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Abstract

Urban mobility is a crucial aspect in shaping the sustainability and functionality of cities. This article presents an analysis of urban mobility in the Calle 49 Road Corridor in Medellín, Colombia. Using data from various sources, including open data repositories and municipal records, we examine key aspects such as demand, supply, and infrastructure to provide insights into the transportation dynamics of this vital urban artery. The Ayacucho Road Corridor, which serves as the backbone of the City's public transportation network, emerges as a focal point of the research. This study covers different aspects such as the distribution of transportation modes, bicycle usage, and metro ridership. With the collected information, a statistical analysis is conducted, including measures of central tendency, bar charts, and pie charts. The results reveal a high dependence on non-motorized and public transportation, with significant usage of the tram. Significant differences in bicycle usage between genders and age groups indicate potential for improvement in cycling infrastructure and promotion of more inclusive mobility. Additionally, metro ridership patterns, with peaks during morning and evening hours and seasonal variations, underscore the need for integrated and adaptable planning to the environment. These findings provide a solid foundation for informed decision-making and the development of strategies that promote sustainable, efficient, and equitable urban mobility in the City of Medellín.

Keywords: urban mobility; tram; sustainability; road infrastructure; supply and demand; cyclist; influx; traffic incidents; road tramway; transportation; power bi.

Analisis de la Movilidad Urbana Sostenible en Medellin-Colombia Corredor Vial Tranvia de Ayacucho

Resumen

La movilidad urbana es un aspecto crucial en la configuración de la sostenibilidad y funcionalidad de las ciudades. En este artículo se realiza un análisis de la movilidad urbana en el Corredor Vial Calle 49 de Medellín, Colombia con datos de diversas fuentes, incluidos repositorios de datos abiertos y registros municipales, examinamos aspectos clave como la demanda, la oferta, la infraestructura para proporcionar perspectivas sobre la dinámica del transporte en esta arteria urbana vital, centrándose en el corredor vial de Ayacucho, el cuál sirve como columna vertebral de la red de transporte público de la ciudad, emerge como un punto focal de la investigación, cubriendo diferentes aspectos como la distribución de modos de transporte, el uso de bicicletas y la afluencia al metro. Con la información recolectada se realiza un análisis estadístico, que incluye medidas de tendencia central, gráficos de barra y circulares. Los resultados muestran una alta dependencia en el transporte no motorizado y público, con un uso significativo del tranvía. Las diferencias marcadas en el uso de bicicletas entre géneros y grupos etarios destacan oportunidades para mejorar la infraestructura ciclista y promover una movilidad más inclusiva. Además, los patrones de afluencia al metro, con picos durante horas de la mañana y tarde, y variaciones estacionales, subrayan la necesidad de una planificación integrada y adaptable al entorno. Estos hallazgos proporcionan una base sólida para la toma de decisiones informadas y el desarrollo de estrategias que promuevan una movilidad urbana sostenible, eficiente y equitativa en la ciudad de Medellín.

Palabras clave: movilidad urbana; tranvía; sostenibilidad; infraestructura vial; oferta y demanda; biciusuario; afluencia; incidentes viales; corredor vial; transporte; power bi.

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1. Introducción

Demographic growth in cities has exacerbated a number of urban mobility problems, including pollution, congestion and infrastructure deterioration. In this context, the promotion of active and sustainable mobility options emerges as a priority need to promote sustainable development and improve the quality of life of residents (ONU, 2021). Implementing policies that incentivize the use of public transportation, cycling, and walking can help reduce greenhouse gas emissions and improve overall urban sustainability (Litman, 2015).

Sustainable urban mobility is a fundamental pillar in the design of modern, efficient and environmentally friendly cities. Addressing it from a comprehensive perspective requires the consideration of several interrelated aspects, as established by Interim Decree 1720064594 of 2022 (Decreto provisional 1720064594 de 2022). This comprehensive approach includes not only road infrastructure and urban planning, but also the implementation of innovative and sustainable solutions such as micromobility (Martínez et al., 2019).

In this context, micromobility and sustainable mobility have the potential to transform cities into more sustainable and livable environments. By reducing reliance on traditional, carbon-intensive modes of transport, these new mobility options can reduce traffic congestion, lower emissions, and improve the quality of urban life. It is essential that local authorities consider micromobility as an integral part of urban planning, using recent studies that identify user patterns and behaviors to implement appropriate policies (Comi et al., 2024). Furthermore, analyzing the spatiotemporal patterns of human mobility is crucial for better understanding urban dynamics and planning effective interventions. Estimating the mobility potential of each region can guide urban planning and improve the experience of citizens in their daily travels (Yang et al., 2024; Escolano-Utrilla et al., 2024). Therefore, in this article an analysis of the sustainable urban mobility of the ayacucho roadway corridor in medellin-colombia is carried out.

In this context, the specific case of the Ayacucho Tram in Medellín is a paradigmatic example of how transport infrastructure can

positively influence active and sustainable mobility. Located along the 49th Street corridor, this project not only redefines the urban environment, but also promotes intermodality and encourages the use of more environmentally friendly modes of transportation (Área Metropolitana del Valle de Aburrá, 2022).

A detailed analysis of the operation of the Ayacucho Tram and its impact on active mobility allows us to explore the complexity of the interaction between different modes of transport and their influence on the daily lives of citizens. Likewise, this study offers an anthropological perspective on the streets of Medellín, delving into the causes of traffic accidents and evaluating road safety in the context of this innovative transportation project (Observatorio de Movilidad de la Secretaría de Movilidad de Medellín, 2022).

The methodology used to collect and analyze the data is characterized by its rigor and comprehensiveness, combining quantitative and qualitative methods to obtain a holistic understanding of the phenomena under study (Medellín, 2021). The results shed light on the social impacts of intermodality and the Ayacucho Tram, providing valuable insights to inform future urban mobility policies and strategies (Gehl, 2014).

This article includes the following sections, among others: Section 2 presents an overview of urban mobility in both national and international contexts. Section 3 details the materials and methods related to the data used and the analytical tool employed. In addition, it provides a thorough description of the methodology used in the development of the article. Section 4 presents the results, detailing the sources of information used, the types of mobility, mobility demand, and some figures that aid in the análisis. Section 5 offers a discussion related to urban mobility. Finally, section 6 presents the conclusions of the study.

2. Urban Mobility

This section provides an overview of urban mobility and its importance in Medellín, Colombia. It also describes sustainable urban mobility and its relationship with different road users. In addition, it provides

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a contextualization of urban mobility at the international and national levels, highlighting its importance in cities.

2.1. Urban mobility and its importance in Medellin-Colombia

Urban mobility is defined as the set of processes, systems and services that facilitate the efficient, equitable and sustainable movement of people and goods within an urban environment. This concept encompasses both the physical transport infrastructure and the policies, strategies and practices related to the planning and management of urban mobility (ONU, 2021). Urban mobility is not only an essential element of daily life, but its proper development is crucial for improving living conditions and preventing urban decay (Montenegro-Méndez, 2019).

Urban mobility is also essential for promoting social inclusion and equity, ensuring equitable access to public transport and taking into account the needs of vulnerable groups, such as low-income people or people with disabilities. The ideal street prioritizes respect for pedestrians and cyclists, develops inclusive policies, and promotes the active participation of different entities and citizens, thus creating a safer and more welcoming urban environment for all (Gehl, 2014; Vidal-Koppmann, 2022).

In the context of Medellín, Colombia, urban mobility has been developed in an integrated manner through the implementation of different public transport systems and complementary solutions aimed at improving accessibility, efficiency, and sustainability in urban transport (Montenegro-Méndez, 2019). The City has a variety of transportation modes, including the metro, tram, cable cars, and bus rapid transit, all of which operate in an integrated manner. In addition, walking and cycling are encouraged, and policies are in place to reduce traffic congestion and pollutant emissions. These efforts are primarily managed by the Empresa de Transporte Masivo del Valle de Aburrá Limitada (Metro de Medellín Ltda.), which plays a key role in the planning, construction, management, and operation of these services (Área Metropolitana del Valle de Aburrá, 2022).

Data and statistical analyses have demonstrated the importance of efficient urban mobility, showing significant reductions in travel times

and congestion, as well as improvements in travel patterns. These positive changes are also reflected in socioeconomic benefits, such as increased labor productivity and reduced costs for individuals and businesses (Medellín, 2021). In terms of environmental impact, well-managed urban mobility contributes to climate change mitigation and improves air quality by promoting more sustainable modes of transport and reducing pollutant emissions (Área Metropolitana del Valle de Aburrá, 2022).

2.2. Sustainable Urban Mobility

Sustainable urban mobility focuses on developing efficient transportation systems that minimize environmental impacts, reduce congestion, and promote more sustainable modes of transportation (Mendoza-Hatjchecorne, 2013). This includes prioritizing pedestrians and cyclists, encouraging the use of public transportation, reducing pollution, improving accessibility for people of all abilities, and creating more functional and livable cities (Bergasa et al., 2020).

Urban mobility involves not only physical movement, but also access to the resources and services offered by the City. This access is essential for participation in collective life and social exchange. The institute for the City on the move highlights the right to mobility as a crucial element for inclusion and urban development. According to Mendoza-Hatjchecorne (2013) the balance between movement and stability in urban design facilitates interaction between people and urban resources.

Figure 1 shows the mobility pyramid, which prioritizes pedestrians at the top, followed by bicyclists, public transport users, freight transporters, and finally private car users.

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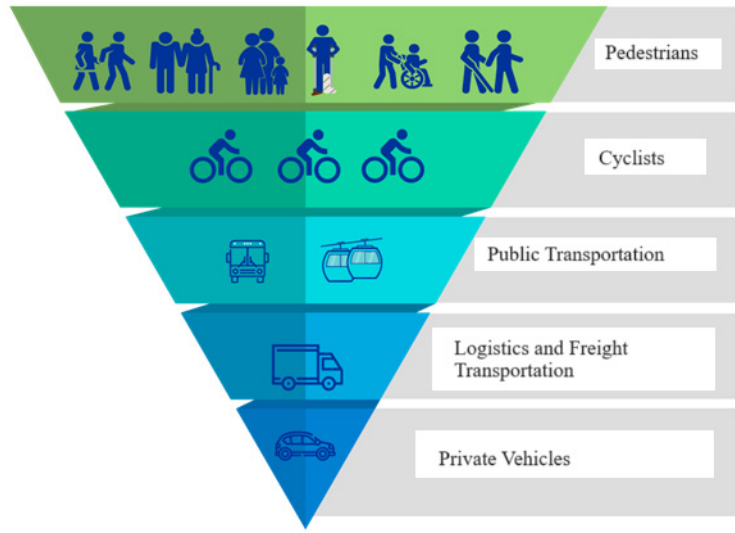
Figure 1. *Mobility Pyramid*



Note. According to Figure 1, it can be concluded that pedestrians occupy the top of the mobility pyramid. They are followed in descending order by 2) bicyclists; 3) public transit users; 4) freight and distribution service providers; and 5) private automobile users. Taken from (https://movilidadynoticias.com.gt/piramide-de-la-movilidad-urbana-sostenible/)

From the perspective of urban planning and City building, the issue of urban mobility is of fundamental importance for the sustainable development of cities and the quality of life of their inhabitants. In the context of demographic growth and urban expansion, the challenge of properly planning mobility is a crucial one for the creation of more efficient, equitable, and environmentally friendly cities (Decreto provisional 1720064594 de 2022).

Comprehensive mobility planning considers various interconnected aspects, including road infrastructure and public transportation, in order to promote active modes of transportation such as cycling and pedestrianization of urban spaces. This mobility model prioritizes equitable access to services and opportunities, reduces dependence on private cars, and encourages more sustainable modes of transportation. The process of City building, understood as the shaping of urban space, influences how people move. This is influenced by a number of determining factors, including land use distribution, population density, the location of facilities, and the connectivity between neighborhoods (Gehl, 2014; Ivanova et al., 2023).

It is of paramount importance to integrate mobility planning with urban planning, creating an environment that favors active mobility and efficient public transportation. Citizen participation and the inclusion of various social actors in the planning process are of critical significance. Listening to the needs and demands of the community and involving users in decision-making contribute to the design of mobility solutions that are better suited and accepted by the population (Gehl, 2014).

The integration of micromobility and other forms of sustainable mobility has the potential to transform cities into more liveable places. Local authorities must consider micromobility as an essential part of urban planning, as recent studies suggest that identifying and understanding user patterns and behaviours can guide the implementation of appropriate measures (Comi et al., 2024). Furthermore, it is essential to analyse space-time patterns of human mobility. This entails estimating the potential of each region in terms of mobility in order to quantify and characterize its attractiveness and diagnose its needs. The daily movements of people, aggregated into spatial units, form mobility flows that can be modeled by geospatial networks. These structures reflect and influence how cities are experienced, perceived, and planned (Yang et al., 2024; Escolano-Utrilla et al., 2024).

2.3. International Context

At the international level, urban mobility is a priority on the sustainable development agenda, as cities play a crucial role in combating climate change and promoting equitable and sustainable urban development. International organizations such as the United Nations and the World Health Organization have emphasized the importance of sustainable urban mobility in achieving the Sustainable Development Goals (SDGs). The implementation of policies that promote public transportation, active mobility, and pedestrian-oriented urban planning is encouraged (ONU, 2021).

Europe is a region that has adopted a number of ambitious measures to improve urban mobility. cities such as Amsterdam, Copenhagen, and Barcelona are internationally recognized for their sustainable

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transportation policies, which include extensive networks of bike lanes, efficient public transportation systems, and pedestrianization of urban áreas (Kuss & Nicholas, 2022). The sustainability of urban mobility stands as one of the key challenges and priorities for European cities in the 21st century. The current reality is taken into account in the development of an intelligent urban management model, which is employed to analyse the multifaceted measures being taken across its various dimensions. These include urban infrastructure and planning, the legal and regulatory environment, technology and innovation, shifts in habits and behaviours, and the emergence of new business models (Berrone et al., 2022).

In Latin America, several cities are also working on implementing sustainable mobility policies (Hidalgo & Huizenga, 2013). For instance, Bogotá has been a pioneer in the promotion of public transportation and bicycle use through initiatives such as the TransMilenio public transportation system and the Sunday Ciclovía program.

Several European countries have distinguished themselves with strategic plans for sustainable mobility that have achieved successful results. For example, the Netherlands is known for its extensive network of bicycle lanes and high rate of urban cycling, which has significantly reduced carbon emissions and improved the quality of life in its cities (Pucher & Buehler, 2008). Similarly, Sweden has implemented a comprehensive mobility approach that combines efficient public transport, pedestrian and cycling infrastructure, and vehicle restriction policies, making Stockholm one of the most sustainable cities in Europe (Börjesson & Eliasson, 2012). Other countries, such as Germany, Denmark, and Norway, also stand out for their ambitious mobility plans that prioritize active transportation and transit-oriented urban development and serve as models for other European cities to follow (Buehler & Pucher, 2021).

These initiatives have been consolidated through the implementation of institutional policies, educational programs on bicycle usage, integration with public transportation, and improvements to infrastructure.

2.4. National Context

In Colombia, urban mobility is of great importance due to the rapid growth of cities and the challenges related to traffic congestion, environmental pollution, and inequity in access to transportation. In response, the Colombian government has implemented policies and programs to improve mobility, especially in cities like Bogotá, Medellín, and Cali. The National Development Plan 2018-2022 includes specific objectives for sustainable mobility, such as promoting public transportation, bicycle usage, and pedestrianization of urban areas. Additionally, measures have been implemented to reduce greenhouse gas emissions, such as the introduction of electric vehicles and the improvement of public transportation infrastructure (Departamento Nacional de Planeación, 2018; Zamudio, 2019).

Law 1811 of 2016 establishes provisions to promote sustainable mobility and road safety by improving road infrastructure, regulating public transportation, and encouraging the use of non-motorized means of transportation (Ley 1811 de 2016). At the local level, several cities have implemented Sustainable Urban Mobility Plans (PMUS) with the objective of enhancing quality of life and mitigating the adverse effects of transportation on the environment. These plans encompass the construction of bicycle lanes, the expansion of public transportation, and the promotion of ride-sharing (Ministerio de Transporte de Colombia, 2020; Jaramillo, 2023). The master mobility plan for Bogotá aims to achieve safe, equitable, intelligent, integrated, environmentally respectful, and sustainable mobility. The public bike system in Bogotá is one of the largest and most diverse in Latin America, featuring inclusive stations and bicycles, connections with public transportation, and expansion plans to cover more areas of the City (Acero, 2011; González, 2017).

Programs and plans for cyclists focus on integrating bicycles with public transportation, facilitating longer trips, and reducing operating costs. The Economic Commission for Latin America and the Caribbean (ECLAC) posits that offering incentives to cyclists in the form of discounts on public transportation could potentially boost their numbers. The National Council of Economic and Social Policy (CONPES) recommends that an appropriate methodology for assessing active mobility should include data collection and characterization of

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movements in cities (Departamento Nacional de Planeación, 2020), such as:

- Origin-Destination Survey: Conducted every 5 years in the Metropolitan Area of the Aburrá Valley to understand travel patterns and plan mobility (Área Metropolitana del Valle de Aburrá, 2022).
- Cycle Infrastructure Evaluation: Measures the impact of bicycle infrastructure on urban mobility, assessing aspects such as safety, accessibility, and efficiency (Ministerio de Transporte de Colombia, 2016).
- Speed and Travel Time Studies: Evaluate the quality of vehicular movement and determine traffic delays, crucial aspects for improving the efficiency of the transportation system (Ministerio de Transporte de Colombia, 2016).
- Accessibility Indexes: Measure the ease of movement in the City, considering road infrastructure and connectivity of different modes of transportation (Ministerio de Transporte de Colombia, 2016).
- Road Safety Assessment: Analyzes accident prevention and life protection on public roads, managing data and information for the planning of mobility and road safety policies and strategies (Ministerio de Transporte de Colombia, 2016).

These methodologies provide a comprehensive view of active mobility and its relationship with public transportation, enabling sustainable urban planning and the design of policies that promote more efficient, healthy, and environmentally friendly mobility. The integration of bike lane networks, public transportation, and interconnections between them can improve accessibility and reduce carbon emissions, contributing to public health (Departamento Nacional de Planeación, 2020). The enactment of pro-bicycle legislation has facilitated the regulation of bicycle use and contributed to the advancement of active mobility and public transportation (Ministerio de Transporte de Colombia, 2016).

3. Materials and Methods

In order to facilitate the collection, management, and analysis of relevant data, a number of strategically selected tools and technologies were employed. These included specialized software for data organization, visualization, and analysis, such as Microsoft Excel, Microsoft Power BI, and Power Query. The use of these tools enabled the collection of data in a flexible manner, suitable for a variety of situations and environments.

3.1. Materials

Data Sources: the data utilized in this study were derived from a multitude of reliable sources, including:

- Public documents: Information retrieval from available open data on urban mobility.
- Specific consulted sources: Medellín metro, Aburrá Valley Metropolitan Area, and the Medellín City Hall.

Data Management and Analysis:

- Organization: The utilization of Microsoft Excel, Microsoft Power BI, and Power Query for data management is employed to classify and store the collected information.
- Visualization: The creation of charts and thematic maps is achieved through the aforementioned tools.
- Statistical analysis: The application of statistical techniques such as pie charts, stacked bar charts, and frequency tables is utilized.

Data validation: the reliability and validity of the data were given special attention, with a view to ensuring its quality and accuracy. This was achieved through cross-checking of sources and a thorough review of the collected information.

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Considerations: as the materials used are of an informative and public nature, no special manipulation was required, such as commercial grade, reagent, or sterilization. The focus was on data extraction and analysis for scientific research purposes.

3.2. Methodology

The research methodology employed is based on the precise collection of data through specific instruments and techniques designed to capture the necessary information to characterize active mobility in relation to the mass public transportation system, the Ayacucho Tram. To achieve this, Microsoft Excel, Microsoft Power BI, and Power Query (Microsoft Corporation, 2021) applications are utilized for the analysis and synthesis of open data. In terms of the instruments employed, geospatial data is collected and analysed in order to gain insight into mobility patterns and urban environment characteristics within the study area. Such data may include information on traffic density, the location of tram stops, the distribution of bicycle and pedestrian infrastructures, among other factors. Geospatial analysis enables the identification of congestion areas, conflict points, and potential avenues for improvement in urban mobility.

It is important to note that Microsoft Power BI (Microsoft Corporation, 2021) enables the efficient and dynamic visualization and synthesis of information. This enables the identification of patterns, trends, and relationships among the variables under study, thereby providing valuable insights for understanding urban mobility in the context of the Ayacucho Tram. Figure 2 provides a summary of the methodology to be employed.

Figure 2. *Data flow chart*

Note: Figure 2 illustrates a sequential process of six stages for data-driven decision-making. The process begins with the identification and search of open databases housing relevant information, followed by the collection of this data. Subsequently, data processing is conducted for cleansing and organization, followed by analysis to uncover trends and patterns. Then, data visualization is performed through graphs for clear and concise understanding. Finally, the process concludes by making decisions based on data analysis.

Research Type: The research is case study in the center of Medellín-Colombia, specifically in the Calle 49 Tram Corridor between Carreras 46 and 42, focusing on quantifying data collection and analysis. For this purpose, the Microsoft Power BI tool (Microsoft Corporation, 2021) is utilized.

Microsoft Suite: It is a suite comprising Microsoft Excel, Microsoft Power BI, Power Query, analytical tools that provide access to various data sources and enable the creation of detailed and exhaustive reports (Microsoft Corporation, 2021).

Research Method: The selected research method is quantitative, as it utilizes information from databases to facilitate a better understanding of the phenomenon under study.

Initial Data Collection: Data collection is carried out through various sources of information available in the City of Medellín. Public information sources such as the Metropolitan Area of Valle de Aburrá, the Mayor's Office of Medellín, and open data from the Medellín metro are consulted. These sources provide valuable information to characterize the current mobility scenario in the City. Some of the obtained data include:

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- The Origin-Destination Survey of 2017
- The geographic information system (GIS) software utilized was MapGis5.
- A map of the cycle routes of the Municipality of Medellín, as outlined in the POT 2014-2027.
- The En-Cicla public bicycle system, proposed by the Metropolitan Area of the Aburrá Valley, is a strategy designed to promote sustainable mobility in the City region.

Study Population and Location

The case study is situated in the center of Medellín, Colombia, specifically in the Calle 49 Tram Corridor between Avenue 46 and 42 (see, Figure 3). This area is part of Comuna 10, La Candelaria, one of the most frequented and dynamic zones of the City. Comuna 10 is renowned for its rich history, distinctive architecture, and pivotal role as a cultural and commercial epicenter. The Calle 49 Tram Corridor traverses an area comprising a diverse array of commercial, cultural, and residential activities, encompassing both small local businesses and significant historical edifices. The Ayacucho Tram in this corridor facilitates connectivity between the northern and southern parts of downtown Medellín (Concejo de Medellín, 2014).

Figure 3. *Study area map*

Note. Figure 3, which is based on Agreement 048 of 2014 POT of Medellín, depicts the area of the case study on Calle 49 (Ayacucho) between the San José Tram Station and Pabellón del Agua. Additionally, the areas adjacent to the case study are highlighted. Taken from (https://www.medellin.gov.co/mapgis9/mapa.jsp?aplicacion=1&css=css/app_mapas_medellin.css)

This location (see Figure 3) has been selected as the case study due to its geographical and functional significance, as well as its role as a convergence point for various forms of mobility and urban activities. The interaction between active mobility (walking and cycling) and the public transportation system (the tram) creates an ideal environment to examine intermodality and its impact on the daily lives of residents and visitors. The strategic location in the Calle 49 Tram Corridor offers a unique setting for the examination of the interactions between different modes of mobility, the understanding of social and urban dynamics, and the development of strategies for more efficient and sustainable mobility in downtown Medellín (Concejo de Medellín, 2014).

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4. Results

The corridor has been selected as a case study for its high population density, historical and cultural significance, and its role as a central node of urban connectivity. The urban diversity and the intersection of active mobility with the public transportation system present a unique opportunity to analyze the challenges and opportunities of intermodality. A comprehensive examination of quantitative data will elucidate the manner in which these dynamics impact the daily lives of residents and the configuration of the urban environment. This analysis will provide a robust foundation for the development of strategies that promote more efficient and sustainable mobility in Medellín.

Population Density: the 2018 DANE census indicates that the area along the Calle 49 Tram Corridor has a population density of approximately 12,483.13 inhabitants per 0.1 square kilometers. For Comuna 10, the population is estimated to range between 52,628 and 88,710 people, reflecting a high concentration of residents and transit users in the area. This underscores the significance of the area in a densely populated and diverse urban context (Medellín, 2021).

Tramway User Flow: the Ayacucho Tram transports an Average of 2,255,494 passengers annually and 313 daily between the San José and Pabellón del Agua stations. This data, derived from the Metro de Medellín ridership records from 2019 to 2023, serves to illustrate the pivotal role of the tram as a fundamental component of the public transportation system. It underscores the necessity to ensure the tram's continued efficiency and accessibility in order to meet the growing mobility demands of the City of Medellín (Medellín, 2021).

Bicycle Use and Active Mobility: the Secretariat of Mobility reports that approximately 1,251 individuals utilize bicycles on a daily basis along the Calle 49 Tram Corridor. This figure underscores the significance of active mobility in the local transportation system and the necessity for the implementation of adequate infrastructure to ensure the safety of cyclists (Medellín, 2021).

Cycling Network: the term "cycling network" is used to describe the set of roads, streets, or designated routes that are suitable for bicycle traffic in a City or region. This network may include various

types of infrastructure such as bike lanes, dedicated bicycle lanes on streets, and bike paths in parks or recreational areas. The objective of the cycling network is to provide safe and efficient connections for cyclists throughout the territory (Ley 1811 de 2016).

Bicycle path: a bicycle path is a specific segment of the cycling infrastructure that is physically separated from motor vehicle traffic. It can be located on streets, along main roads, or in green areas. Bike paths are designed to provide a safe and comfortable environment for cyclists, with appropriate signage and features that promote an enjoyable mobility experience (Ley 1811 de 2016).

Accident Rates and Road Safety: the incidence of traffic accidents and the associated casualties in the study area has been monitored over a 15-year period. Between 2008 and 2023, there have been 7 recorded accidents, resulting in 10 victims, primarily pedestrians and cyclists. These data indicate a need for the implementation of road safety measures and the improvement of urban infrastructure with the objective of reducing accidents and promoting safer and more sustainable mobility (Medellín, 2021).

Urban Diversity: the corridor is characterised by a diverse array of historic and modern buildings, local businesses, cultural institutions, and residential spaces. This diversity contributes to the complexity of interactions between active mobility and the tram, reflecting the variety of activities and users in the area.

Strategic Connectivity: the strategic location of the corridor renders it a crucial convergence point for mobility in downtown Medellín. The Ayacucho Tram efficiently connects different areas of the City's central-east, facilitating mobility between the north and south through Line T and its connection with Metro Line A.

History and Culture: Comuna 10, La Candelaria, is renowned for its rich history and cultural contributions to the City. The presence of iconic landmarks such as the Paraninfo de la UdeA, the Plazoleta San Ignacio, the Universidad Bellas Artes, and Calle La Pascasia bestows a unique identity to the area, influencing mobility patterns and the perception of urban space.

Intermodality of Mobility Modes: the corridor serves as a nexus between active mobility and the public transportation system

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of the tramway. This intermodality presents both challenges and opportunities for understanding how these modes of transport coexist, affecting citizens' choices and shaping the urban environment. However, a complete integration between public transportation and active mobility is still lacking.

Databases: the following open mobility data were subjected to analysis, transformation, and adjustment. These included the number of trips by mode of transportation (bus, bicycle, motorcycle, automobile), the number of passengers in the Medellín metro system, gender, age, the bicycle user network, and population projection.

Mobility Offer: the mobility offer in the Ayacucho Tram Corridor encompasses the following transportation modes:

- **Tramway**: the tramway is the most utilized mode of transportation in the corridor, with an annual passenger flow of 49,752 passengers during the morning rush hour from 7:00 to 8:00 a.m.
- **Bus:** the bus is the second most utilized mode of transportation, accounting for 26% of the total trips made in Comuna 10.
- **Bicycle**: the bicycle is the third most utilized mode of transportation, comprising 22% of the total trips made in Comuna 10.
- **Motorcycle**: the motorcycle is the fourth most utilized mode of transportation, representing 15% of the total trips made in Comuna 10.
- **Car**: the car is the fifth most utilized mode of transportation, also representing 15% of the total trips made in Comuna 10.

Mobility Demand: the mobility demand in the Ayacucho Tram Corridor is considerable, particularly during the morning rush hour. It is estimated that the population of Comuna 10 will increase from 50,000 inhabitants in 2010 to 100,000 inhabitants by 2030, which could exert pressure on the transportation infrastructure in the future.

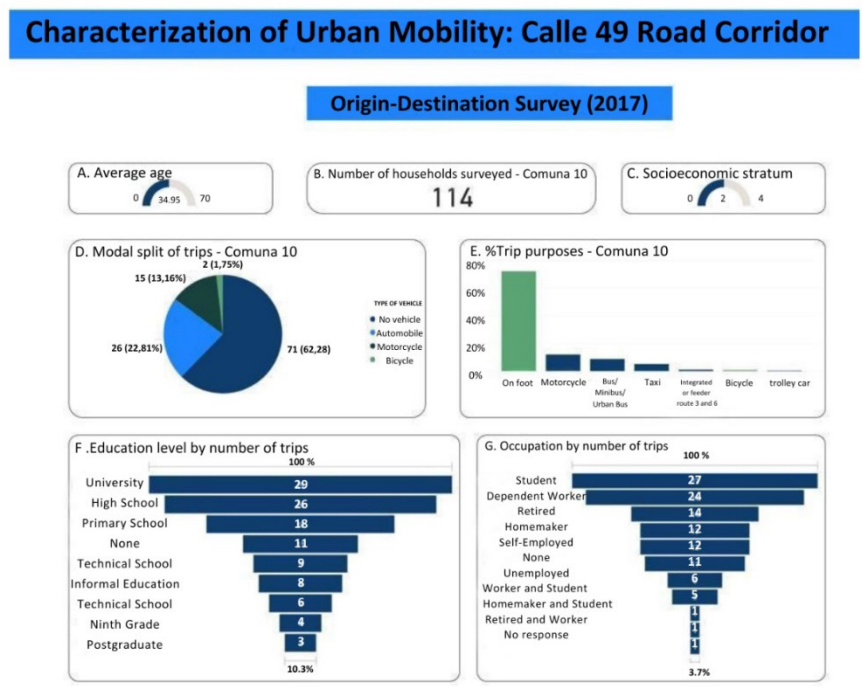
Characterization of Urban Mobility: the tramway and bus are the most utilized modes of transportation in the corridor, with the

tramway being the most heavily used. Passenger flow on the tramway is highest during the hours of 7:00 to 8:00 in the morning. The incidence of traffic incidents in the corridor is low, especially among cyclists. Limited bicycle infrastructure is a further issue. The length of the bicycle network in the corridor is only 4.2 kilometers. The population of Comuna 10 is growing, which could exert pressure on the transportation infrastructure in the future.

Interpretation of data

In Figures 4, 5, and 6, the origin-destination survey, bicycle usage characterization, and population influx are depicted, respectively. Subgroups are defined based on a series of variables such as mode of transportation, age, gender, and time of day, among others.

Figure 4. *Origin - destination survey 2017*



Note. Figure 4 represents a subset of the data collected on travel motives (E), age (A), socioeconomic stratum (C), education level (F), ocupation (G) and modal Split (D).

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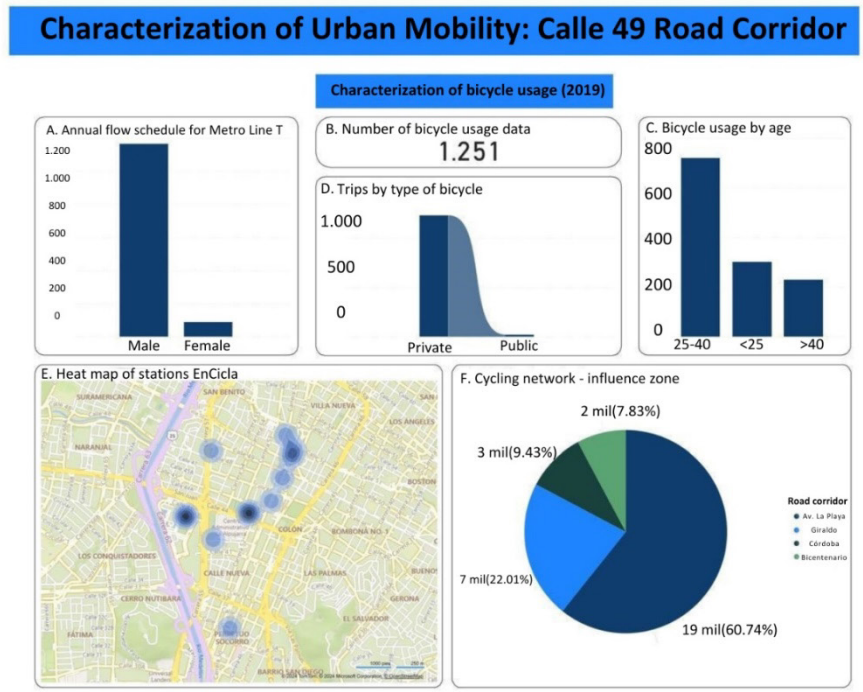
Figure 4 presents data from the origin-destination survey conducted in 2017 in Medellín, Colombia, encompassing 117 households. This survey reveals several important characteristics about urban mobility in the Calle 49 Road Corridor, including the following:

Age and Socioeconomic Status: the sample is comprised of individuals with an average age of approximately 35 years (ranging from 0 to 70 years). The majority of these individuals belong to socioeconomic strata 2 and 4. This suggests moderate diversity in terms of age and a significant representation of the lower-middle socioeconomic strata.

Modal Split of Trips: the modal split of trips indicates that the majority of trips are made without the use of a private vehicle (62.28%), including walking and public transportation. Car usage (22.81%) and motorcycle usage (13.16%) are also notable, while bicycle usage (1.75%) is minimal. This likely reflects a significant reliance on public transport and non-motorized mobility, indicating a trend towards reducing congestion in this sector of the City.

Education and Occupation: The educational background of respondents indicates that a considerable number of individuals with university education (29%) and secondary education (26%) undertake the majority of trips, while other education levels have a lower participation. In terms of occupation, students (27%) and dependent workers (24%) are the most mobile groups. This could be related to the daily transportation needs for education and work. Other groups, such as the unemployed and independent workers, have a lower participation in mobility.

Figure 5. *Characterization of bicycle use*



Note. Figure 5 represents a subset of the data collected for the purpose of characterizing bicycle use, with particular attention paid to gender (A), age (C), type of bicycle (D), heat map (E) and zone (F).

Figure 5 presents a characterization of bicycle usage in the Calle 49 Road Corridor in Medellín, Colombia, for the year 2019. The information details various aspects of bicycle usage, as follows:

Gender and Age Distribution: the distribution of gender and age among bicycle users is noteworthy. Men account for over 1,000 users, representing a significant proportion of the total. This observation suggests a gender gap in the adoption of bicycles as a mode of transportation. Additionally, the majority of cyclists are in the 25 to 40 age range, followed by those under 25. This indicates that young and middle-aged populations are more inclined to use bicycles for transportation.

Heat Map: the heat map of EnCicla stations reveals the areas with the highest concentration of shared bicycles, with the City center exhibiting the greatest density. Notably, the La Candelaria area exhibits

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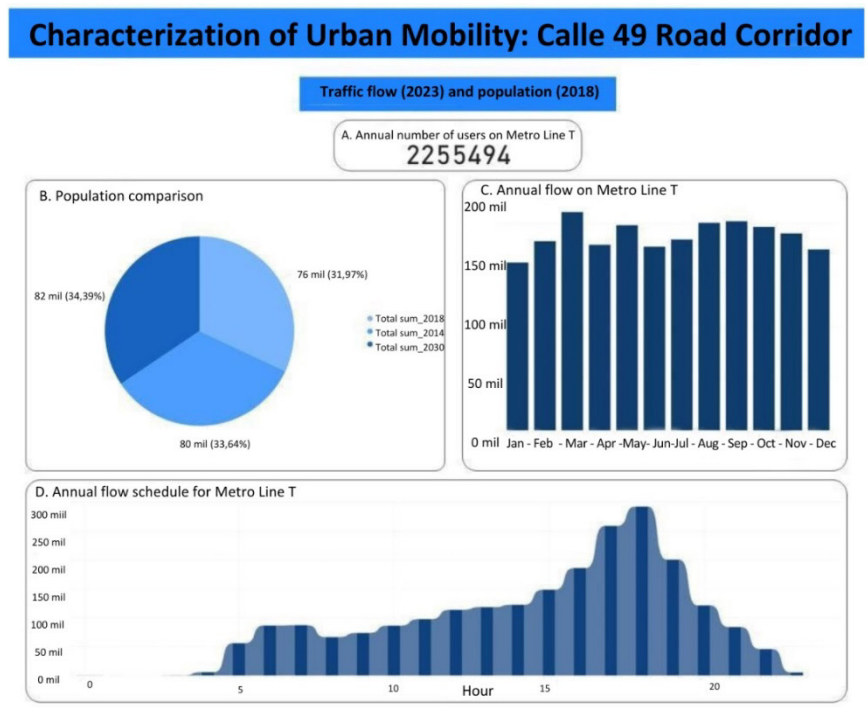
the highest frequency of bicycle extractions. It is crucial to highlight that there are no docking points for bicycles in the Tram Corridor. These areas may serve as pivotal locations for enhancing cycling infrastructure or implementing safety measures.

Cycling Network: the cycling network displays a pronounced influence from the Bicentenario corridor, followed by La Playa, which suggests that these are the principal axes of bicycle mobility in the area. The Av. La Playa corridor is identified as the most significant in the City center and the closest to the tramway's area of influence. It is notable that, according to the planning department, the Tram Road Corridor is not included in the cycling network but is designated as a bike path.

Figure 6. *Population of the Road Corridor in the year 2023*



Note. Figure 6 presents a subset of metro's inflow data and DANE's estimated population growth for 2018 to 2023.

Figure 6 presents data on affluence and population density in the metro line T area of the Calle 49 Road Corridor in Medellín, Colombia. The following interpretation is offered:

Annual Number of Users: the T Line of the metro is a crucial component of the City's public transportation system, with 2,255,494 annual users. This reflects a high level of dependence and consistent use throughout the year.

Monthly Ridership: The monthly ridership data exhibits a seasonal pattern, with a peak in March that exceeds 200 users. This increase could be related to factors such as weather, special events, or fluctuations in transportation demand. The consistency in September and October indicates stable metro usage during these months, which slightly decreases in November and December.

Hourly Demand Distribution: the hourly demand distribution exhibits two pronounced peaks: one in the morning between 5:00 and 7:00 a.m., and another in the afternoon around 5:00 p.m. These peaks align with the typical commute times for work and study. The gradual increase from the early morning and the subsequent decline after the evening reflect the typical work and daily activity schedules.

5. Discussions

The results obtained from the analysis of mobility in the Calle 49 Tram Corridor in Medellín, Colombia, raise several discussion topics that are relevant from a multidisciplinary perspective. Open data on sustainable urban mobility in Medellín's Tram Corridor represent an opportunity to foster collaboration in scientific research. These data offer new opportunities to validate and share knowledge in this field. However, in order to use them effectively, it is essential to understand the methods used to collect them, as well as the metrics that indicate their use and application by different stakeholders interested in sustainable urban mobility.

On the other hand, data from the Origin-Destination Survey conducted in 2017 by the Metropolitan Area of the Aburra Valley, compared to the data from the 2022 survey, reveal a series of significant

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changes in urban mobility. One of the most notable aspects is the increase in the use of sustainable modes of transport, such as walking, cycling and public transport. This change can be attributed to the different initiatives implemented in the City to promote sustainable mobility, as well as the growing environmental awareness of citizens (Área Metropolitana del Valle de Aburrá, 2017). In addition, there are changes in the travel patterns of the population, which can be influenced by factors such as urban development, availability of road infrastructure, and individual mobility preferences. These changes are crucial for understanding how mobility is changing in Medellín and provide important information to guide the development of future policies and projects in this area (Área Metropolitana del Valle de Aburrá, 2022).

In general terms, intermodality refers to the seamless and efficient integration of different modes of transportation within an urban mobility system. In other words, it involves the possibility of combining different modes of transportation, such as bicycles and public transport, in a coordinated and smooth manner to facilitate the movement of people in urban environments (Marqués et al., 2015). From the perspective of mobility in Medellín, specifically in the Tram Corridor, intermodality between bicycles and public transport could offer a number of significant benefits. For example, bicycles are a sustainable and healthy mode of transport that can perfectly complement the tram service by providing a solution for the first and last miles of the journey. This can help reduce traffic congestion, improve air quality, promote more active and healthy lifestyles among citizens, and increase accessibility and connectivity in the Tram Corridor.

The integration of the tram with other modes of public transport can be improved by creating multimodal transfer stations that allow users to easily switch from one mode to another (Área Metropolitana Valle de Aburrá, 2022). These stations could include facilities for bicycle parking and nearby bus and taxi stops. To extend the tram's reach to peripheral areas of the City, bus routes could be established to connect these areas to the nearest tram stations. The planning of intermodal transportation networks should consider the mobility

needs of different user groups, including travel schedules, destinations, and mode preferences (Área Metropolitana del Valle de Aburrá, 2022).

Social and territorial integration can be promoted by planning tram routes that connect diverse communities and facilitate access to opportunities for education, employment, tourism and basic services. Therefore, the use of the tram as a sustainable mode of transport can be promoted through awareness campaigns on the environmental benefits of the tram and by offering incentives for its use, such as reduced fares during peak pollution periods. The integration of the tram with green spaces and pedestrian areas can be achieved by creating green corridors along tram routes and improving pedestrian facilities at tram stations (Capasso et al., 2019; Shahraki, 2022).

In general, mechanisms for citizen participation may include public consultations, surveys, and community meetings. A model of collaborative planning and participatory governance could be implemented by creating tram planning committees that include community representatives. Social monitoring and evaluation of the impact of the tram can be carried out by conducting user and community surveys to identify benefits and challenges, and to make necessary adjustments in the planning and management of the system.

6. Conclusions

The results underscore the significance of urban mobility in the Calle 49 Road Corridor of Medellín, Colombia, encompassing a multitude of factors, including the distribution of transportation modes, bicycle usage, and metro ridership. The utilization of the Ayacucho Tram is highlighted for its impact on reducing vehicular congestion and promoting safer and more accessible mobility. However, areas for improvement are also identified, particularly in achieving full integration between public transport and active mobility. This analysis enables the formulation of specific recommendations for transportation management in this corridor, which contribute to the development of a more connected and sustainable City.

On the other hand, the analyzed data indicates a high level of passenger traffic on the tram, particularly during the morning

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and afternoon hours. This is accompanied by a notable mobility of students and workers. Additionally, there is evidence of limited infrastructure for bicycle use, which could affect its potential as an alternative mode of transportation. The distribution of transportation modes reveals a trend towards public and non-motorized transport. This highlights an opportunity to improve public transportation and promote the integration of the transport system to offer efficient and accessible connectivity options, especially in coordination with cycling infrastructure and pedestrian areas. Notably, the analyzed data reveals a significant gender gap in bicycle usage, with higher male participation. This suggests the need to implement measures that promote gender equity in urban mobility.

It is crucial to acknowledge that the lack of EnCicla stations along the Tram Corridor represents a significant limitation to intermodality. This hinders connectivity between different modes of transport, as tram users are unable to conveniently combine their journey with the use of shared bicycles. This may potentially discourage the adoption of more sustainable transportation modes. Furthermore, current mobility demand is high, and considering the population growth in Comuna 10, this could place pressure on public transportation infrastructure in the near future. Consequently, it is imperative that the relevant authorities engage in strategic planning, involving the community and considering the needs of all public transport users, in order to anticipate and meet the growing mobility demand in the area.

Finally, the study of mobility in Medellín prompts reflection on the necessity for an integrative vision of transportation modes that addresses mobility from a multidisciplinary perspective. The City has the potential to become a model of sustainability and urban equity, but this requires a strong commitment to planning, citizen participation, and the implementation of effective public policies.

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