transit mode in urban settlements (Alshalalfah et al., 2012; Brand & Dávila, 2011; Flesser & Friedrich, 2022). Firstly, ACT could overpass areas of the city with topographic difficulties like hilly terrains or rivers where other transit modes cannot be implemented. Secondly, it is crucial to consider that only ACT stations and towers are constructed on the terrain. The rest of the system is aerial and can follow any direction but is always in a straight line between the stations. Thus, ACT disrupts neighbourhoods to a lesser extent compared to other transport infrastructure projects (e.g. building highways or dedicated bus lanes), especially in hilly terrain where space is limited. Thirdly, cheaper costs (up to 8 times cheaper compared with rail systems Alshalalfah et al. (2012)) and fast construction times make it an attractive option, especially among politicians with limited periods to show results to the community. Fourthly, ACT runs on electric power, reducing local air pollution and generating environmental and health benefits for residents.

Mostly technical and operational aspects of ACT have been reviewed in the literature, including technical advantages compared with other modes of transport, the frequency of implementations worldwide (Alshalalfah et al., 2012, 2014), and their costs, business, and operational models (Canon Rubiano et al., 2020). Tiessler et al. (2020) reviewed the existing ACT systems' planning, construction, operation aspects and case studies. They focus on the Emirates Air Line (London, UK) experience, transferring knowledge to German cases for future implementations. In another work, Flesser and Friedrich (2022) conducted a systematic literature review on urban aerial cable cars (ACC) as a sustainable transport mode, focusing on environmental, societal, economic, services and infrastructure aspects. The authors noted that most ACC systems today are concentrated in LAC, reaching 24.8% of the total ACC share worldwide, with 62% implemented as a transit mode (Flesser & Friedrich, 2022). For instance, LAC has constructed ACC in 12 cities and seven countries in the past two decades (Vergel-Tovar, 2022).

While previous reviews have addressed technological and financing characteristics (Alshalalfah et al., 2012; 2014; Canon Rubiano et al., 2020) and their implications for sustainability (Flesser & Friedrich, 2022), there is a lack of research into the societal impacts of ACC systems using empirical studies. Furthermore, the importance of including Spanish research databases and LAC cases specifically has been established (Flesser & Friedrich, 2022; Reichenbach & Puhe, 2022). Consequently, the following research questions have been raised for this literature review:

- Which ACT technologies have been developed, and which is the most commonly used transit mode in the LAC context?
- What are the socio-demographic, topographical, and daily mobility characteristics of ACC's service area, and what is the role that ACC plays in the public transport system?
- What are the societal impacts of using ACC as a transit mode, considering the empirical evidence in transportation research?

This literature review approaches these questions by focusing on the empirical evidence about LAC case studies. The reasoning for doing so is that ACT technology has been established as a niche transit mode there (Flesser & Friedrich, 2022; Vergel-Tovar, 2022), which has produced questions for policymakers about further investments in ACT systems as a transit mode. The article is structured as follows: Section 2 explains the methodology to retrieve the studies necessary to fulfil the study's aims. Section 3 reports the evolution of the ACT into a transit mode in urban settlements from a historical perspective. The most prominent technologies are also described by comparing their capacity and operational speed, establishing a coherent terminology for academics and practitioners. Section 4 reviews five relevant implementations of ACC in LAC, focusing on the service area's socio-demographic, topographical, and daily mobility characteristics, and their role in the public transport system. Section 5 reviews the empirical evidence, extracting the societal impacts of implementing the ACC. Finally, the conclusions sections include public policy recommendations and future research needs.

## 2. Methodology

The methodology of the literature review is twofold. First, section 3 started with the most recent literature review articles (Alshalalfah et al., 2012; 2014; Flesser and Friedrich 2022; Tiessler et al. 2020), complemented with manufacturers' technical reports to retrieve the most recent advances in the technology regarding transport capacity and operational speed. Secondly, Sections 4 and 5 are based on peer-reviewed articles, conference proceedings and book chapters published in English, Spanish, or Portuguese research databases (see Figure 1). Web of Science and Scopus as English databases and Redalyc and Scielo as Spanish and Portuguese databases were considered. Google Scholar was used to complement the search in both languages. The search was conducted in December 2022 and used the following keywords based on previous literature review articles on the topic (e.g. Flesser & Friedrich, 2022; Tiessler et al., 2020):

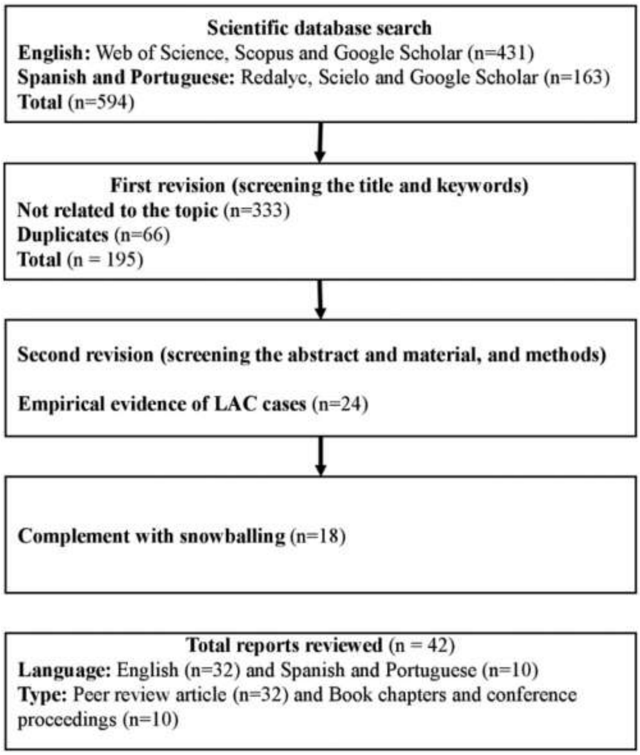


**Figure 1.** Methodology flow chart.

- Scopus query: TITLE-ABS-KEY ((aerial AND cableway* AND transit) OR (aerial AND ropeway* AND transit) OR (cable AND propelled AND transit) OR ((urban OR (transit OR (public AND transit) OR (public AND transport*) OR (transit AND mode))) AND (cableway OR (cable AND car) OR gondola OR ropeway)))
- Scielo query: *transporte público* AND (*cable aéreo* OR *teleférico* OR *telecabina*)

A total of 593 reports (431 in English and 163 in Spanish and Portuguese) were obtained. The title and keywords were screened, finding 333 unrelated to the research topic and 66 duplicates. The abstract, materials, and methods of the rest of the reports were reviewed, classifying those related to ACC case studies in LAC that encompassed empirical evidence about the implementation. Studies related to hypothetical projects were not considered. Twenty-four research documents fit the abovementioned criteria, complemented by 18 from the snowball method (32 in English, 6 in Spanish, and 4 in Portuguese). The reports focused on the case studies of Bogotá, Medellín, and Manizales (Colombia), Rio de Janeiro (Brazil), and La Paz (Bolivia) (see Appendix 1 for a complete list of the reports). Despite the concentration of the studies in those cases, results can be extrapolated to other cities in LAC because of social, cultural, and economic similarities among countries. The main findings were related to social urbanism and community engagement, mobility, accessibility, social inclusion, and tourism.

## 3. The evolution of the aerial cableway into a transit mode

This section focuses on the evolution of the ACT into a transit mode in urban settlements. First, the ACT technology is described considering the operational characteristics: capacity and speed. Second, a brief historical perspective of the ACT as a transit mode is presented.

### 3.1. The technology behind ACT

ACT systems are composed of cabins, stations, towers (or pylons), the cable (or rope) as the heart of the system, and the evacuations and rescue system (Alshalalfah et al., 2012, 2013). The literature recognises two prominent ACT technologies for urban areas (Tiessler et al., 2020): Aerial tramways (AT) and Detachable Gondolas (DG). DG is distinguished by the number of cables: Monocable (MDG), Bicable (BDG), and Tricable (TDG). In transport literature, DG is traditionally referred to as "aerial cable cars" (ACC) (Alshalalfah et al., 2012, 2013; Brand & Dávila, 2011; Flesser & Friedrich, 2022). The main differences between these technologies are the cabin and line capacity and the operational speeds (see Figure 2).

AT comprises two parallel cabins simultaneously transporting passengers in opposite directions (Alshalalfah et al., 2012). The renovation of the New York AT in 2010 allowed the generation of separate cables to carry the two cabins, called Dual Haul Aerial Tramway (DHAT), allowing greater flexibility to respond to passenger demand (Alshalalfah et al., 2012, 2013). The AT cabin capacity could vary from 4 to 230 people with a maximum

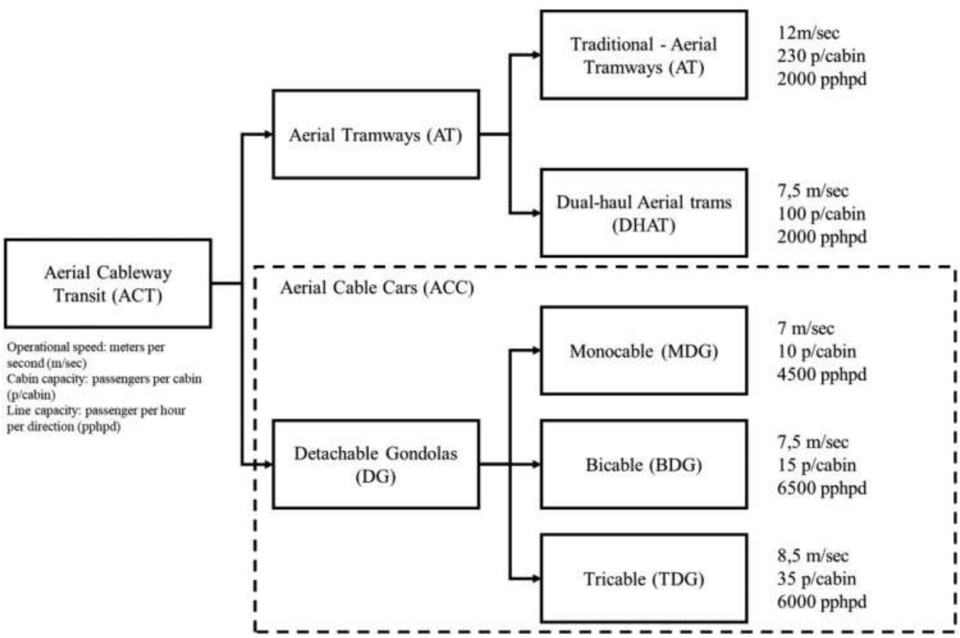


**Figure 2.** Aerial Cableway Transit categories and their maximum operation speed, cabin, and line capacity. Source: Own elaboration considering data reported by Alshalalfah et al. (2012) and technology brochures from ACT manufacturers.

speed of 12 meters per second (m/s), reaching a line capacity of up to 2000 passengers per hour per direction (pphpd) (Alshalalfah et al., 2012, 2013; Leitner, n.d.-a).

On the other hand, Monocable (MDG), Bicable (BDG), and Tricable (TDG). Detachable Gondolas cabins transport up to 10, 15, and 35 people per cabin with operational speeds of between 6 and 8.5 m/s (Alshalalfah et al., 2012, 2013) (see Figure 2). Since cabins can follow each other at shorter distances than aerial tramways, MDG line capacity reaches up to 4500 passengers per hour per direction (pphpd) (Canon Rubiano et al., 2020; Leitner, n.d.-c) while theoretical capacities of BDG and TDG reach up to 6500 and 6000 pphpd (Leitner, n.d.-d); however, in practice TDG systems work with lower capacities, as they are installed in the global north such as Germany and France serving medium and small-sized cities (Canon Rubiano et al., 2020). Higher line operational capacity makes DG more suitable as a transit mode since travellers prefer higher frequencies, perceiving the waiting and transfer times to be longer than transport times, especially in the global south with less operational reliability (Fan et al., 2016; Heinrichs & Bernet, 2014; Tirachini et al., 2022). However, integrating ACT into other transit systems like trains, metro, trams, or buses with lower frequencies, lower reliability, and larger capacity is challenging with regard to designing comfortable transfers that avoid crowding and waiting times (Reichenbach & Puhe, 2022; Težak et al., 2016).

DG technology has been continually developed over the past decade. At the beginning of 2010, BDG had better wind stability and operational speeds than MDG without the costs of TDG (Alshalalfah et al., 2012, 2013); however, advances in MDG safety technology, maintaining their lower construction costs and increasing their capacity, relegated the BDG option in comparison to MDG. Recently, manufacturers have developed a BDG technology that surpasses the line and cabin capacity of MDG and TDG, establishing it as an interesting option for systems with high potential passenger demand (Leitner, n.d.-b).

DG is currently preferred as a transit mode over AT, considering the systems operating worldwide. On the other hand, most of the DG deployed are MDG (45 urban lines worldwide, of which 73.3% are in LAC). Implementation costs could vary considering the context, topographic characteristics, and street layout. Findings suggest that costs per kilometre are highly variable, e.g. costs for MDG projects in Colombia vary from 13 million (*Miocable*–Cali) to 106 million (*Metrocable*-Medellín). Besides, there is no strong evidence regarding which technology presents the lowest overall costs. Previous reviews remarked that MDG is affordable; nevertheless, the evidence shows that the most expensive projects per kilometre are MDG: Metrocable (Medellín) and the Emirates Air Line (London). Despite the costs, MDG is the primary ACT technology implemented among global south countries, e.g. in LAC and Northern Africa (Alshalalfah et al., 2012; Canon Rubiano et al., 2020; Flesser & Friedrich, 2022; Vergel-Tovar, 2022). For a more detailed summary of ACC capital costs, business models, and operational characteristics, please check Canon Rubiano et al. (2020).

### 3.2. ACT as a transit mode

The use of the ACT to move passengers and goods goes back two centuries, specifically in America and Asia (Alshalalfah et al., 2014; Taylor, 1938). This section presents some of the most relevant historical examples of ACT. In Manizales (Colombia), ACT systems connected people and goods during the first part of the twentieth century, including the world's most extensive ACC line: 72 km between Manizales and Mariquita, which was inaugurated in 1922 and closed operations in 1961 to prioritise investment in roads (Escobar et al., 2015; Pérez Angel, 1997). During the second half of the century, ACT was more frequently associated with ski resorts and tourist attractions in the global north, like Europe and North America, which stimulated the development of their technology in terms of passenger capacity, comfort, and safety (Alshalalfah et al., 2012; Brand & Dávila, 2011; Garsous et al., 2019; Sarmiento et al., 2020).

In the second part of the twentieth century, the first AT line in Argel (Algeria) was inaugurated in 1956, with three more lines constructed between 1984 and 1987. Their success boosted renovations in the first decade of the 2000s and the construction of two ACC lines in 2014 and 2019 (Canon Rubiano et al., 2020). In 1976, an AT system was deployed in New York (US) as a temporary transit solution while New York's subway expansion was finished in 1989 (Alshalalfah et al., 2012). After that, the Roosevelt Island Aerial Tramway gained enough popularity to continue as a tourist attraction. The system was renovated in 2010, implementing a DHAT that increased its wind stability and flexibility to adapt to passenger demand (Alshalalfah et al., 2012).

The first ACT system using MDG technology as a transit mode was inaugurated in 2004 in Medellín (Colombia). The *Metrocable Line K* connects inaccessible and low-income informal neighbourhoods located on mountains with steeper terrain to relevant destinations in the *Aburra* Valley and the Metro system (Brand & Dávila, 2011). Today, Colombia has ten lines deployed in five different cities (see Figure 3), making the country the leader in ACC implementation as a transit mode worldwide. Since 2014, the world's most extensive and densest ACC network has been built in La Paz and El Alto (Bolivia), designed to connect inhabitants living at different altitudes, especially between and within the two city centres (Garsous et al., 2019; Koch, 2013). The *Mi Teleférico* ACC network now includes ten lines, 30.5 kilometres and 36 stations. Recently, the second line of *Cable bus* in México City was recorded in the Guinness Book of Records as the longest ACC line with 10.55 km (El Financiero, 2021). México City has three more ACC lines integrated into their public transport systems; the most recent was inaugurated in 2023 (Mexicable, 2023) and another is scheduled to be inaugurated at the end of 2023 (Gómez, 2023).

After Medellin's *Metrocable Line K* inauguration in 2004, 33 ACC lines were inaugurated in seven LAC cities; 90.9% of them after 2010 (Canon Rubiano et al., 2020; Vergel-Tovar, 2022). Six more lines are currently under construction. Those have given momentum to the technology, becoming an established alternative transit mode (Flesser & Friedrich, 2022; Reichenbach & Puhe, 2022). ACC has been increasingly considered as an urban mobility solution for practitioners, transport authorities, and operators due to these specific transport planning advantages over other transit modes. It is time to review ACC transit implementations in LAC to reap insights about the societal impacts of ACC systems to inform policymakers when deciding about upcoming ACC projects (Vergel-Tovar, 2022).

## 4. Understanding aerial cable cars in LAC

This section will concentrate on two ACC typologies emerging from empirical studies of LAC cases: (i) Medellín, Bogotá, and Rio de Janeiro, and (ii) La Paz and Manizales. A


**Figure 3.** Aerial Cable-Cars lines deployed in LAC cities. Own elaboration.

description of the socio-demographic, daily mobility and topographic characteristics of the ACC's service area is presented to understand which population segments are served and the ACC's role in the public transport system.

### *4.1. The ACC to reduce spatial inequity: Medellín, Bogotá and Rio de Janeiro*

The ACC service areas in Bogotá, Medellín, and Rio de Janeiro share certain similarities. The ACC works as a feeder serving low-income neighbourhoods located in hillside terrain in the city's peripheries or spatially disadvantaged areas. These neighbourhoods have an inadequate provision of essential services, including public transport, road infrastructure, water, and sewerage (Duarte Santos & Soares Gonçalves, 2017; Heinrichs & Bernet, 2014; Sarmiento et al., 2020). Some relevant examples include *Comunas 1* and *2* in Medellín (2004) (Brand & Dávila, 2011), *Ciudad Bolivar* in Bogotá (2018) (Sarmiento et al., 2020) or the favelas of *Complexo do Alemao* (2011) and *Providencia* (2014) in Rio de Janeiro (Duarte Santos & Soares Gonçalves, 2017). In addition, ACC systems in these cities reach neighbourhoods with a more structured urban shape but with topographical constraints. For instance, the following ACC lines inaugurated in Medellín (e.g. *Line J's* 2008) mainly influenced social housing projects (Coupé & Cardona, 2013; Goodship, 2015).

However, the success of ACC differs between Bogotá and Rio de Janeiro (Freire-Medeiros et al., 2020). The ACC in Brazil were constructed as a part of an ambitious government investment project in the favelas (Duarte Santos & Soares Gonçalves, 2017). The idea came from politicians who visited Medellín's case, using the most significant part of the budget to build the ACC. However, the favelas' inhabitants preferred to attend to other priorities in their neighbourhoods, such as sewerage or water provision (Braga, 2017; Duarte Santos & Soares Gonçalves, 2017). Furthermore, the idea was to use the ACC with a mixed purpose, especially in *Complexo do Alemao*, attracting tourists while offering residents transport for free (Freire-Medeiros et al., 2020; Freire-Medeiros & Name, 2015). Rio de Janeiro's ACC closed operations in 2016, and efforts to open again have not been made (Cavalcanti & Campos, 2022). On the contrary, the ACC in *Ciudad Bolivar* (*Transmicable*) was an ambition following many years of community struggle for a transit mode that could be implemented in their steeper terrain, complemented with social urbanism investment in the neighbourhood (Guevara-Aladino et al., 2022; Sarmiento et al., 2020). Ciudad Bolivar's *Transmicable* currently transports 27,000 inhabitants daily (Guzmán, Arellana et al., 2023), while the last ridership reports in *Complexo do Alemao* were below 11,000 passengers daily (Duarte Santos & Soares Gonçalves, 2017).

The ACC lines in all three cities are fully integrated as a feeder of the public transport system (Garnica Quiroga, 2020; Morales-Betancourt et al., 2023; Okami et al., 2022). Residents can use the system paying only one ticket or a differential fare. After their success with *Line K* in 2004, Medellín built four more ACC transit lines, integrating with Metro, Bus Rapid Transit (BRT), Tram, and traditional buses (see Figure 4). Meanwhile, Bogotá's ACC (see Figure 4) is connected, and fare integrated with the BRT system of the city (*Transmilenio)* (Guzman et al., 2022; Guzman, Arellana et al., 2023). On the other hand, during Rio de Janeiro's ACC operation, it was free of charge for residents in the favelas. It is physically integrated into the train network, Light Rail Transit (LRT) and BRT system, paying only the fare to enter the other transit modes in contrast the tourists must pay the complete fare (Duarte Santos & Soares Gonçalves, 2017).

Before implementing the ACC lines in Medellin and Bogotá, BRT bus feeders and traditional buses or paratransit supplied the public transport in the neighbourhoods of both cities without integration with the city's public transport system. Consequently,

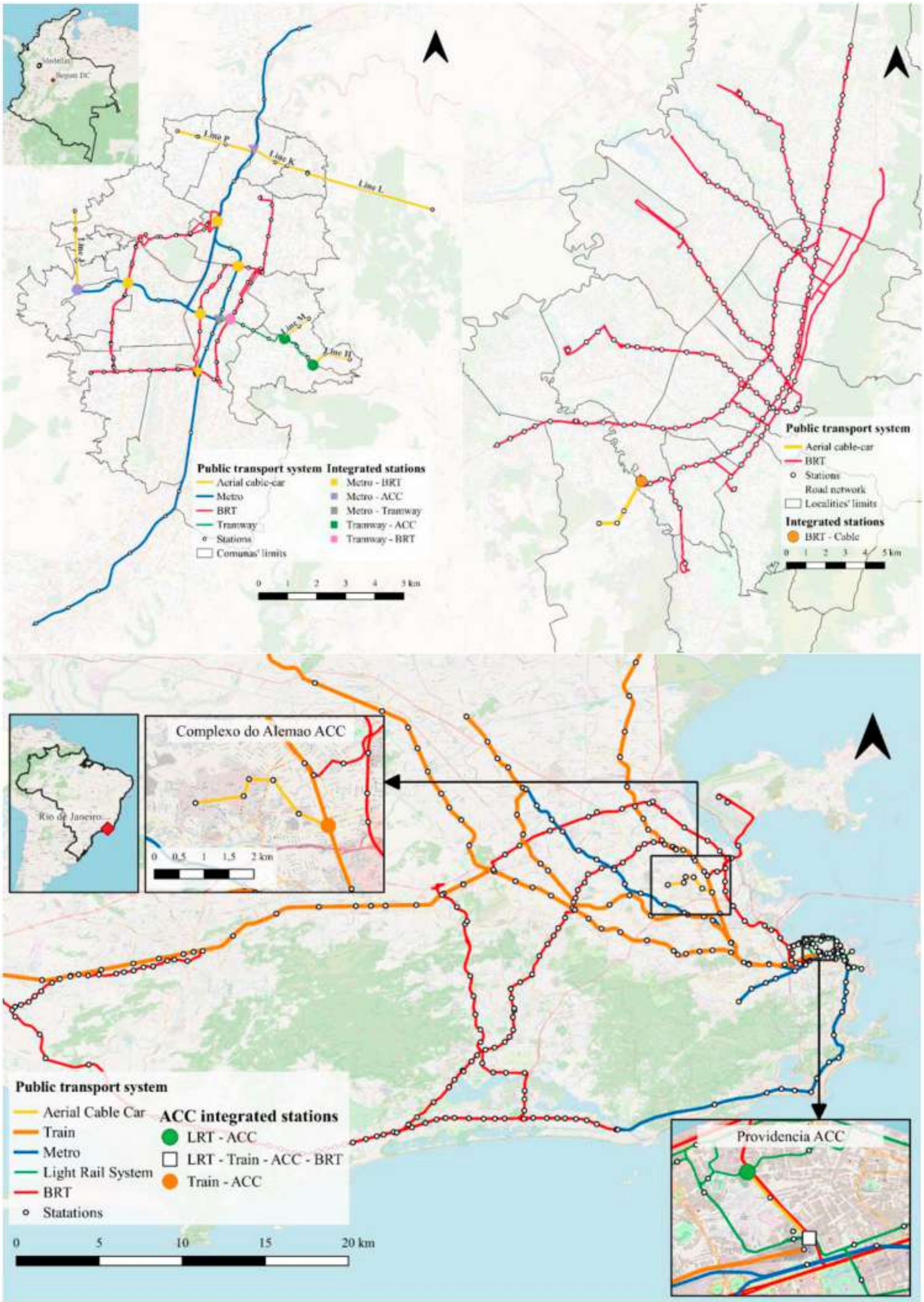


**Figure 4.** Medellín's (top-left), Bogotá's (top-right) and Rio de Janeiro's (bottom) public transport system. Circles represent integrations with two, triangles with three, and squares with four transit modes. Own elaboration with open data gathered from Medellín's, Bogotá's, Rio de Janeiro's government, and Openstreetmaps.

travellers pay multiple fares, increasing their transport budget and travel time to reach the essential parts of the city, especially the city centre, where most of the employment is (Bocarejo et al., 2014; Brand & Dávila, 2011; Garnica Quiroga, 2020; Guzman et al., 2022). In Bogotá, the paratransit system, provided by private cars with limited capacity, was not affected by the ACC line but expanded to rural areas of the neighbourhood to connect travellers to the ACC stations (Villar-Uribe, 2021). In Rio de Janeiro's case, the daily mobility of *Complexo do Alemao* and *Providencia* inhabitants before the ACC introduction were by foot or using paratransit services. Pedestrian connections were through steep stairs and narrow alleys. Paratransit modes comprised vans, kombis, and moto-taxis (Espósito Galarce & da Silva, 2016; Freire-Medeiros & Name, 2017; Gonçalves & Bandeira, 2017). Despite higher costs and uncertainty, those paratransit systems offer greater flexibility and coverage than the ACC, since the ACC service is fixed to specific stations and covers specific areas. For instance, most of the residents in *Complexo do Alemao* complained about the location of the stations on the hilltop of the favelas because they must climb the mountain if they wanted to use the system, despite its free cost (Duarte Santos & Soares Gonçalves, 2017). Moreover, the ACC did not allow the transport of bulk cargo inside the cabins, a disadvantage when favela residents go for groceries outside the neighbourhood due to a lack of access to food (Braga, 2017; Worms & Sluyter, 2018).

The daily mobility of most of the dwellers in the service area of ACC lines in Medellin, Bogota, and Rio de Janeiro is within their neighbourhood; therefore, the frequent ACC users are workers and students (Agudelo V. et al., 2013; Brand & Dávila, 2011; Coupé, 2013; Duarte Santos & Soares Gonçalves, 2017; Gonçalves & Bandeira, 2017; Guzman et al., 2022). For them, the fare integration of the public transport system increases their accessibility to opportunities and zones they can reach with lower costs and travel time (Bocarejo et al., 2014).

### *4.2. The ACC to structure public transport: La Paz and Manizales*

The steeper topography and the city size were crucial considerations in La Paz (Bolivia) (*Mi Teleférico*) and Manizales (Colombia) (*Cable Aéreo*) to structure their public transport system around ACC (see Figure 5). They installed the ACC between their city centres first, expanding the network around those high-demand lines, e.g. connecting with their neighbouring towns: El Alto (Bolivia) and Villamaría (Colombia) (Escobar et al., 2015; Garsous et al., 2019). La Paz developed a Master Plan in 2012, which included the construction of an ACC network composed of 11 lines and 39 stations (see Figure 5) to supply part of the daily mobility of 1.7 million trips by their inhabitants (Garsous et al., 2019; Koch, 2013; Martinez et al., 2018). Before the ACC network operated by *Mi Teleférico* company, paratransit modes (Minibus, Micros, and Trufis) supplied the inhabitants' public transport needs (see Garsous et al. (2019) page. 175 for a complete description of the transit modes). Today, these services compete with *Mi Teleférico* because the Master Plan did not consider their integration with the ACC network. Their flexibility and lower fares are attractive to a massive segment of travellers, e.g. Garsous et al. (2019) reported that 57% of dwellers used Minibus, 5% used Micros, and 5% used Trufis, compared with 2% using the ACC network. The results are consistent with those of Martinez et al. (2018), where *Mi Teleférico* in the first phase represents 3.78% of the modal share in La Paz. *Mi*

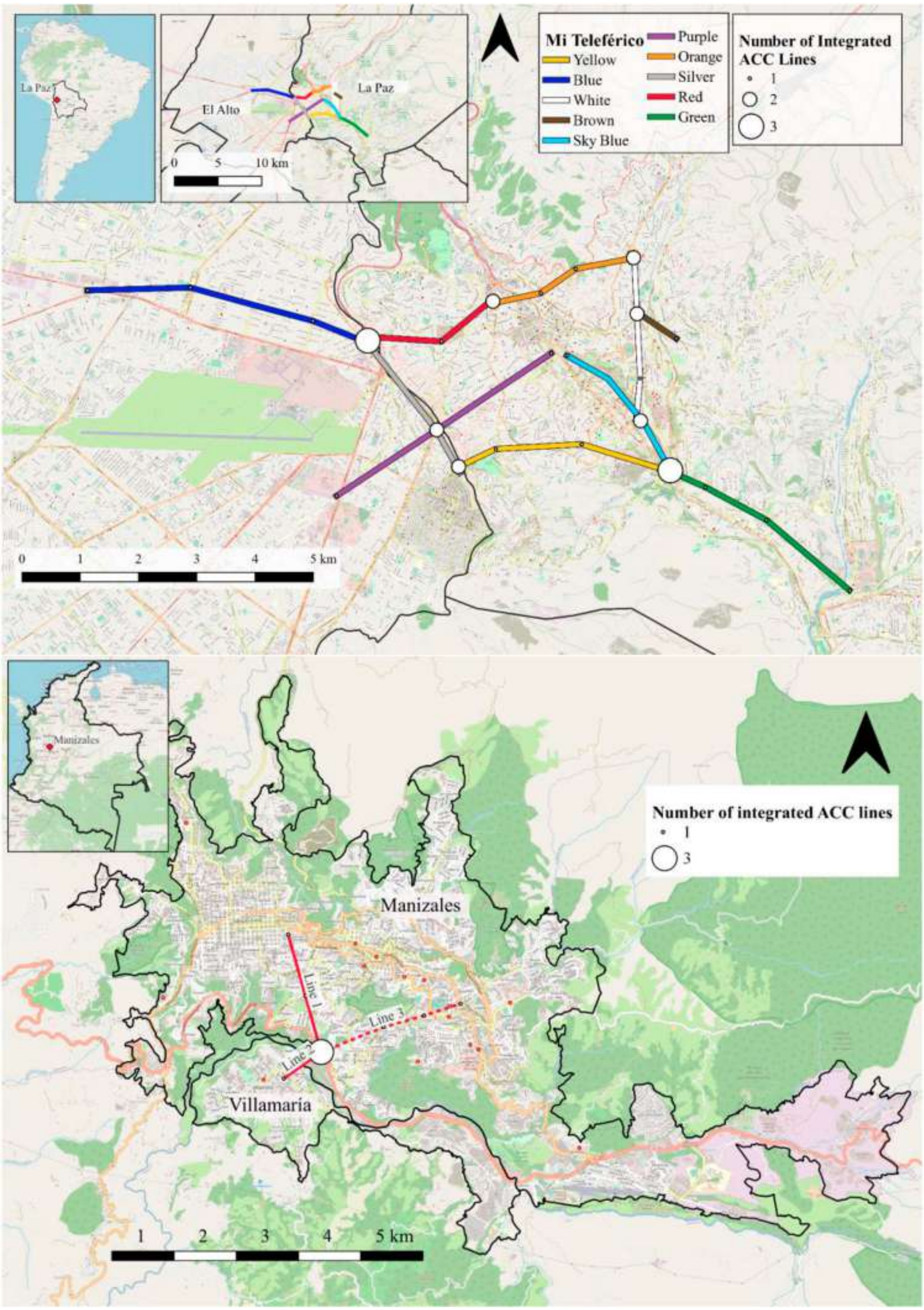


**Figure 5.** La Paz (above) and Manizales (below) aerial cable-car system. Own elaboration with open data gathered from La Paz's and Manizales' government's websites and Openstreetmaps.

*Teleférico* shows that the frequent users have higher incomes and levels of education (Martinez et al., 2018). These reports considered data from 2015, when only the first phase of *Mi Teleférico,* composed of Lines Red, Green, and Yellow, operated without physical integration. Moreover, before the Covid-19 pandemic, the system reported 96 million journeys (approximately 250,000 per day) in 2019, with ten ACC lines working (the Golden line is still in the planning phase) (Mi Teleférico, 2022). Before *Mi Teleférico* construction, some authors like Koch (2013) questioned their implementation because the ACC lines would not fulfil the necessities of travel demand as other transit modes (such as BRT) would. Furthermore, fully integrating all the transit modes would be necessary to reach the public transport system's equity, efficiency, and sustainability objectives in La Paz (Koch, 2013).

The country's budget support allows La Paz to develop the ACC network faster than Manizales. The government's effort in the medium-sized city of Manizales enabled the inauguration of two lines in 2009 and 2013 (one more is under construction). Their service area covers the city centres of Manizales and Villamaría and middle-income neighbourhoods in the southwest hillsides of Manizales (Escobar et al., 2015; Escobar & Garcia, 2011). Two additional lines are necessary to complete the ACC network defined in the mobility plans (Escobar et al., 2015, 2022). Similar to La Paz, competition with traditional buses has been a constant challenge in their operation because integration (physical or fare) was not considered in the ACC planning, resulting in low passenger demand and underuse (Escobar et al., 2015). The rest of the public transport needs are supplied by vehicles with 15–40 passengers, operated by private companies and covering almost all of the city with 71 bus routes (Rodas-Zuleta et al., 2022). The traditional buses are paid by cash, and the bus stops are flexible, offering users a high degree of accessibility compared to the ACC network.

## 5. Societal impacts

Most of the empirical studies concentrated on the cases of Medellín, Rio de Janeiro, and Bogotá, where the ACC was designed as a feeder of the public transport system. On the other hand, case studies such as La Paz and Manizales, where the ACC is the city's public transport structure, have not been extensively investigated. This section discusses the societal impacts of both ACC types discussed above in more detail. Results were grouped into categories of social urbanism and community engagement, mobility, accessibility and social inclusion, tourism, and politics and governance. Other societal impacts, such as environmental and health outcomes and impact on violence and crimes, have received less attention among scholars, and we lack evidence to report such outcomes.

### *5.1. Mobility, accessibility, and social inclusion*

Travel time and cost reductions are the benefits most directly perceived by the population and researched by scholars after ACCs implementations (Bocarejo et al., 2014; Brand & Dávila, 2011; Escobar et al., 2015; Escobar & Garcia, 2011; Garnica Quiroga, 2020; Garsous et al., 2019; Guevara-Aladino et al., 2022; Heinrichs & Bernet, 2014; Martinez et al., 2018; Matsuyuki et al., 2020). *Metrocable Line K* users reported reductions of 45 min using the ACC to connect with the Metro system (although the increase in waiting times because of long queues during rush hours could affect the overall reduction) (Brand & Dávila, 2011; Heinrichs & Bernet, 2014). At the same time, reductions of 20% (22 min) in commuting travel times for residents of Ciudad Bolivar, Bogotá, around the area of influence of *Transmicable* were measured (Guevara-Aladino et al., 2022). The average commute time in Bogotá is 52 min; nevertheless, vulnerable and low-income communities located in the peripheries of the city experience higher commuting times (Garnica Quiroga, 2020; Guevara-Aladino et al., 2022), a pattern frequently repeated in other LAC cities.

On the other hand, research on travel time impacts at the city level has distinct results. For instance, a significant impact on commuting time was found in the first phase of *Mi Teleférico* in La Paz, with a reduction of 22% in travel times (Garsous et al., 2019). They compare single-mode trips made in the ACC network against other transit modes (e.g. minibuses) and private vehicles (e.g. cars and motorcycles). Moreover, Martinez et al. (2018) found reductions of 70 min in commute times for *Mi Teleférico* frequent users. The time was reallocated to education and recreational activities. Meanwhile, reductions in travel time of 7.7% were observed in Medellín (Bocarejo et al., 2014) and 3.4% in Manizales (Escobar et al., 2015; Escobar & Garcia, 2011) at the city level.

Travel cost reductions are mainly related to fare integration with the public transport system, especially in those cases where the ACC works as a feeder (Bocarejo et al., 2014; Coupé, 2013; Guzman et al., 2022; Heinrichs & Bernet, 2014). However, travel times and cost benefits are limited because not all the residents are frequent users of the ACC, and most people's daily mobility is within the neighbourhood (Cavalcanti & Campos, 2022; Heinrichs & Bernet, 2014).

The empirical evidence has shown increased accessibility, social inclusion, and quality of life. The ACC has boosted the change of vocational jobs (Matsuyuki et al., 2020) and doubled the accessibility to employment in the surroundings of the first *Metrocable* line (Bocarejo et al., 2014). Moreover, according to Cordoba et al. (2014), *Metrocable* increased the average number of trips per day among the area of influence (an average of 2 trips per person per day), decreasing the risk of social exclusion. Remarkably, the introduction of ACC also led to an increase in the use of public transport, especially among low-income residents and women (Milan & Creutzig, 2017).

Different results have been reported regarding access to the ACC stations, especially between Medellín and Rio de Janeiro. In Medellín, the ACC stations are located on the hillside, while in Rio de Janeiro, they were placed on the hilltop of the favelas, making access difficult (Duarte Santos & Soares Gonçalves, 2017). For example, during Rio de Janeiro's ACC operation, the influenced area reached only 10 min of walking around the stations (Braga, 2017; Gonçalves & Bandeira, 2017). Most residents preferred other modes of transport, especially paratransit services, because the location of ACC stations is unattractive. On the other hand, *Metrocable* users are willing to walk more (up to 1 h) because of the integration with the Metro system and the travel cost savings (Agudelo V. et al., 2013).

The residents in *Metrocable* area of influence report that modal choice was driven by the transport budget and travel time; however, safety in the surroundings of the stations is also essential, especially when crime and violence are frequent (Agudelo V. et al., 2013; Sarmiento Ordosgostia et al., 2013), something prevalent in neighbourhoods where the ACC used to be deployed (Brand & Dávila, 2011; Freire-Medeiros et al., 2020). For instance, women perceived the buses to be safer because the walking distance to the bus stop is lower than ACC station, i.e. they spend less time exposed to violence and crime in the neighbourhood (Agudelo V. et al., 2013; Sarmiento Ordosgostia et al., 2013). On the contrary, the *Transmicable* case showed that in-vehicle security perception for women ACC users is high (Guzman et al., 2022), i.e. they feel more secure than expected inside the ACC cabins. Differences in safety perception among case studies can be related to the context and methods applied. In addition, the increase in gender-based violence inside public transport vehicles, particularly buses, has been recently studied in LAC (Quiñones, 2020; Rodas-Zuleta et al., 2022). Nevertheless, no reports about those situations considering ACC were found. Furthermore, Guzmán, Cantillo-García et al. (2023) found an increase in social capital with the inauguration and use of Transmicable, i.e. this was an essential variable in the modal choice.

The long-term impact of *Line K* in Medellín on travel behaviour reveals that traditional buses remain the predominant transport mode in the neighbourhoods. At the same time, the ACC is primarily used to access the Metro system (Okami et al., 2022). Okami et al. (2022) found an increase in the use of private modes, particularly among young males who commute more frequently using motorcycles. Additionally, the ACC had a minor effect on the modal shift from private vehicles in La Paz, as a higher percentage of ACC users previously used other transit modes (Martinez et al., 2018).

Findings show that Manizales' ACC ridership is below the forecast passenger demand. It reduces users' travel and waiting times; nevertheless, the system has failed to attract more ridership, causing economic problems for the operator (Escobar et al., 2015). On the other hand, disruptions in the ACC operation have been reported during heavy storms or maintenance periods in Medellín (Agudelo V. et al., 2013; Coupé, 2013; Matsuyuki et al., 2020). For example, heavy storms could cause unexpected disruption in the ACC operation, forcing the users to take other transit modes or to wait in the cabins while the operation continues (Agudelo V. et al., 2013). However, no statistical differences in the travel times were found between the ACC and alternative transit modes (e.g. buses) during maintenance periods in Medellín, showing excellent planning to tackle the disruptions (Matsuyuki et al., 2020).

Finally, the paratransit options in the neighbourhoods were not affected by the ACC implementations, and they continue to be an essential part of daily mobility because of their flexibility and low costs (Braga, 2017; Capillé & Reiss, 2019; Duarte Santos & Soares Gonçalves, 2017; Villar-Uribe, 2021). Paratransit routes expanded to work as a feeder of the ACC in Bogota (Villar-Uribe, 2021). Meanwhile, some people in Rio de Janeiro perceived that integrating paratransit services and the ACC could increase coverage and accessibility (Braga, 2017; Duarte Santos & Soares Gonçalves, 2017).

### *5.2. Social urbanism and community engagement*

Social urbanism is an urban planning initiative related to investing in high-impact and quality projects in zones with historical government deficits, e.g. informal neighbourhoods (Brand, 2010). Coined during Fajardo's administration in Medellín (2004–2007), it is related to projects (Brand & Dávila, 2011), such as the improvement of public spaces and housing, creation of education and cultural facilities, provision of water and sewerage, increase of green space and parks, among others (Brand, 2010; Brand & Dávila, 2011). The ACC has commonly been the start of solid investment in social urbanism in several cities in LAC (e.g. Medellín, Bogotá, and Rio de Janeiro) (Duarte Santos & Soares Gonçalves, 2017; Espósito Galarce & da Silva, 2016; Galvin & Maassen, 2020; Guevara-Aladino et al., 2022). Usually, social urbanism projects impact less frequent ACC users in the neighbourhood (Brand & Dávila, 2011, 2013; Coupé, 2013; Guevara-Aladino et al., 2022). For instance, women frequently use the Employment and Entrepreneurship Support Centre (CEDEZO) or the España Library Park (closed since 2015 due to reparations) in Medellín, two of the most important complementary projects around *Metrocable* (Matsuyuki et al., 2020). Moreover, increased physical activity, mental health and well-being were observed with the renovation of public parks in the surrounding areas of *Transmicable* in Bogotá (Guevara-Aladino et al., 2022).

The cases of Medellín and Bogotá have also shown high levels of community engagement through participatory budgeting, giving the inhabitants the power to decide how to allocate investments in their neighbourhood, usually for small projects, but not involved in crucial decisions such us the ACC itself (Galvin & Maassen, 2020; Guevara-Aladino et al., 2022). A general increase in the sense of pride, satisfaction with their neighbourhood, and the perception of neighbourhood visibility regarding the rest of the city have been observed, which is even higher among frequent ACC users (Brand & Dávila, 2011, 2013; Coupé, 2013; Guevara-Aladino et al., 2022; Matsuyuki et al., 2020). For example, travel and life satisfaction increases in Ciudad Bolivar with the inauguration of *Transmicable* (Guzmán, Arellana et al., 2023). Similarly, Milan and Creutzig (2017) found that the quality of life around the *Metrocable* service areas has also improved, considering socio-economic well-being, public infrastructure, and social capital indicators. Conversely, lower levels of community engagement were found in the second *Metrocable* line in Medellín (*Line J*) because complementary projects and neighbourhoods dynamics were not adequately connected (Brand & Dávila, 2011, 2013; Coupé & Cardona, 2013; Milan & Creutzig, 2017). No research was found regarding the recent Medellín ACC's lines (*Line H*, *Line M* and *Line P*).

The case of Rio de Janeiro's ACC was characterised by a lack of complementary projects and community engagement (Braga, 2017; Duarte Santos & Soares Gonçalves, 2017; Espósito Galarce, 2020; Espósito Galarce & da Silva, 2016; Freire-Medeiros et al., 2020; Freire-Medeiros & Name, 2015, 2017), and a profound disconnection between residents' needs and government objectives (Cavalcanti & Campos, 2022; Worms & Sluyter, 2018). For example, nearly 50% of the budget allocated to investment in the favelas was used to build the ACC; however, residents would prefer those investments in other areas such as water, sewerage, sidewalks, and roads (Duarte Santos & Soares Gonçalves, 2017; Worms & Sluyter, 2018). On the contrary, between six and seven times Medellín's ACC cost was invested through participatory budgeting in complementary projects in the next four years after the inauguration of the first line (Brand & Dávila, 2011, 2013).

Around ACC's towers and stations in Medellín and Rio de Janeiro there is evidence of the appropriation of residual spaces (Agudelo V. et al., 2013; Coupé & Cardona, 2013; Espósito Galarce, 2020; Espósito Galarce & da Silva, 2016; Freire-Medeiros & Name, 2015; Goodship, 2015). Residual spaces are open spaces in urban contexts that urban designers often overlook. The rise in pedestrian flow around the ACC stations has led to an increase in the presence of informal street sellers and formal businesses such as shops, bars, and restaurants (Agudelo V. et al., 2013; Braga, 2017; Coupé & Cardona, 2013; Freire-Medeiros & Name, 2015; Goodship, 2015; 2016). However, the disconnect in planning processes between residents and the government has generated disputes around the residual spaces created by the ACC in *Complexo do Alemao*. For example, the residents installed a ping pong table, and some businesses flourished around it.

Nevertheless, the government replaced this space with an outdoor gym that is rarely used (Espósito Galarce, 2020; Espósito Galarce & da Silva, 2016).

### 5.3. Tourism

The ACC as a transit mode is linked with tourism because it offers a panoramic view of the city and the service area (Freire-Medeiros & Name, 2015). The first Metrocable line attracted a high flow of tourists, even though its primary objective was to supply daily mobility for residents (Jurado & Mesa-Arango, 2019). However, the quality of service for commutes has been reduced because of long queues due to the high demand (Jurado & Mesa-Arango, 2019). However, few tourists venture to the other lines, which indicates that tourism-related effects are usually concentrated in certain areas and lines. On the other hand, Rio de Janeiro's ACC was designed for mixed use as both a transport facility for favelas residents and as a city tourist attraction (Freire-Medeiros & Name, 2015). The ACC was the opportunity for politicians to sell the favela landscape as a tourist destination, taking advantage of the view from the sky (Duarte Santos & Soares Gonçalves, 2017; Freire-Medeiros et al., 2020; Freire-Medeiros & Name, 2015, 2017; Worms & Sluyter, 2018). The residents adapt to the flow of tourists, creating positive relationships between them and the ACC, e.g. visit guide tours through *Complexo do Alemao* ACC were offered and stands selling drinks and snacks were located outside the stations (Espósito Galarce & da Silva, 2016; Freire-Medeiros & Name, 2015). However, the ACC in Rio de Janeiro failed in their objectives. Despite being free, the favela's residents did not use the ACC, and the tourist flow did not cover operational costs (Cavalcanti & Campos, 2022). Consequently, both systems (*Complexo do Alemo* and *Providencia*) closed operations in 2016 (Cavalcanti & Campos, 2022; Duarte Santos & Soares Gonçalves, 2017; Espósito Galarce, 2020).

### 5.4. Politics and governance

Political decisions have played a pivotal role in implementing ACC projects in LAC. For instance, the first *Metrocable* line (Colombia) was a local effort, primarily because the national government chose not to support it due to concerns about project uncertainty (Brand & Dávila, 2011). After its success, the national government developed public policies to support and promote similar projects in other cities, including Manizales, Cali, Pereira, Bogotá, and additional lines in Medellín. Meanwhile, Rio de Janeiro's politicians implemented the ACC (2010) without considering proper technical support, i.e. inhabitant's necessities were left aside (Cavalcanti & Campos, 2022; Duarte Santos & Soares Gonçalves, 2017). They concentrated more on the prestige and tourist flow brought by important events such as the Olympic Games (2016) and the FIFA World Cup (2014), leaving aside the social impacts on the community (Cavalcanti & Campos, 2022; Freire-Medeiros et al., 2020; Freire-Medeiros & Name, 2015). In contrast, the La Paz ACC network (2014) had the total support of the national government, creating an ambitious plan to connect the city through this technology (Garsous et al., 2019; Koch, 2013; Martinez et al., 2018). Nevertheless, frictions between the national and local governments were reported due to different visions of mobility in the long run for La Paz (Koch, 2013).

### *5.5. Crime, health, and housing*

Regarding crime and violence, a positive impact in Medellín was found, in the neighbourhoods where the ACC was built. For instance, there is a decrease in the homicide rate and residents' reports of violence, especially near the stations (Cerdá et al., 2012; Matsuyuki et al., 2020). Furthermore, the role of ACC as a mechanism of presence and control of the state has also been pointed out due to an increase of people observing the neighbourhoods' dynamics from the sky (Capillé & Reiss, 2019; Coupé, 2013; Freire-Medeiros et al., 2020).

Impacts on the health regarding physical activity and environment, and the housing market and rent have been scarcely studied. The *Transmicable* ACC registered the lowest exposure to pollutants during travel compared to BRT feeders, traditional buses, paratransit services and walking (Morales-Betancourt et al., 2023). Nevertheless, residents do not experience the air quality benefits after the ACC implementation despite high expectations before the construction (Guzman et al., 2022). In addition, the project help to maintain a high level of physical activity in the neighbourhood through transport-related walking trips (Baldovino-Chiquillo et al., 2023).

Finally, no relation has been found in the housing prices and rental market with the deployment of the ACC in Medellín, despite the transactions increasing after implementing the first line (Bocarejo et al., 2014; Coupé, 2013). However, changes in the land use near the stations (e.g. the flourishing of businesses, shops, bars, etc.) and neighbourhood dynamics (changes in the rental market, increase of touristic flow) suggest effects of gentrification in the long term that should be studied. For example, Posada and García-Suaza (2022) found a decrease in informal housing with the construction of *Metrocable Line H* (Medellín) increased by the proximity to the ACC's stations; however, the authors remarked that several mechanisms could influence this causal relationship, e.g. the increase of accessibility to the labour market and housing rents.

## 6. Conclusions

The Aerial Cableway Transit (ACT) technology in urban environments is divided in two: Aerial Tramways (AT) and Detachable Gondolas (DG) (Aerial Cable Cars-ACC in transport literature). The first has a maximum capacity of 2000 pphpd, while DG could reach up to 6500 pphpd. Monocable Detachable Gondolas (MDG) are the most adopted technology in LAC as a transport mode. Other DG technologies, such as Tricable or Bicable, have been implemented in global north countries. The main differences are the cabin and line capacity and the construction costs. Our review has not found Aerial Tramway (AT) deployments as a transit mode over the past decade.

The topographical difficulties and spatial inequity patterns in many LAC cities have led to the more rapid adoption of ACC in this context, especially since 2010, when more than 90% of the lines were built. Our review identifies two main roles of ACC in LAC cities in relation to the service area's sociodemographic, topographic, and mobility characteristics. First, the ACC reached low-income and vulnerable neighbourhoods placed in hilly terrain and the peripheries of the cities. The ACC works as a feeder of broader transport systems, increasing the accessibility and social inclusion of these zones. Second, the ACC has been planned as the structure of the public transport system, reaching multiple zones of the city (especially the most attractive zones, e.g. the centre) due to a steeper topography throughout the built environment. In both cases, the limited capacity of the technology could be a burden in relation to an increase in passenger demand or the expansion of the ACC network.

The ACC implementations have a deep connection with social inclusion. The empirical evidence shows how complementary projects and social urbanism were essential to impact vulnerable communities comprehensively. Furthermore, travel time and cost reductions were the most crucial mobility outcome. Politics and governance have been crucial in adopting this transit mode in LAC cities. Initially, the local authorities took most of the effort and risks. At the same time, the national government started to be more involved as the success and societal benefits of the first lines were discovered. The empirical evidence found allowed us to identify future research directions and recommendations for policymakers which will be described next.

### 6.1. Future research needs

While significant empirical research has shed light on the impacts of aerial cable cars (ACC) as a transport mode, there remains a need for further investigation into several key areas. Specifically, research should delve into the effects of ACC on gentrification, road safety, or air pollution. Notably, transport equity from an accessibility perspective has only been examined in the case of Medellín by Bocarejo et al. (2014). Future research should build upon this line, employing innovative calculations that move beyond aggregated measures to individual measures (Vecchio et al., 2020). Researchers can analyse the effects in greater detail by utilising accessibility-activity models and incorporating individual characteristics from household travel surveys and built environment variables from secondary sources (Luz et al., 2022; Vecchio et al., 2020).

Moreover, to enhance our understanding of travel behaviour about ACC, there is a need for further exploration of user profiles and the modal shift between different transport modes. Existing studies have highlighted the influence of factors such as violence and crime, social capital, satisfaction with the neighbourhood, and other latent variables in the modal choice of ACC, particularly in transport-disadvantaged communities (Agudelo V. et al., 2013; Guzman, Cantillo-García, et al., 2023; Guzman, Arellana et al., 2023; Sarmiento Ordosgostia et al., 2013). It is essential to identify additional latent variables that influence the use of ACC in these communities.

Additionally, while traditional buses, paratransit, motorcycles, and walking play significant roles in daily mobility, ACC primarily attracts workers and students. Further research is needed to understand why people prefer other transport modes, especially when making the modal shift from private vehicles to ACC to enhance sustainable mobility (Okami et al., 2022). Multimodality is another crucial aspect that warrants investigation, particularly regarding the modal choice for first and last-mile trips to access the ACC. Furthermore, examining the combination of ACC with micromobility options, such as transporting bicycles and scooters inside the cabins, presents potential for enhancing the overall transportation experience.

Finally, research around case studies should consider three unexplored dimensions. First, most of the studies found involved cities where ACC operates as a feeder of the public transport system, while there is scarce analysis when it is the system's backbone. Second, the city's size has implications for the transport system due to differences in the service area and travel behaviour; exploring medium-sized cities should be a priority. Thirdly, the impact of ACC in other contexts in LAC (e.g. México, Ecuador, Venezuela, or Dominican Republic), Northern Africa (e.g. Algeria) and Europe (e.g. France, Germany, or the UK) must be studied. Differences between global south and north countries' case studies would be relevant to analyse.

### *6.2. Policy recommendations*

ACCs can help reduce spatial inequity and social exclusion in transport-disadvantaged communities (Posada & García-Suaza, 2022). Complementary projects are crucial and participatory budgeting has shown promising results in increasing community engagement with the ACC, which is critical for the success of the transport project. The implementation of ACC's should be complemented with other transit modes to ensure accessibility due to a limitation in transport capacity and flexibility. Moreover, the political role should be guided by technical decisions, prioritising the societal impacts.

The integration of the ACC into the public transport system should follow: (i) physical and fare integration with other transit modes, preventing competition among transit modes potentially increasing the ACC's ridership; (ii) Paratransit services should be considered as stakeholders, especially to complement the first and last mile part of the journey (Villar-Uribe, 2021), (iii) Bikes and micro-mobility vehicles should be allowed to transport inside ACC cabins (see examples of Manizales, Bogotá, and La Paz) without additional costs to other passengers. This will prompt multimodal trips and increase the ACC's service area. Additionally, fare policies must be considered with the integration, especially among usual travellers and vulnerable groups.

Furthermore, the built environment around the stations and towers must prompt active mobility (walking and cycling) as the first and last-mile mode of transport. The project should include construction and optimisation of sidewalks and bike paths and improving lighting to raise security. This objective is challenging to achieve in zones with rugged topography; outdoor electric stairways (Medellín or Rio de Janeiro) are good examples of complementary infrastructures that could increase the local accessibility of the community (Naef, 2018).

Finally, the ACC systems will always have the potential to attract a significant flow of tourists because of their privileged view of the city. Nevertheless, these benefits could be concentrated in specific spots, like in the first *Metrocable* line in Medellín. Transport planners and decision-makers should communicate this potential to the residents with the positive and negative effects. Including tourism stakeholders in the design phase could help to achieve these goals.

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## Appendix 1. Articles reviewed

| | | Main Methodology | |
|---|---|---|---|
| Case Study | Quantitative | Qualitative | Mixed |
| Medellín (Colombia) | Cerdá et al. (2012), Sarmiento Ordosgostia et al. (2013), Bocarejo et al. (2014), Cordoba et al. (2014), Goodship (2015, 2016), Jurado and Mesa-Arango (2019). Matsuyuki et al. (2020), Okami et al. (2022), Posada and García-Suaza (2022) | Brand (2010), Brand and Dávila (2013), Coupé (2013), Agudelo V. et al. (2013), Milan and Creutzig (2017), Capillé and Reiss (2019), Galvin and Maassen (2020) | Brand and Dávila (2011), Coupé and Cardona (2013), Heinrichs and Bernet (2014) |
| Bogotá (Colombia) | Garnica Quiroga (2020), Guzman et al. (2022), Guzman, Arellana, et al. (2023), Morales-Betancourt et al. (2023), Guzman, Cantillo-Garcia, et al. (2023), Baldovino-Chiquillo et al. (2023) | Guevara-Aladino et al. (2022) | Villar-Uribe (2021) |
| Manizales (Colombia) | Escobar et al. (2015), Escobar and Garcia (2011) | | |
| Rio de Janeiro (Brazil) | | Espósito Galarce and da Silva (2016), Espósito Galarce (2020), Freire-Medeiros and Name (2015, 2017), Gonçalves and Bandeira (2017), Worms and Sluyter (2018), Freire-Medeiros et al. (2020), Cavalcanti and Campos (2022) | Duarte Santos and Soares Gonçalves (2017), Braga (2017) |
| La Paz (Bolivia) | Garsous et al. (2019), Martinez et al. (2018) | | |

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# Activity participation among disadvantaged communities and the impact of an aerial cable car: The case of TransMiCable, Bogotá

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A R T I C L E I N F O

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Built environment

A B S T R A C T

In Latin America and the Caribbean, topographical difficulties and urban spatial inequity patterns exacerbate transport complexities and challenges among disadvantaged communities. Aerial cable cars (ACC) have emerged as an innovative transit solution to address these disparities. This study measures the effects of an ACC system on activity participation in a disadvantaged community in the Global South. Using cross-sectional data before and after, we compare the impact of TransMiCable ACC in Ciudad Bolívar with that in San Cristóbal, two neighbourhoods with similar sociodemographic and travel behaviour characteristics in Bogotá, Colombia. Activity participation levels of total, mandatory, flexible, and care activities were measured using an ordered logit model controlled by temporal, neighbourhood, individual, and household characteristics. The results indicate that ACC increased activity participation, which was influenced by the rise in flexible and care activities. Interestingly, females are less likely to participate in care activities in 2019, a trend found to be independent of the ACC's influence. Additionally, the built environment exhibited different scale effects considering the type of activity. For instance, mandatory activities, typically conducted outside the neighbourhood, are more influenced by destination accessibility, whereas flexible and care activities, mainly conducted inside, are more influenced by distance to bus stops, population density, and land use mix. These findings suggest that decision-makers should consider the differential effects of sociodemographic and built environment variables on activity participation to maximise the social benefits of new transit infrastructures.

## 1. Introduction

Mobility is a fundamental right that allows people to enjoy the city's opportunities (Rodas et al., 2022), increasing accessibility and social inclusion (Lucas, 2012). Urban settlements in developing countries, such as Latin America and the Caribbean (LAC), often present an unfair distribution of transport and land use created by their unique topology, urban planning decisions, and autonomous and unplanned processes (Cheng et al., 2013; Oviedo & Dávila, 2016). For instance, low-income people have been pushed to the city's peripheries to access more affordable housing (Oviedo & Dávila, 2016; Posada & García-Suaza, 2022). Those zones are at a higher risk of natural hazards (floods or landslides), usually in hilly terrains, making it difficult to provide public transport and essential services (Brand & Dávila, 2011; Oviedo, 2021). This has led to informal settlements (slums) (Oviedo & Dávila, 2016), with nearly 20.9 % of the LAC population living in slums, and almost 50 % of them lack public transportation access (UN, 2024).

Aerial cable car (ACC) systems have been implemented to supply better public transport in disadvantaged communities established in hilly terrains or cities with steeper topography (Brand & Dávila, 2011; Cardona et al., 2024). This has been an increasingly popular solution among transport planners. Since 2010, 90.9 % of the 33 operative lines have been inaugurated as public transport modes in seven countries in LAC (Cardona et al., 2024). While ACC's systems have been increasingly adopted in disadvantaged communities in hilly terrain (Cardona et al., 2024), there is limited evidence of their impact on travel behaviour and activity participation (Okami et al., 2022). This is more evident in the Global South, where research among disadvantaged communities remains scarce (Luz et al., 2022; Okami et al., 2022), particularly in studies about activity participation (Nayak & Pandit, 2023). This research addresses the above gaps by measuring the impacts of ACC implementation on inhabitants' activity participation, focusing on disadvantaged communities established in steeper topography. We focus on changes in activity participation in the Ciudad Bolivar locality in

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Bogotá before and after the TransMiCable was inaugurated in 2018, using repetitive cross-sectional data collected by the household travel survey (HTS) in 2015 (before) and 2019 (after). This study uses an ordered logit framework to identify how the ACC implementation and the individual, household and built environment characteristics determine the activity participation among disadvantaged communities in hilly terrain.

The paper is composed of five sections. The following section presents the literature review about travel behaviour among disadvantaged communities and the impact of ACC on travel behaviour, accessibility and social inclusion. Then, section 3 presents the materials and methods in conjunction with the case study TransMiCable in Ciudad Bolívar (Bogotá). The fourth section includes the main results of the activity participation models. Finally, the last two sections present the research's conclusions and discussion.

## 2. Literature review

The literature review is focused on understanding the empirical findings about the travel behaviour of disadvantaged communities, paying special attention to activity participation, how the hilly terrain can exacerbate their social exclusion and how ACC, as a transit mode, impacts travel behaviour among individuals in their area of influence. We understand disadvantaged communities (DC) as characterised by low-income people who often live in the peripheries and/or hillside terrains. In some cases, these communities may also manifest informal development.

### *2.1. Transport in disadvantaged communities: Challenges and travel behaviour*

DC are characterised by several transport issues that limit their enjoyment of the city's opportunities, potentially leading to social exclusion (Lucas, 2012; Luz et al., 2022). Their low income limits the affordability of private and public transport (Guerra et al., 2022; Ureta, 2008). For example, Bogota's low-income people spend more than 20 % of their monthly income on public transport (Oviedo & Dávila, 2016). Furthermore, being in the city's peripheries increases their commuting travel time and distance, reducing their free time to engage in other activities during the day, negatively impacting their accessibility to essential services and quality of life (Brikman, 2021; Cheng et al., 2013, 2019; Oviedo & Dávila, 2016). In many cases, public transport is the only commuting option, as a private vehicle is not affordable (Cheng et al., 2013; Guerra et al., 2022; Oviedo & Dávila, 2016; Pieroni et al., 2021). In addition, their informal development lacks adequate transport planning, and the hilly terrain presents challenges for effective urban planning (Brand & Dávila, 2011; Kamalipour & Dovey, 2019; Okami et al., 2022; Sarmiento et al., 2020). Space to expand sidewalks and roads or to implement transit modes with larger capacities is particularly limited. The first and last-mile connections to mass transport systems are challenging. Inhabitants consequently rely on paratransit services or low- to medium-capacity diesel-powered buses, which share roads with private vehicles, reducing their average speed and road safety and increasing pollution (Oviedo & Dávila, 2016; Villar-Uribe, 2021).

Walking is often observed as the primary mode of transport, e.g., it is used for accessing public transport and reaching maintenance activities such as grocery shopping and visiting friends (Brikman, 2021; Cheng et al., 2013, 2019; Garnica, 2020; Manoj & Verma, 2015; Okami et al., 2022; Oviedo, 2021; Salon & Gulyani, 2010; Ureta, 2008). Empirical evidence from Asia and Africa shows high levels of trips on foot. For example, in Huzhou (China), 73 % of the maintenance trips among low-income people are done walking (Cheng et al., 2013), while in Nairobi (Kenia), 65 % of slum residents walk to work (Salon & Gulyani, 2010). Similar shares were observed in Bangalore (India), where 78 % of non-work trips by low-income households are made walking (Manoj & Verma, 2015). Similarly, investigations from Latin America evidence that the hilly terrain does not seem to prevent walking trips. For instance, inhabitants of hilly neighbourhoods in Colombia (Medellín "Comunas" and Ciudad Bolívar in Bogotá) and Brazil (Complexo do Alemao in Rio de Janeiro) walk on most of their daily trips, especially for intra-neighbourhood trips (Duarte & Soares Gonçalves, 2017; Garnica, 2020; Okami et al., 2022). On the other hand, cycling is less common among disadvantaged communities due to topographical constraints.

The mentioned lack of transport directly impacts travel behaviour, with evidence suggesting that people in DC travel less than other groups (Cheng et al., 2013, 2016, 2019; Okami et al., 2022). For instance, in Medellín, Colombia, DC residents engaged in less than two trips per person per day (Cordoba et al., 2014). These challenges are further exacerbated for specific groups, particularly females. Since there are deep gendered mobility inequalities across several societal groups (de Madariaga, 2013), females in DC often face additional barriers due to their multiple social roles, including income generation, caregiving, household responsibilities, and maintenance of social relationships (de Madariaga, 2013; Montoya et al., 2020; Salon & Gulyani, 2010). As a result, females made more and shorter trips, mainly focused on specific purposes such as maintenance (e.g., buying groceries), social (e.g., visiting friends or family) and caregiving (e.g., escorting children to school), relying heavily on public transport- including paratransit services- and active mobility (Cheng et al., 2019; Duarte & Soares Gonçalves, 2017; Guerra et al., 2022; Montoya et al., 2024; Okami et al., 2022; Ureta, 2008).

### *2.2. Aerial cable cars to bring transport equity to disadvantaged communities*

The ACC has been established as a transit mode to provide accessible and affordable public transport in Latin American and the Caribbean (LAC) cities, being an innovative solution to transport challenges, particularly among DC in hilly terrains (Cardona et al., 2024). The ACC has produced diverse outcomes in mobility, travel behaviour and quality of life, shaped by individual (e.g., income level, gender, occupation, etc.) and the built environment (topography, access to transit systems, local accessibility, etc.) characteristics in the communities it serves. These outcomes reveal the importance of placing the ACC implementations in their context, paying special attention to the role of the ACC in the mobility system.

The ACC system in LAC has been implemented in two main ways. Its most common use is as a first- and last-mile connection to broader public transport systems like metro or BRT systems (as in Medellín, Bogotá, México, etc.). On the other hand, cities with steeper topography, such as La Paz and Manizales, have developed a public transport system around ACC. The ACC have brought transport equity and reduced social exclusion among communities in their area of influence (Cardona et al., 2024). The ACC is an air-based transportation system that moves cabins (with capacities between 8 and 35 people) through a continuous loop using a cable and stopping in stations that allow passengers to access and egress (Cardona et al., 2024). The first ACC as a transit mode was inaugurated in Medellín (Colombia) in 2004, serving a disadvantaged community in hilly terrain and connecting them to the Metro system (Brand & Dávila, 2011). The ACC are usually part of Social Urbanism projects, strategic interventions in the built environment that address social inequalities in DC through upgrading urban space and providing new public facilities. The most successful ACC implementations, such as Medellín's Metrocables and Bogotá's TransMiCable, have comprehensively integrated Social Urbanism principles during the planning, design, and implementation phases (Brand & Dávila, 2013; Cardona et al., 2024).

The ACC potentially impacts accessibility, social inclusion, and activity participation by providing more direct access to the city-wide transit system (Cardona et al., 2024). The inauguration of the ACC reduced the average travel time among commuters in the DC communities by 45 min in Medellín and 22 min in Bogotá, enabling residents to reallocate time to leisure or work activities (Guevara-Aladino et al., 2023; Heinrichs & Bernet, 2014). The fare and physical integration of the ACC with Metro or Bus Rapid Transit (BRT) systems reduced travel costs, raising affordability among commuters (Bocarejo et al., 2014; Guzman et al., 2022; Heinrichs & Bernet, 2014). These benefits were highly perceived among ACC users, particularly males (Guzman et al., 2024). Furthermore, in Medellín, the first Metrocable line increased the probability of finding jobs (Matsuyuki et al., 2020), while employment accessibility doubled (Bocarejo et al., 2014). These outcomes reveal ACC's role as a first- and last-mile connector, expanding access to facilities outside neighbourhoods, especially the labour market, and improving the efficiency of the public transport network.

On the other hand, the ACC improved local accessibility by increasing the facilities in the neighbourhood through Social Urbanism projects (Baldovino et al., 2023; Brand & Dávila, 2013; Guevara-Aladino et al., 2023), impacting intra-neighbourhood trips mostly related to flexible activities like visiting friends or family or buying groceries. For instance, park renovations were implemented in parallel with Bogota's ACC, producing increased physical activity, mainly among boys and males (Baldovino et al., 2023).

In addition, the ACC potentially impact travel behaviour and quality of life. In Medellín, Cordoba et al. (2014) found that ACC potentially reduced the risk of social exclusion by increasing the number of daily trips, while Milan and Creutzig (2017) found an increase in public transport, walking, and biking modal share, especially among low-income and female residents. The perception of the benefits is influenced by ACC use and gender (Guzman et al., 2022). Females perceived fewer benefits in terms of travel time savings, while male users perceived larger benefits in this item. Meanwhile, female users perceive higher in-vehicle security. Crime and security have been a major concern among females, being a relevant predictor of mode choice (Sarmiento et al., 2013). For instance, in Medellín, females prefer traditional buses over ACC for intra-neighbourhood trips because bus stops are closer than ACC stations. Therefore, they are less exposed to crimes when walking to the bus stops (Sarmiento et al., 2013).

This research hypothesises that the ACC inauguration positively impacts activity participation among disadvantaged communities. There is evidence about the positive influence of public transport on activity participation in the Global North (Allen & Farber, 2020) and South (Luz et al., 2022) contexts. Therefore, we will investigate how ACC impacts participation in total, mandatory, flexible, and care activities, and how individual, household, and built environment characteristics influence out-of-home activity levels. We are particularly interested in identifying how gender influences the ACC effect of activity participation, considering that females have different mobility patterns; the new transport facility will consequently impact their travel behaviour differently. Furthermore, the characteristics of the built environment are measured at the residential and destination levels. Improving mobility by directly connecting to the broader public transport system will generate impacts for trips mainly conducted outside the neighbourhood, such as for work or study. On the other hand, local accessibility potentially impacts flexible trips (visiting friends or family, buying groceries) that are shorter and mainly conducted inside the neighbourhood. Those effects will be considered through built environment variables like destination accessibility (city-level), distance to bus stops, population density, land use diversity, and road intersection design (neighbourhood level).

## 3. Materials and methods

This section describes the case study and data sources in more detail, followed by a description and model of the method specification.

### 3.1. Case study and data

In this study, we will focus on the case of Ciudad Bolivar's TransMiCable, which was inaugurated in Bogotá (Colombia) in December 2018. Bogotá is the capital city of Colombia, with more than 7 million inhabitants and a population density of 177.55 inhabitants per hectare. This city has been recognised for developing public transportation around the Bus Rapid Transit (BRT) system called TransMilenio (red lines in Fig. 1) (Hidalgo & Huizenga, 2013). TransMilenio has demonstrated an increase in the accessibility and affordability of public transport; nevertheless, the benefits diminished in the peripheries, where most of the low-income population have settled (Bocarejo & Oviedo, 2012; Oviedo & Dávila, 2016). TransMiCable is the first ACC implemented in the city, serving Ciudad Bolívar's locality on the south periphery of the city (yellow line in Fig. 1) and designed as a Social Urbanism project, including investment in complementary projects in the neighbourhood (Sarmiento et al., 2020). Ciudad Bolivar has nearly 850,000 inhabitants, with 85.5 % of the households classified as low-income, and it is characterised by its steep terrain, making it difficult to develop traditional public transport projects (Sarmiento et al., 2020; Villar-Uribe, 2021). The ACC is 3.43 km long and has four stations, being an alternative that is directly connected to the BRT system. It is used by 22,000 passengers daily, reducing travel time (by 22 % on average for commuting) and costs (Cardona et al., 2024; Guevara-Aladino et al., 2023).

We used data from government portals and open sources. Bogota's open data portal (Datos Abiertos Bogotá for its acronym in Spanish) allowed us to download Bogota's Household Travel Survey (HTS), the cadastral data with land use information and employment data (2021) at the block level, and the General Transit Feed Specification from July of 2023 (Datos Abiertos Bogotá, 2023). The HTS collected cross-sectional data every four years and considers inhabitants' travel patterns and sociodemographic variables at the individual (gender, age, education, occupation, etc.), household (income, car ownership, etc.) and Traffic Analysis Zone (TAZ) levels. This research used the HTS of 2015 (collected between March and August) and the HTS of 2019 (collected between February and November). Although the ACC began operations in December 2018, and the HTS 2019 was collected from February, ridership reports from TransMilenio (2025) indicate rapid adoption. For instance, TransMiCable reported an average usage of 19 thousand passengers daily in 2019, similar to the ridership of 21 thousand passengers daily in 2024. Besides, there is empirical evidence about the shock effects of new transit systems in the short term (see Termida et al. (2016) or Ingvardson et al. (2025)), demonstrating that less than one year is enough to observe changes in travel behaviour. On the other hand, the population at the block level was retrieved from the Census of Population and Households 2018 (CNPV, its acronym in Spanish) collected by the National Administrative Department of Statistics (DANE, its acronym in Spanish) (DANE, 2018). Finally, we downloaded road networks from OpenStreetMap in July 2023 (OpenStreetMap contributors, 2017).

### 3.2. Methods

This research uses a natural experiment following recommendations from previous studies on ACC implementations in the area (see Sarmiento et al., 2020). A natural experiment is used to evaluate the changes in travel behaviour produced by a new transport infrastructure (Sun et al., 2020). It considers an intervention group, where the new transport infrastructure is operating and the control group, where no transport infrastructure was installed. The control group must have similar sociodemographic and built environment characteristics to facilitate comparisons. In the case of our study, the intervention group corresponds to Ciudad Bolívar, where the first ACC operates (see Fig. 1). The control group is represented by the locality of San Cristóbal (see Fig. 1), where the second ACC line has been under construction since 2023, with operations projected to begin in 2026. The natural experiment considered households in the HTS (2015 and 2019) within an 800-m buffer around Ciudad Bolívar's ACC stations and the projected San

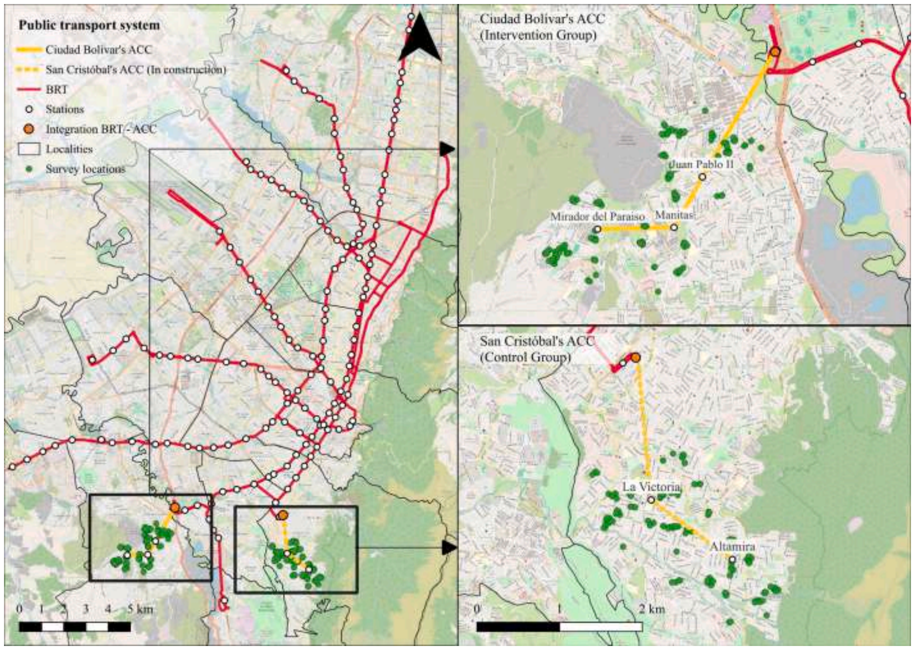


**Fig. 1.** Study zone. Bogota's public transport system. Ciudad Bolívar (Upper-right), San Cristóbal (Bottom-right). Green dots are households in the zone of influence of ACC stations retrieved from the Household Travel Survey. Source: Own elaboration using Bogotá's Open Data Portal and Open Street Maps data. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Cristóbal's ACC (green dots in Fig. 1), considering only those over 18 years old in the analysis areas.

We estimated an Ordered Logit (OL) model to calculate the probability of an individual conducting a certain number of activities per day. It considers the ordered number of activities based on a latent utility ($V_{AP}$) (Mahdi & Esztergár-Kiss, 2023; Soza-Parra et al., 2019). Furthermore, sociodemographic (SD) and built environment (BE) characteristics are used as independent variables (see eq. 1). We used the Apollo R package to estimate the OL with a BGW algorithm for maximum likelihood optimisation (Bunch et al., 1993; Hess & Palma, 2019). To account for the causal relationships in the impact of the ACC on activity participation in Ciudad Bolivar (CB), we included variables of interest regarding the HTS periods ( $\beta_{2019}$), the neighbourhoods ( $\beta_{CB}$), and the interaction between them ( $\beta_{CB-2019}$). Finally, we included a scale factor ($\lambda_{year}$) to adjust for the possible heteroscedasticity across HTS samples (i.e. difference in the variances of the cross-sectional samples of two different years) (Soza-Parra et al., 2019). As both scale factors cannot be estimated separately, we fix the one for 2015 to 1.

$$V_{AP} = \lambda_{year} * \Big( \beta_{2019} * Year_{2019} + \beta_{CB} * Neighbourhood_{CB} + \beta_{CB-2019} * Year_{2019} * Neighbourhood_{CB} + \sum \beta_{SD} * SD + \sum \beta_{BE} * BE \Big) \tag{1}$$

### 3.2.1. Activity participation

Activity participation (AP) is all the out-of-home activities conducted during a day, e.g., to work, study, visit relatives or go to the gym (Allen & Farber, 2020; Luz et al., 2022). We calculated AP using the travel diaries reported in the HTS, using travel purposes as a proxy (Luz et al., 2022). We categorised travel purposes from the HTS 2015 and 2019 into work, study, leisure, social, care, health, and other by merging the reported by people in each survey, considering the questionnaire options. We must acknowledge that some developments were made in the questionnaire, obtaining a more refined categorisation of the travel purposes in the HTS 2019. Then, the AP was categorised into total activities (TA), mandatory activities (MA), flexible activities (FA) and care activities (CA). Table 1 presents the AP categories, the travel purpose categories, and the original options in the HTS.

**Table 1**
Categorisation of activity participation.

| Activity | Category | Travel Purposes |
|---|---|---|
| Total activities (TA) | Work, Study, Leisure, Social, Care, Health, Other | All out-of-home activities |
| Mandatory activities (MA) | Work and Study<br>Study | Work, Work Issues<br>Study |
| Flexible activities (FA) | Leisure | Shopping*, Recreation*, Recreation and Culture, Religious activities, Physical activity and sport, |
| | Social | See someone, pick up/drop off something, pick up/drop off someone who does not need your care*, eating/drinking, errands |
| Care activities (CA) | Care | Pick up/drop off someone who needs your care*, pick up/drop off someone, care for people |

* Only present in HTS 2015.

We considered care activities a separate category because of their imbalanced distribution among gender groups (Gómez-Varo et al., 2023). Females generally performed more care tasks than males, especially in developing countries and disadvantaged communities like the studied neighbourhoods (Guevara-Aladino et al., 2023; Guevara et al., 2024; Montoya et al., 2020; Murillo-Munar et al., 2023; Orjuela & Schwanen, 2023; Rodas et al., 2022). We defined care activities as accompanying someone in the household who needs some level of assistance or care (Gómez-Varo et al., 2023; Orjuela & Schwanen, 2023).

### 3.2.2. Sociodemographic variables

We calculated sociodemographic variables at the individual (1846 observations) and household (773 observations) level. Descriptive statistics of the variables are presented in Tables 2 and 3. The samples are equilibrated for the intervention and control groups at the individual level (see Table 2), except for education levels, where fewer people with primary education were surveyed in 2019. The average family household size is similar for both periods and between the groups (see

**Table 2**
General statistics at the individual level.

| Variables | | Ciudad Bolívar 2015 ($n$ = 595) | Ciudad Bolívar 2019 (n = 370) | San Cristóbal 2015 ($n$ = 511) | San Cristóbal 2019 ($n$ = 370) |
|---|---|---|---|---|---|
| Gender | Female | 53.9 % | 47.6 % | 53.8 % | 47.6 % |
| | Male | 46.1 % | 52.4 % | 46.2 % | 52.4 % |
| Age | 18–30 | 29.2 % | 35.4 % | 26.0 % | 30.3 % |
| | 30–45 | 28.9 % | 26.5 % | 33.1 % | 25.4 % |
| | 45–60 | 21.3 % | 19.7 % | 21.7 % | 20.0 % |
| | >60 | 20.5 % | 18.4 % | 19.2 % | 24.3 % |
| Education level | Primary | 71.3 % | 49.2 % | 65.9 % | 35.7 % |
| | Middle | 17.3 % | 36.2 % | 14.9 % | 39.5 % |
| | Technical | 6.9 % | 11.4 % | 13.9 % | 17.8 % |
| | Higher | 4.5 % | 3.2 % | 5.3 % | 7.0 % |
| Occupation | Worker | 58.2 % | 51.1 % | 58.9 % | 57.3 % |
| | Student | 2.5 % | 5.9 % | 3.3 % | 7.6 % |
| | Household-chores | 23.2 % | 28.4 % | 22.9 % | 24.3 % |
| | Other | 16.1 % | 14.6 % | 14.9 % | 14.6 % |
| Relation with household head | Head | 41.7 % | 42.2 % | 41.9 % | 40.3 % |
| | Partner | 26.4 % | 27.0 % | 29.7 % | 21.4 % |
| | Nuclear Family | 28.6 % | 25.9 % | 26.0 % | 31.6 % |
| | Extended Family | 2.5 % | 1.9 % | 2.2 % | 4.1 % |
| | Other Family | 0.8 % | 3.0 % | 0.2 % | 2.7 % |

**Table 3**
General statistics at the household level.

| Variables | | Ciudad Bolívar 2015 ($n$ = 252) | Ciudad Bolívar 2019 ($n$ = 156) | San Cristóbal 2015 ($n$ = 216) | San Cristóbal 2019 ($n$ = 149) |
|---|---|---|---|---|---|
| Family size (average) | | 3.41 | 3.43 | 3.42 | 3.43 |
| Presence of children (<12 years old) | | 46.8 % | 53.8 % | 44.9 % | 38.3 % |
| Presence of cars | | 7.6 % | 10.9 % | 14.4 % | 15.4 % |
| Presence of motorcycles | | 12.3 % | 16.7 % | 14.8 % | 20.1 % |
| Household Income (USD)* | <252 | 57.5 % | 62.8 % | 48.1 % | 55.0 % |
| | 252–456 | 34.1 % | 28.2 % | 47.2 % | 23.5 % |
| | 456–761 | 6.3 % | 7.1 % | 4.2 % | 14.1 % |
| | >761 | 2.0 % | 1.9 % | 0.5 % | 7.4 % |

[*] A value of COP 3289 per USD was used for the calculations, representing the mean value for 2019. Values for 2015 were adapted to 2019 categories.

Table 2). Furthermore, a slight increase in private motorised ownership was observed from 2015 to 2019, especially in Ciudad Bolívar and the category of motorcycles (see Table 3). As we described previously, these neighbourhoods are mainly comprised of disadvantaged communities (household income of less than USD 456 monthly) with low affordability for private vehicles (<30 %). In HTS, household income was self-reported, allowing the participants to skip the question. Some values are, therefore, missing. We imputed the missing monthly household income values (207 in 2015 and 18 in 2019) using a Multinomial Logistic Regression considering socioeconomic strata (SES) as a proxy of the socioeconomic level (Cantillo et al., 2019), the number of household members, neighbourhood (Ciudad Bolivar or San Cristobal), and the number of vehicles as independent variables.

### *3.2.3. Built environment variables*

We measured the built environment considering the five D's categories presented by Ewing and Cervero (2010): density, diversity, design, distance to public transport at the residential level and destination accessibility. We used cross-sectional data to calculate built environment variables (except for destination accessibility, where the availability of the ACC before and after its inauguration was considered).

The density category considered the population per block from the 2018 census (CNPV), and it was aggregated to TAZ in inhabitants per hectare (inhab/ha). We calculated the diversity of land use using the entropy index (E), which considered the cadastral data. Bogota's cadastral data contains 98 land use categories. We reclassified the land use categories into 10 to calculate the entropy index per TAZ: housing, commercial, industrial, institutional, educational, health, security, cultural and recreational. In this case, the airport was considered a separate category due to its size and influence in the city. Eq. 2 presents the formula used to calculate the entropy index, where $p_i$ is the proportion of land use, and $n$ is the number of land use categories. The $E$ is normalised from 0 to 1, with values near one, meaning it is more diverse regarding land use. Furthermore, we calculated the design as the road intersection density per TAZ (int/ha) using the OSM road networks considering walking, cycling, and driving.

$$E = \frac{-\sum_{i=1}^{n} p_i * \ln(p_i)}{\ln(n)} \tag{2}$$

Distance to public transit stops and destination accessibility were calculated at the household level. We used a multimodal network, considering Bogota's GTFS for public transport and the OSM walking network. Calculations were conducted using the *R5R* package of R language (Pereira et al., 2021). The distance to the nearest ACC and BRT station and bus stop was calculated using the household's origin, considering only the walking network. Furthermore, we used the cumulative opportunities accessibility measure. Cumulative opportunities are the percentage of employment opportunities reached by a household in a defined travel time (Wu & Levinson, 2020). Employment data was aggregated at the TAZ level. Travel times were calculated from household locations to TAZ centroids using the multimodal network (walk+transit). We estimated the average travel time in the morning peak hour, considering departure times from 5 to 8 am every 5 min. This allowed us to account for temporal variations (Pereira, 2019). Eq. 2 presents the cumulative opportunities (*Ai*) approach where $i$ are the households in the study zone, $j$ is the TAZ destination, $Oj$ are the employment opportunities in TAZ $j$ and $f(C_{ij})$ is the isochronic impedance function considering the time threshold. We tested accessibility values (Ai) in the OL models, considering travel time thresholds (t) from 15 to 120 min, every 15 min.

$$Ai = \sum_{j=1}^{J} g(O_j) f(C_{ij}) \tag{3}$$

$$f(C_{ij}) = \begin{cases} 1 \; if \; C_{ij} \leq t \\ 0 \; otherwise \end{cases}$$

The average of the built environment variables at the TAZ level are presented in Table 4. Both groups have similar population densities but are much higher than the city's density (177.55 inhab/ha). On average, San Cristóbal presents a lower land use diversity. The density of walking road intersections is higher than those for cycling and driving road networks. Values in Ciudad Bolívar are larger among groups. Bus stops are the nearest among transit modes for distance to transit. It is plausible that a lower average distance value to ACC stations in Ciudad Bolívar is

**Table 4**
General statistics at the TAZ level.

| Variable | | Ciudad Bolívar ($n$ = 17) | San Cristóbal ($n$ = 18) |
|---|---|---|---|
| Population density (inhab/ha) | | 296.04 | 293.43 |
| Land Use Entropy | | 0.26 | 0.20 |
| Road intersection density (int/ha) | Walking | 4.45 | 3.58 |
| | Cycling | 2.90 | 2.55 |
| | Driving | 2.81 | 2.38 |
| Distance to transit (km) | ACC stations | 0.74 | 7.43 |
| | BRT stations | 3.22 | 2.81 |
| | Bus stops | 0.17 | 0.14 |

due to it being the intervention group. Similarly, the average distance to BRT stations is more than 2.8 km in both cases, showing the low supply of mass transport systems in those parts of the city.

Accessibility analysis shows significant differences after the inauguration of the ACC in Ciudad Bolivar. For instance, the percentage of jobs reached by Ciudad Bolivar's inhabitants raised an average of 5.13 % for 75 min and 4.39 % for 90 min. Fig. 2 shows the percentage of cumulative jobs reached in the study zone per time threshold. We observe the same accessibility in the studied periods for San Cristóbal because no changes in public transit supply were considered. Results show that San Cristóbal exhibits better access, i.e., their inhabitants could reach a higher percentage of jobs at the same time as Ciudad Bolívar's inhabitants. This is because San Cristobal is geographically closer to the employment hotspots in the city.

## 4. Results

Levels of activity participation are similar in both neighbourhoods. The average total number of activities was 0.878 in 2015 and 1.132 in 2019 (see Table 5). Approximately 20 % of the individuals in the intervention and the control group do not report activity participation during the day, i.e., they did not conduct out-of-home activities. In addition, we observe an increase in the average frequency of all activity categories from 2015 to 2019, except for mandatory activities in Ciudad Bolivar, where a slight decrease of 7.9 % is registered. Interestingly, San Cristobal experienced an increase of 41.49 % in the average of Mandatory Activities. On the other hand, flexible and care activities were more impacted in Ciudad Bolívar. For instance, the average flexible activities increased by 87.66 % compared to 45.16 % in San Cristobal. Finally, care activity levels show development in both neighbourhoods, reaching 0.218 in Ciudad Bolivar and 0.148 in San Cristobal.

Table 6 shows the percentage of activities conducted inside and outside the neighbourhoods. Remarkably, there is an increase in the percentage of activities conducted inside the neighbourhood in Ciudad Bolivar by 2019, particularly for total (19.79 %), flexible (24.61 %), and care (10 %) activities. In the case of San Cristobal, there is a reduction in the activities conducted inside the neighbourhood, except for care activities, which increase by 3.29 %.

Table 7 presents the Ordered Logit (OL) results for the activity participation (AP) models divided into total activities (TA), mandatory activities (MA), flexible activities (FA), and care activities (CA). We found strong evidence for the positive effect of the ACC on the likelihood of engaging in more total activities in Ciudad Bolivar in 2019 (estimator = 0.377, *p*-value = 0.021) after the inauguration of TransMiCable. This increase could be influenced by larger numbers of flexible and care activities (see Table 5). Interestingly, the increase in mandatory activity participation in Ciudad Bolívar from 2015 to 2019 is lower than that of San Cristobal (estimator = −0.361, *p*-value = 0.008), despite a general increase in mandatory activities in 2019 (estimator = 0.331, p-value = 0.003) and higher likelihood for Ciudad Bolivar to engage in work and study activities (estimator = 0.412, p-value <0.000) compared to San Cristóbal.

Being female increases the probability of performing more out-of-home activities (estimator = 0.169, *p*-value = 0.011). This result is highly influenced by levels of flexible activities (estimate = 0.209, *p*-value = 0.01) and care activities (estimate 0.738, p-value <0.000). On the other hand, being male strengthens the chances of engaging in more mandatory activities, considering a negative estimate for females in this activity category (estimate = −0.193, *p*-value = 0.007). Changes in care activities through the years exhibit that females are less likely to engage in those activities in 2019 (estimate = −0.601, p-value = 0.006), while there are non-significant effects for the rest of the activities. Finally, we isolated the effect of the ACC by gender through the interaction: year-neighbourhood-gender. We do not find significant results; therefore, the changes in activity participation by gender are independent of the ACC, particularly for care activities.

Being occupied in household chores negatively influences the levels of total (estimate = −0,521, *p*-value <0.000) and mandatory activities (estimate = −1388, *p*-value <0.000) but increases the likelihood of engaging in more flexible (estimate 0,411, *p*-value <0.000) and care activities (estimate = 0.303, p-value = 0.01). In addition, the OL models show that being the household head's partner diminishes total activity levels (estimate = −0.184, p-value = 0.007), while being older (>60 years old) reduces the chances of engaging in out-of-home activities (total, mandatory and care activities). In addition, being a young adult (18 to 30 years old) increases the mandatory activity participation levels (estimator = 0,162, *p*-value = 0.036). Interestingly, flexible activity levels are not influenced by age.

The variables at the household level show that the number of household members reduced the probability of conducting out-of-home activities (estimate = −0.054, *p*-value = 0.01). As we expected, the presence of children positively impacted the likelihood of being involved in care activities (estimate = 0.201, *p*-value = 0.016), and car and motorcycle ownership did not affect activity participation levels. However, in the case of total (estimate = 0.106, p-value = 0.087) and care activities (estimate = 0.122, p-value = 0.058), the presence of motorcycles indicates a higher tendency of the activity.

Finally, the distance to transit stops positively influences the likelihood of activity participation: an increase in the distance to bus stops decreases the levels of total (estimate −0.474, *p* = 0.059), flexible (estimate −0.673, *p* = 0.015), and care activities (estimate −0.602, *p* = 0.020). Remarkably, job accessibility has a slightly positive effect on the likelihood of engaging in mandatory activities (estimator = 0.008, *p*-value = 0.093), while land use entropy has the opposite effect (estimate = −0.527, p-value = 0.097). The rest of the built environment variables do not strongly relate to the activity participation models.

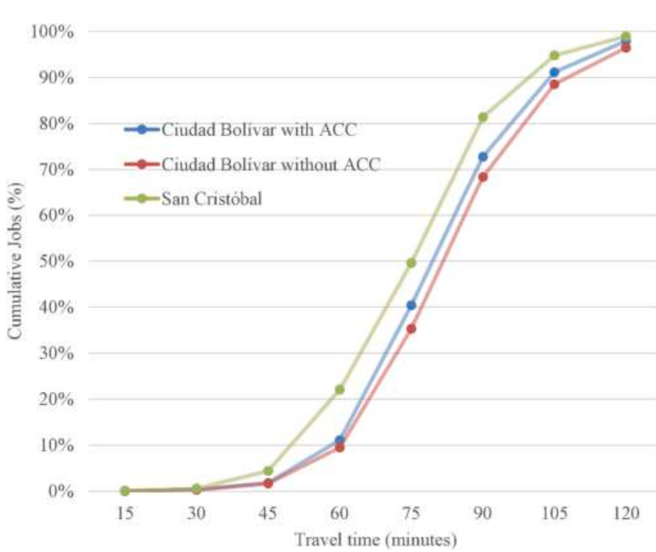


**Fig. 2.** Cumulative accessibility to jobs (percentage).

## 5. Discussion

This section is split into four segments. First, the effect of ACC on activity participation levels is discussed, with attention to the descriptive statistics and the model results. This provides hypotheses about the effects that drive these outcomes. Secondly, we discuss the relevance of the gender variable and the particular effect of ACC in shaping their activity participation. Thirdly, the effects of built environment variables are discussed by considering the city and residential level impacts on the different activity participation categories. Finally, general findings of activity participation in disadvantaged communities are discussed by considering their sociodemographics and contrasting them with similar empirical studies.

**Table 5**
Activity participation in the study zone.

| | Total | | | | Ciudad Bolivar | | | | San Cristobal | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2015 | | 2019 | | 2015 | | 2019 | | 2015 | | 2019 | |
| Total Activities (TA) | | | | | | | | | | | | |
| 0 | 225 | 20.3 % | 135 | 18.2 % | 103 | 17.3 % | 63 | 17.0 % | 122 | 23.9 % | 72 | 19.5 % |
| 1 | 807 | 73.0 % | 428 | 57.8 % | 457 | 76.8 % | 198 | 53.5 % | 350 | 68.5 % | 230 | 62.2 % |
| 2 | 58 | 5.2 % | 133 | 18.0 % | 28 | 4.7 % | 80 | 21.6 % | 30 | 5.9 % | 53 | 14.3 % |
| 3 | 16 | 1.4 % | 32 | 4.3 % | 7 | 1.2 % | 20 | 5.4 % | 9 | 1.8 % | 12 | 3.2 % |
| 4 or more | 0 | 0.0 % | 12 | 1.6 % | 0 | 0.0 % | 9 | 2.4 % | 0 | 0.0 % | 3 | 0.8 % |
| *Average per day* | 0.878 | | 1.132 | | 0.897 | | 1.227 | | 0.855 | | 1.038 | |
| Mandatory Activities (MA) | | | | | | | | | | | | |
| 0 | 641 | 58.0 % | 404 | 54.6 % | 317 | 53.3 % | 220 | 59.5 % | 324 | 63.4 % | 184 | 49.7 % |
| 1 | 452 | 40.9 % | 311 | 42.0 % | 270 | 45.4 % | 136 | 36.8 % | 182 | 35.6 % | 175 | 47.3 % |
| 2 or more | 13 | 1.2 % | 25 | 3.4 % | 8 | 1.3 % | 14 | 3.8 % | 5 | 1.0 % | 11 | 3.0 % |
| *Average per day* | 0.432 | | 0.488 | | 0.481 | | 0.443 | | 0.376 | | 0.532 | |
| Flexible Activities (FA) | | | | | | | | | | | | |
| 0 | 887 | 80.2 % | 521 | 70.4 % | 464 | 78.0 % | 238 | 64.3 % | 423 | 82.8 % | 283 | 76.5 % |
| 1 | 203 | 18.4 % | 175 | 23.6 % | 122 | 20.5 % | 101 | 27.3 % | 81 | 15.9 % | 74 | 20.0 % |
| 2 or more | 16 | 1.4 % | 44 | 5.9 % | 9 | 1.5 % | 31 | 8.4 % | 7 | 1.4 % | 13 | 3.5 % |
| *Average per day* | 0.212 | | 0.355 | | 0.235 | | 0.441 | | 0.186 | | 0.270 | |
| Care Activities (CA) | | | | | | | | | | | | |
| 0 | 1058 | 95.7 % | 639 | 86.4 % | 572 | 96.1 % | 311 | 84.1 % | 486 | 95.1 % | 328 | 88.6 % |
| 1 | 36 | 3.3 % | 67 | 9.1 % | 16 | 2.7 % | 38 | 10.3 % | 20 | 3.9 % | 29 | 7.8 % |
| 2 or more | 12 | 1.1 % | 34 | 4.6 % | 7 | 1.2 % | 21 | 5.7 % | 5 | 1.0 % | 13 | 3.5 % |
| *Average per day* | 0.054 | | 0.182 | | 0.050 | | 0.216 | | 0.058 | | 0.148 | |

**Table 6**
Activities conducted inside and outside the study zone.

| Neighbourhood | Activity category | 2015 | | 2019 | |
|---|---|---|---|---|---|
| | | Inside | Outside | Inside | Outside |
| Ciudad Bolivar | TA | 15.40 % | 84.60 % | 35.19 % | 64.81 % |
| | MA | 6.30 % | 93.70 % | 8.82 % | 91.18 % |
| | FA | 20.14 % | 79.86 % | 44.76 % | 55.24 % |
| | CA | 62.50 % | 37.50 % | 72.50 % | 27.50 % |
| San Cristobal | TA | 22.43 % | 77.57 % | 18.69 % | 81.31 % |
| | MA | 13.04 % | 86.96 % | 5.52 % | 94.48 % |
| | FA | 30.53 % | 69.47 % | 25.51 % | 74.49 % |
| | CA | 53.57 % | 46.43 % | 56.86 % | 43.14 % |

### 5.1. *The effect of ACC on activity participation*

After our analysis, we can see that the ACC has a relevant impact on increased activity participation in Ciudad Bolívar, driven by the rise in flexible and care activities, but it has no clear effects on mandatory activities. TransMiCable was a social urbanism project that invested in local amenities parallel to the ACC transport project (Sarmiento et al., 2020). We consider complementary projects to play an essential role in increasing total activity participation by increasing people's local accessibility. For instance, analysis of the percentage of trips made inside Ciudad Bolivar shows an increase, particularly for flexible and care activities (see Table 6). The interventions parallel to the ACC include cultural (library, museum, tourism office), institutional (citizen service office, community centres), recreational (sports centres, bike trails, renovation of urban parks), and commercial facilities (local markets), which increased local accessibility and activity participation among ACC users and non-users (Baldovino et al., 2023; Guevara-Aladino et al., 2023). Regular ACC users mostly benefit from the reduction of travel time, allowing the allocation of these savings to other activities during the day (Guzman et al., 2024), while maintaining healthy levels of physical activity by walking to the ACC stations in the access and egress parts of the journey (Baldovino et al., 2023).

The insights from mandatory activities are intriguing. Our analysis suggested a lower likelihood of engaging in work and study activities in Ciudad Bolivar, while an increasing trend is observed in San Cristobal. Explorations of time allocation after the ACC inauguration with longitudinal data suggest that regular ACC users are more likely to engage in work and study activities (Guzman et al., 2024). Consequently, the effect of mandatory activity participation in our study could be driven by economic and social determinants beyond the effect of the transport project.

### 5.2. *Activity participation among females and the ACC effect*

Our findings evidence substantial gender differences in activity participation. While males have higher levels of mandatory activities (work or study), females are more involved in flexible activities (e.g., shopping, visiting family) and accompanying dependants (e.g., children, seniors) to their activities. This indicates a general gap, when controlling for other individual characteristics like occupation, education, and relations with the household head in the model. Therefore, females are more involved in care activities, even when they are occupied with something else (de Madariaga, 2013; Gómez-Varo et al., 2023; Murillo-Munar et al., 2023). This is aligned with recent findings in the gendered mobility literature in the Global North (Gómez-Varo et al., 2023; Montero et al., 2023; Scheiner & Holz-Rau, 2017) and South (Montoya et al., 2020; Murillo-Munar et al., 2023; Orjuela & Schwanen, 2023).

This trend seems to have been changing over the years, considering that females were less likely to engage in care activities in 2019 in both neighbourhoods; results from other processes beyond the ACC effect. For instance, Bogotá is the first LAC city to implement a Care System policy (Alcaldía Mayor de Bogotá, 2025a), building Care Blocks, which is a hub with free services designed to attend to the necessities of unpaid caregivers and their dependants, including caregiving, education, healthcare and legal assistance, recreation, among others (Alcaldía Mayor de Bogotá, 2025b; Guevara et al., 2024). Care Blocks have been built in several localities, including Ciudad Bolívar (in ACC station Manitas, see Fig. 1) and San Cristóbal.

### 5.3. *The role of built environment variables in activity participation*

Previous research in activity participation found a significant relationship with built environment variables (Allen & Farber, 2020; Cheng et al., 2019; Fransen et al., 2018; Luz et al., 2022). Furthermore, studies on the ACC's impact on mobility and accessibility have found local and city-level effects. Although our findings do not indicate strong effects for the built environment variables, we could identify some interesting trends. For example, destination job accessibility slightly influences

**Table 7**
Ordered logit models for activity participation.

| | Total Activities | | Mandatory Activities | | Flexible Activities | | Care Activities | |
|---|---|---|---|---|---|---|---|---|
| | Estimate | p-value | Estimate | p-value | Estimate | p-value | Estimate | p-value |
| Neighbourhood (reference San Cristóbal) | | | | | | | | |
| Ciudad Bolivar | 0.113 | 0.113 | **0.412** | **0.000** | 0.104 | 0.161 | −0.169 | 0.152 |
| Year (reference 2015) | | | | | | | | |
| 2019 | **0.236** | **0.063** | **0.331** | **0.003** | **0.274** | **0.013** | 0.192 | 0.145 |
| Interaction: Neighbourhood - Year | | | | | | | | |
| Ciudad Bolivar - 2019 | **0.377** | **0.021** | **−0.361** | **0.008** | 0.241 | 0.081 | 0.216 | 0.116 |
| Gender (reference Male) | | | | | | | | |
| Female | **0.169** | **0.011** | **−0.193** | **0.007** | **0.209** | **0.010** | **0.738** | **0.000** |
| Interaction: Year - Gender | | | | | | | | |
| Female - 2019 | 0.093 | 0.281 | 0.157 | 0.139 | −0.039 | 0.402 | **−0.601** | **0.006** |
| Interaction: Year - Neighbourhood - Gender | | | | | | | | |
| Female-Ciudad Bolivar - 2019 | −0.140 | 0.251 | −0.184 | 0.152 | −0.125 | 0.224 | 0.008 | 0.471 |
| Age (reference "45–60") | | | | | | | | |
| 18–30 | 0.121 | 0.086 | **0.162** | **0.036** | −0.043 | 0.320 | 0.001 | 0.493 |
| 30–45 | 0.114 | 0.078 | 0.092 | 0.127 | −0.072 | 0.201 | **0.130** | **0.049** |
| >60 | **−0.262** | **0.002** | **−0.295** | **0.003** | 0.072 | 0.202 | **−0.255** | **0.010** |
| Household income (reference "<252") | | | | | | | | |
| 252–456 | −0.037 | 0.283 | **0.117** | **0.039** | 0.023 | 0.372 | **−0.174** | **0.025** |
| 456–761 | 0.122 | 0.129 | 0.090 | 0.202 | 0.012 | 0.455 | 0.093 | 0.117 |
| >761 | **−0.312** | **0.040** | 0.022 | 0.445 | **−0.390** | **0.034** | −0.019 | 0.440 |
| Education level (reference "Primary") | | | | | | | | |
| Middle | −0.053 | 0.228 | −0.004 | 0.480 | −0.099 | 0.094 | −0.007 | 0.454 |
| Technical | 0.057 | 0.277 | 0.053 | 0.284 | **0.178** | **0.034** | **−0.164** | **0.043** |
| Higher | **0.200** | **0.064** | **0.264** | **0.022** | 0.199 | 0.075 | **−0.290** | **0.036** |
| Occupation (reference "Work") | | | | | | | | |
| Household-chores | **−0.521** | **0.000** | **−1.388** | **0.000** | **0.411** | **0.000** | **0.303** | **0.002** |
| Study | 0.013 | 0.466 | −0.108 | 0.207 | −0.027 | 0.434 | 0.170 | 0.111 |
| Other | **−0.533** | **0.000** | **−1.369** | **0.000** | **0.351** | **0.000** | **0.259** | **0.019** |
| Relation with the household head (reference Head) | | | | | | | | |
| Partner | **−0.184** | **0.007** | −0.087 | 0.140 | **−0.201** | **0.007** | 0.002 | 0.487 |
| Other | **−0.292** | **0.000** | 0.085 | 0.152 | **−0.247** | **0.003** | **−0.170** | **0.041** |
| Total of household members | **−0.054** | **0.009** | 0.005 | 0.412 | −0.045 | 0.059 | 0.004 | 0.406 |
| Presence of children (dummy) | 0.014 | 0.416 | −0.015 | 0.412 | −0.085 | 0.107 | **0.201** | **0.016** |
| Presence of cars (dummy) | −0.060 | 0.243 | −0.016 | 0.428 | −0.023 | 0.400 | −0.005 | 0.475 |
| Presence of motorcycles (dummy) | 0.106 | 0.087 | 0.029 | 0.355 | −0.028 | 0.364 | 0.122 | 0.058 |
| Built environment | | | | | | | | |
| Population density | 0.174 | 0.355 | −0.387 | 0.219 | 0.368 | 0.224 | 0.763 | 0.066 |
| Land Use entropy | −0.414 | 0.143 | −0.527 | 0.097 | 0.202 | 0.308 | 0.179 | 0.313 |
| Road intersection density (walking) | 0.020 | 0.233 | 0.020 | 0.245 | −0.006 | 0.421 | −0.024 | 0.207 |
| Distance to bus stops | −0.474 | 0.059 | 0.126 | 0.346 | **−0.673** | **0.015** | **−0.602** | **0.020** |
| Accessibility to jobs (60 min) | −0.002 | 0.360 | 0.008 | 0.093 | −0.008 | 0.094 | −0.001 | 0.411 |
| Scale factor - year (reference 2015) | | | | | | | | |
| 2019 | **0.569** | **0.014** | **1.066** | **0.000** | **1.129** | **0.016** | **3.068** | **0.019** |
| tau_activity_1 | −2.124 | 0.000 | 0.096 | 0.407 | 1.257 | 0.002 | 4.395 | 0.000 |
| tau_activity_2 | 1.549 | 0.000 | 4.298 | 0.000 | 3.617 | 0.000 | 5.799 | 0.000 |
| tau_activity_3 | 3.148 | 0.000 | | | | | | |
| tau_activity_4 | 4.793 | 0.000 | | | | | | |
| Goodness-of-fit measures | LL | −1627.7 | LL | −1039.56 | LL | −1098.64 | LL | −506.69 |
| | $R^2$ | 0.4521 | $R^2$ | 0.4874 | $R^2$ | 0.4583 | $R^2$ | 0.7502 |
| | AIC | 3323.4 | AIC | 2143.13 | AIC | 2261.28 | AIC | 1077.38 |
| | BIC | 3511.1 | BIC | 2319.79 | BIC | 2437.94 | BIC | 1254.05 |

mandatory activity levels, while land use diversity has the opposite effect. Interestingly, mandatory activities, which usually have fixed locations, are not influenced by the distance to the transit stops in the neighbourhood. This evidence shows that the built environment influences mandatory activities at the destination rather than in the residential area. For instance, most individuals in the study zone must travel long distances outside the neighbourhood to reach the employment hot spots in the city centre, despite the travel time reductions due to TransMiCable (Guzman et al., 2024). Consequently, policy interventions must consider the effects of increasing the opportunities for flexible and care activities among commuters near their fixed activity location to positively impact their activity participation levels.

On the other hand, built environment variables in the residential area positively affect flexible and care activities, considering that most of their trips are inside the neighbourhood. An increase in the distance to bus stops negatively influences activity participation. In this area of Bogotá, where the TransMilenio has no nearby stations (>2.8 km away), the buses are frequently used for inter and intra-neighbourhood travel (Guevara et al., 2024; Villar-Uribe, 2021). Furthermore, traditional buses continue as the primary transit mode after the inauguration of ACC projects, which is evidence of their importance in those areas (Cardona et al., 2024). Interestingly, population density slightly increases care activities, evidence that high-density areas need more attention regarding care policy. This result is opposite to those found in Barcelona, where the population density is associated with a decrease in the number of trips for daily shopping and accompanying others (Gómez-Varo et al., 2023).

### *5.4. The effects of socioeconomic characteristics on activity participation among disadvantaged communities*

Activity participation levels increase for both neighbourhoods in the studied period, reducing the risk of social exclusion (Cordoba et al., 2014). However, sociodemographic characteristics can reveal hidden inequalities among different groups. For instance, people who are highly educated have a higher probability of engaging in more activities, particularly mandatory and flexible activities, when their participation in care activities diminishes. Similarly, occupation exacerbated activity participation differences, e.g., people involved in household chores engaged in more flexible and care activities, but fewer mandatory activities, a pattern consistent with findings in LAC (Luz et al., 2022; Murillo-Munar et al., 2023) and Europe (Gómez-Varo et al., 2023). The relationship between the household head and participation levels is interesting. The partners participate less, but this effect is insignificant in the care activity category. For example, a recent study in Ciudad Bolivar's care block program found that most unpaid caregivers are female heads of households (Guevara et al., 2024).

While previous studies in LAC found a positive relationship between age and activity participation (Luz et al., 2022), our findings suggest a non-linear relationship, which has also been evidenced in studies in the Global North (Allen & Farber, 2020; Fransen et al., 2018). People over the age of 60 conducted fewer activities compared to people aged between 45 and 60 years. Furthermore, being young (age 18 to 30) increases the possibility of participating in mandatory activities. Finally, age is not a significant predictor of flexible activities. This is an interesting result, considering that being an older adult does not hinder their flexible activity levels, as it negatively influences other activity categories; therefore, public policy efforts should focus on preserving this equity across age groups.

We also found that an increase in the number of household members reduces the probability of participating in out-of-home activities at the individual level, which is aligned with the literature among low-income residents (Cheng et al., 2019). Besides, the presence of children increases the likelihood of engaging in care activities, similar to other case studies about care mobility (Gómez-Varo et al., 2023). In addition, car ownership is low in both neighbourhoods and, therefore, does not influence activity participation, which aligns with previous research conducted in the area (Guzman et al., 2024). On the other hand, motorcycle ownership positively impacts care activities. Diverging from the Global North, where car ownership is a high predictor of activity participation and a driver of social exclusion (Allen & Farber, 2020; Fransen et al., 2018), motorcycles in LAC are more affordable and accessible, particularly among low-income households (Chiu et al., 2023; Hagen et al., 2016), making them an option for many travel purposes, including care-related trips.

## 6. Conclusions

This research outlines the impact of an ACC on activity participation by examining the effects of Ciudad Bolivar's TransMiCable. Furthermore, it provides empirical evidence about the role of individual, household and built environment variables in shaping activity participation among disadvantaged communities in LAC, something underexplored in the Global South context. By using repetitive cross-sectional data, the research demonstrates its potential to make ex-post evaluations of transport projects. However, the time gap between the household travel surveys constrains the control over unplanned processes and public policies implemented independently from the ACC project. In addition, changes in the questionnaire and travel purposes options, particularly for flexible and care activities, can influence our results. These limitations were mitigated by employing a natural experiment and the model specification by incorporating controls for temporal and neighbourhood changes and respondents' individual and household characteristics. Finally, there are three primary conclusions.

First, we found that the ACC increased activity participation, which was mainly influenced by the rise in flexible and care activities. Results presented in this article provide empirical evidence of how ACC projects positively affect travel behaviour by decreasing commuting travel time and costs and increasing activity participation for travel purposes that are principally conducted at the residential level. This highlights the impact of complementary projects that came with the intervention of social urbanism. These findings reinforce recommendations that decision-makers should prioritise complementary projects as key strategies to magnify the impact of ACC transit projects in disadvantaged communities. The impacts of ACC are also highly context-dependent and influenced by its role in the transit network. The transferability of these outcomes to other ACC projects must, therefore, be carefully analysed. More empirical evidence must also be collected among case studies where ACC plays an essential role in the public transport network. In addition, there is a potential to explore the impact of the ACC on transport poverty by considering its linkages with activity participation (e.g. Allen & Farber, 2020; Luz et al., 2022; Tiznado-Aitken et al., 2024), something that could be developed in future investigations.

The second primary conclusion deals with the associations of gender on activity participation and the particular effect of the ACC. The outcomes reveal a lower likelihood of females conducting care activities in 2019; nevertheless, we find the results to be independent of the ACC project. This could be related to public policies like the District Care System and Care Blocks Program, which were implemented throughout the city. This is the first study exploring the effects of an ACC in care activities as a separate category through an activity participation-based model. Future research should focus on the impact of public policies and transport projects on the just distribution of care activities and gender roles in society. Besides, efforts should be made to refine care-related activity categories, especially for shopping and errand activities related to family care.

The third key finding is related to the scale effects of the built environment on activity participation, which is relevant for decision-makers. Mandatory activity participation is more influenced by the land use in the destination, e.g., job accessibility, while variables at the residential level, such as bus stop proximity and population density, influence more flexible and care activity levels. This is relevant in policymaking because transport projects and facility provisions should be designed to focus on the main impacts of specific activity participation categories. In addition, the lack of significant effects of bus proximity in mandatory activities suggests that commuters among disadvantaged communities are constrained by their fixed activity location, trip distance, and the high competitiveness of accessing the labour market. Future research should investigate this effect by providing evidence by considering job accessibility, trip distance and the labour market competitiveness at the individual level while controlling for the effects of the process at the city level. This can be potentially addressed in future investigations by including person-based accessibility and spatial availability measures in the models.

## CRediT authorship contribution statement

**Santiago Cardona-Urrea:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jaime Soza-Parra:** Writing – review & editing, Validation, Supervision, Software, Methodology, Investigation. **Dick Ettema:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Conceptualization.

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## Declaration of competing interest

No potential conflict of interest was reported by the author(s).

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## Data availability

Open data from government portals were used. The links to search the data were provided.

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# Journal of Transport Geography


## Breaking barriers: Evaluating the Aerial Cable Car’s impact on Accessibility of discretionary activities: Case of TransMiCable, Bogotá

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| **Abstract:** | Transport policies may aim to make city transport more equitable and fairly distribute its benefits among the population segments in the greatest need. This article quantifies the accessibility effects on transport equity brought by TransMiCable, an Aerial cable car (ACC) in Bogotá, Colombia. We consider the spatial and individual distribution of benefits, using location-based (potential accessibility and cumulative opportunity) and person-based accessibility (spatio-temporal accessibility) measures to evaluate the impact of accessibility to discretionary activities presented by the ACC. Two scenarios were evaluated. The baseline scenario considered the public transport system without the ACC, while the ‘after’ scenario considered the ACC. Additionally, the Concentration Index (CI) was calculated to assess the transport equity levels for each scenario and accessibility measure. The ACC slightly increased accessibility of discretionary activities, independent of the accessibility measure. The benefits are concentrated around the ACC stations, reaching an average increase of 15.1% in the potential accessibility measure, 23.7% in the cumulative opportunity measure, and 18.6% in the spatio-temporal accessibility measure. Although the city’s transport inequity (CI) is reduced with the ACC, the accessibility distribution continued to favour the high-income groups. Regarding individual benefits, teens, individuals who are occupied with household chores, and households with children or cars all benefited less from the ACC. Remarkably, low-income households benefited more in the ACC’s area of influence. We conclude that while TransMicable contributes to a more equitable transport at the city scale and delivers the greatest benefits for disadvantaged communities at the local level around their stations, its benefits do not translate to other neighbourhoods where accessibility disparities persist. |

Utrecht University

7 November 2025

Dear Isabelle Nilsson, *UNC Charlotte, United States* and Mark Zuidgeest, *University of Cape Town, South Africa*

Editors-in-Chief, *Journal of Transport Geography*

I am pleased to submit the manuscript "*Breaking barriers: Evaluating the Aerial Cable Car's impact on Accessibility of discretionary activities: Case of TransMiCable, Bogotá*" for consideration in the *Journal of Transport Geography.* Our paper measures the impact of an innovative transit mode, such as aerial cable cars (ACC), on accessibility to discretionary activities. It focuses on a case study in Bogotá, Colombia, among disadvantaged communities, mainly composed of low-income households settled in hilly terrain, which exacerbates their transport and spatial inequalities.

We employed both location-based accessibility measures (potential accessibility and cumulative opportunity) and person-based accessibility measures (spatio-temporal accessibility) to evaluate the impact of the ACC. Two scenarios were evaluated. The baseline scenario considered the public transport system without the ACC, whereas the 'after' scenario considered the system with the ACC. In addition, we estimated the Concentration Index (CI) to assess the transport equity levels for each scenario across income and accessibility measures.

Our findings reveal three key outcomes: (1) ACC positive impact on accessibility, reducing transport inequalities among disadvantaged communities regardless of the measure used (location or person-based); (2) accessibility distribution remains unequal towards higher income groups, particularly for access to healthcare and education; and (3) Spatio-temporal accessibility helps to identified which segments of population benefited most, showing that teens, people living with children, and household with car were less impacted by the ACC.

This empirical study aligns closely with the journal's aims and scope, as it investigates the impacts of a new transport infrastructure on accessibility from a geographical perspective, highlighting which parts of the city derive the largest benefits. Additionally, it provides an in-depth analysis of which population groups (based on sex, age, income, etc.) benefited the most from this innovative transit mode.

I hope you consider this manuscript for publication.

Kind regards,

Santiago Cardona Urrea, Utrecht University, Department of Human Geography and Spatial Planning, Princetonlaan 8A, 3584 CB, Utrecht, The Netherlands, s.cardonaurrea@uu.nl

# Breaking barriers: Evaluating the Aerial Cable Car's impact on Accessibility of discretionary activities: Case of TransMiCable, Bogotá

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**Abstract:** Transport policies may aim to make city transport more equitable and fairly distribute its benefits among the population segments in the greatest need. This article quantifies the accessibility effects on transport equity brought by TransMiCable, an Aerial cable car (ACC) in Bogotá, Colombia. We consider the spatial and individual distribution of benefits, using location-based (potential accessibility and cumulative opportunity) and person-based accessibility (spatio-temporal accessibility) measures to evaluate the impact of accessibility to discretionary activities presented by the ACC. Two scenarios were evaluated. The baseline scenario considered the public transport system without the ACC, while the 'after' scenario considered the ACC. Additionally, the Concentration Index (CI) was calculated to assess the transport equity levels for each scenario and accessibility measure. The ACC slightly increased accessibility of discretionary activities, independent of the accessibility measure. The benefits are concentrated around the ACC stations, reaching an average increase of 15.1% in the potential accessibility measure, 23.7% in the cumulative opportunity measure, and 18.6% in the spatio-temporal accessibility measure. Although the city's transport inequity (CI) is reduced with the ACC, the accessibility distribution continued to favour the high-income groups. Regarding individual benefits, teens, individuals who are occupied with household chores, and households with children or cars all benefited less from the ACC. Remarkably, low-income households benefited more in the ACC's area of influence. We conclude that while TransMicable contributes to a more equitable transport at the city scale and delivers the greatest benefits for disadvantaged communities at the local level around their stations, its benefits do not translate to other neighbourhoods where accessibility disparities persist.

**Keywords:** accessibility, transport equity, aerial-cable cars, disadvantaged communities, spatio-temporal accessibility

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## 1. Introduction

Countries in the global south face serious transport and spatial inequalities (Creutzig et al., 2020; Oviedo and Sabogal-Cardona, 2022; Pereira et al., 2017). In Latin America and the Caribbean (LAC), public transport, walking, and cycling are the most used transport modes, particularly among low-income people who experience low accessibility of essential services in cities (Hidalgo and Huizenga, 2013; Rivas and Serebrisky, 2021). Public transport in this region remains crucial to diminish spatial and transport inequalities (Hidalgo and Huizenga, 2013; Oviedo, 2021; Oviedo and Dávila, 2016; Pereira et al., 2019). Aerial cable cars (ACC) have been an innovative and popular transit mode in LAC, serving disadvantaged communities established in hilly terrain, and generating positive impacts in terms of accessibility, mobility and social inclusion among inhabitants in their service area (Cardona-Urrea et al., 2024).

Disadvantaged communities (DC) in LAC refer to segments of low-income populations who are often situated in peripheral areas of cities, and often constrained by hilly terrains or water bodies (Brand and Dávila, 2011; Cardona-Urrea et al., 2026; Oviedo and Dávila, 2016; Posada and García-Suaza, 2022). For instance, in the LAC region, 20.9% of the population resides in informal settlements (United Nations Statistics Division, 2023). These communities experience barriers to participation in economic, social, political, and cultural aspects of society (Lucas, 2012; Luz et al., 2022; Oviedo, 2021; United Nations, 2016), exacerbated by the lack of access to transportation systems (Lucas, 2012; Luz and Portugal, 2022; Oviedo, 2021). As a response, transport policies (e.g., public transport systems, fare subsidies, etc.) aim to mitigate this issue, fostering equitable distribution of benefits, with a primary focus on addressing the transportation needs of population segments in greatest need (Pereira et al., 2017; van Wee and Mouter, 2021; Vecchio et al., 2020). The goal of these policies is to achieve a fairer distribution of safe, affordable, and reliable transport resources (Pereira et al., 2017; van Wee and Mouter, 2021). Nevertheless, high-income individuals often experience better public transport services, and new transport policies disproportionately benefit them (Arellana et al., 2021; Pereira et al., 2019). This is because transport policies tend to overlook communities with the greatest transport and social needs, hampering their full participation in society and contributing to social exclusion (Lucas, 2012).

Aerial cable cars (ACC) are a specialised transit mode that supplies public transport to DC communities in LAC, where most ACC projects have been implemented (Cardona-Urrea et al., 2024). ACC connects low-income neighbours in the city's periphery and hillsides to the zones with a high concentration of opportunities, such as jobs and education. They also serve as the first and last-mile connection of broader public transportation systems, reducing travel time and costs (Cardona-Urrea et al., 2024).

While ACC systems have been developed to increase the accessibility of DC, the extent to which they do, and for whom, has not been assessed quantitatively to date (Cardona-Urrea et al., 2024). Therefore, this paper aims to quantify the accessibility effects of ACC on transport equity. To this end, we apply accessibility measures as an objective way to quantify the impact on accessibility and identify the communities that benefit most (Israel et al., 2023; Lucas, 2012; Vecchio et al., 2020). We aim to answer how accessibility gains are distributed spatially throughout the city. We also aim to identify how those benefits are distributed among individuals. Finally, we consider the spatial and individual accessibility benefits to identify whether the ACC is a fair transport policy, following the principles of distributed justice.

To answer these questions, we used a case study that considered the implementation of TransMiCable in Bogotá (Colombia). TransMiCable is an ACC that serves the Ciudad Bolivar locality in the south periphery of the city (Sarmiento et al., 2020). We will compare location-based accessibility (cumulative opportunities and potential accessibility) and person-based accessibility (spatio-temporal accessibility) measures concerning the effect of the ACC. Person-based accessibility measures contribute to the empirical evidence in LAC, where location-based measures have been used extensively to estimate city accessibility (Vecchio et al., 2020). This also facilitates analysis of individual accessibility gains, overcoming the limitations of focusing on the locations (Vecchio et al., 2020). Before and after scenarios will be evaluated. The before scenario corresponds to public transport system without the ACC; the after scenario includes it. Finally, drawing on Rawls' egalitarianism theory, we analyse the distributive justice of this transport policy (Pereira, 2019; Pereira et al., 2017; van Wee and Mouter, 2021).

The structure of the paper includes five more sections. Section 2 reviews the literature on accessibility in the Latin American context. Section 3 explains the case study, and Section 4 explains the materials and methods, including the data and sources. Section 5 describes the main results, and Section 6 discusses the distribution of justice brought by the ACC in Bogotá and Ciudad Bolivar's inhabitants. Finally, Section 7 presents the conclusions of the study.

## 2. Accessibility Measures in the Latin American Context

Geurs and van Wee (2004) have defined four primary accessibility measures: infrastructure-based, location-based, person-based, and utility-based. Most of the transport equity and accessibility research conducted in LAC has concentrated on location-based accessibility (Vecchio et al., 2020), using the cumulative opportunities measure (see Boisjoly et al., 2017, 2020; Guzman and Oviedo, 2018; Hernandez, 2018; Herszenhut et al., 2022; Pereira, 2019; Pereira et al., 2019; Rodriguez et al., 2017) or the potential accessibility based on the gravity-based model (see Arellana et al., 2021; Bocarejo et al., 2014; Bocarejo and Oviedo, 2012; Delmelle and Casas, 2012; Guzman et al., 2017; Oviedo et al., 2019; Oviedo and Sabogal-Cardona, 2022; Oviedo et al., 2025). They require less data to be calculated, and the results are easier to interpret than person- and utility-based measures (Geurs & van Wee, 2004; Vecchio et al., 2020). However, location-based measures fail to account for peoples' individual characteristics, because they use aggregated data (Fransen and Farber, 2019; Vecchio et al., 2020). They are also sensitive to spatial and temporal issues like the ecological fallacy (Pereira et al., 2019) and the modifiable areal unit problem (MAUP) and modifiable temporal unit problem (MTUP) (Pereira, 2019; Pereira et al., 2019). For instance, the MAUP focuses on how the changes in the boundaries of areas can bias accessibility results (Pereira et al., 2019), which is similar to how the choice of cut-off times in the MTUP can influence results (Pereira, 2019; Pereira et al., 2019). Recently, utility-based measures have been used to evaluate transport policies, addressing issues pertaining to the interpretability of results by calculating the consumer surplus using the difference between before and after scenarios (Guzman et al., 2023b, 2025). Remarkably, person-based measures have not been extensively implemented in the region (Vecchio et al., 2020) because of the challenges presented by the lack of data and computational requirements for their calculations.

Studies in LAC have consistently found similar results regarding accessibility in cities. For instance, low-income communities living in the peripheries experienced lower levels of accessibility of opportunities using public transport (Arellana et al., 2021; Bocarejo and Oviedo, 2012; Boisjoly et al., 2017, 2020; Delmelle and Casas, 2012; Figueroa Martínez et al., 2018; Guzman et al., 2017; Hernandez, 2018; Lessa et al., 2019). Furthermore, most transport policy evaluations (e.g., new fare structure, public transport expansions) have shown how high-income groups experienced larger gains in accessibility (Bocarejo et al., 2014; Guzman et al., 2018; Herszenhut et al., 2022; Oviedo et al., 2019; Pereira et al., 2019; Rodriguez et al., 2017). Conversely, some studies indicate progress in achieving distributive justice in future public transport plans, such as the BRT in Rio de Janeiro (Pereira, 2019) and the ACC in Pereira (Velasquez-Villada et al., 2018).

Aerial Cable cars (ACC) have been an innovation in public transport with a high potential to impact low-income communities located on hillside terrains in LAC, reducing their social exclusion (Bocarejo et al., 2014; Brand & Dávila, 2011; Cardona-Urrea et al., 2024; Sarmiento et al., 2020). Cities in Colombia, Brazil, Venezuela, México, the Dominican Republic, Ecuador, and Bolivia have implemented nearly 33 ACC lines in the last two decades, more than 90% of them after 2010 (Cardona-Urrea et al., 2024). Several societal benefits have been related to ACC projects in LAC (see Cardona-Urrea et al. (2024) for an overview), including a reduction of local air pollution (Morales-Betancourt et al., 2023) and activity participation (Cardona-Urrea et al., 2026; Guzman et al., 2024a), an increase of security (Cerdá et al., 2012), social capital (Guzman et al., 2023a), and subjective well-being and satisfaction with the neighbourhood (Guevara-Aladino et al., 2022; Guzman et al., 2023b).

Accessibility impacts of the ACC have been scarcely studied quantitatively. For instance, Bocarejo et al. (2014) found that the first ACC line in Medellín doubled the accessibility of jobs in the area of influence, while the gains at the city level were less than 10%. Higher accessibility impacts were also found among high-income segments within the DC (Bocarejo et al., 2014). Recently, Guzmán et al. (2025) found a significant positive impact on accessibility because of TransMiCable, largely attributed to the benefits obtained by savings in travel time and costs.

Few studies have focused on disadvantaged communities (DC) and the effects of new transport policies on accessibility (Oviedo & Dávila, 2016; Pereira, 2019; Pereira et al., 2019; Velasquez-Villada et al., 2018). In particular, insight is lacking into the effects of ACC on the accessibility of DC, and transport equity. The lack of insight not only concerns how the DC as a whole, given its location, gain accessibility benefits from ACC construction, but also how these potential gains are distributed across individuals with different characteristics within DC. The latter would imply using person-based accessibility measures, which have been scarcely used in accessibility evaluations in LAC (Vecchio et al., 2020). Given the significance of accessibility in addressing transport equity concerns, it is essential to explore how public transport construction benefits individuals living in disadvantaged communities (Bocarejo et al., 2014; Guzman et al., 2018; Herszenhut et al., 2022; Oviedo et al., 2019; Pereira et al., 2019; Rodriguez et al., 2017).

# 3. Bogotá and its first aerial cable car in Ciudad Bolivar

Bogotá is the capital city of Colombia, located in the country's centre, 2600 meters above sea level (Figure 1). It has nearly 7.4 million inhabitants and 16 million daily trips (Guzman et al., 2023b), most of them made by public transport (35%), walking (25%), and micro-mobility (7.4%). The city has a deep transport inequity, expressed in low-income groups relying on public transport and active modes (biking and walking), featuring long distances and travel times (Guzman et al., 2023b). On the other hand, high-income people use more private vehicles (cars and motorcycles) and are in privileged locations, e.g., near opportunity and employment centres (Figure 1).

Bogotá is world-renowned due to TransMilenio's Bus Rapid Transit (BRT), a system implemented at the end of the 1990s (red lines in Figure 1) (Guzman et al., 2018). In recent years, the system has suffered from deficiencies in operation (e.g., overcrowding, old fleet, payment evasion, etc.). Furthermore, the benefits diminish in the peripheries where most low-income people live (Bocarejo and Oviedo, 2012; Oviedo and Dávila, 2016). The hilly terrain in the south and east has hindered the expansion of the BRT system, for example (Guzman et al., 2018). These geographical constraints lead to innovation in supplying public transport in steeper terrain, such as aerial cable-cars (ACC) technology (Cardona-Urrea et al., 2024).

TransMiCable is the first Bogota ACC, built in the Ciudad Bolivar locality (CB) (600,000 inhabitants) in the southern periphery of the city (Sarmiento et al., 2020). It has connected the inhabitants to the BRT system through 4 stations and 3.43 km since December 2018 (yellow line in Figure 1) (Sarmiento et al., 2020). Daily mobility in CB is up to 1 million trips, 51% by foot and 26% by public transport, with average travel times of 22 and 93 minutes, respectively. High travel times are experienced due to an unequal distribution of essential opportunities, e.g., most of the employment is in the centre-east of the city. Furthermore, the first- and last-mile travel times are long because of the location of the nearest BRT station (Garnica Quiroga, 2020). Reports show travel times of between 32 and 62 minutes to reach the nearest BRT station (Sarmiento et al., 2020). Several disadvantaged communities in large LAC cities show similar travel behaviour (e.g., México (Guerra et al., 2022), Colombia (Hidalgo and Huizenga, 2013), Brazil (Duarte Santos and Soares Gonçalves, 2017), Bolivia (Garsous et al., 2019), Chile (Mora et al., 2021)), exacerbated by their location in the peripheries (Posada and García-Suaza, 2022).

The ACC has reduced the travel time and costs for CB inhabitants, and especially for commuters, because of its reliability and direct connection to the BRT stations. For instance, an average reduction of 20% has been reported among CB inhabitants (Guevara-Aladino et al., 2023). Reductions reach 26% when only travel times exceeding 100 minutes are considered (Garnica Quiroga, 2020). Those reductions have led to improvements in activity participation (Cardona-Urrea et al., 2026; Guzman et al., 2024b) and accessibility, particularly among males in the first years after the introduction (Guzmán, et al., 2025). Positive impacts extend beyond mobility (Cardona-Urrea et al., 2024), and include factors such as local pollution and health. For instance, the air inside the ACC cabins is cleaner than other transport modes, including walking (Morales-Betancourt et al., 2023). Physical activity has also been maintained, as the ACC promotes walking as the first and last mile mode to reach the stations (Baldovino-Chiquillo et al., 2023). On the other hand, the perception of safety around the stations increased (Garnica Quiroga, 2020; Guzman et al., 2022), similar to neighbourhood satisfaction (Guevara-Aladino et al., 2023). However, accessibility is still in the initial exploratory phase, while the spatial distribution of these gains across urban communities and individuals has not yet been investigated.

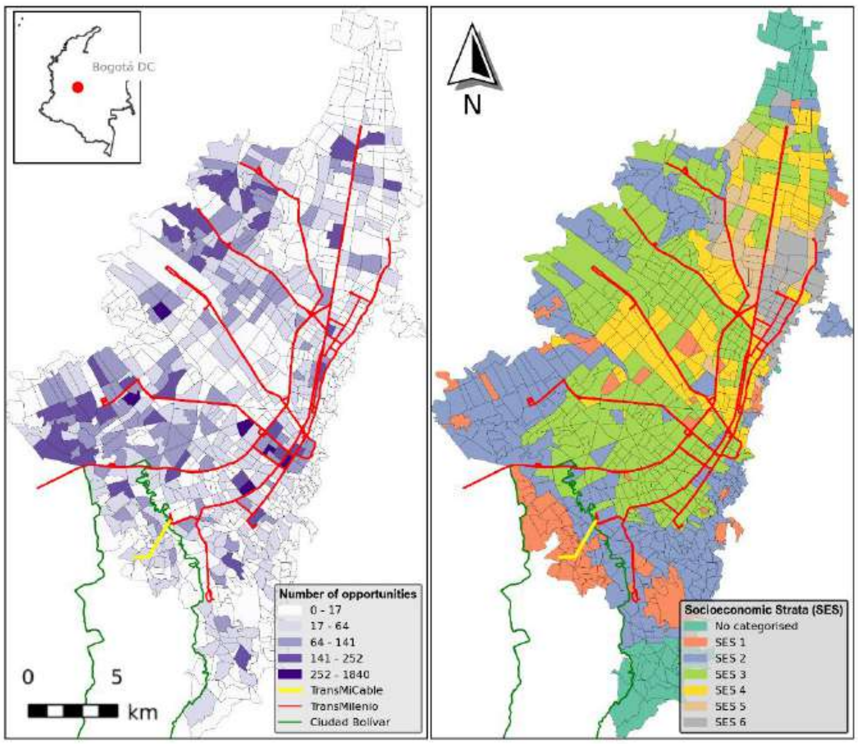


**Figure 1 Study area. Total number of opportunities (left) and socioeconomic strata (SES) (right) per TAZ.**

# 4. Materials and methods

## 4.1. Data

Table 1 summarises the data used in this research and its sources. First, the Master Mobility Plan of 2019 allowed us to obtain the urban Traffic Analysis Zones-TAZ (883 included in the analysis) as a geographic unit of analysis (SIMUR, 2019). The household travel survey (HTS) was also used to calibrate the beta parameter necessary for potential accessibility, and travel diaries were used to measure spatial-temporal accessibility. Individual and household characteristics were then calculated based on the HTS. Secondly, population and households per socioeconomic strata (SES) were calculated at the TAZ level (see right part of Figure 1) using the data from the National Census of

Population and Households of 2018 (DANE, 2018). SES is the official household government socioeconomic categorisation (Cantillo-García et al., 2019). SES categorised households into six levels, with one being the lowest and six the highest income levels. This index is used to assign subsidies in the country, and it has been validated as a proxy of household income in transport analysis (Cantillo-García et al., 2019). Third, the opportunities dataset was requested from Guzmán et al. (2024b), who calculated the economic establishments into blocks using the Census of Economic Establishments of Bogotá in 2017 (Guzmán et al., 2024b). Data on the public parks and sports facilities were gathered from the IDECA (Infraestructura de Datos Espaciales para el Distrito Capital), the entity responsible for the spatial data in Bogotá. Fourth, we used the General Transit Feed Specifications (GTFS) published and organised by TransMilenio S.A., Bogotá's public transport operator. GTFS from July 2023 were validated and used in this study (Datos Abiertos Bogotá. (2023). Finally, the walking road network was retrieved from Open Street Maps, and the elevation from the Copernicus Global Digital Surface Model (DSM) at a 30-meter resolution (European Space Agency, 2021). Using data from different years and sources is a limitation of our study; we therefore decided to keep the population and travel patterns data constant and only change the public transport supply to evidence the impact of the introduction of the ACC.

**Table 1 Summary of data and sources.**

| **Source** | **Data** |
|---|---|
| Master Mobility Plan (SIMUR, 2019) | Traffic Analysis Zones (TAZ)<br>Household Travel Survey (2019) |
| National Census of Population and Households (Dane, 2018) | Population and households at the block level |
| Guzmán et al. (2024) from the Urban Planning Office of Bogotá and IDECA | Economic establishments (2017)<br>Public Parks and Sports Venues |
| TransMilenio (2023) | General Transit Feed Specifications (GTFS) of July 2023. |
| Open Street Maps (2023) | Walking road network |
| Digital Elevation Model at 30-meter resolution | Copernicus Global Digital Surface Model |

### 4.1.1. Opportunities dataset

We calculated accessibility of five different categories of discretionary activities (including study) (Guzmán et al., 2024b). The five categories are education, healthcare, recreation, groceries, and services and commerce. Opportunities were aggregated to the TAZ level. Table 2 shows the opportunity categories and their total in the study area.

**Table 2 Opportunities categories.**

| Category | Establishments | Total |
|---|---|---|
| Healthcare | Hospitals, medical services | 2650 |
| Education | Preschool, Primary School, High School, Technical Institutes, Vocational Training, and Universities | 2848 |
| Recreation | Parks and Green areas, Sports venues, Cultural | 5415 |
| Groceries | Grocery and Convenience store market | 41917 |
| Services and commerce | Bank, Drugstore, Local Shops, Clothing Store, Laundry, Hairdresser, Bar, Restaurants, Veterinary | 86264 |

### 4.1.2. Travel time matrix using R5R

We built a multimodal transit network for travel time calculations, considering GTFS data, the walking network, and the digital elevation model to estimate slope, using the R package *R5R* (Higgings et al., 2022; Pereira et al., 2021). *R5R* enabled us to calculate travel times by considering the origin and destination coordinates, the start times of the trips, and the modes of transport involved. We used the TAZ centroids as the origin and destination, while we defined 7 a.m. as the starting time. In addition, we considered the combination of "WALK" and "TRANSIT" as transport modes; nevertheless, the baseline scenario only considered "BUS", while the after scenario considered all the transit modes, including the ACC. In the case of the "WALK" trip leg, the elevation influences the speed through Tobler's equation (Tobler, 1993). This is essential because the study area is situated in hilly terrain, and the slope can significantly impact walking speed, particularly when accessing transit stops (Coelho et al., 2025).

## 4.2. Accessibility measures

We used the cumulative opportunities measure, potential accessibility as a location-based measure, and spatio-temporal accessibility as a person-based measure.

### 4.2.1. Cumulative opportunities measure

This measure represents the total number of opportunities a person can reach within a specific travel time using a particular mode of transport (Páez et al., 2012; Pereira, 2019). In this study, the unit of analysis was the TAZ. Consequently, all the households and individuals in a TAZ experienced the same level of accessibility. Equation 1 presents the general definition of the cumulative opportunities measure, where *i* is the TAZ, *j* is the destination TAZ, *Oj* is the number of opportunities per category in TAZ *j*, and $f(C_{ij})$ is the cost function expressed as an isochronic impedance function (Páez et al., 2012; Pereira et al., 2019). Travel time (*t*) thresholds for the isochronal impedance function were evaluated every 15 minutes from 15 to 120 minutes, serving as a sensitivity analysis in this accessibility measure (Pereira, 2019; Stępniak et al., 2019). The isochronic impedance allowed us to include all the opportunities reached in the threshold travel time, weighted equally.

$$A_{COMi} = \sum_{j=1}^{J} g(O_j) f(C_{ij}) \quad \text{eq. 1}$$

$$f(C_{ij}) = \begin{cases} 1 \; if \; C_{ij} \leq t \\ 0 \; otherwise \end{cases} \quad \text{eq. 2}$$

### 4.2.2. Potential accessibility

Potential accessibility is one of the most traditional measures in accessibility analysis. First defined by Hansen (1959), the potential accessibility of zone *i* included the attractiveness of a defined zone, in this case, the number of opportunities per category *Oj* and the cost function $f(C_{ij})$, i.e., the impedance or friction to access those opportunities. For instance, people are more likely to access zones with more opportunities and those that are more frequently visited by travellers. The formulation is the same as the cumulative opportunities measure (eq. 1) but has a different cost function. The cost function (eq. 3) considers a decay function for the travel time (Vale and Pereira, 2016). Consequently, the probability of accessing opportunities decreased with increased friction, i.e., travel time, cost, or distance. The beta parameter ($\beta_l$) expresses the user's willingness to travel (Escobar et al., 2020; Vale and Pereira, 2016). It was calibrated for Bogotá, considering the mobility patterns of the household travel survey 2019 for mandatory (study and jobs) and non-mandatory travel purposes (healthcare, groceries, recreation, services and commerce) and public transport as the mode of transport. The beta parameter calibrations resulted in -0.0959 for mandatory trips and -0.0825 for non-mandatory trips.

$$A_{PAi} = \sum_{j=1}^{J} g(O_j)\, e^{\beta_l * C_{ij}} \text{ eq. 3}$$

### 4.2.3. Spatio-temporal accessibility measure

The spatio-temporal accessibility measure calculates the amount of time a person can allocate on additional activities, considering their available time between fixed activities (Fransen et al., 2018; Fransen and Farber, 2019). To do so, it is necessary to have a travel diary with the start and end times of daily activities. We used the HTS 2019 travel diary to estimate the start and end times of daily activities, considering travel purposes (Fransen et al., 2018). Traditional spatio-temporal accessibility measures require calculating a space-time prism (STP) and the potential path area (PPA)(Fransen et al., 2018). The STP estimates an individual's spatial coverage in a defined period between fixed activities. Projecting the STP, the PPA is estimated to define the opportunities the individual can potentially access, given their spatio-temporal constraints. The main components to calculate the spatio-temporal accessibility are:

- Fixed activities: We considered work, study, and care-related trips as fixed activities, i.e., activities that must be conducted in a defined time and location.
- Temporal constraint ($T_c$): This is the available time to access additional activities, calculated as the time between fixed activities, e.g., the end of a fixed activity and the beginning of the next one. In this study, we assumed that people began their day when they started the first trip and finalised when they arrived home in the last trip of the day.
- Spatial constraints ($S_c$): This is the origin ($O_{sc}$) and destination ($D_{sc}$) constraints, considering that individuals started their trips in a fixed location and must be in another location to begin the next fixed activity. We assumed that the last fixed location is their home.
- Travel time to potential destinations ($t_{pd}$) : It is the travel time by public transport to potential destinations (see eq. 4) accounting for the spatial constraints ($S_c$). This includes two components: travel time from origin fixed activity location ($O_{sc}$) to potential intermediate destination ($P_{id}$) and the travel time from the potential intermediate destination ($P_{id}$) to the final fixed activity destination ($D_{sc}$) (see eq. 4).

$$t_{pd} = t_{O_{SC}-P_{id}} + t_{P_{id}-D_{sc}} \text{ eq. 4}$$

The spatio-temporal accessibility (eq. 5) per individual ($A_{STAi}$) is calculated by aggregating the product of the time the individual can spend in the potential destinations

$\left(f\left(C_{jk}\right)\right)$ by their number of opportunities $\left(g\left(O_j\right)\right)$ in this TAZ. In this case, we only limit the time the individual can spend in the location by considering 1 minute or more (see eq. 6) (Fransen et al., 2018). Thus, this measure should not be interpreted as actual potential activities that could be conducted, but as potential minutes of access to different services depending on the temporal and spatial constraints.

$$A_{STA_i} = \sum_{j=1}^{J} f\left(C_{jk}\right) * g\left(O_j\right) * \quad \text{eq. 5}$$

$$f\left(C_{jk}\right) = \begin{cases} T_c - t_{pd}, T_c - t_{pd} > 0 \\ 0, T_c - t_{pd} \leq 0 \end{cases} \quad \text{eq. 6}$$

## 4.3. Transport equity indicators and modelling approach

The Concentration Index (CI) was used to measure accessibility inequalities, considering socioeconomic strata as a proxy for income (Karner et al., 2024). This index measures the systematic relationship between inequalities in a variable, such as accessibility, and income (or other socioeconomic variables) (Cardona-Urrea et al., 2025; Karner et al., 2024)). The CI ranges from -1 to 1 (see equations 7 and 8). A value of -1 indicates that accessibility is distributed among lower-income groups, 1 represents a concentration towards higher-income groups, and 0 represents perfect equality.

$$CI = \frac{2}{n * \mu} \sum_{i=1}^{n} a_i * R_i - 1 \quad \text{eq. 7}$$

$$R_i = \frac{2r_i - 1}{2n} \quad \text{eq. 8}$$

Where $n$ is the number of observations, $\mu$ is the average value of accessibility, $a_i$ is the value of accessibility for the observation $i$, and $R_i$ is the fractional socioeconomic status of observation, which is calculated considering the socioeconomic rank per observation ($r_i$).

Moran's I was used to calculate the spatial dependence of accessibility (Anselin, 1995). The K-Nearest Neighbourhoods method was used as a weight matrix. This method helped to identify the grade of spatial clustering of accessibility values.

In addition to comparing before- ($A_b$) and after ($A_a$) accessibility scenarios, the direct accessibility difference (eq. 10) was calculated, allowing us to obtain the additional opportunities reached per TAZ or the additional minutes an individual can spend in potential opportunities. Then the gradient impact was calculated to obtain the accessibility change in percentage between scenarios (eq. 11) (Escobar et al., 2020).

$$D_{op} = A_a - A_b \text{ eq. 10}$$

$$G\,(\%) = 100 * \left(\frac{A_a - A_b}{A_b}\right) \text{ eq. 11}$$

Finally, we analysed the impacts at the individual level using the spatio-temporal accessibility results. We used a subset composed of individuals living in the Ciudad Bolivar locality. We used statistical tests to uncover the differences in sex, age, income, and occupation. Then we estimated a linear model considering the gradient impact as the dependent variable and several sociodemographic and household variables as regressors.

Table 3 shows the individual and household characteristics of the HTS 2019 sample and Ciudad Bolívar's subset. The sample in Ciudad Bolívar is represented mainly by individuals with primary and middle education (80.27%) and low-income families: 74.6% have a monthly income of less than 456 USD per month. In addition, there is lower access to cars, but a higher share of motorcycles than in the rest of the city.

**Table 3 Individual and household characteristics of the HTS dataset and Ciudad Bolívar subset.**

| Variables | | HTS 2019 (n = 35441) | | Ciudad Bolívar (n = 2043) | |
|---|---|---|---|---|---|
| Sex | Female | 18885 | 53.29% | 1093 | 53.50% |
| | Male | 16556 | 46.71% | 950 | 46.50% |
| Age | Teen (Less than 18) | 7078 | 19.97% | 528 | 25.84% |
| | Young (18 – 30) | 8199 | 23.13% | 505 | 24.72% |
| | Young Adult (30 – 45) | 7530 | 21.25% | 411 | 20.12% |
| | Adult (45 – 60) | 6451 | 18.20% | 328 | 16.05% |
| | Senior (More than 60) | 6183 | 17.45% | 271 | 13.26% |
| Education level | Primary | 11202 | 31.61% | 314 | 42.43% |
| | Middle | 9017 | 25.44% | 280 | 37.84% |
| | Technical | 6352 | 17.92% | 108 | 14.59% |
| | Higher | 8870 | 25.03% | 38 | 5.14% |
| Occupation | Worker | 16574 | 46.77% | 894 | 43.76% |
| | Student | 9166 | 25.86% | 586 | 28.68% |
| | Household-chores | 5143 | 14.51% | 340 | 16.64% |
| | Other | 4558 | 12.86% | 223 | 10.92% |
| Relation with the household chief | Head | 12893 | 36.38% | 638 | 31.21% |
| | Partner | 6381 | 18.00% | 393 | 19.23% |
| | Nuclear Family | 13833 | 39.03% | 871 | 42.61% |
| | Other Family | 2334 | 6.59% | 142 | 6.95% |
| Variables | | Households (n = 15932) | | Households (n = 812) | |
| Household Income (USD)* | Less than 252 | 4019 | 25.2% | 367 | 45.2% |
| | 252 - 456 | 3126 | 19.6% | 239 | 29.4% |
| | 456 - 761 | 3152 | 19.8% | 129 | 15.9% |
| | More than 761 | 5635 | 35.4% | 77 | 9.5% |
| Family size | | 3.04 | | 3.49 | |
| Presence of children (less than 12 years old) | | 22.20% | | 32.27% | |
| Presence of Cars | | 40.49% | | 19.58% | |
| Presence of Motorcycles | | 13.55% | | 19.21% | |
| Presence of Active vehicles (Bicycles or Scooters) | | 48.27% | | 43.72% | |

# 5. Results

The results are divided into four sections. First, the analysis at the city level considers the average values and the concentration index (CI). Second, the spatial distribution of accessibility is presented, considering the total accessibility of discretionary activities and the global Moran's I. Third, we present the spatial distribution of the benefits due to the ACC. Finally, we present the analysis at the individual level, using the spatio-temporal accessibility results.

## 5.1. City's accessibility and transport equity

Table 4 presents the average result for potential accessibility, cumulative opportunities, and spatio-temporal accessibility. Besides, we present the increase in accessibility at the city level by comparing the scenarios with and without the ACC. For the cumulative opportunity measure, several time thresholds were calculated, and the 60-minute threshold is presented as it was the most balanced between population and opportunity coverage throughout the city. The spatio-temporal accessibility measure is reported as the cumulative minutes people can potentially spend in additional opportunities between fixed activities.

There is a positive but small impact of the ACC on accessibility at the city level, independent of the accessibility measure. The relative impact of the cumulative opportunities measure is the highest, followed by the potential accessibility and the spatio-temporal accessibility. Interestingly, accessibility of groceries registered the highest increase, independently of the accessibility measure, followed by accessibility of service and commerce. This impact is particularly high in the location-based measures. In addition, the accessibility of healthcare and education, which increased after the ACC inauguration, are almost similar across measures.

**Table 4 Comparison of city accessibility for different measures. Accessibility with and without the aerial cable car is presented.**

| Type | Potential accessibility (N=883) | | Cumulative opportunity - 60 minutes (N=883) | | Spatio-temporal accessibility (n =29861) | |
|---|---|---|---|---|---|---|
| | Opportunities* | Grad(%) | Opportunities * | Grad(%) | Minutes * | Grad(%) |
| Total | 2774 | 0.076% | 59235 | 0.117% | 15 691 000 | 0.026% |
| Education | 39 | 0.040% | 1235 | 0.060% | 392 012 | 0.019% |
| Healthcare | 57 | 0.046% | 1204 | 0.076% | 369 566 | 0.019% |
| Recreation | 40 | 0.096% | 2046 | 0.107% | 702 880 | 0.027% |
| Groceries | 779 | 0.114% | 16678 | 0.141% | 5 491 336 | 0.034% |
| Service and commerce | 1808 | 0.061% | 38071 | 0.100% | 11 695 100 | 0.023% |
| * Average values; Grad (%): comparing before and after scenarios | | | | | | |

Table 5 presents the concentration index (CI) for the scenarios before and after the ACC, along with its gradient (%) of impact. The CI is positive across all the accessibility measures, scenarios and opportunity categories, indicating that accessibility is relatively higher for higher-income individuals. The unique exception is the potential accessibility of groceries, where a negative CI was found; consequently, the accessibility distribution benefits low-income groups more.

Remarkably, the ACC decreased accessibility inequalities across income groups, as evidenced by a reduction in the Concentration Index (CI) values. The degree of this reduction at the city level is limited and varies across the accessibility measures. Potential accessibility shows the most significant decrease in the CI value, 1.102% considering the total aggregation of opportunities, followed closely by the cumulative opportunity measure (1.094%). On the other hand, the spatio-temporal accessibility exhibits a smaller change of 0.163%. This is in line with the fact that accessibility due to the ACC increased less when measured with the spatio-temporal measure. In addition, the impact levels differ across opportunity categories for each measure. In the potential accessibility measure, the greatest reduction of inequality is shown in the accessibility of recreation, whereas accessibility to groceries is greatest for the cumulative opportunity measure. Finally, the greatest reduction in the spatio-temporal accessibility is related to service and commerce.

**Table 5. Concentration Index (CI) per accessibility measure and opportunity category. Accessibility with the aerial cable car and its difference without it is presented.**

| Opportunity | Scenario | Potential accessibility (N=883) | | Cumulative opportunity 60 minutes (N=883) | | Spatio-temporal accessibility (n =29861) | |
|---|---|---|---|---|---|---|---|
| | | CI | Gradient (%) | CI | Gradient (%) | CI | Gradient (%) |
| Total | Before | 0.0481 | -1.102% | 0.0805 | -1.094% | 0.06757 | -0.163% |
| | After | 0.0476 | | 0.0796 | | 0.06746 | |
| Education | Before | 0.1269 | -0.315% | 0.1341 | -0.436% | 0.04912 | -0.216% |
| | After | 0.1265 | | 0.1335 | | 0.04901 | |
| Healthcare | Before | 0.1407 | -0.355% | 0.1362 | -0.674% | 0.05022 | -0.215% |
| | After | 0.1402 | | 0.1352 | | 0.05011 | |
| Recreation | Before | 0.0702 | -0.712% | 0.1046 | -0.537% | 0.05212 | -0.140% |
| | After | 0.0697 | | 0.1041 | | 0.05205 | |
| Groceries | Before | -0.0219 | 2.421% | 0.0384 | -1.942% | 0.04132 | -0.195% |
| | After | -0.0224 | | 0.0376 | | 0.04124 | |
| Service and commerce | Before | 0.0766 | -0.705% | 0.0949 | -1.017% | 0.04916 | -0.220% |
| | After | 0.0761 | | 0.0939 | | 0.04905 | |

## 5.2. The spatial distribution of accessibility

For the spatial analysis, we present the results of total accessibility, including the ACC (across types of destinations). We must acknowledge that the spatial pattern of accessibility is susceptible to the measure and scale of analysis, as well as the visualisation method. We visualised accessibility using quintiles, allowing for map comparison across accessibility measures. Figure 2 shows the results of the location-based measures. The general spatial patterns of both maps are similar. The TAZs in the highest (5$^{th}$ quintile) accessibility levels are in the centre-west of the city. This zone grows mainly to the west and south. Interestingly, that region mainly comprises middle-income TAZ (see SES 3 and 4 in Figure 1). On the other hand, the TAZs with the lowest accessibility levels (1st and 2nd quintile) are located in the northern and southern peripheries. For instance, the Ciudad Bolívar locality (green in the maps), where the ACC is located, exhibits a high concentration of TAZ with the lowest accessibility. This area houses a large number of people, compared to the north, which has low population density levels.

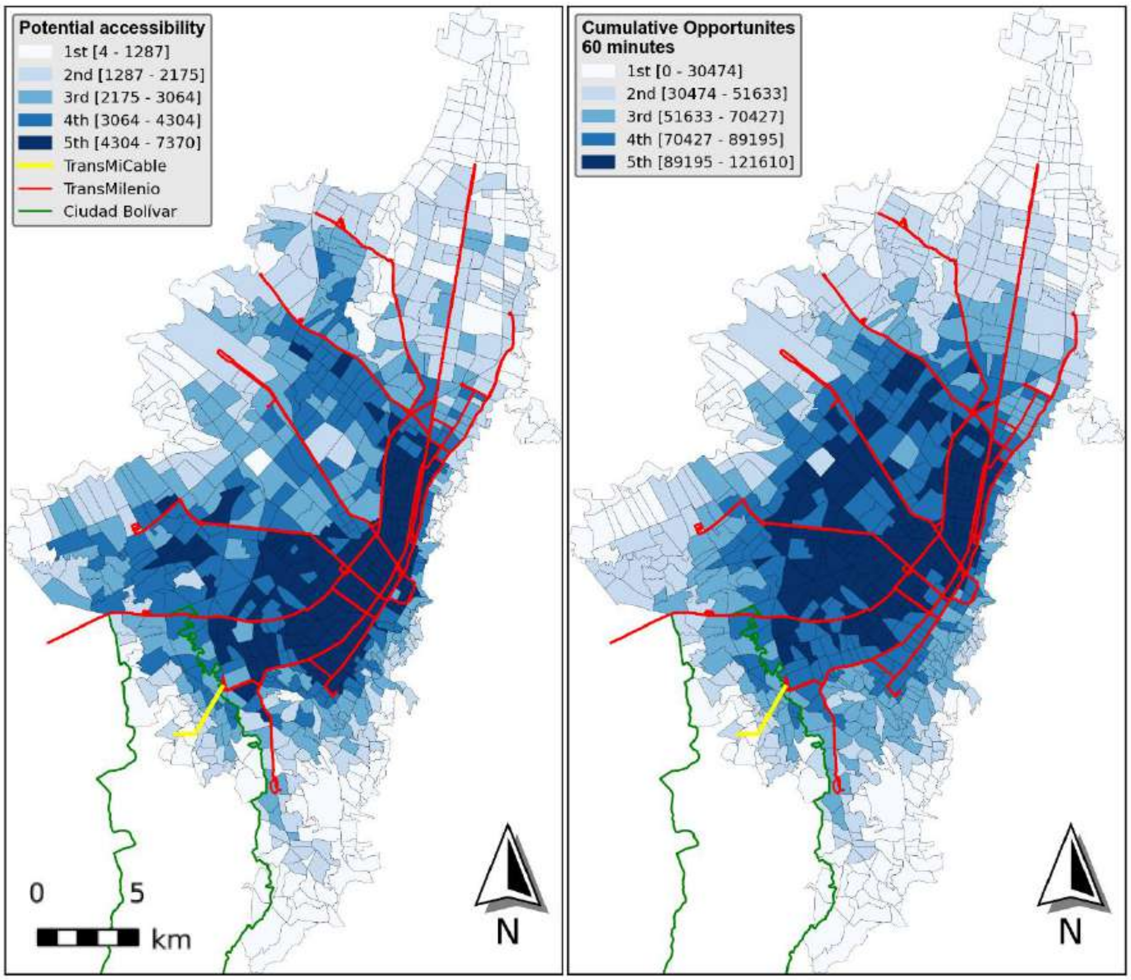


**Figure 2. Potential accessibility (left) and cumulative opportunities – 60 minutes (right) to points of interest. Classes were defined using quintiles.**

For the spatio-temporal accessibility results, we aggregated to the TAZ as the average of its individuals, allowing its representation in Figure 3. We must acknowledge that of the 883 urban TAZs in the study, no accessibility could be calculated for 188, because no people are living in those areas and they are mainly destination hotspots (e.g., public parks, green areas, etc). Consequently, no responses were gathered in the HTS. For instance, a large area in the city's north is labelled NULL (see hatched areas in Figure 3), which resulted in low accessibility values in the location-based measures. In addition, the number of HTS observations per TAZ used to aggregate the average total accessibility can skew the results; consequently, we must analyse this result carefully, considering that there is an average of 50 HTS observations per TAZ, and 57.7% of the TAZs have more than 30 observations.

The spatial distribution of spatio-temporal accessibility is more complex and scattered than location-based measures (see the right part of Figure 3). Interestingly, some TAZ located in the peripheries exhibit medium to high STA levels, patterns that cannot be identified in location-based measures. This could be because people's travel behaviour follows different patterns, even though they live in the same area. For instance, individuals living in peripheral areas can have high accessibility if their workplace or other activities are located in more central areas. As a result, location-based measures may under- or overestimate the accessibility values by giving the same value to everyone in the same area.

The right part of Figure 3 shows the percentage of individuals who did not report trips during the HTS and who were labelled as having zero PBA. In some TAZs, between 34.88% and 75% of their individuals did not report trips during the HTS. However, this finding must be interpreted with caution. These individuals may have the potential to move during the day without time restrictions, implying their accessibility may be limited only to their household location. In this study, we concentrate on people who reported temporal and spatial constraints through the HTS; hence, those with zero PBA were excluded from further analysis.

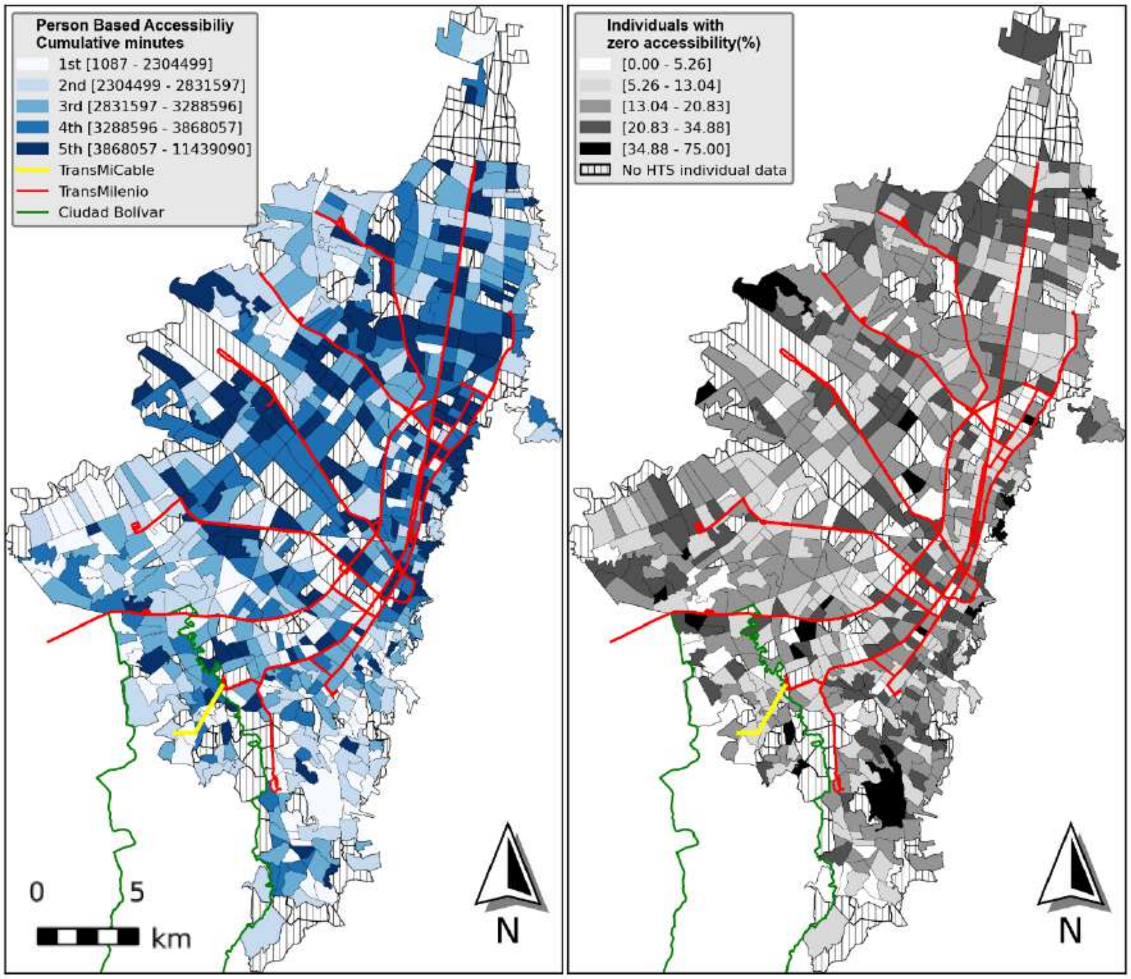


**Figure 3 Person-based accessibility (right) and the percentage of individuals with zero accessibility (left).**

To identify the degree of spatial clustering among the accessibility measures, we estimated Global Moran's I for spatial dependence. For instance, Moran's I for the potential accessibility and the cumulative opportunity measure reach 0.805 and 0.863 (using 7 neighbourhoods for the weight matrix), meaning that accessibility is not a random spatial pattern. However, it clusters by levels, e.g., high accessibility in the centre and low accessibility in the peripheries. On the other hand, Moran's I for the spatio-temporal accessibility results in 0.047, meaning that the aggregation of accessibility levels through the space is weaker. This confirms our previous analysis that spatial patterns are more challenging to identify for spatio-temporal accessibility.

## 5.3. The effect of TransMiCable on accessibility: A comparison across accessibility measures

To identify the effect of TransMiCable on accessibility in specific TAZs, we calculated the difference in total accessibility per TAZ(presented in the left part of Figures 5, 6, and 7) for the potential accessibility, cumulative opportunity measure, and spatio-temporal accessibility, respectively. In this case, the natural breaks approach of 5 classes was used for visualisations. The spatial distribution of accessibility impacts is similar for the three accessibility measures, despite the difference in the unit of analysis between location and person-based measures. The benefits are focused on the TAZ around the TransMiCable (yellow in the Figures) in Ciudad Bolívar (outlined in green).

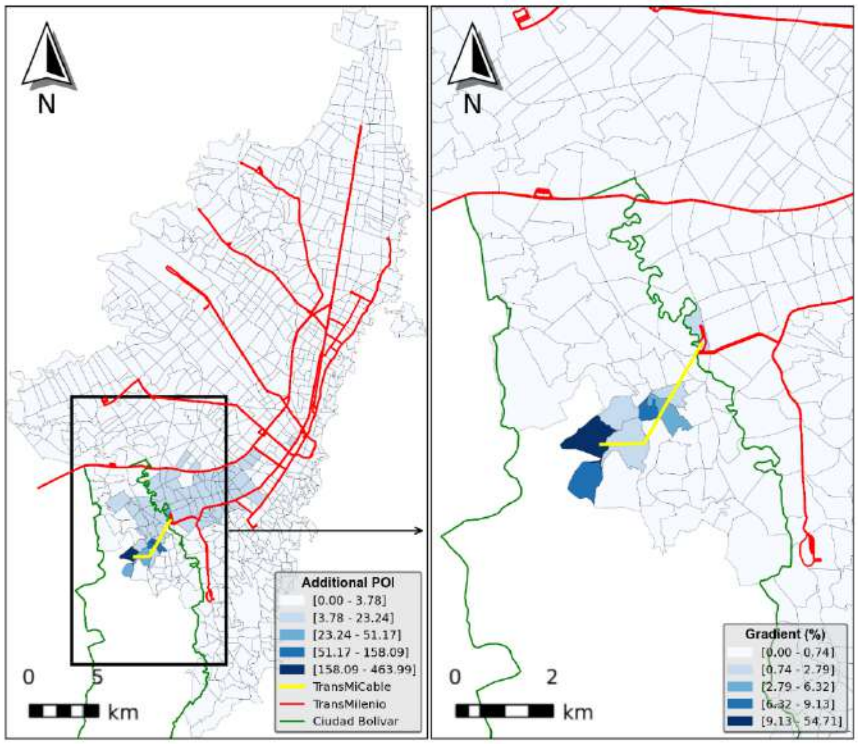


**Figure 5 Difference in potential accessibility (left) and gradient (right) for the weighted total opportunities.**

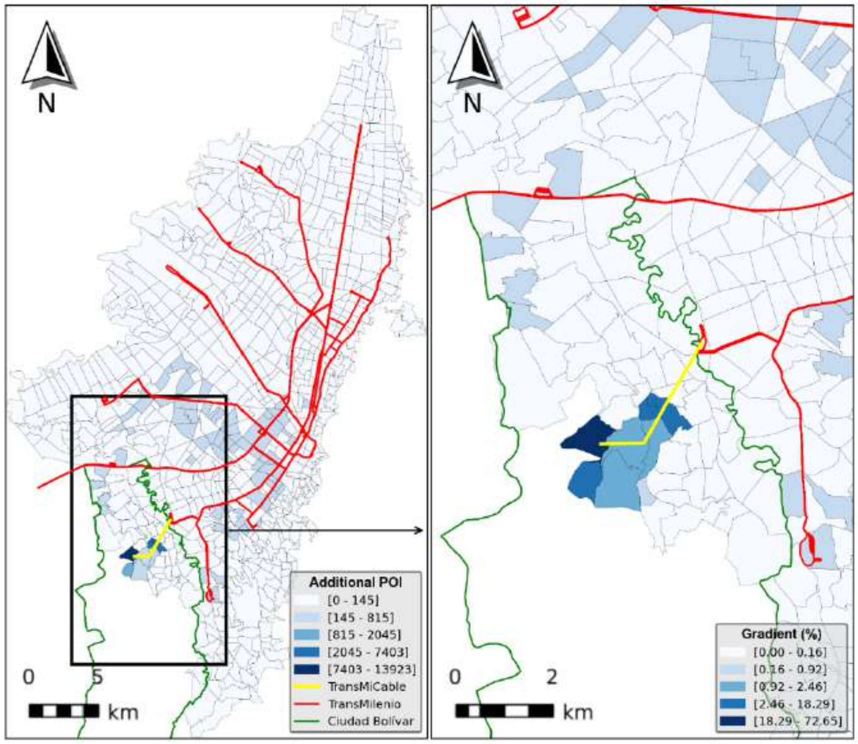


**Figure 6 Difference in cumulative opportunity measure (left) and gradient (right) considering a 60-minute threshold and weighted total opportunities.**

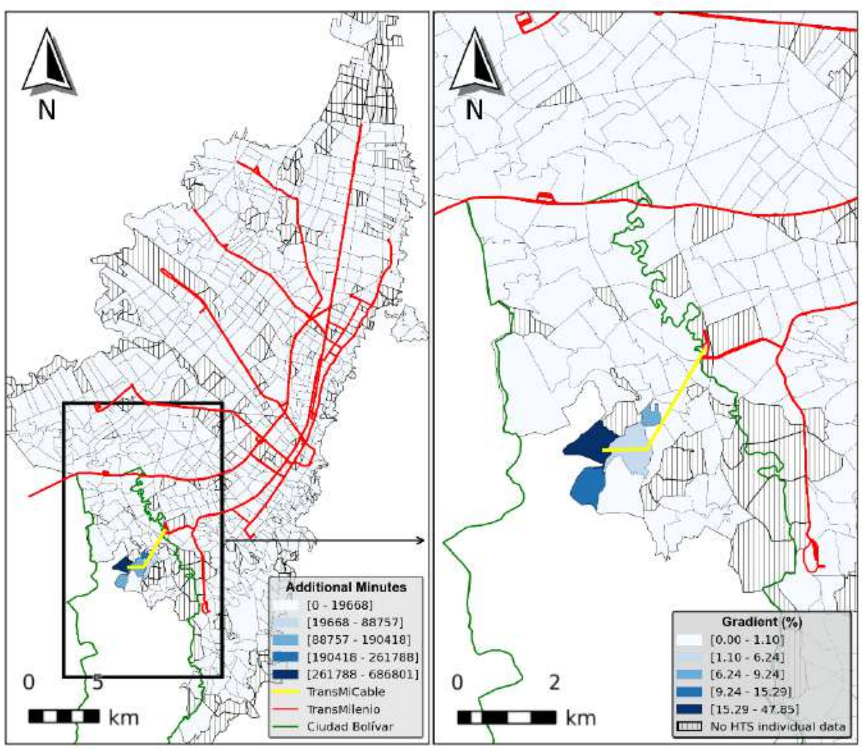


**Figure 7 Difference in spatio-temporal accessibility (left) and gradient (right) considering the average weighted total opportunities per TAZ.**

Table 6 presents the average gradient of total accessibility for Ciudad Bolivar's TAZ, indicating that impacts within the ACC's area of influence exceed the benefits at the city level (see Table 4). The effect maximises around the ACC itself, with average gradients of 15.1% in the potential accessibility, 23.8% in the cumulative opportunity measure, and 18.6% in the spatio-temporal accessibility. The spatial distribution of these gradients (right part of Figures 5, 6, and 7) shows local variation, with maximum values of 72.7% in the cumulative opportunity measure and 47.9% in the spatio-temporal accessibility measure.

**Table 6. Average gradient impact of total accessibility per measure considering Ciudad Bolivar, and ACC's area of Influence.**

| Accessibility Measure | Ciudad Bolivar | ACC's area of influence |
|---|---|---|
| Potential Accessibility | 1.88% | 15.1% |
| Cumulative Opportunity – 60 minutes | 2.79% | 23.7% |
| Spatio-temporal accessibility | 2.01% | 18.7% |

## 5.4. Individual determinants of person-based accessibility inequality

In this section, we provide an in-depth analysis of the spatio-temporal accessibility results, considering the individual and household characteristics of the respondents. In this case, we will focus on Ciudad Bolívar's TAZ, considering that the ACC project operates in this locality. A total of 2043 individuals from 812 households are part of this subset (see Table 3). Similar to previous analysis, we excluded 309 individuals (15.14%) who did not answer the trip section of the HTS.

We use the gradient impact (%) by individual, considering the total accessibility. Firstly, we identified 841 individuals (41.21%) who had no gradient impact among Ciudad Bolívar's localities. Remarkably, one individual had a positive accessibility in the ACC scenario after having zero accessibility in the baseline. This observation is excluded from the subsequent analysis because no gradient impact can be calculated.

We conducted non-parametric inference tests to determine the statistical significance of gradient impact differences, given that our data do not follow a normal distribution (Shapiro-Wilk Test, W = 0.0889, $p < 0.0001$). We analyse four variables: sex, age, income, and occupation, to determine if there are statistical differences in the gradient impact among groups (see Table 6). We identified that there are statistically significant differences within the groups, except for sex. However, the average impact for males is higher than for females. In addition, adults aged between 30 and 45 benefited the most among age groups, with an average impact of 4.26%, translating to an additional percentage of time spent at destinations. Regarding income, the lowest groups benefit the most compared to the highest income groups. Interestingly, workers benefited most, with an average gradient of 2.51%.

**Table 7. Average gradient impact and inference statistical analysis per sex, age, income, and occupation.**

| | Variable | Mean | Test |
|---|---|---|---|
| Sex | Male | 2.11% | D = 0.0594, p = 0.091 |

| | Variable | Mean | Test |
|---|---|---|---|
| | Female | 1.30% | U = 361995, p = 0.316 |
| Age | Teen (Less than 18) | 1.91% | H (4) = 108.2, p < 0.0001 |
| | Young-Adult (18 – 30) | 0.62% | |
| | Adult between 30 – 45 | 4.26% | |
| | Adult between 45 – 60 | 1.74% | |
| | Senior (More than 60) | 1.84% | |
| Income (USD) | Less than 252 | 2.01% | H (3) = 13.91, p < 0.01 |
| | 252 - 456 | 2.53% | |
| | 456 - 761 | 1.81% | |
| | More than 761 | 0.83% | |
| Occupation | Worker | 2.98% | H (3) = 73.9, p < 0.0001 |
| | Student | 1.68% | |
| | Household-chores | 1.08% | |
| | Other | 0.64% | |

U =Mann-Whitney U Test; D = Kolmogorov-Smirnoff Test; H = Kruskal-Wallis H test

Table 8 shows the results for the linear regression considering the gradient impact. We applied a logarithmic transformation, allowing for a normal distribution in the gradient impact. This model shows the individual characteristics that enabled TransMiCable to benefit more. As expected, individuals living in TAZ with ACC coverage experienced a massive increase in their accessibility by 4043.81% ($\beta = 3.724$, $p < 0.0001$). In addition, being part of a household with a monthly income of between 252 and 456 USD tends to slightly increase the gradient impact ($\beta = 0.155$, $p = 0.070$). On the contrary, teens (lower than 18) ($\beta = -0.401$, $p = 0.041$) and people who are involved in household chores ($\beta = -0.392$, $p < 0.0001$) benefited 33.02% and 32.46% less, respectively, compared to adults between the ages of 45 and 50 and workers. Remarkably, the presence of children and cars in the household significantly reduces the gradient impact by 18.42% and 20.90%.

**Table 8. Results of the linear regression model of gradient impact (log transformation).**

| | Estimate (s.e.) | Change (%) | p-value |
|---|---|---|---|
| Constant | -3.416 (0.14) | - | 0 |
| Sex (reference Male) | | | |
| Female | 0.05 (0.08) | 5.13% | 0.510 |
| Age (reference “Adult between 45-60") | | | |
| Teen (Less than 18) | -0.401 (0.2) | -33.02% | 0.041 |
| Young 18 – 30 | 0.059 (0.13) | 6.08% | 0.641 |
| Adult between 30 – 45 | 0.184 (0.12) | 20.21% | 0.129 |
| Senior (More than 60) | 0.201 (0.13) | 22.24% | 0.123 |
| Household income (reference "Less than 252") | | | |
| 252 - 456 | 0.155 (0.09) | 16.78% | 0.070 |
| 456 - 761 | -0.054 (0.1) | -5.22% | 0.607 |
| More than 761 | -0.118 (0.13) | -11.11% | 0.378 |
| Education level (reference "Primary") | | | |
| Middle | -0.102 (0.09) | -9.67% | 0.273 |
| Technical | 0.018 (0.12) | 1.84% | 0.882 |
| Higher | 0.236 (0.16) | 26.60% | 0.139 |
| Occupation (reference "Work") | | | |
| Study | -0.188 (0.16) | -17.10% | 0.226 |
| Household-chores | -0.392 (0.11) | -32.46% | 0.000 |
| Other | -0.184 (0.12) | -16.84% | 0.119 |
| Relation with the household head (reference Head) | | | |
| Partner | 0.15 (0.11) | 16.20% | 0.162 |
| Nuclear Family | 0.117 (0.11) | 12.40% | 0.301 |
| Other | -0.113 (0.16) | -10.68% | 0.486 |
| Total number of household members | -0.009 (0.03) | -0.88% | 0.739 |
| Presence of children (dummy) | -0.204 (0.08) | -18.42% | 0.015 |
| Presence of cars (dummy) | -0.234 (0.09) | -20.90% | 0.012 |

| | | | | |
|---|---|---|---|---|
| Presence of motorcycles (dummy) | | 0.141 (0.09) | 15.12% | 0.110 |
| Taz with ACC coverage (dummy) | | 3.724 (0.12) | 4043.81% | 0.000 |
| Goodness-of-fit measures | Rho-squared | | 0.410 | |
| | AIC | | 6187 | |
| | BIC | | 6312 | |

# 6. Discussion

This section will discuss the patterns of (in)equalities in the city, considering different destinations and the extent to which they differ across accessibility measures. We will also explore the transport justice brought by TransMiCable, and whom it benefits most.

## 6.1. Transport (in)equity in Bogotá across destinations and accessibility measures

The accessibility of discretionary activities in Bogotá shows a persistent transport inequality that benefits high-income zones and individuals more. This is consistent with previous results of studies in the city where accessibility of employment and study is better among high-income neighbourhoods because there is a high public transport supply around those locations (Guzman et al., 2017).

Nevertheless, we found differences in the concentration index (CI) among opportunity categories and between location and person-based measures. Regarding location-based measures, accessibility of healthcare and education is better in high-income zones; meanwhile, the CI for accessibility of groceries shows a distribution nearly equal among income groups. This difference may be related to the number and geographical distribution of facilities. For instance, healthcare and education present a similar number of facilities (see Table 2), geographically distributed towards wealthier areas of the city. On the other hand, the number of grocery stores is much higher (see Table 2), and they are more concentrated in the south and west parts of the city, closer to medium and low-income groups. This leads to lower travel times for those income groups to groceries throughout the city, making their accessibility better, as observed in the results.

The spatial-temporal accessibility measure (STA) leads to lower CI results than location-based measures. Nevertheless, there are no fundamental differences across measures, all of which show transport inequity patterns across opportunity categories and the positive effect of TransMiCable on accessibility. Furthermore, there is no clear difference among opportunity categories. Therefore, the combination of temporal and spatial constraints can underpin inequality patterns that are not evident in the location-based measures. For instance, a person living in the peripheries working near the city centre will have a higher STA because they are closer to opportunities from their work. On the other hand, another person living in the exact location but working in a zone with low opportunity concentration may travel more from their fixed activity to access additional opportunities. Despite both cases living in the exact same location, they have different STA because of their fixed activity location and transit supply; meanwhile, in the location-based measures, they will have the same accessibility values based on their household location.

This shows that transport equity analysis is sensitive to the accessibility measure and the resolution. Nevertheless, location- and person-based measures each have advantages that can complement one another. While location-based measures tend to overestimate transport inequalities (compared to person-based measures), they show areas of the cities in the most need, providing a good overview at the city level. Conversely, person-based measures usually result in lower levels of transport inequalities; nevertheless, they can help reveal which population groups are most disadvantaged, providing a higher-resolution perspective.

## 6.2. Transport justice effects of TransMiCable

TransMiCable slightly reduces transport inequity in the city but has a considerable impact on its area of influence in Ciudad Bolivar's locality, a neighbourhood with social and transportation disadvantages. This is consistent with recent studies that found Ciudad Bolivar's inhabitants experienced a 1.27 USD increase in perceived welfare on accessibility due to TransMiCable, mainly related to travel time and cost savings (Guzman et al., 2025).

We calculated accessibility by public transport to discretionary activities (including study) and obtained positive and consistent effects of the ACC, independently of the measure used. In addition, the transport inequity distribution was slightly reduced, as observed through the Concentration Index (CI). Similar results have been found in previous studies on transit subsidies in Bogotá (Guzman and Oviedo, 2018), where the distribution of benefits, measured by the Gini Index and Palma Ratio, impacted more disadvantaged communities in Bogotá. However, these indices (Gini and Palma ratio) have limitations in their calculations and alignment with transport equity ethical theories (Karner et al., 2024). Therefore, the CI allows for addressing some of those limitations, particularly by including sociodemographic variables, to understand which sociodemographic groups have better accessibility and benefit more from the ACC.

Thus, TransMiCable is an effective transport intervention from a transport equity perspective, considering that it benefited the people in greatest need first, in line with Rawls's Egalitarianism theory (Pereira et al., 2017). Interestingly, the accessibility impacts are positive independent of the measure used: location-based or person-based measures. However, person-based measures allowed us to identify which individuals benefited the most from this intervention. In addition, spatio-temporal accessibility considers the temporal and location constraints per individual, resulting in a more accurate accessibility calculation.

## 6.3. Who benefited the most from TransMiCable

The spatio-temporal accessibility measure allows for comparisons between individuals with different activity patterns, which is rare in accessibility analysis in LAC (Vecchio et al., 2020). As expected, individuals living in TAZ with TransMiCable benefited more, as shown in Tables 6 and 8.

We did not find strong evidence of differential impacts by gender. Guzman et al. (2025) recently reported that males had larger accessibility benefits in the short term after the inauguration of TransMiCable. Nevertheless, this effect disappears after five years of the operation, indicating that although the positive impact remains, gender no longer influences the results. Similarly, studies about travel behaviour found no significant effects of TransMiCable on females' levels of activity participation (Cardona-Urrea et al., 2026) or changes in the time allocation of activities (Guzman et al., 2024).

Regarding age, teens under 18 were less impacted by the ACC than adults between 45 and 60. This is reasonable because the daily mobility of teens is usually accompanied by their parents, who often escort them in private vehicles, particularly in developing countries (Sukmayasa et al., 2025). Additionally, they are primarily engaged in fixed study activities, making it difficult to access additional activities during the day, which was the main focus of the study.

Households with the presence of children (less than 12) also experience fewer accessibility benefits. People living with children tend to conduct care-related activities that are shorter and usually take place within the neighbourhood (Cardona-Urrea et al., 2026; de Madariaga, 2013). Therefore, TransMiCable is less convenient for these types of trips, considering that its greatest accessibility benefits are concentrated on longer commute trips outside the neighbourhood (Cardona-Urrea et al., 2026, 2024; Garnica Quiroga, 2020).

Finally, results show that low-income individuals in Ciudad Bolivar benefited more from the ACC. This is a positive result from a transport equity perspective, considering that people in the most need inside disadvantaged communities experienced more benefits. For example, Bocarejo et al. (2014) found an opposite result regarding Medellín's Metrocable, indicating that higher-income households within the area of influence benefited more. In addition, households with cars benefited less from the ACC. It could be that households with cars have good levels of accessibility in the baseline; therefore, they were less impacted by the ACC. Transport policies should consider the impact on private vehicle users (cars and motorcycles) and how to attract public transport and effectively promote sustainable mobility interventions like the ACC.

# 7. Conclusions

In this study, we calculated location and person-based accessibility measures to identify the impact of TransMiCable on the accessibility of discretionary activities. Particularly, we calculated potential accessibility, cumulative opportunities, and spatio-temporal accessibility. We found a positive but low impact on accessibility at the city level. Moreover, the benefits are spatially concentrated in Ciudad Bolivar, showing improved transport equity distribution through disadvantaged communities in the most need, following Rawls' Egalitarianism theories. Remarkably, accessibility benefits are obtained independently of the measure used. However, only spatio-temporal accessibility allows us to identify which individuals benefited the most.

We identified which segments of the population benefited more from the ACC. For instance, low-income households in Ciudad Bolivar show a larger impact. In contrast, teens (under 18 years old), individuals involved in household chores, and households with children or cars were less impacted. It is crucial to understand how the benefits were distributed and to define targeted interventions to expand the benefits of the ACC to those who benefitted less. For instance, understanding the travel behaviour among teens, their escorts, and households with cars will be crucial to designing transport policies that promote the use of the ACC. This can be explored in future research through choice model experiments.

Finally, the Concentration Index (CI) was an interesting measure that assessed the distribution of accessibility across various dimensions, including income levels and opportunity categories. Remarkably, the accessibility of groceries is closer to being distributed equally across income groups, while, accessibility of healthcare and education is distributed more towards higher-income zones. The CI is sensitive to the accessibility measure and the spatial resolution, which are controlled in the spatio-temporal measure and calculated at the individual level. Future research should focus on retrieving more empirical evidence about transport equity using the CI, while exploring the effects of the spatial dependence, particularly on location-based measures.

This research does not lack limitations. First, the GTFS data is from 2023; therefore, the transport supply is constant for that year, changing only the provision of the ACC. GTFS data for previous years were impossible to obtain because the public transport operator began their construction in 2020. Moreover, only GTFS from recent years was validated for use in the R5R package. Second, the travel time matrix for person-based accessibility was calculated at the TAZ level, only considering the morning period. This is related to computational limitations, considering that it was not easy to calculate at the household level in an adequate amount of time. Despite these limitations, the decision to maintain constant public transport, varying only in the provision of the ACC, provided us with enough stability to calculate the effects of this transit mode on accessibility to discretionary activities.

Future research should focus on the impact of ACC on local accessibility, e.g., answering how the ACC affects walkability in the neighbourhoods and shorter trips, such as maintenance, care, and flexible activities. Finally, the potential of the ACC to address geographical exclusion for higher-income individuals and the potential for a modal shift from private vehicles to public transport may be explored. However, it should be accompanied by a profound reflection on the distribution of justice in the provision of public transport and the reduction of private car use.

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Journal of Public Transportation

# The role of transport exclusion and aerial cable cars in shaping commuting choices in steep cities

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| Abstract: | This paper investigates the factors affecting commuting mode choice, with a particular focus on the consideration and choice of aerial cable cars (ACC). It also examines the impact of transport-related social exclusion (TRSE) on mode choice, understood as the limited participation in society due to a lack of transport options. The case study is situated in Manizales, Colombia, a medium-sized city renowned for pioneering ACC as a transit mode and distinguished by its steep topography and residential development in hilly terrain, thereby providing a unique context for examining the impact of ACC on mobility. Data was collected through a questionnaire survey, and responses were analysed using factor analysis and a nested logit model. We performed a Confirmatory Factor Analysis on the TRSE scale, based on a structure of six theoretical domains (physical, fear, time, money, information, and geographical-based exclusion) explored in the survey. Interestingly, females show a lower likelihood of choosing the ACC, while the presence of cars among workers also reduces the likelihood of using the ACC. Furthermore, we found that physical, information, and geographical-based exclusion have the potential to explain mode choice. For instance, a high perception of physical-based exclusion, related to the quality of transport infrastructure, reduces the likelihood of choosing transit modes, particularly buses. Additionally, individuals with a higher perception of information-based exclusion tend to favour modes that require less information to ensure a reliable journey, such as the ACC, motorcycle, or walking. Regarding fear-based exclusion, we found that a high fear perception increases the disutility of time; therefore, individuals prefer a faster arrival at the destination, thereby reducing the probability of incidents. Finally, we simulated the modal share with the inauguration of a new ACC line, resulting in a significant increase in the ACC commuting modal share. Nevertheless, new users initially came from buses, showing a lack of attraction for private vehicle users (cars and motorcycles). This study emphasises the importance of including ACC as a mode choice and identifies specific characteristics that influence its selection. Lastly, it highlights the relevance of |

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| | perceptions of transport-related social exclusion on commuting mode choice by considering distinct effects for particular modes, enabling specific recommendations to improve city mobility. |
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Cover letter

Utrecht University

3 February 2026

Dear Oded Cats, PhD, *Delft University of Technology, Delft, Netherlands*
Editor-in-Chief, *Journal of Public Transportation*

I am pleased to submit the manuscript "THE ROLE OF TRANSPORT EXCLUSION AND AERIAL CABLE CARS IN SHAPING COMMUTING CHOICES IN STEEP CITIES" for consideration in the Journal of Public Transportation.

The paper explored commuting modal choice while directly incorporating aerial-cable cars (ACCs) as a public transport alternative, an alternative that remains overlooked in travel behaviour research. We focus on Manizales (Colombia), a steep city where the ACC plays a structuring role in the mobility system and serves as an alternative for daily commutes among its residents. This context offers relevant lessons for other hilly cities seeking to integrate ACC with conventional public transport networks.

In addition, we explored how perceptions of transport-related social exclusion influence mode choice via latent variables derived from its theoretical domains. Finally, we forecast the impacts of the opening of new ACC on mode choice by simulating its effects on people living around the system.

Beyond technology, the study addresses transport-related social exclusion by embedding its theoretical dimensions within a discrete-choice framework via latent variables. This allows us to better understand how perceived transport limitations shape everyday mobility decisions, such as mode choice. We also simulate the effects of a newly inaugurated ACC line to provide insights into how such investments may reshape modal shares and travel patterns.

Our results contribute to debates on public transport planning and equity by showing that (1) ACC usage patterns differ by gender, (2) subjective transport limitations constraints influence mode choices, and (3) new ACC infrastructure can substantially increase ridership, primarily by attracting users from buses and walking.

We believe these findings are of interest to the journal because they combine behavioural analysis with practical implications for the planning, integration, and equitable deployment of innovative public transport systems in challenging topographies.

Kind regards,

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# THE ROLE OF TRANSPORT EXCLUSION AND AERIAL CABLE CARS IN SHAPING COMMUTING CHOICES IN STEEP CITIES

**Abstract**: This paper investigates the factors affecting commuting mode choice, with a particular focus on the consideration and choice of aerial cable cars (ACC). It also examines the impact of transport-related social exclusion (TRSE) on mode choice, understood as the limited participation in society due to a lack of transport options. The case study is situated in Manizales, Colombia, a medium-sized city renowned for pioneering ACC as a transit mode and distinguished by its steep topography and residential development in hilly terrain, thereby providing a unique context for examining the impact of ACC on mobility. Data was collected through a questionnaire survey, and responses were analysed using factor analysis and a nested logit model. We performed a Confirmatory Factor Analysis on the TRSE scale, based on a structure of six theoretical domains (physical, fear, time, money, information, and geographical-based exclusion) explored in the survey. Interestingly, females show a lower likelihood of choosing the ACC, while the presence of cars among workers also reduces the likelihood of using the ACC. Furthermore, we found that physical, information, and geographical-based exclusion have the potential to explain mode choice. For instance, a high perception of physical-based exclusion, related to the quality of transport infrastructure, reduces the likelihood of choosing transit modes, particularly buses. Additionally, individuals with a higher perception of information-based exclusion tend to favour modes that require less information to ensure a reliable journey, such as the ACC, motorcycle, or walking. Regarding fear-based exclusion, we found that a high fear perception increases the disutility of time; therefore, individuals prefer a faster arrival at the destination, thereby reducing the probability of incidents. Finally, we simulated the modal share with the inauguration of a new ACC line, resulting in a significant increase in the ACC commuting modal share. Nevertheless, new users initially came from buses, showing a lack of attraction for private vehicle users (cars and motorcycles). This study emphasises the importance of including ACC as a mode choice and identifies specific characteristics that influence its selection. Lastly, it highlights the relevance of perceptions of transport-related social exclusion on commuting mode choice by considering distinct effects for particular modes, enabling specific recommendations to improve city mobility.

**Keywords**: aerial cable cars, transport-related social exclusion, modal choice, discrete choice models, travel behaviour.

## 1. INTRODUCTION

Public transport is crucial for reducing transportation inequalities, particularly in Global South cities that face significant urban and transportation challenges (Acheampong, 2020; Cardona-Urrea et al., 2026; Oviedo, 2021). In Latin America and the Caribbean (LAC), the social, economic, and geographical context exacerbates these challenges. Many residents are pushed to the peripheries to access affordable housing, which is often located in hilly terrain, prone to natural hazards such as flooding and landslides, and lacking proper public transport (González and Flórez, 2022; Oviedo, 2021). These factors can lead to transport-related social exclusion (TRSE), defined as limited opportunities for participation resulting from inadequate transport supply (Ettema et al., 2025; Lucas, 2012). Public transport planning is essential for mitigating TRSE and enabling people to travel to and reach destinations equitably (Vos et al., 2025).

Aerial cable cars (ACC) have gained popularity in LAC cities as a high-quality transit mode for low-income, informal housing areas in hilly terrains (Cardona-Urrea et al., 2024). ACC systems have been shown to reduce TRSE, increase job accessibility (Bocarejo et al., 2014), redistribute time spent on activities (Guzman et al., 2024), and increase activity participation (Cardona-Urrea et al., 2026). While studies have examined ACC's impacts on social exclusion, mobility, and tourism, research on the factors that drive commuters' use of ACC remains limited (Cardona-Urrea et al., 2024). Research is lacking in the development of modal choice models for travel behaviour analysis and forecasting, especially in cities where the ACC system is designed to cover the whole city, rather than serving as a feeder to the urban public transport system, such as Manizales (Colombia) or La Paz (Bolivia) (Cardona-Urrea et al., 2024). These cities face different challenges compared to those where ACC functions as a feeder, such as Bogotá or Medellín (Colombia).

Research on the effects of ACC on travel behaviour has focused on its role as a feeder of broader transit modes (Cardona-Urrea et al., 2024), leading to significant reductions in travel time and costs, particularly for commuters. For instance, Cordoba et al. (2014) found that *Metrocable* (Medellín) increases the average number of daily trips in the area of influence, thereby reducing the risk of social exclusion. Similarly, Milan and Creutzig (2017) found that ACCs in Medellín increased public transport use among low-income individuals and women, particularly in their service area. Similarly, Agudelo V. et al. (2013) and Sarmiento Ordosgostia et al. (2013) found that females in ACC's service area are more likely to use traditional buses because the bus stops are near. ACCs in Latin America and the Caribbean are usually located in vulnerable neighbourhoods with high crime rates (Brand and Dávila, 2011; Cardona-Urrea et al., 2024). Therefore, females in Medellín reported that shorter distances to bus stops reduce their exposure to crimes and violence. Research on modal choice, including ACC as an option, is limited; for example, Okami et al. (2022) examined travel behaviour among low-income residents in areas influenced by Medellín's ACC. However, they lack ACC as a regular commuting option because 82% of riders connect to the metro system; therefore, ACC was not considered as a choice in this study.

There are a few studies on the effects of transport and travel behaviour on cities that introduced the ACC to structure their mobility systems (Cardona-Urrea et al., 2024). For example, in La Paz, the introduction of *Mi Teleférico* led to a minor modal shift from private vehicles; meanwhile, most of the ACC modal share came from other transit modes (Martinez et al., 2018). This highlights the challenges ACC faces in attracting private vehicle users. For instance, an ex-post analysis of *Cable Aéreo* in Manizales (Colombia) shows that ridership is below the forecast demand, exposing the difficulties in attracting more users due to the lack of physical and fare integration with other transit modes (Escobar et al., 2015).

This study aims to understand commuters' modal choices in a city with a city wide ACC system. Modal choice is assumed to depend on attributes related to the transport mode, the person and the city's built environment and structure (Acheampong, 2020; Vos et al., 2016). Studies in different contexts have consistently found that females, young individuals, students and low-income households tend to have a higher likelihood of choosing public transport and active modes of transport (e.g., walk or bike) (Acheampong, 2020; Blandin et al., 2024; Giubergia et al., 2025; Hu et al., 2018; Okami et al., 2022; Peña et al., 2022; Rodríguez and Joo, 2004; Sun et al., 2017). Regarding the built environment, population density is associated with a higher proportion of walking, whereas higher road density is associated with increased car use (Sun et al., 2017). Public transport availability is also important for mode choice, serving as an essential predictor of public transport use, in terms of the number of bus stops (Giubergia et al., 2025) and distance to stations (Okami et al., 2022; Peña et al., 2022). Lastly, topography can affect cycling and walking choices (Rodríguez and Joo, 2004) and hinder access to transit stops (Coelho et al., 2025).

In addition to the above factors, authors have researched a set of attitudinal, motivational, and preference factors that can impact mode decisions (Hu et al., 2018; Vos et al., 2016). A portion of the literature focuses on attitudes towards modes of transport, sustainable mobility policies, and environmental awareness, among other topics. In particular, research on the subjective dimensions of transport, such as perceived accessibility and transport disadvantages (Currie and Delbosc, 2010; Ettema et al., 2025; Lättman et al., 2018; Pot et al., 2024), has grown. These studies have focused on how transport limitations influence social exclusion and well-being, and how perceptions differ across several sociodemographic groups and transport poverty indicators (Currie and Delbosc, 2010; Ettema et al., 2025). Research on their influence on mode choice is more limited. For example, Blandin et al. (2024) found that lower perceived accessibility decreases the likelihood of choosing a car or public transport over biking. In this case, perceived accessibility was understood as the general perception of ease of reaching destinations by mode of transport (bike, car, or public transport), which is closely related to the built environment. This shows that evidence on how subjective transport limitations or perceived accessibility can influence mode choice is lacking, particularly in socially disadvantaged contexts and cities in the Global South where ACC are usually operating. Following the approach taken by Blandin et al. (2024), we hypothesised that individual perceptions of general transport limitations, expressed as transport-related social exclusion domains, could directly influence mode choice. For example, perceptions of available travel information or time can affect the choice between public transport and private modes differently.

Given the above, this study aims to identify the factors (individual, household, and built environment) that drive the choice of ACC for commuting. A case study was conducted in Manizales, Colombia, to answer those questions. This medium-sized city has three aerial cable-car lines that structure its transit system, reaching disadvantaged and non-disadvantaged communities across its hilly terrain. We used data collected in 2024 when two lines were operating, and the third was under construction, inaugurated in September of 2025. In particular, we want to identify the influence of subjective transport limitations on commuting modal choice, especially in areas with ACC presence. In this case, we operationalised transport-related social exclusion by drawing on its theoretical domains, allowing respondents to report their perceptions of transport limitations in areas such as physical, time, economic, geographical, fear, and information exclusion (Lucas, 2012; Luz and Portugal, 2022). Finally, we examine the impact of new ACC projects using modal choice models, focusing on the third line as a case study. To do this, we forecast the city’s modal share, including a new ACC alternative, to distinguish differences between the baseline and future scenarios. This enables us to identify the main modal shifts and assess the transport policy in relation to various public policy objectives.

The following section will introduce the case study. The survey design, data collection, and methods are then described in Section 3. The methods involved discrete choice models and factor analysis. The fourth section presents the results, followed by a discussion and conclusions.

## 2. STUDY AREA

The case study is in Manizales (see Figure 1), a medium-sized Colombian city with approximately 400,000 inhabitants, offering interesting characteristics for studying travel behaviour and social exclusion. First, the city has steep topography because it is established in the Andes Mountains with an average altitude of 2150 meters above sea level. Therefore, developing housing, public space, and transport infrastructure is complex (Cardona-Urrea et al., 2023). For example, flat areas suitable for building houses are scarce; consequently, most people's housing was developed in the hills (with a slope of more than 50%), some of which are at risk of landslides (González and Flórez, 2022). In addition, it is challenging to allocate space and infrastructure for all road users (Cardona-Urrea et al., 2024). Most roads are built for motorised vehicles, with no prioritised lanes for mass transit systems, and bike paths are scarce (Cardona-Urrea et al., 2023; Sabogal-Cardona et al., 2025).

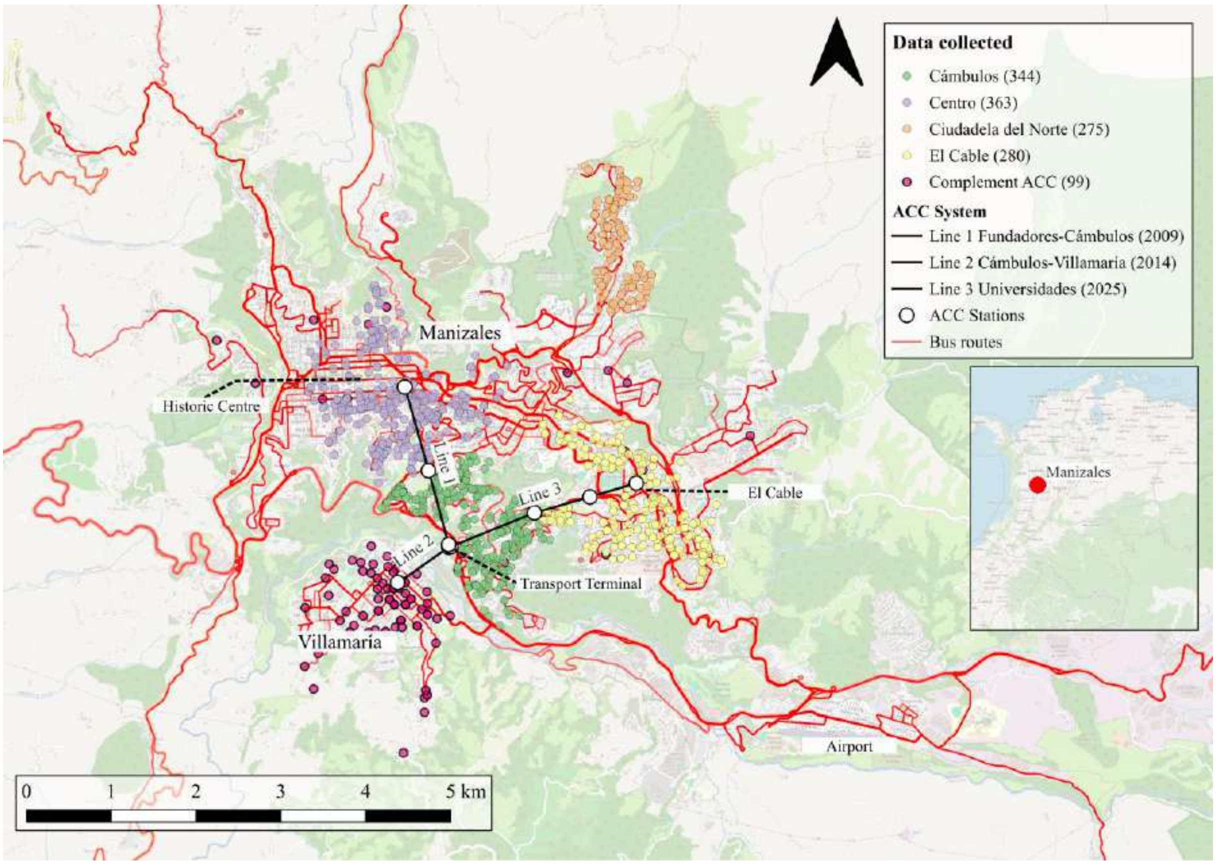


**Figure 1. Case study location, georeferenced data collection and public transport mobility system of Manizales.**

These challenges led to the construction of an aerial cable car (ACC) system in 2009, known as *Cable Aéreo*, a pioneer in utilising this technology as a transit mode (Cardona-Urrea et al., 2024). Manizales was the first city in LAC to plan the structure of its public transport system around the ACC. However, the plan has developed slowly and currently has only two ACC lines connecting the historic city centre with the regional transport terminal and the city centre of Villamaría, the neighbouring city (see Figure 1) (Cardona-Urrea et al., 2024). The third line was recently inaugurated in September 2025, connecting with an economic centre called "El Cable". Two additional lines are in the municipality's mobility plans to complete a robust system in the city (Escobar et al., 2022).

Before the inauguration of the third line, the ACC served approximately 8,500 passengers daily, which accounted for roughly 0.76% of the city's daily trips, according to the 2017 Household Travel Survey (HTS). The ACC has failed to attract more ridership (Escobar et al., 2015) due to the lack of physical or fare integration with the bus system, which accounts for nearly 25% of daily trips (Cardona-Urrea et al., 2024). Buses are operated by private companies with vehicles of different capacities on 117 routes, covering almost all of the city (red lines in Figure 1). The bus system is highly unreliable, and buses must share space with private vehicles (cars and motorcycles), leading to considerable delays during congestion. Besides, there are not adequate bus stops in the city; consequently, the system is flexible, allowing continuous passengers access and egress along the route (Cardona-Urrea et al., 2024; Montoya et al., 2024).

Apart from public transport, walking is the primary mode of transport for 29% of daily trips, followed by cars (20%) and motorcycles (12.5%). The motorcycle has gained popularity among Latin American cities (LAC), particularly among low-income residents, due to its affordability and flexibility in navigating congested urban areas (Chiu et al., 2023; Hagen et al., 2016). In Manizales, the motorcycle motorisation rate has tripled between 2009 and 2020 (Manizales Cómo Vamos, 2020).

These characteristics made Manizales an interesting case for studying travel behaviour, with particular attention to the influence of ACC as an alternative for commuting, the competition with buses, and the rise in motorcycle motorisation. Furthermore, the city's characteristics are interesting in understanding how transport-related social exclusion influences mode choice, particularly in relation to the topography and the lack of information about transport options. Finally, the new ACC line, inaugurated in September 2025, presents an opportunity to forecast the commuting modal share it will attract.

# 3. SURVEY DESIGN, DATA COLLECTION AND METHODS

## 3.1. Survey design

The survey was conducted in the Manizales urban area among people aged 18 or older, including the neighbourhood city of Villamaría. The questionnaire was structured into five sections: sociodemographic characteristics, mobility patterns, transport-related social exclusion, transport attitudes, and social outcomes (life satisfaction, social support, and mental health). In this study, we focused on the first three sections. The sociodemographic characteristics retrieved data about sex, age, educational level, occupation, monthly income, driving license, number of vehicles in the household, household type and members' composition, household location, and years of living in the household and the city. The section on mobility patterns includes commuting (for work and study), as well as care, social, and recreational activities, and shopping and errands. In this study, we focus on commuting, defined as whether people reported travelling outside the household at least once in the last week for work or study. This subsection inquired about the job location, the most common mode of transport, the travel time, the availability of alternative modes of transport if the usual choice was unavailable, and the preferred mode of transport.

TRSE was assessed through 14 questions on a five-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree," and included perceptions regarding six theoretical TRSE domains: physical, fear, time, money, geographical, and information-based exclusion (see Table 1) (Lucas, 2012; Luz and Portugal, 2022). Regarding physical-based exclusion, the questions focused on infrastructure quality, including sidewalks, bike paths, and roads. On the other hand, fear-based exclusion inquired about safety perceptions while moving regarding three categories of violence: theft and attacks, sexual harassment, and road crashes. Money-based exclusion focuses on transport affordability, whereas time-based exclusion focuses on transport availability and the time spent on mobility. Geographical-based exclusion questions focused on perceptions of their household location and the built environment around it, particularly topography, given Manizales's hilly terrain. Lastly, information-based exclusion inquired about the availability of information for planning their trip using transit (e.g., routes, schedules) or other modes (e.g., shortest paths in online maps). Based on the literature review, the observed variables were designed to contribute to specific TRSE domains (Lucas, 2012; Luz and Portugal, 2022). Some statements were defined considering recent research on transport adequacy (e.g., Ettema et al., 2025).

**Table 1. TRSE statements per domain.**

| TRSE Domain | Please answer if you agree or disagree with the following statements: |
|---|---|
| Physical-based Exclusion $(\eta_1)$ | The quality of the sidewalks is excellent and suitable for my travels $(y_1)$<br>The quality of the bike paths is excellent and suitable for use $(y_2)$<br>The quality of the roads is excellent and suitable for use $(y_3)$ |
| Fear-based Exclusion $(\eta_2)$ | I feel safe from theft/attack while I am travelling on my own $(y_4)$<br>I feel safe from sexual harassment while I am travelling on my own $(y_5)$<br>I feel safe from being crashed by a car or motorcycle while I am travelling on my own $(y_6)$ |
| Money-based Exclusion $(\eta_3)$ | I can travel as I would like because I can pay for it $(y_7)$<br>I have to spend more money on necessary travel in a week than I can afford $(y_8)$ |
| Time-based Exclusion $(\eta_4)$ | There is always a transport option available to me at the times I need it $(y_9)$<br>I spend much more time travelling than I'd like $(y_{10})$ |
| Geographical-based Exclusion $(\eta_5)$ | I think my household location is advantageous $(y_{11})$<br>I think the topography (e.g., hills) of my neighbourhood makes it easy to move around $(y_{12})$ |
| Information-based Exclusion $(\eta_6)$ | I can access information about my transport options, e.g., routes, timetables, and bus stops $(y_{13})$<br>I can use various modes of transportation due to the information available to me $(y_{14})$ |

## 3.2. Data collection and sampling

We conducted in-person interviews with a sample selected through a two-stage stratified sampling approach. First, we defined four sub-areas in Manizales based on their proximity to operational, in-construction, and projected ACC stations. These sub-areas were categorised into disadvantaged and non-disadvantaged communities based on their income levels, topographic characteristics, and city location. Therefore, we obtain four groups (see Figure 1): Disadvantaged communities with the presence of ACC (*Cámbulos*), non-disadvantaged communities with the presence of ACC (*Centre*), disadvantaged communities without the presence of ACC (*Ciudadela del Norte*), and non-disadvantaged communities without the presence of ACC (*El Cable*). Second, the sample size is balanced across sex and age, as shown by the most recent Population and Household Census results from the Department of Administrative National Statistics (DANE, 2018) (see Appendix A-1). Paper-and-pencil questionnaires were collected by a survey team composed of anthropologists who intercepted potential respondents in the streets, near the targeted sub-areas, or in city activity hotspots. After initial explorations, we observed that fewer than 1% of the responses utilised the ACC as the primary commuting mode of transport, which is one of the study's primary aims. Consequently, we increased the number of responses from ACC commuters using a convenience sample, interviewing people within the ACC system and around the stations. The data were collected between April and August 2024, before the inauguration of Line 3. Fifteen (15) supermarket vouchers for 25 USD and three bicycles for 300 USD were given away among the participants as a token of appreciation for participating in the survey. The Science-Geosciences Ethics Review Board (SG ERB) of Utrecht University approved the study (Geo-24-0005).

We collected 1309 responses using the in-person approach, and the household locations in the targeted sub-areas were validated for 1262 (see dots in Figure 1). In addition, 99 responses were collected from ACC users (red dots in Figure 1). We combined these datasets, recognising that we aim to increase the number of commuter observations using the ACC to estimate the modal choice model. Finally, we have 1362 responses, from which 894 reported being working or studying (commuting). This revealed-preference (RP) dataset will undergo data cleaning and the calculation of trip attributes.

## 3.3. Data Cleaning and Trip Attributes

The RP dataset was augmented with trip attributes related to mode choice and alternatives. To do so, a fixed job location point is needed. First, 98 respondents who reported working or studying permanently from home were discarded. In addition, 89 observations were excluded for the following reasons: i) they reported having multiple job locations (n = 62), ii) they worked moving around the city as drivers or in delivery services (n = 13), iii) they reported job locations outside the urban area (n =12) and iv) some were not possible to geolocate from the address reported (n = 2). Finally, we calculated trip attributes for 707 observations.

The trip attributes were calculated according to the recommendations of Guzman et al. (2021), where travel time, distance, and costs were retrieved from the Google Maps API and calculated using Geographic Information System (GIS) methods. Car shortest paths were calculated from the Google Maps API. The motorcycle was assumed to be as fast as cars, considering the minimal differences in average speeds at main avenues in Manizales, calculated using data from fixed speed cameras (see Appendix A-2) (Secretaría de Movilidad de Manizales, 2024). Travel costs for cars and motorcycles were calculated based on the distance and average operational costs reported by Guzman et al. (2021) and projected to 2024, accounting for increases in fuel costs. A cost of $0.32 USD per kilometre ($1347 COP per kilometre) was considered for cars and $0.08 USD per kilometre ($337 COP per kilometre) for motorcycles. Walking shortest paths were calculated in QGIS using the QNEAT plugin, based on the GIS road network from a previous research study published for the city (Aristizábal et al., 2023; Cardona-Urrea et al., 2023). Those road networks considered differential speeds based on the road slope gradient. No travel costs were considered for walking.

Finally, for the buses and aerial cable-car trip attributes, a multimodal network was built using the *R5R* package in R language, considering a static General Transit Feed Specification (GTFS) (Pereira et al., 2021), the walking network, and the elevation from the Copernicus Global Digital Surface Model (DSM) at 30-meter resolution (European Space Agency, 2021). The DSM model enabled the calculation of differential walking speeds in the road network using elevation and Tobler's equation (Tobler, 1993). The GTFS was constructed for this research by considering the official routes and schedules of the municipal government. Additionally, we assumed an average bus speed of 17.5 km/h. The ACC includes an average speed of 13.68 km/h and a frequency of 1 minute between cabins (Asociación Cable Aéreo Manizales, 2025).

The multimodal network considered access and egress travel time by walking, in-vehicle time, and waiting time. Trip attributes for buses and ACC were calculated separately, assuming non-fare or physical integration into the public transport system; consequently, people cannot transfer between bus routes and ACC, or vice versa. A cost of $0.64 USD per trip ($2,700 COP) for public transport is assumed, as it is the official fare for 2024. Additionally, the complement survey of ACC users allowed us to identify intermodal trips that combine the ACC with bus, car, or bike, using those modes in the journey's access and/or egress stages. Among those, we considered only walking and bus intermodality with the ACC, as car and bike access/egress were minimal (n = 8).

We excluded observations where participants' walking travel time was less than 2 minutes (n = 27). Additionally, some observations were excluded during exploratory data analysis of travel times. For instance, respondents with trips longer than 60 minutes by bus (n = 13) or ACC (n =10), and observations with significant differences between the choice and faster alternatives (n = 47). Additionally, we excluded observations that reported using a car or motorcycle when these modes were not available in their household (n = 8). We also removed data for respondents who chose taxi (n = 12), bike (n = 14), or other modes (n = 10), as these represent less than 5% of the modal share. Lastly, only one response indicated sex as "other", which will be excluded from further analysis. The final dataset comprises 557 responses. The sample is balanced in terms of sex and age (see Table 2), most of the people are working (79.71%), and a high proportion have higher education (technical or university). In addition, a similar proportion of respondents reported having a vehicle in their household, specifically a car (35.40%) or a motorcycle (38.94%).

**Table 2. Descriptive Statistics of the in-person survey.**

| | N = 557 | % |
|---|---|---|
| **Sex** | | |
| Male | 288 | 51.71% |
| Female | 269 | 48.29% |
| **Age** | | |
| 18 - 30 | 191 | 34.29% |
| 31 - 40 | 126 | 22.62% |
| 41 - 50 | 108 | 19.39% |
| 51 - 60 | 81 | 14.54% |
| More than 60 | 51 | 9.16% |
| **Occupation** | | |
| Study | 113 | 20.29% |
| Work | 444 | 79.71% |
| **Education level** | | |
| Elementary, Middle or High School | 178 | 31.96% |
| Technical education (complete or ongoing). | 134 | 24.06% |
| University (complete or ongoing) | 241 | 43.27% |
| No education | 4 | 0.72% |
| **Household Socioeconomic Strata (SES)*** | | |
| 1 | 67 | 12.03% |
| 2 | 125 | 22.44% |
| 3 | 234 | 42.01% |
| 4 | 53 | 9.52% |
| 5 | 40 | 7.18% |
| 6 | 38 | 6.82% |
| **Presence of vehicles (household)** | | |
| Car | 35.91% | |
| Motorcycle | 39.14% | |
| Car and Motorcycles | 12.93% | |
| Bicycles | 31.78% | |

The socioeconomic strata (SES) is a Colombian public policy that categorises households into 1 (low) to 6 (high) based on social and economic characteristics, enabling the allocation of public subsidies. It has been validated as a proxy of household income for transportation models (Cantillo-García et al., 2019)

The availability of transport modes (Table 3) was determined considering the following assumptions. Walking is available for all the respondents. Cars and motorcycles are available if there is a car or motorcycle in the household, and the respondent reports having the option available. The bus and ACC are available for all respondents, with the shortest path obtained from *R5R*. For ACC, access and egress were assumed to be walking if the travel time was less than 15 minutes; otherwise, a bus was assumed. In this case, the individual must pay double the fare, which is accounted for in the model.

**Table 3. Sample share of observed choices by the final dataset**

| Mode | Times chose | | Times available | Percentage chosen when available | Average travel time (min) ** |
|---|---|---|---|---|---|
| | n | Percentage | | | |
| Car | 92 | 16.52% | 124 | 74.19% | 11.69 |
| Motorcycle | 119 | 21.36% | 142 | 83.80% | 11.99 |
| Walking | 148 | 26.57% | 557 | 26.19% | 13.28 |
| Traditional Bus | 122 | 21.90% | 499 | 24.45% | 23.79 |
| Aerial Cable Car* | 76 | 13.64% | 113 | 67.26% | 35.03 |

* 5 of the ACC times chose came from the first data collected.
** Average travel time when chosen

## 3.4. Methods

We estimated a Nested Logit model (NL) to answer the research questions using the Revealed Preferences (RP) of commuters' modal choice. The model considers the following alternatives: car, motorcycle, walking, bus, and aerial cable car (see Table 3). We include travel time and cost parameters in the utility function. Additionally, several sociodemographic and built environment characteristics were included in the models. Finally, a Confirmatory Factor Analysis (CFA) was conducted to identify underlying latent variables from the TRSE scale, which then served as independent variables in the NL.

### 3.4.1. Modelling approach

We estimated the models using R software, employing the Lavaan package for CFA and the Apollo package for the NL (Hess and Palma, 2019; Rosseel, 2012). Using CFA, we derived latent variables for each TRSE domain using the observed variables in Table 1 as indicators. We conducted a reliability test (Cronbach's Alpha) to assess the internal consistency of the TRSE scale.

We estimated a Nested Logit Model (NL) using equation 1 for the systematic utility. The NL generalises the Multinomial Logit Model (MNL) by relaxing the Independence Irrelevant Alternatives (IIA) assumption by grouping the alternatives into *nests* (Ortúzar and Willumsen, 2011). Based on the literature, we tested different nested structures considering private modes, public transport, individual modes, active modes, and sustainable mobility modes. The final model grouped public transport alternatives into a single nest to account for their correlation. At the same time, car, motorcycle, and walking were found to be independent and therefore modelled as separate alternatives at the root level (see Figure 2). The dissimilarity parameter ($\lambda_{pt}$) was used to validate the structure and the use of NL over MNL, given its significance and theoretical value below 1. Other structures were not significant or exceeded theoretical values for the dissimilarity parameter.

$$V_i = \Big(ASC_i + \sum \beta_{SD_i} * SD + \sum \beta_{BE_i} * BE + \beta_{PE_i} * \eta_1 + \beta_{FE_i} * \eta_2 + \beta_{ME_i} * \eta_3 + \beta_{TE_i} * \eta_4 + \beta_{GE_i} * \eta_5 + \beta_{IE_i} * \eta_6\Big) + T_i * \left(\beta_t + \beta_{FB_t} * \eta_2\right) + T_{walk_i} * \left(\beta_{t_{walk}} + \beta_{FB_t} * \eta_2\right) + C_i * (\beta_{cost_i}) \tag{1}$$

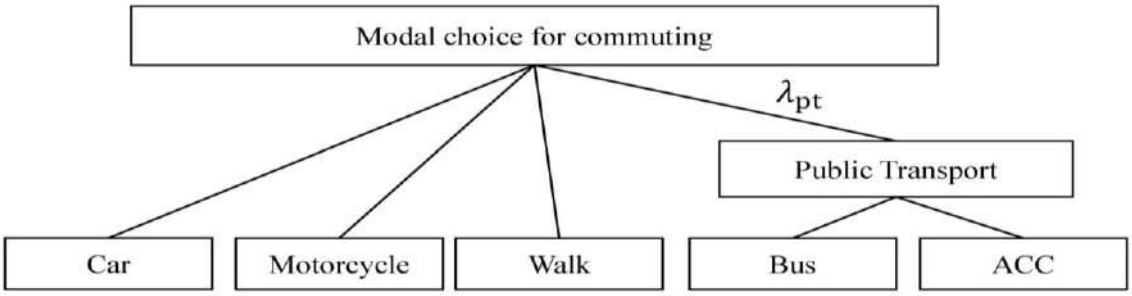


**Figure 2. Nested structure of modal choice for commuting.**

The alternative specific constant ($ASC_i$) was estimated per mode of transport ($i$), and alternative specific coefficients were estimated for sociodemographic (*SD*) variables of sex, age, income, and presence of cars ($\beta_{SD}$). Latent variables ($\eta_j$) were included in the systematic utility functions of NL through interactions with the alternative specific constants ($ASC_i$), which captures how unobserved perceptions of transport-related social exclusion deviate from preferences for particular transport modes. In addition, we estimated alternative specific coefficients for built environment variables ($\beta_{BE}$) of population density, the number of bus routes, the presence of ACC, and the average road slope. Those were calculated using a circle buffer around the household. We tested buffer distances from 100 to 500 meters in increments of 100 meters.

Travel time ($\beta_{time}$) and cost ($\beta_{cost}$) parameters were estimated across modes, except for walking ($\beta_{t-walk}$). Regarding the bus and aerial cable car, the travel time includes the access, egress, transfer and waiting times. Finally, we tested systematic variations in time and cost, considering latent variables related to transport exclusion (e.g., time, money, and fear-based exclusion). Only fear-based exclusion showed significant differences which was included in the final model.

### 3.4.2. Modal choice simulations

We conducted simulations of various scenarios considering the inauguration of Cable Aéreo Linea 3 (Line 3, as shown in Figure 1). We used the NL model, updating the trip attributes to consider the additional ACC alternative. First, we identified potential users from our sample by filtering respondents who live and work within the ACC's area of influence, defined as a 15-minute walk from the stations. Second, the new trip attributes for ACC were calculated by updating the GTFS, including the new ACC line, with operational characteristics similar to those of the other ACC lines. In this case, the sub-sample geographically represented trips made within the area of influence of the ACC system, comprising Lines 1, 2, and 3.

Before calculating the systematic utility, we must adjust the ASC, recognising that the population's modal shares differ from those in our sample because we include additional observations of ACC users. Equation 2 presents the correction to the ASC considering the modal share in our sample ($q_i$) and the population modal share ($Q_i$), calculated from the last Household Travel Survey (HTS), collected in 2017. We used the entire sample (n = 557) to make the corrections; meanwhile, we filtered the HTS observations to include only those within the survey's geographical extent.

$$ASC_i^{corrected} = ASC_i^{estimated} - Ln(\frac{q_i}{Q_i}) \quad (2)$$

# 4. RESULTS

We first present the results of the CFA and explain the latent variables underlying the TRSE scale. Second, we present the results of the NL, which considers the socio-demographic, built environment, and TRSE domains. Finally, we present the simulation approach to include the new ACC line and the resulting modal share.

## 4.1. Latent Variables based on Transport-Related Social Exclusion domains

Reliability analysis reveals good internal consistency among the 14 items of the TRSE scale, with a Cronbach's alpha of 0.76. A baseline CFA model was estimated based on the structure shown in Figure 3, with observed variables assigned to specific TRSE domains (see Table 3). We fixed the factor loadings of the first observed indicator to 1. The goodness-of-fit indices of this model were below expectations. Consequently, we used the modification indices to infer correlations between observed variables in the CFA. Based on the first model, we assumed correlations between the observed variables representing cost ($y_8$) and time ($y_{10}$) transport deprivations. In this specification, the model shows well goodness-of-fit indices (see Table 4). Latent variables were reversed to indicate greater transport exclusion, i.e., higher values indicate greater perceived exclusion in a particular domain.

The standardised coefficients, presented in Figure 3, reveal which observed variables explain more of the underlying latent variables based on TRSE domains. For instance, the physical-based exclusion factor explains how people perceive the quality of transport infrastructure for walking, cycling and driving. The time-based exclusion factor explains how people perceive the time spent in the transportation system and their availability of transport options; meanwhile, the money-based exclusion factor refers to perceptions regarding transport affordability. Additionally, the fear-based exclusion item illustrates how safe people feel regarding thefts/attacks, sexual harassment, and traffic crashes while travelling on their own. The factor of geographical exclusion explains how people perceive the benefits of their household location. Additionally, it is closely connected to the built environment, particularly in terms of topography. Lastly, the information-based exclusion factor describes whether individuals believe they have good access to information about their transport options, such as transit timetables or optimal routes in different transport modes.

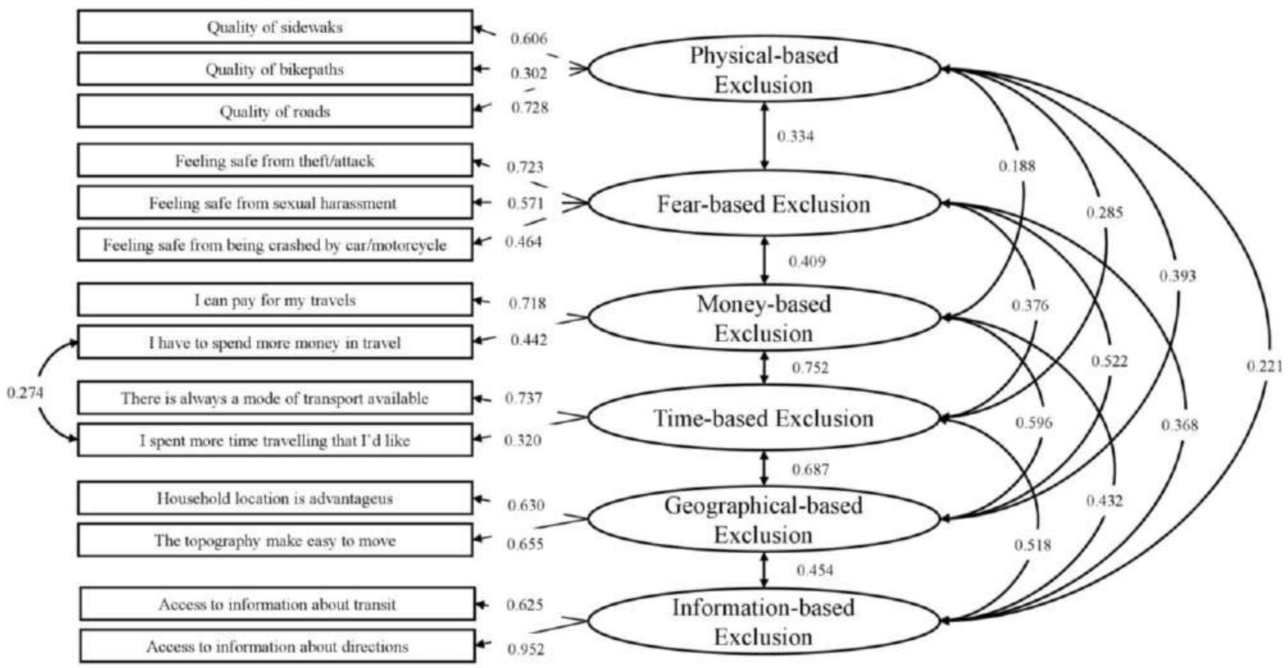


**Figure 3. Structure and results of the confirmatory factor analysis.**

**Table 4. Goodness-of-fit indices of the confirmatory factor analysis.**

| Goodness-of-fit indices | Value |
|---|---|
| Chi-square | 143.430 (p-value: 0.000) |
| Degree of Freedom | 61 |
| RMSEA | 0.049 |
| CFI | 0.94 |
| GFI | 0.963 |
| SRMR | 0.046 |

## 4.2. Nested Logit Model Estimations

The NL presented in this section resulted from an iterative process of testing several sociodemographic, household, built environment and TRSE latent variables. The process involves a stepwise backward test, excluding variables based on their significance in the model. Table 5 presents the best model, which balances explanatory power, model fit, and the inclusion of significant variables. The results are presented in two stages: first, the analysis of sociodemographic and built environment variables; second, the effect of transport limitations, considering the TRSE latent variables derived from the CFA model.

### 4.2.3. Sociodemographic and Built environment variables

Table 5 presents the estimation results for the NL model, based on the dataset of 557 respondents after the cleaning step (Section 4.2). The time (estimate: -0.082, p-value: 0.004) and cost (estimate: -0.865, p-value: 0.010) parameters are significant and negative, indicating that customers prefer faster and cheaper options, as expected. Walking time (estimate: -0.159, p-value < 0.001) imposes a disutility at least twice that of other transport modes. The subjective value of time (SVT) is estimated at $5.67 USD per hour and $11.04 USD per hour for the walking parameter. The estimated dissimilarity parameter for public transport is significant and different from 1 (lambda public transport: 0.555, p-value: 0.0344); therefore, the ACC and bus shares have unobserved attributes, supporting the use of the NL model under this nested structure.

Females are less likely to choose ACC (estimate: -0.976, p-value: 0.029) or a motorcycle (estimate: -1.914, p-value: 0.0134) as compared to males. Age was tested in the models, but no significant results were found. Interestingly, the income coefficient is significant for motorcycle, bus, and walking choices, indicating that high-income individuals are less likely to choose these modes than the car or ACC. The presence of a car has a significant impact on workers (excluding students), indicating that car availability reduces the likelihood of choosing an alternative mode of transportation. This effect is more substantial for transit modes, such as buses and ACC.

Regarding the effects of the built environment on modal choice, the high number of bus routes around the house increases the likelihood of choosing to walk (estimate: 0.029, p-value: 0.0204) or taking the bus (estimate: 0.026, p-value: 0.0488). Other variables are only marginally significant (at 90%), such as population density and the presence of ACC. However, they can provide insights about tendencies, e.g., an increase in population density around the house tends to raise the chances of choosing the bus (estimate: 0.309, p-value: 0.0704); meanwhile, the presence of ACC around the house appears to reduce the probability of walking (estimate: -1.691, p-value: 0.0536). We tested including the average road slope, but it was not significant for any of the modes.

**Table 5. Nested Logit Model estimation results.**

| | Car | Motorcycle | Walk | Bus | ACC |
|---|---|---|---|---|---|
| Time | | | -0.083 (0.029) ** | | |
| Time*Fear-based exclusion | | | -0.048 (0.024) * | | |
| Time (walk) | | | -0.160 (0.017) *** | | |
| Cost | | | -0.865 (0.336) ** | | |
| Lambda Public Transport | | | 0.555 (0.21) * | | |
| ASC | - | 2.349 (1.464) | 2.325 (0.934) * | 0.397 (1.055) | 3.875 (1.08) *** |
| Sex (reference Male) | | | | | |
| Female | - | -1.914 (0.774) * | - | - | -0.977 (0.448) * |
| Monthly Income (reference "Low/Medium") | | | | | |
| High | - | -4.152 (1.062) *** | -1.786 (0.854) * | -2.214 (1.13) ▪ | - |
| Workers and Car presence | - | -2.272 (1.013) * | -1.870 (0.939) * | -3.545 (0.993) *** | -3.081(1) ** |
| Built environment (300 meters) | | | | | |
| Population density (inh/ha) | - | 0.166 (0.386) | - | 0.309 (0.171) ▪ | - |
| Bus routes | - | 0.025 (0.017) | 0.029 (0.012) * | 0.026 (0.013) * | 0.050 (0.027) ▪ |
| ACC lines | - | - | -1.691 (0.876) ▪ | - | - |
| Transport-related social exclusion | | | | | |
| Time-based exclusion | - | -4.128 (2.374) ▪ | -1.486 (1.83) | -1.150 (1.935) | -2.295 (2.197) |
| Money-based exclusion | - | -1.173 (1.748) | 1.627 (1.251) | 1.411 (1.372) | -0.183 (1.494) |
| Fear-based exclusion | - | 0.597 (0.75) | 0.732 (0.671) | 1.079 (0.652) ▪ | 1.442 (0.763) ▪ |
| Physical-based exclusion | - | 0.375 (0.802) | -0.619 (0.544) | -1.446 (0.659) * | -1.159 (0.705) ▪ |
| Information-based exclusion | - | 1.464 (0.697) * | 0.994 (0.559) ▪ | 0.453 (0.614) | 1.532 (0.665) * |
| Geographical-based exclusion | - | 6.216 (2.603) * | 0.941 (1.921) | 1.117 (2.121) | 1.585 (2.1) |
| Goodness-of-fit measures | LL | | | -190.09 | |
| | AIC | | | 478.18 | |
| | BIC | | | 689.99 | |

Robust standard errors are in parentheses.
▪ < 0.1; * < 0.05; **<0.01; ***<0.001; p-value considers the robustness t-ratio under the null hypothesis = 0, except by lambda which considers null hypothesis = 1

#### 4.2.3. The role of transport limitations on shape modal choice

As mentioned in the CFA analysis, we reversed the scale of the latent variables; consequently, a positive value indicates higher perceptions of transport exclusion within each domain. Related to physical exclusion, an increase in this item reduces the likelihood of choosing transit, particularly the bus (estimate: -1.445, p-value: 0.0282). Interestingly, a larger perception of information-based exclusion increases the utility of choosing a motorcycle (estimate: 1.464, p-value: 0.0356), walking (estimate: 0.994, p-value: 0.0752), and ACC (estimate: 1.532, p-value: 0.0213). Moreover, people who feel more geographically excluded are more likely to prefer motorcycles (estimate: 6.216, p-value: 0.0169). Lastly, we found that fear-based exclusion is significant when considered as a systematic variation of time (estimate: -0.048, p-value: 0.0476), indicating that a higher perception of fear-based exclusion increases the disutility associated with time.

Initially, we found that variables related to time, money, and fear-based exclusion were either not significant or only marginally significant across most transport modes; however, we decided to present those that were significant at the 90% level. For instance, perception of time-based exclusion tends to reduce the likelihood of choosing a motorcycle (estimate: -4.128, p-value: 0.0819). Additionally, a higher perception of fear-based exclusion increases the probability of choosing transit modes (e.g., buses or ACCs).

## 4.3. Modal Choice Simulations based on the New Aerial-Cable Car alternative

Table 6 presents the ASC estimates and their corrections, along with the sample ($q_i$) and population ($Q_i$) modal shares, considering the geographical area where the survey was collected. Additionally, it displays the First Preference Recovery (FPR) and the choice probability in both the estimated and corrected models. We observed significant differences between sample and population modal shares, supporting our decision to correct the ASC. The differences are more evident for ACC, considering the oversampling performed during data collection to facilitate the estimation of the modal choice model. These corrections enable the prediction of modal shares that are similar to the actual modal shares. In addition, we observed that the NL model has good predictive power, as measured by FPR, since we are comparing the predicted choice with the individual's actual choice. In this case, car (94.56%), motorcycle (95.79%), and ACC (96.05%) present the highest FPR values. Finally, the estimated model results ($P_i^{estimated}$) show similar modal share to the sample choices ($q_i$), while the ASC correction resulted in modal shares ($P_i^{corrected}$) similar to those of the population ($Q_i$), diminishing differences particularly for ACC, Bus, and walking.

**Table 6. Comparison of estimated and corrected values for ASC, modal share, and choice probabilities.**

| Mode of transport | $ASC_i^{estimated}$ | $q_i$ (%) | FPR | $Q_i$ (%) | $ASC_i^{corrected}$ | $P_i^{estimated}$ (%) | $P_i^{corrected}$ (%) |
|---|---|---|---|---|---|---|---|
| Car | 0.000 | 16.52% | 94.56% | 22.68% | 0.317 | 16.49% | 17.34% |
| Moto | 2.349 | 21.36% | 95.79% | 18.35% | 2.197 | 21.52% | 20.88% |
| Walk | 2.325 | 26.57% | 83.11% | 22.51% | 2.159 | 26.53% | 23.46% |
| Bus | 0.397 | 21.90% | 72.13% | 35.57% | 0.882 | 21.89% | 35.71% |
| ACC | 3.875 | 13.64% | 96.05% | 0.89% | 1.145 | 13.57% | 2.61% |

Finally, Table 7 presents the results of the baseline and simulated scenarios, focusing on a sub-sample of 248 respondents who have the potential to use the new ACC line (ACC L3). Additionally, we consider a scenario in which users can transfer between ACC and the bus for free, and vice versa (ACC L3 + Bus Fare Integration). The baseline scenario indicates that 5.17% of people are likely to use ACC, considering the system with lines 1 and 2. Moreover, nearly 40.55% use buses, while private vehicles (cars and motorcycles) account for almost 33.46% of the modal share. The first simulation, involving ACC Line 3, shows that the ACC's modal share increases to 10.83%, nearly twice the baseline scenario's. This is a significant finding for the adoption of ACC in the city, as the new ACC line 3 has the potential to attract a share of trips, thereby boosting system use. Furthermore, most trips originate from walking (1.31%) or buses (3.38%). Additionally, the simulation that includes fare integration between ACC and the bus—allowing free transfers—demonstrates that ACC's usage probability rises to 12.91%, a 1.16-fold increase over the systems without fare integration. Similar to the previous scenario, growth primarily came from bus trips (1.22%) and walking (0.49%), while private vehicle usage remains relatively steady.

**Table 7. Comparison of estimated and corrected values for ASC, modal share, and choice probabilities.**

| Mode of transport | Baseline | ACC L3 | ACC L3 + Bus (Fare Integration) |
|---|---|---|---|
| Car | 17.06% | 16.44% | 16.39% |
| Motorcycle | 16.40% | 16.05% | 16.03% |
| Walk | 20.81% | 19.50% | 19.01% |
| Bus | 40.55% | 37.18% | 35.96% |
| ACC | 5.17% | 10.83% | 12.61% |

# 5. DISCUSSION

This section is divided into three parts. First, we discuss the NL model results, emphasising the sociodemographic and built environment variables, and compare them with empirical evidence on commuting modal choice. Second, we focus on the effects of transport-related social exclusion on modal choice, discussing hypotheses regarding the causal mechanisms underlying this phenomenon. Third, the simulation results of introducing the new ACC line are compared with similar research on modal choice and public transport.

## 5.1. Commuting mode choice in Manizales: the role of ACC

This study is a pioneer in estimating a modal choice model that includes the ACC as an alternative for commuting, given that most cities serve as feeders to larger transit systems (Cardona-Urrea et al., 2024). In our case, the ACC served as an alternative to commuting, serving as the primary mode of transport for a portion of daily trips in Manizales. First, we estimated the Subjective Value of Time (SVT) for commuters in Manizales at $5.67 USD per hour in 2024. Previous studies in the country have found that Bogotá, the capital city, has a SVT of $ 5.20 USD per hour, which varies depending on the income level (Guzman et al., 2021). We need to acknowledge that these cities differ significantly in size, population, transportation, and urban form. However, as studies on SVT in Colombia are scarce, these values serve as a starting point for future comparisons.

Regarding individual characteristics, we found that females are less likely to use motorcycles or Aerial Cable Cars (ACC). This is a relevant finding, considering that previous studies in both developed and developing contexts have reported that females are more likely to use public transportation, while males are more likely to use a car (Blandin et al., 2024; Giubergia et al., 2025; Sun et al., 2017). This result aligns with those in Metrocable (Medellín), which found that females are less likely to use ACC than traditional buses, considering that walking distances to bus stops are shorter than to ACC stations, thereby reducing their exposure to crime and violence (Agudelo V., 2013; Sarmiento Ordosgostia et al., 2013). Additionally, we found that the presence of cars in the household and being a worker increases the likelihood of choosing that mode of transport, which is consistent with the literature in both developed (Giubergia et al., 2025; Rodríguez & Joo, 2004) and developing countries (Blandin et al., 2024; Hu et al., 2018; Sun et al., 2017), despite having different levels of motorisation (Van et al., 2014). Interestingly, the presence of cars reduces the likelihood of choosing motorcycles. We also tested the effect of presence of motorcycles in the model, yielding non-significant results. We found that only 12.93% of individuals reported having both vehicles in their household, reinforcing the idea that car and motorcycle ownership are structurally different, particularly in cities in the Global South, where motorcycle is a popular commuting mode (Chiu et al., 2023; Hagen et al., 2016; Rodriguez-Valencia et al., 2024).

Regarding built environment variables, as expected, a higher number of public transport routes positively affects the choice of walking, bus, and ACC, aligning with previous literature on modal choice (Giubergia et al., 2025). Usually, a high level of public transport provision is positively correlated with the number of facilities, jobs, population density, and other land-use factors, increasing the likelihood of choosing walking as a commuting mode. Lastly, the presence of ACC lines, located in areas with steep slopes and hilly terrain, appears to affect walking as a mode of commuting negatively. This may be understood from the fact that topographical conditions around ACC lines make it less likely to walk, whereas the presence of ACC itself does not. For instance, some studies report that road slopes increase travel time, reducing the likelihood of choosing walking and biking (Rodríguez & Joo, 2004) and limiting access to bus stops (Coelho et al., 2025). In addition, recent studies have shown that ACC presence helps maintain physical activity levels among its users, particularly during the access and egress parts of the journey, which are usually walked (Baldovino-Chiquillo et al., 2023).

### 5.2. Influence of transport-related social exclusion on commuting modal choice

Physical-based exclusion is related to the quality of sidewalks, bike paths, and road infrastructure. Our results show that a higher perception of physical-based exclusion reduces the likelihood of choosing transit, particularly buses. In this case, we can link the transit use with the access and egress parts of the trip, which in Manizales is usually made on foot. Therefore, efforts must be made to reduce this perception by improving sidewalk infrastructure, particularly around bus stops and ACC stations. For instance, outdoor electric stairways have been employed in hilly areas to enhance accessibility and reduce the time and effort required for walking (Naef, 2018). This can be incorporated into the design of ACC stations, aiming to better link the built environment around the stations and improve the first and last miles of the journey (Cardona-Urrea et al., 2024).

Individuals with a high perception of information-based exclusion are more likely to choose motorcycles, walking, and ACC. Commuters facing information availability issues favour modes of transportation that require less information to ensure a reliable journey. The information available for private modes of transportation and walking appears sufficient for a reliable trip, as users can verify optimal routes and delays online via services like Google Maps or Waze. Similarly, the operation of ACC is highly reliable, considering the frequency with which the cabins circulate continuously through the stations. Furthermore, ACC is a well-established system; therefore, frequent users are familiar with station locations and potential destinations. Conversely, there is a lack of information for users on bus routes, frequencies, and schedules, which may reduce the likelihood of selecting this mode, as it could negatively impact their journey and increase waiting times at bus stops. Nonetheless, an absence of information does not represent a significant factor in bus selection, as it may be attributed to the individual’s experience and familiarity with the system. Given that most routes have been established for many years and users are accustomed to the service's frequency, this explanation is likely valid. Although this situation functions effectively for regular trips, such as commuting, it may restrict the use of new trip purposes and destinations. The creation, updating, and enhancement of the city's General Transit Feed Specification (GTFS) to make it accessible online for transit route planning could significantly improve the transit experience, particularly for young individuals who are more engaged with technology.

On the other hand, geographically based exclusion refers to household location and perceptions of the built environment, such as the topography surrounding the residence. For example, individuals who feel geographically excluded are more inclined to select motorcycles as their mode of commuting. Generally, those with elevated perceptions of geographical exclusion tend to reside in the city outskirts, which are often characterised by a lack of public transport and limited opportunities to walk long distances. For these individuals, motorcycles serve as a means to feel included in the city, as they facilitate easy access to transportation, often at a lower cost than public transit (Chiu et al., 2023; Hagen et al., 2016; Rodriguez-Valencia et al., 2024). Nonetheless, the growing popularity of motorcycles has adversely affected urban mobility. For instance, motorcycle users in Colombia are more frequently involved in road crashes, often with fatalities (Escobar et al., 2021). Policymakers should prioritise promoting sustainable mobility modes among motorcycle users fairly and equitably, recognising that most users belong to low-income households and frequently reside in peripheral areas.

Furthermore, the interaction between fear-based exclusion and the time parameter indicates an increase in disutility over time. Consequently, individuals with a higher perception of fear-based exclusion assign greater importance to the time parameter, indicating a preference for rapid arrival at their destination to minimise exposure to violence and crime. This finding aligns with findings in Medellín, which show that females tend to prefer buses because their stops are closer to ACC stations, thereby reducing their vulnerability to crime and violence. Additionally, an increase in fear-based exclusion was associated with a lower likelihood of selecting transit modes, such as buses and ACC; however, these results were only statistically significant at the 90% confidence level. For example, research on sexual harassment and daily mobility in Manizales has revealed that females are disproportionately more affected by such incidents, particularly when utilising transit or walking; consequently, a significant proportion of female transit users either temporarily or permanently shift to private modes of transportation following incidents of gender-based violence (Rodas-Zuleta et al., 2022).

We acknowledge that we decided to use TRSE latent variables as explanatory variables for modal choice; nevertheless, certain TRSE latent variables may also be outcomes of mode choice decisions, particularly those related to time and fear-based exclusion. For instance, time-based exclusion explains how people perceive the time spent travelling and their availability of transport options. We found a marginally significant negative association between choosing a motorcycle and time-based exclusion. People perceive that this mode makes it easier to navigate the city (Chiu et al., 2023), as it is more flexible and occupies less space than a car, particularly for parking (Hagen et al., 2016). However, it seems related to perception, as operational speeds during the morning peak hours in Manizales are similar to those of a car (see Appendix A-2). Furthermore, we found a marginally significant positive association between transit use and fear-based exclusion, suggesting that the causal direction differs from that assumed in the model. This is related to the literature of mobility and crime, where transit users are consistently the most affected by violent incidents, heightening their fear perceptions of this mode. (Ceccato et al., 2023). As previously mentioned, money-based exclusion did not yield significant effects in the modal choice model, potentially because it was incorporated into the utility function via the cost factor.

## 5.3. The substitution effects of the new ACC line.

We found that the new ACC line 3 will increase ACC's modal share for commuting within its service area. In fact, reports following the opening of the ACC Line 3 in September 2025 show that ridership in the system doubled after its inauguration, reaching nearly 19,000 daily passengers per day (Carmona Caraballo, 2025). These results may be influenced by reductions in travel time, as previous studies indicate that this is the most significant factor in attracting new users to public transport. (Giubergia et al., 2025; Guzman et al., 2021). For instance, Giubergia et al. (2025) found that reducing public transport travel time by 50% would have a greater impact on modal share in Cagliari (Italy) than reducing travel costs. Similarly, Guzman et al. (2021) found that simulated scenarios of transit projects in Bogotá will attract more riders to bus rapid transit (BRT) corridors, driven by reduced travel time. However, in both cases, the attraction from private vehicles is limited, a phenomenon similar to our own, where most of the new ACC ridership came from bus users. For instance, the modal share shifting from buses and walking (4.68%) to ACC is nearly five times that from cars and motorcycles (0.98%).

Furthermore, the fare integration of buses and ACC is expected to increase the modal share by a factor of 1.16. Most new users are anticipated to come from buses (1.22%, see Table 7), which is 18.11 times higher than from cars and motorcycles (0.07%). This suggests that most people with access to a private vehicle (such as a car or motorcycle) will likely maintain their preference, despite improvements in new alternatives in terms of travel time, cost and accessibility. This is consistent with our commuting modal choice model, which shows that the presence of cars among workers diminishes the likelihood of choosing ACC. Moreover, it aligns with findings from Martinez et al. (2018) in La Paz (Bolivia), which found that most of *Mi Teleférico* ACC's ridership came from other transit modes, with a marginal effect on private modes' modal share. In particular, integration with the bus facilitates the use of the bus as a feeder for ACC use at a much lower cost, creating an attractive alternative for many. In addition, it would be helpful to test how increasing travel costs for cars and motorcycles, through congestion taxes or higher parking fees, will affect future modal share. This budget can be used to support the transit and active mobility projects. Moreover, integration for bus routes can be tested by considering transfers within them and with the ACC. This could expand the city's spatial coverage, as some origin-destination pairs can be reached only by using two bus routes and paying double fare (Montoya et al., 2024).

# 6. CONCLUSION

This study examined commuting modal choice, considering Aerial Cable Cars (ACC) as an alternative, tested transport-related social exclusion (TRSE) domains as explanatory variables, and forecasted the modal share of new ACC projects using a case study in Manizales, a medium-sized Colombian city with hilly topography. We can draw three main conclusions from the article.

First, we identified relevant sociodemographic and built environment variables that influence the choice of ACC for commuting in the city. Females are less likely to choose the ACC than males. This is relevant, considering that empirical evidence shows that females use public transport more frequently, given their travel behaviour and the availability of alternatives. This behaviour can be particularly relevant for ACC; consequently, understanding the specific determinants for using the ACC, considering gender, will be crucial to promoting this transit mode in the city. Additionally, we found that the presence of cars among workers decreases the likelihood of using ACC. It will be interesting to understand the impact of the ACC line 3 on modal choice, given that its service area will expand into high-income neighbourhoods with a larger share of cars in households. Our initial explorations in the simulation based on the NL model show that the shift from private vehicles is much smaller than that from buses. This can be confirmed in the future through a follow-up survey, which may include other non-mandatory trip purposes (such as care, shopping, errands, and medical appointments) that have been reported to impact activity participation in the service area of new ACC projects (Cardona-Urrea et al., 2026).

Secondly, the simulations show that the new ACC line 3 will capture a considerable share of commuting trips, particularly from bus users, increasing the modal share by a factor of 2 relative to the baseline. Although this represents a significant increase compared to current usage, the system lacks the ability to attract car and motorcycle users. This is due to its limited spatial coverage and competition with bus routes, as similar origin-destination pairs provided by the ACC are also available by bus, which is more convenient for users because of shorter walk distances. The choice model suggests that the number of bus routes available around the household can increase the usage of ACC; consequently, the city can proceed with implementing the fare and physical integration of the two systems. Future research may focus on understanding how to attract private vehicle users to ACC by testing transport policies that influence choice by increasing travel costs for cars and motorcycles. This can be explored through discrete model choice experiments.

Third, the transport-related social exclusion domains have the potential to explain modal choice. We hypothesised that individual perceptions of physical, geographical, and information-based exclusion can influence commuting modal choice. Nevertheless, we are unable to define causal paths between these topics, which is a limitation of our research. This can be approached in future research by conducting a natural experiment with longitudinal data, using structural equation modelling to define the causal directions between transport exclusion perceptions and mode choice.

# APPENDIX A-1 – Sample size considering census data

| Zones | Total | | | Sex | | Age | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Census Population | % | Sample | Female | Male | 18 - 30 | 31 - 40 | 41 - 50 | 51 - 60 | > 61 |
| Centro | 25488 | 29% | 351 | 54% | 46% | 21% | 17% | 16% | 19% | 28% |
| Ciudadela del Norte | 19220 | 22% | 264 | 53% | 47% | 27% | 20% | 19% | 17% | 17% |
| Cámbulos | 24943 | 29% | 343 | 53% | 47% | 23% | 19% | 17% | 18% | 22% |
| El Cable | 17582 | 20% | 242 | 55% | 45% | 19% | 16% | 13% | 18% | 34% |
| Total | 87233 | 100% | 1200 | 54% | 46% | 23% | 18% | 16% | 18% | 25% |

# APPENDIX A-2 – Comparison of operation speeds of cars and motorcycles

| Days | Hour | Car (km/h) | Motorcycle (km/h) |
|---|---|---|---|
| Tuesday | 6:00 AM | 40.39 | 40.33 |
| | 7:00 AM | 36.9 | 38.23 |
| | 8:00 AM | 36.27 | 37.18 |
| Thursday | 6:00 AM | 39.94 | 38.49 |
| | 7:00 AM | 37.45 | 37.14 |
| | 8:00 AM | 37.03 | 36.24 |
| Average | | 38.00 | 37.94 |

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