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ORIGINAL

Feasibility analysis of the monorail as an alternative form of mass transportation in Córdoba

Análisis de factibilidad del Monorriel como alternativa de transporte masivo en Córdoba

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ABSTRACT

The study analyzed the technical and financial feasibility of implementing an elevated monorail system in the city of Córdoba and its metropolitan area as an innovative alternative to the limitations of existing public transportation. The research was conducted using a mixed-method approach, combining qualitative and quantitative methods. Interviews were conducted with stakeholders from the public and private sectors, as well as focus groups with users, which allowed for the identification of weaknesses, strengths, and opportunities for improvement in the current transportation system. The analysis revealed that Córdoba's urban transportation system had structural problems resulting from disorderly growth, overuse of private vehicles, and the inefficiency of urban buses and trolleybuses. These factors caused congestion, pollution, high social costs, and a decline in citizens' quality of life. Given this scenario, the elevated monorail was evaluated as a sustainable, safe option with greater carrying capacity, as well as environmental benefits and shorter travel times. When compared to other alternatives, such as the subway and commuter rail, the monorail performed better in terms of construction speed, investment per kilometer, operational flexibility, and economic efficiency. It also stood out for its ability to adapt to the urban landscape and its feasibility of financing through public-private partnerships. In conclusion, the study determined that the implementation of the elevated monorail represented a viable and strategic solution to improve mobility, reduce traffic congestion, and promote sustainable urban development in Córdoba and its metropolitan area.

Keywords: Monorail; Public Transportation; Technical Feasibility; Urban Mobility; Córdoba.

RESUMEN

El estudio analizó la viabilidad técnica y financiera de implementar un sistema de Monorriel Elevado en la ciudad de Córdoba y su área metropolitana, como alternativa innovadora frente a las limitaciones del transporte público existente. La investigación se desarrolló bajo un enfoque mixto, combinando métodos cualitativos y cuantitativos. Se realizaron entrevistas con actores del sector público y privado, así como grupos focales con usuarios, lo que permitió identificar debilidades, fortalezas y oportunidades de mejora en el sistema de transporte actual. El análisis reveló que el transporte urbano de Córdoba presentaba problemas estructurales derivados de un crecimiento desordenado, la sobreutilización del vehículo particular y la ineficiencia de los buses urbanos y trolebuses. Estos factores provocaron congestión, contaminación, altos costos sociales y una disminución de la calidad de vida de los ciudadanos. Frente a este escenario, el Monorriel Elevado se evaluó como una opción sustentable, segura y con mayor capacidad de carga, además de beneficios ambientales y tiempos de viaje más cortos. En la comparación con otras alternativas, como el subterráneo y el tren de cercanías, el Monorriel obtuvo mejores resultados en términos de velocidad de construcción, inversión por kilómetro, flexibilidad operativa y eficiencia económica. Asimismo, se destacó su capacidad de adaptación a la trama urbana y su factibilidad de financiamiento a través de asociaciones

público-privadas. En conclusión, el estudio determinó que la implementación del Monorriel Elevado representaba una solución viable y estratégica para mejorar la movilidad, reducir la congestión vehicular y promover el desarrollo urbano sostenible en Córdoba y su región metropolitana.

Palabras clave: Monorriel; Transporte Público; Viabilidad Técnica; Movilidad Urbana; Córdoba.

INTRODUCTION

The purpose of this study is to analyze the technical and financial feasibility of an elevated monorail for the city of Córdoba and its metropolitan area. This proposal serves as an alternative for orderly and integrated mobility planning in the region.[1,2,3,4,5]

Until the 1990s, the city of Córdoba grew concentrically from a central core (as did many of Argentina's major cities). According to the 2010 national census,[1] the capital city of Córdoba accounts for 40,18 % of the province's population, occupying 0,35 % of the provincial territory. Within a radius of approximately 40 km, the main neighboring towns are covered, reaching a total of 1 619 063 inhabitants, many of whom use some form of transportation to get to the city every day.[6,7,8,9,10]

The traditional approach to mobility problems in the capital city of Córdoba and its metropolitan area has proven incapable of providing a novel solution that is technically, economically, and financially feasible, superior to other alternatives, and sustainable.[11,12,13,14] As Sartori and Robledo mention, this situation results in the overuse of individual transportation, such as private vehicles, causing traffic jams in the city's road infrastructure, social exclusion (for those segments of the population who do not own a car), and a decrease in the use of mass transportation. This context leads to a deterioration in the quality of life for citizens and the associated social costs. "If you want different results, don't always do the same thing," Albert Einstein.[15,16,17,19]

The monorail is a public transportation system that transports passengers to and from different points or locations using cars that move along a single rail.[20,21,22,23,24] Currently, there are two types of monorails: rail-mounted and suspended. An electrical system powers them and can be operated manually or automatically.[25,26,27,28]

The purpose of this work is to analyze the technical and financial feasibility of the Elevated Monorail, while also investigating the participation of both the private and public sectors, so that a project of this magnitude can be executed effectively.[29,30,31,32]

This project aims to analyze a new alternative to the current public transportation options in the city of Córdoba and its metropolitan area (city buses and trolleybuses).

Is the implementation of an elevated monorail system in the city of Córdoba and its metropolitan area technically and financially viable as an innovative and sustainable alternative to the limitations of current mass public transportation?[33,34,35,36]

Objective

To investigate the conditions for the implementation of a new, modern, and disruptive means of transport for the city of Córdoba and its metropolitan area.

METHOD

Methodological framework

The research approach will be mixed, incorporating many characteristics of qualitative research, while also seeking to quantify key variables for this study. In terms of design, it will also be mixed; on the one hand, it will be descriptive, as it seeks to present the situation facing the city of Córdoba and its metropolitan area in relation to public transport as accurately and faithfully as possible. On the other hand, it will be explanatory to propose an alternative solution to the mobility problem facing the city.

The sources of information will be:

1. Primary: in-depth interviews with key players: semi-structured interviews are conducted with members of the private sector linked to mass passenger transport services and representatives from the public sector. The guidelines for these interviews are defined as follows:
    - Overview of the current transportation system.
    - Strengths and weaknesses of the current system.
    - Opportunities for improvement.
    - Evolution of the service (number of passengers transported).
    - Main processes.
    - Internal organization and personnel management.
    - Main aspects of quality management.

- Main aspects of process management.

2. Focus groups: focus groups are held, bringing together between 10 and 12 users of the public transport system selected according to the type of transport used, with a moderator, to initiate a debate or exchange of opinions on the functioning of the current system.

Preparation:

- Environment: selection of a suitable physical location for the focus sessions.
- Recruitment of participants: by type of transport used
- Selection of a moderator.
- Development of the guideline.

Inclusion criteria:

- System users.

Exclusion criteria:

- Non-users of the public transportation system.

Discussion guide:

- Level of satisfaction.
- Aspects considered to be strengths and weaknesses.
- Mention at least two opportunities for improvement.

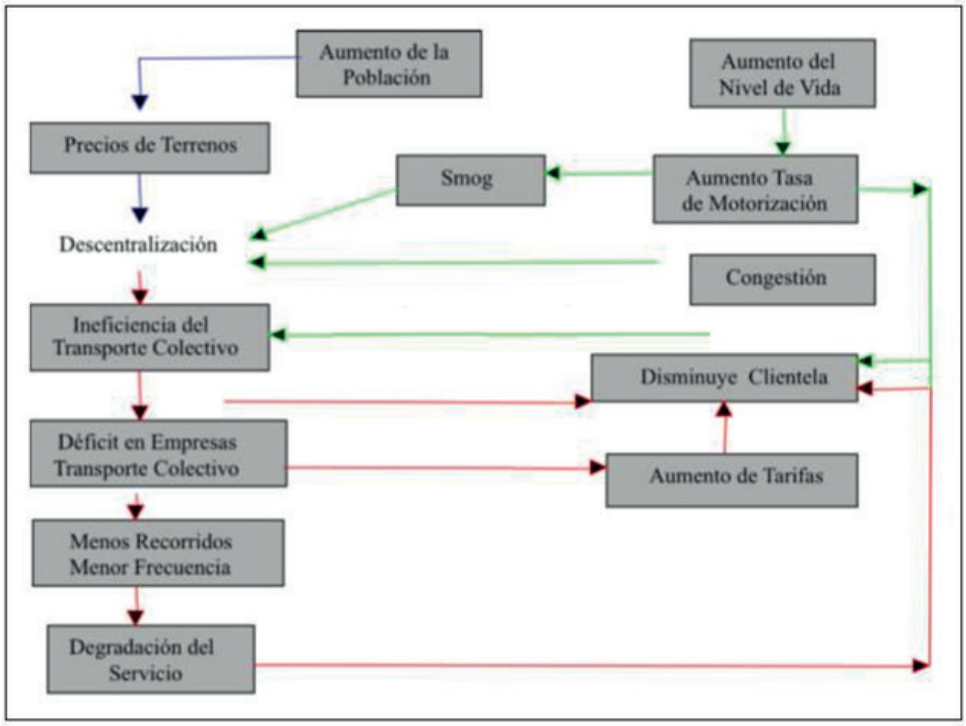
3. Secondary: this type of source will be analyzed through the study of works related to the topics raised, mobility and demographic statistics, reports from supranational organizations, and bibliographies of leading experts and writers.

RESULTS

Evolution and current situation of mass passenger transport in Córdoba and its metropolitan area.

Vicious circle of urban public transport

This is a model developed by Buchanan[18] which shows how a series of interlinked situations leads to a collapse in the transport system, causing it to lose profitability and, in turn, generating increased costs due to transport externalities.



Source: Transport "Vicious" Circle[18]

Figure 1. Vicious circle of urban public transport

Due to population growth, land prices rise. As a result, the price of better-located housing becomes more expensive, leading to a process of decentralization that results in longer journeys and the optimization of transport service provision. In turn, due to the increase in the standard of living, environmental pollution and traffic congestion rise as a result of the decrease in the use of public transport and an increase in the rate of motorization. Traffic congestion causes a reduction in the commercial speed of public transport and, therefore, an increase in travel times, leading to a drop in the number of users. This situation creates a deficit for the company providing the service, which must be covered by increasing fares. This increase will then cause a further drop in users (unless the state subsidizes the system), which will ultimately lead to the deterioration of the service and its subsequent collapse.

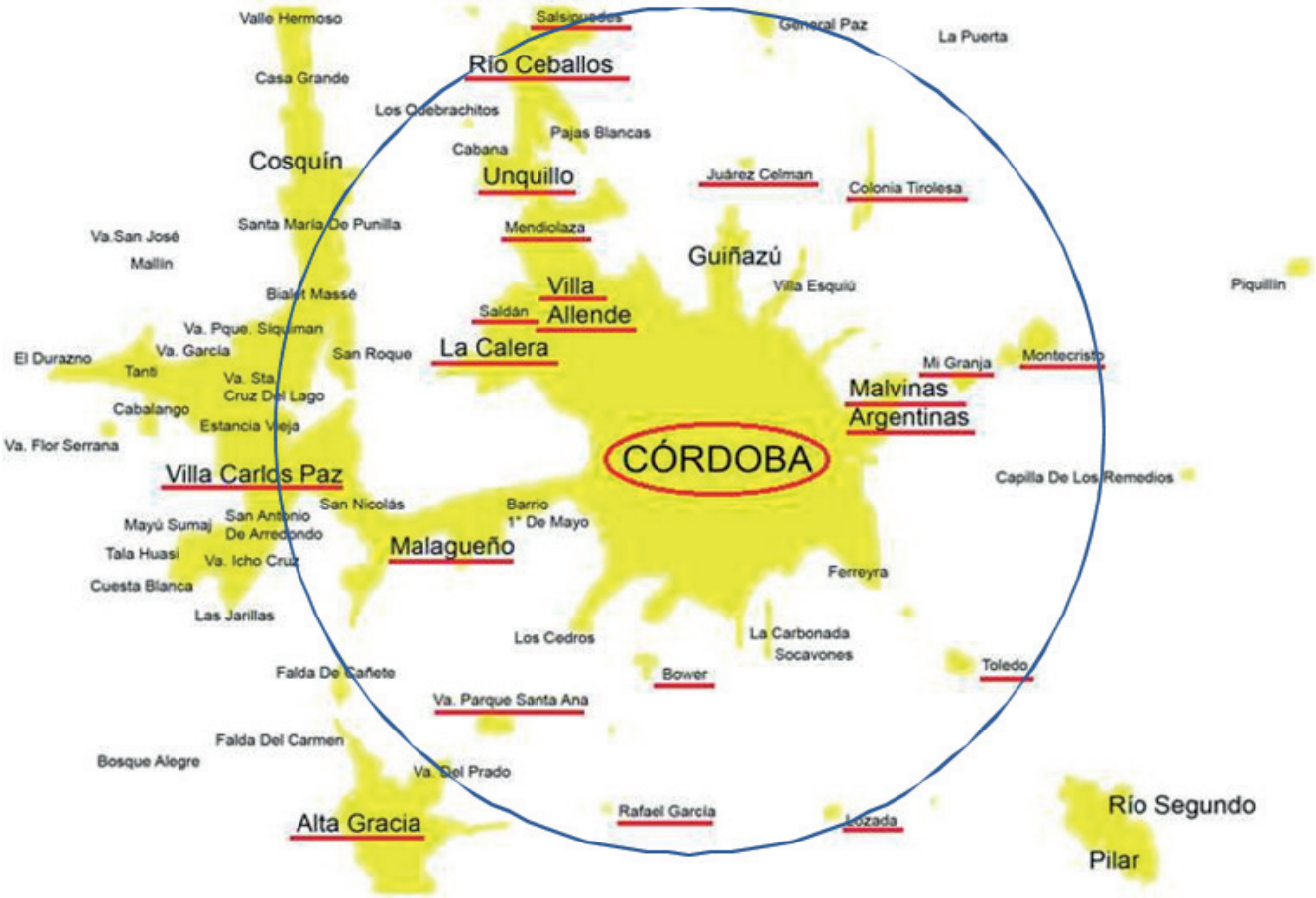
Current context

Córdoba is one of the 24 provinces that make up the Republic of Argentina. Located in the central part of the country with an area of 165 321 km^2, it is divided into 26 departments, representing 4,4 % of the national territory. According to the 2010 census, the province has 3 308 876 inhabitants, with a density of 20 inhabitants/km2 and an intercensal population growth (2001–2010) of 7,9 %.[21] The Capital department, comprising the city of Córdoba, is the principal city in the province.

The city of Córdoba has a municipal area of 576 km^2, with a dense central area where services are concentrated, a constantly expanding periphery, and moderately consolidated intermediate areas. All of these areas are heterogeneous in terms of land use patterns, densities, and public service coverage.

Córdoba and its metropolitan area, like many cities in the developed world, have undergone an evolutionary process of mobility in recent decades based on parameters that are not sustainable over time.

The use of private cars to the detriment of other, more sustainable means of mobility, which is considered a symbol of individual freedom of movement, has led to a loss of the traditional balance in the use of scarce public space.



Source: https://es.wikipedia.org/wiki/Área_Metropolitana_Córdoba#/media/Archivo:Gran_cordoba_mapa.png

Figure 2. Córdoba and its metropolitan area

As can be seen in figure 3, the main conglomerate is the city of Córdoba, which represents 82 % of the population of the territory analyzed (Córdoba Metropolitan Area – AMC). This percentage demonstrates the

real weight that the capital has in relation to its metropolitan area when it comes to proposing innovative and creative solutions to the problem of sustainable mobility.

Localidad	Departamento	Tipo	Población	Distancia (Km)
Córdoba	Capital	Municipio	1.329.604	0
La Calera	Colón	Municipio	30.339	9
Malvinas Argentinas	Colón	Municipio	12.568	16
Los Cedros	Santa María	Comuna	1.033	16
Bouwer	Santa María	Comuna	2.046	20
Villa Allende	Colón	Municipio	27.164	23
Mi Granja	Colón	Comuna	1.212	23
Malagueño	Santa María	Municipio	12.706	24
Toledo	Santa María	Municipio	3.869	24
Villa Parque Santa Ana	Santa María	Comuna	2.499	25
Mendiolaza	Colón	Municipio	8.126	26
Saldán	Colón	Municipio	10.402	28
Estación Juárez Celman	Colón	Municipio	11.848	29
Monte Cristo	Río Primero	Municipio	10.014	29
Unquillo	Colón	Municipio	17.183	31
Río Ceballos	Colón	Municipio	19.133	33
Colonia Tirolesa	Colón	Municipio	5.358	34
Lozada	Santa María	Municipio	1.119	35
Salsipuedes	Colón	Municipio	9.003	36
Rafael García	Santa María	Comuna	525	36
Villa Carlos Paz	Punilla	Municipio	56.454	37
Alta Gracia	Santa María	Municipio	46.858	37
			1.619.063	

Figure 3. Municipalities and communes near the city of Córdoba (37 km radius)

Urban passenger transport

Through Municipal Decree 6.56722 of December 2013, the Municipality of Córdoba granted the Public Urban Passenger Transport Service Concession for a period of 10 years only for corridors operated by private companies. This system began operating in March 2014. Currently, the Public Urban Passenger Transport Service in the city of Córdoba is composed as follows:

EMPRESA	GRUPO	ZONA	URBANO	BARRIAL	DIFERENCIAL	ANULAR	Total de Lineas
Coniferal	1	1	10 al 19		-	-	21
		6	60 al 68	B60+B61	-	-	
Ersa Urbano	2	2	20 al 29		-	-	18
		7	70 al 75	B70	-	AEROBUS	
	3	3	30 al 36	B30+B31	-	-	14
		8	80 al 84		-	-	
	4	4	45				9
		5	50 al 54	B50	-	-	
		Anular	-	-	-	600+601	
Autobuses Cordoba (Aucor)	4	4	40 al 44	-	-	-	5
Tamse	Trolebuses	-	A+B+C	-	-	-	3

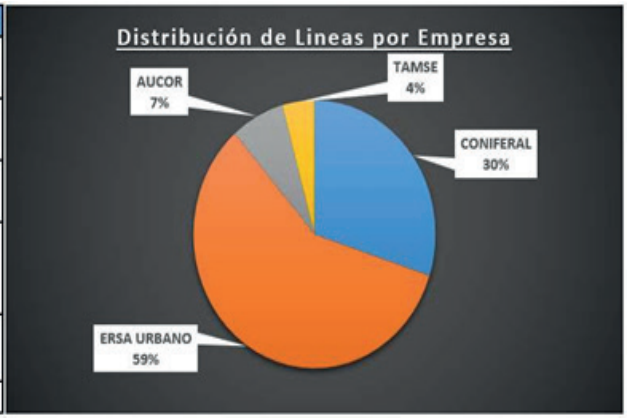


Figure 4. Distribution of transport lines by company

The company Ersa Urbano operates 59 % of the city's corridors, while Tamse (Transporte Automotor Municipal Sociedad del Estado) commercially operates only 4 % of them. Autobuses Córdoba (Aucor) manages 5 lines (7 %) and Coniferal 21 corridors (30 %), respectively.

Below is a graph and table showing the evolution of trips made through the Public Urban Passenger Transport Service from 2014 to 2018 inclusive.

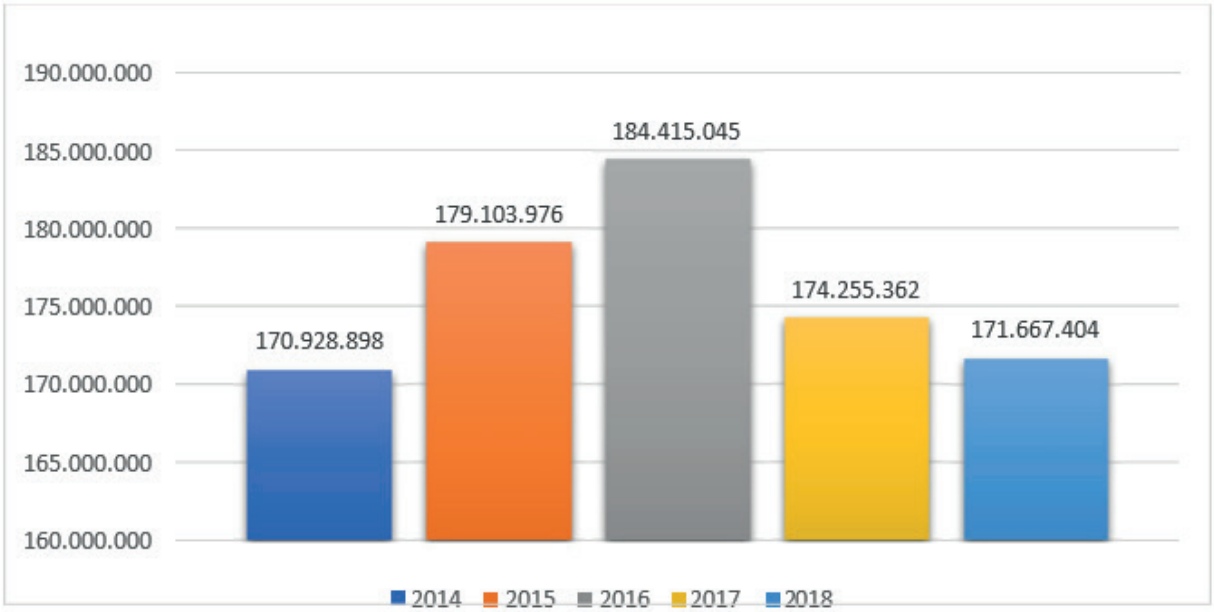


Figure 5. Evolution of Urban Passenger Transport 2014-2018

	2014	2015	2016	2017	2018
Enero	9.945.083	10.788.585	10.745.641	11.600.806	11.192.780
Febrero	11.935.001	11.370.304	12.014.280	11.584.371	11.261.311
Marzo	13.169.074	14.976.727	16.508.639	16.471.492	15.476.803
Abril	13.981.700	16.239.156	16.406.409	14.856.052	15.574.957
Mayo	15.455.448	16.324.585	16.213.608	16.639.236	16.264.169
Junio	15.200.191	16.518.012	15.991.083	10.477.443	14.505.203
Julio	13.460.214	14.873.176	14.002.043	13.832.039	13.356.545
Agosto	15.362.407	15.576.634	17.779.353	17.038.029	16.121.013
Septiembre	16.214.146	16.516.851	17.074.060	16.193.048	14.533.156
Octubre	17.201.769	17.149.597	16.902.068	16.610.046	16.073.376
Noviembre	14.791.166	15.356.733	16.889.031	15.798.068	14.957.757
Diciembre	14.212.699	13.413.616	13.888.830	13.154.732	12.350.334
	170.928.898	179.103.976	184.415.045	174.255.362	171.667.404

Figure 6. Number of passengers 2014-2018 of the Urban Passenger Service

As can be seen in both the graph and the table, the peak in travel occurred in 2016, with 184 415 045 tickets sold, representing a 2,96 % increase compared to 2015. In 2017, there was a 5,5 % drop compared to the previous year, with 174 255 362 tickets sold. In 2018, the downward trend in ticket sales continued, with a total of 171 667 404 trips, representing a 1,48 % decrease from 2017.

The current transportation system in the city of Córdoba is generally viewed negatively by users due to several factors that hinder mobility and accessibility, which are fundamental to the development of any city.

The leading causes are outlined below:

- The traditional approach to mobility problems in Córdoba and its metropolitan area has proven incapable of providing an innovative and sustainable solution.
- The disorderly growth of the city results in a poorly distributed urban sprawl that hinders the provision of various services, including public transportation.
- The deterioration of mass public transport due to its lack of reliability (regularity/frequency).
- The absence of reliable, high-capacity mass transit results in the overuse of private vehicles, causing the city's road infrastructure to collapse. Currently, 10,22 % of the road network is used by mass transit and 88,12 % by private cars, taxis, and remises.
- System with insufficient units adapted for the transport of people with reduced mobility.

Intercity passenger transport

Public transport service for the metropolitan area is provided through short-distance (up to 50 kilometers) intercity public passenger transport lines, which have "a route assigned within the municipality and its stops, as determined by the Municipal Transport and Traffic Authority (AMTT)." This means that interurban transport systems are not allowed to pick up passengers when they enter the city. Likewise, they are not allowed to carry and/or charge fares for journeys originating and ending within the municipal area, unless the Executive Department authorizes it due to force majeure (for example, a strike by the Public Urban Passenger Transport Service).

Five (5) transport companies connect the 16 municipalities and three communes (which make up the metropolitan area) with the city of Córdoba. These are listed below:

Empresas	
* Intercordoba	* Buses Lep
* Sarmiento SRL	* Canello
* Lumasa	* El Milagro
* Emprendimientos SRL	* Ersa Cba
* CarCor	* Malvinas Cba

Figure 7. Companies providing intercity passenger transport services

The following table details the number of interurban trips from the municipalities and communes to the city of Córdoba within a radius of approximately 40 kilometers from 2016 to 2018 inclusive:

	Pasajeros transportados
2016	36.100.063
2017	40.076.401
2018	39.169.014

Figure 8. Companies providing intercity passenger services

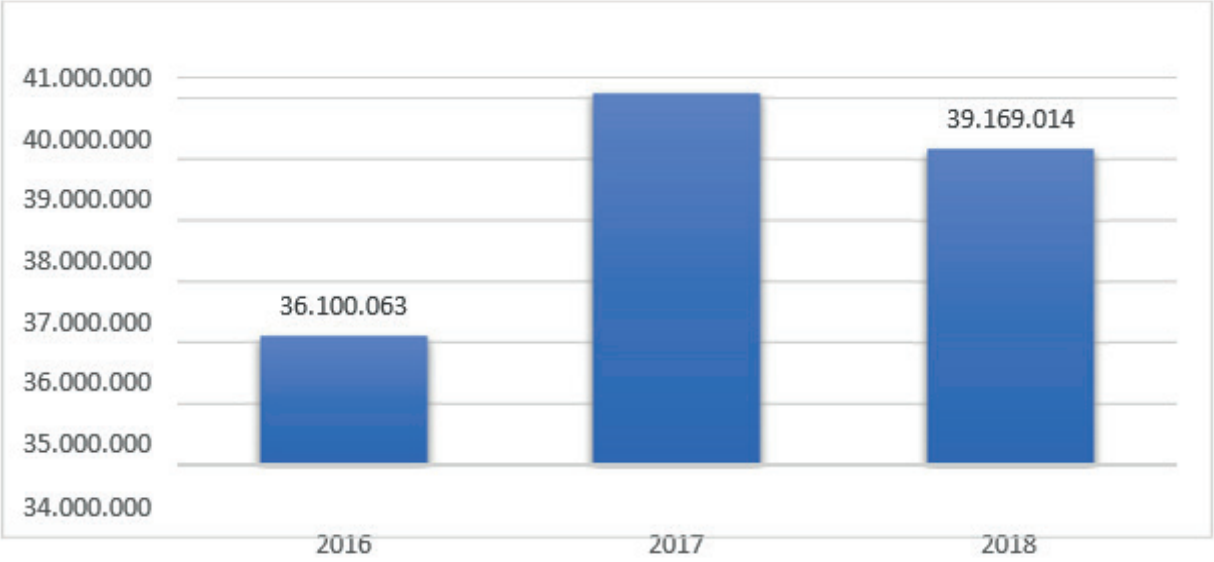


Figure 9. Intercity Transport Passengers (Metropolitan Area)

Comparing 2016 with 2017, there was a 10,9 % increase, while in 2018, a 1,43 % decrease was observed compared to the previous year. So far in 2019, the decline in ticket sales has deepened, with a 30 % year-on-year decrease recorded through July of this year, according to ASETAC and FETAP.

Due to this situation, some companies have gone bankrupt, and others are facing crisis prevention procedures.

These circumstantial factors are described in terms of their importance when analyzing mobility alternatives, while highlighting the exacerbated negativity of the activity at this time and, at the same time, generating a fundamental awareness of the consequences of erratic macroeconomic policies on public services, resulting in declining mass transportation and its consequent impact on the quality of life of citizens. "Efficient mass mobility is a quality of life."

The main factors that accentuate the crisis in the sector are as follows:

- Increase in fuel prices. In December 2018, the price differential for grade 2 diesel was $10 per liter, while in March of this year, the price was around $20 per liter.
- Removal of subsidies by the national government. For 2019, national subsidies for metropolitan transport will be only 542 million pesos. This will be reinforced by funds contributed by the province, subsidizing the supply by spending more than 499 million pesos (this amount represents 25 % of the total committed by the province. Fifty-five percent goes to the city of Córdoba, 12 % to urban areas in the interior, and the remaining 8 % to interurban regions).
- Union pressure to close new collective bargaining agreements. In August, negotiations were reopened to update the salaries of employees of transport companies covered by the AOITA labor agreement. The union is requesting a 12,5 % salary increase for the second half of 2019.
- Constant fluctuation in the value of the dollar, which directly affects supplies (spare parts), making preventive and corrective maintenance of vehicles difficult. From January 2015 to August of this year, the US dollar appreciated 580 % against the peso (January 2015 official exchange rate: $9,85 / August 2019 official exchange rate: $57,20).

Creation of the Metropolitan Area Transportation Authority

Currently, no entity coordinates the various transport and transit activities between municipal jurisdictions and the province. There are no projects for comprehensive and sustainable development that involve the province, municipalities, and communes jointly.

The Metropolitan Area Transport Authority will be the body responsible for planning standard public policies, managing shared projects, and implementing joint actions in the transportation sector.

The Metropolitan Area Transport Authority will be responsible for:

- Ensuring the full development of the economic activities of the participating cities.
- Approving regulations that are binding on the parties.
- Planning, coordinating, and scheduling metropolitan transportation policies, while respecting the autonomy of its members.
- Promoting coordination, harmonization, and regulatory compatibility among member municipalities and communes.
- Enter into assistance or cooperation agreements with public or private, local, provincial, national, or international organizations in the field of transportation.
- Gather, organize, and systematize information on the Metropolitan Area.
- Establish the contributions that each of the cities and communes must make to sustain their operation, maintaining a criterion of equity.
- Take any other action, within the legal, statutory, and regulatory powers determined by its authorities, aimed at fulfilling the purpose and objectives of the Metropolitan Area.
- Establish or join trusts, consortia, or any other associative entity designed to fulfill its purpose.

Analysis of alternatives for mass passenger transport in the city of Córdoba and the metropolitan area

This section will analyze three alternatives that can provide a sustainable mass transit system, improving connectivity between the metropolitan area and the city center while discouraging the use of private vehicles.

The systems to be analyzed are:

- Subway
- Commuter train
- Monorail

For this study, a survey was conducted among a group of users of the Urban Passenger Transport Service who use both buses and trolleybuses (gathered in focus group meetings); they were asked to indicate their opinion on a group of predetermined attributes and to rank them from highest to lowest according to the importance they attributed to them.

As can be seen in the figure 10, the most essential attribute for the sample taken is the ticket price, followed by punctuality and frequency, and finally the condition of the vehicles.

A fundamental aspect of any urban passenger transport alternative is the ability to incorporate transfer centers. According to the Comprehensive Traffic and Transportation Plan of the City of Buenos Aires, transfer

centers are "locations whose purpose is to integrate and facilitate the different modes of transportation that converge there, thus reorganizing the provision and interaction of services and organizing the random or complementary activities that take place there (economic, cultural, etc.).

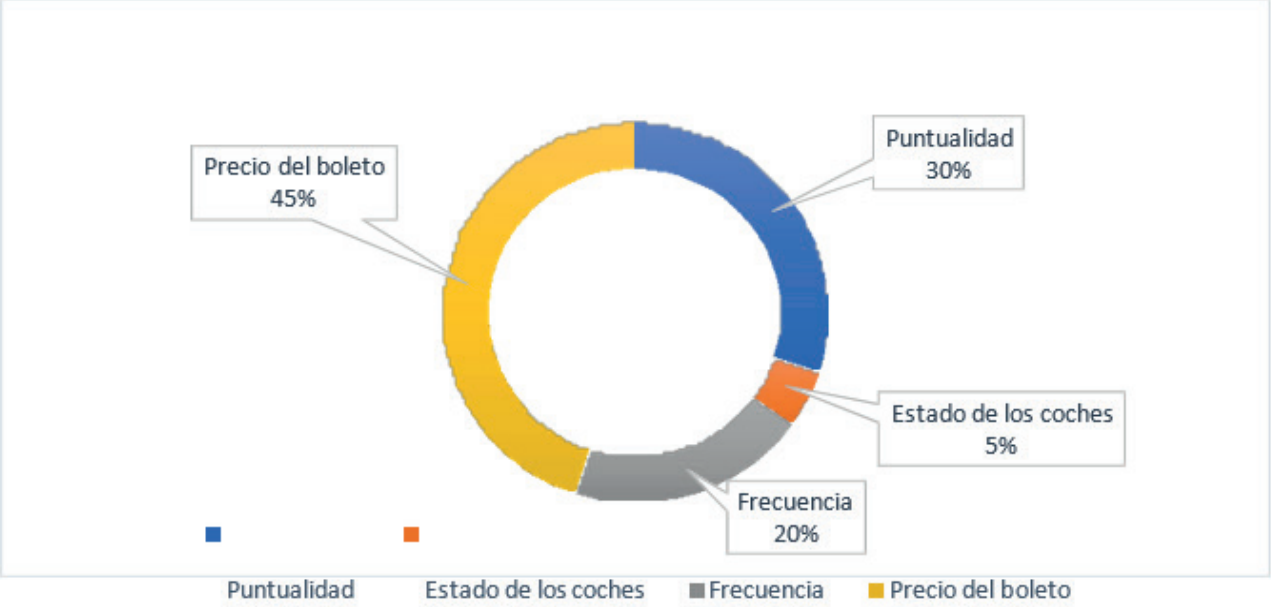


Figure 10. Importance of Urban Passenger Transport attributes for users

Subway

This means of transport is a system used to connect different points within a city and its metropolitan area, with high capacity and frequency for passenger transport. Its route is generally built underground, and the service is provided by electric cars that integrate formations and operate on different lines that make up a network, stopping at predetermined stations.

One alternative solution to the mobility problems of the city of Córdoba and its metropolitan area is the construction of a subway, providing a safe and clean means of mass transportation.

The intention to build a subway in Córdoba is not a new concept. The most recent project dates back to 2007, when a group of private companies announced their willingness to move forward with the construction of a subway in the city. For its part, the Municipality announced that it was beginning technical and financial feasibility studies. In 2008, an agreement was signed between the Municipality of Córdoba and the National Government for the implementation of an underground transportation system in the city with the intention of "creating behavioral changes in the transportation and mobility patterns of users, giving priority to public transportation over private transportation, facilitating intermodal transportation, and improving the attractiveness of public transportation to users." In the second clause of the Agreement, the National Government undertook to "issue a call for public tender for the contracting of the executive project, the construction of civil works (lines, parking lots, and other related structures), the provision of rolling stock, the equipment of the integrated system, and financing, through the modality of Public Works, and the operation of the service under the regime it may determine, all within the framework of Law No. 26,352. The borrower of the financing, as required in the framework of the tender as mentioned above, was to be the NATIONAL GOVERNMENT."

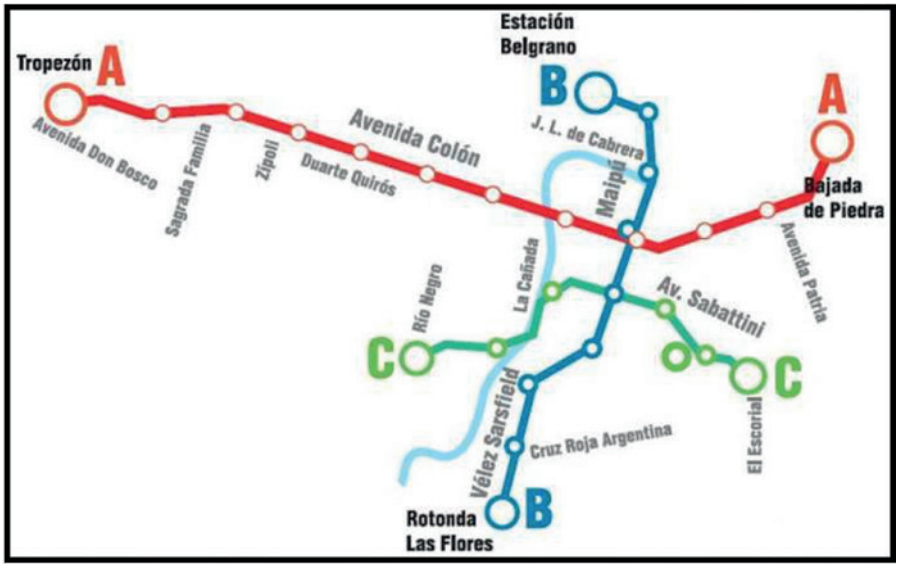
In January 2012, the Municipality approved the official route, which was 22 850 meters long and included 26 stations and three maintenance workshops (one for each line).

The following is detailed information about the project:

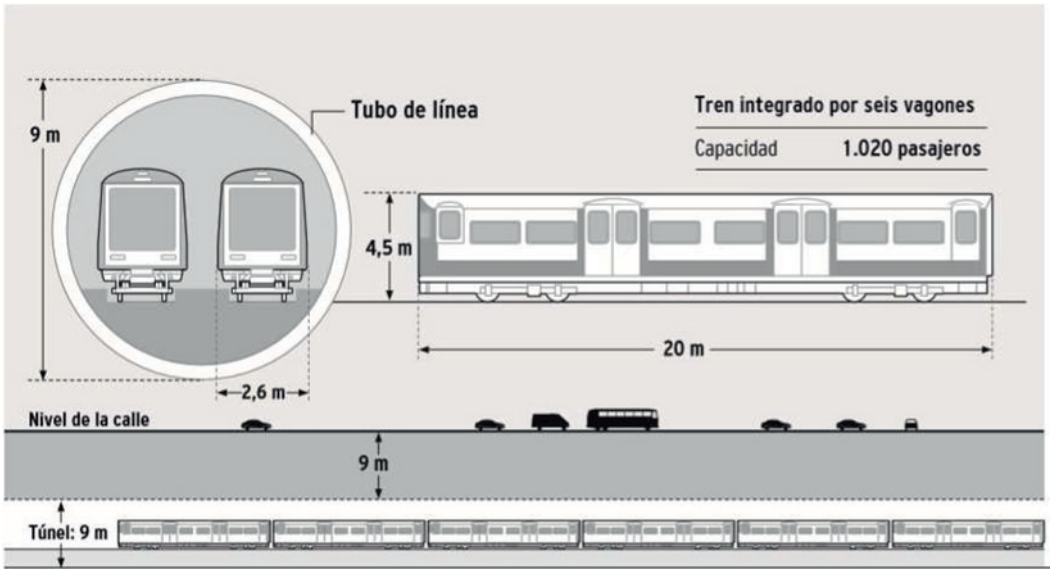
	Línea A	Línea B	Línea C
Dirección	oeste - este	sur-norte	Sudoeste - Sudeste
Inicio de traza	El Tropezón	Rotonda Almirante Brown (B° Las Flores)	Rotonda del Ala (Avenida Fuerza Aérea Argentina)
Fin de traza	Avenida Patria	Avenida Juan B. Justo	Avenida Amadeo Sabattini (altura calle El Escorial)

Extensión (mts)	10.680	6.490	5688
Cantidad de Estaciones	11	8	7
Distancia entre Estaciones (mts)	1.100	800	700
Taller de mantenimiento	Barrio Pueyrredón	Estación Belgrano (Alta Córdoba)	Parque Sarmiento

Figure 11. Relevant data Córdoba Underground



Source: Municipality of Córdoba
Figure 12. Estimated routes for the Córdoba subway



Source: La Voz del Interior newspaper
Figure 13. Characteristics of the Córdoba Underground

The investment was to be covered by the national government. It was estimated to be around US$2,74 billion, with financing agreed upon for 15 years, a three-year grace period, and an interest rate of 8,5 percent. The project was expected to take 17 years to complete.

In March 2016, the national government notified the municipality that it had no intention of financing the project, supporting instead the implementation of the BRT ("Solo Bus") rapid bus system.

Commuter Train

The commuter or metropolitan train is an efficient and sustainable solution that improves the city's connectivity with the metro area by enhancing the existing railway infrastructure. This alternative also aims to reverse dependence on a single system by providing a railway alternative and promoting a multimodal system of complementary modes of transport.

The first project to implement an urban train for the city of Córdoba dates back to the late 1950s, to provide a new alternative to the Mass Passenger Transport System, and utilize the railway line that crosses the city.

In April 2019, the provincial government presented a project to carry it out jointly with the municipality. It was called "Ferrourbano Metropolitano" and was part of the Metropolitan Mobility Plan, an alternative transportation system designed to improve connectivity between the metropolitan area and the city center, while discouraging the use of private vehicles.

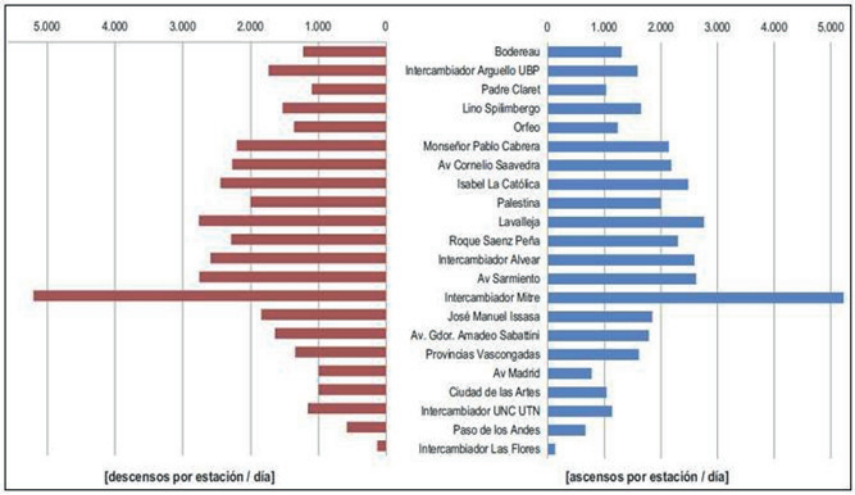
To carry out this plan, the Provincial Secretary of Transportation worked jointly with the Higher Institute of Transportation Engineering (ISIT) of the National University of Córdoba and other provincial, national, and international organizations (Argentine Institute of Transport, International Union of Public Transport, National Transport Management Secretariat, Metropolitan Planning Institute, among others) to provide a safe, low-environmental-impact option that can be easily combined with other more permeable modes and that brings predictability to public passenger transport. Likewise, a Framework Collaboration Agreement was signed between the Government of Córdoba and the State Railway Operating Company (SOFSE) for the valuation and use of the railway line that crosses the urban area of Córdoba.

It is worth highlighting the preliminary draft analyzed by the Higher Institute of Transport Engineering (ISIT), which studied "passenger demand for the railway corridor known as the Herradura Project: Bodereau - Flores Station in the city of Córdoba," as it laid the foundations for the final project presented in April 2019 by the provincial government. The most relevant points of the project are detailed below:

- It establishes that operations will begin in 2020 (project, infrastructure construction, and commissioning).
- 15-year useful life of rolling stock
- 25-year useful life of infrastructure

Ramal	Variables e Indicadores			
	Pas	Pas.km	Km	Pas.km/km
Ramal Norte (Bodereau - Int. Mitre)	25.848	149.999	17,65	8.496
Ramal Sur (Int. Mitre - Est. Flores)	6.784	25.471	14,50	1.756
Ramal Completo (Bodereau - Est. Flores)	40.111	258.141	32,16	8.028

Figure 14. Passenger indicator per kilometer of network separated by North-South branch. 2020 projection



Source: Study of demand for the urban rail corridor in the city of Córdoba: Herradura Bodereau Project – Flores Station – FINAL REPORT. Higher Institute of Transport Engineering (ISIT)

Figure 15. Boardings and alightings per station. 2020 projection

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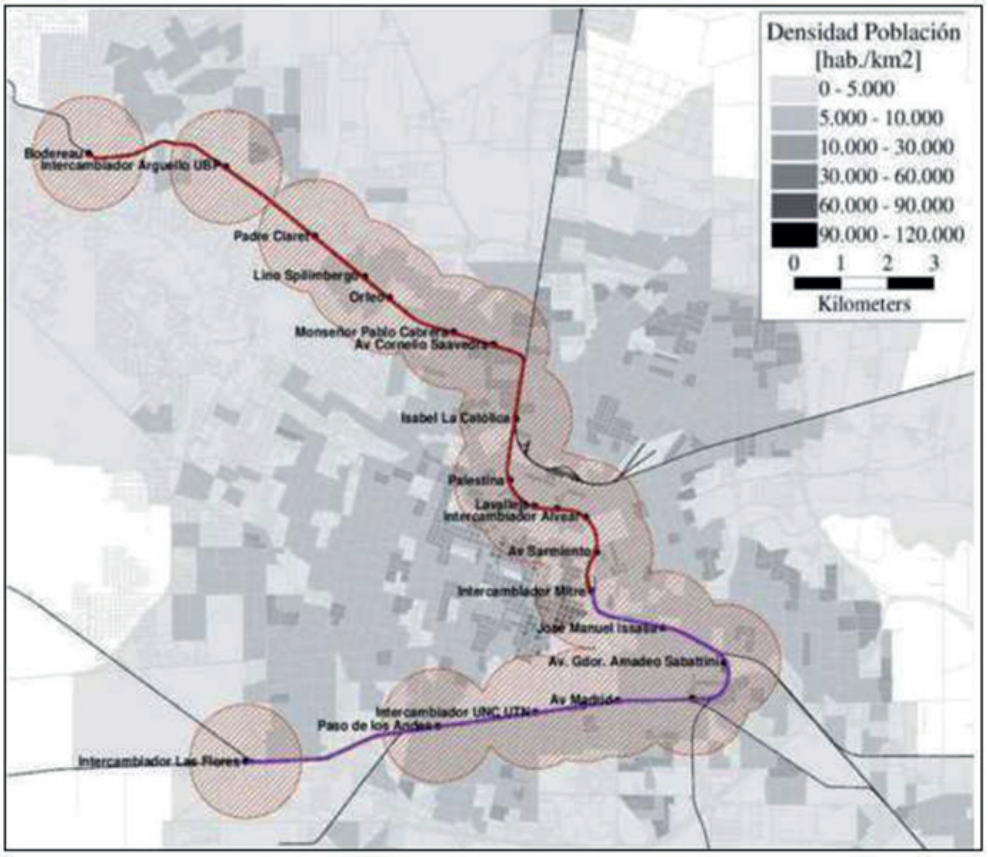
Tramo		Sentido de circulación	
		Norte --> Sur [pas/día]	Sur --> Norte [pas/día]
Bodereau	Intercambiador Arguello UBP	1.309	1.221
Intercambiador Arguello UBP	Padre Claret	2.705	2.763
Padre Claret	Lino Spilimbergo	3.556	3.673
Lino Spilimbergo	Orfeo	4.985	4.979
Orfeo	Monseñor Pablo Cabrera	5.774	5.888
Monseñor Pablo Cabrera	Av Cornelio Saavedra	6.913	7.093
Av Cornelio Saavedra	Isabel La Católica	7.855	8.121
Isabel La Católica	Palestina	9.087	9.315
Palestina	Lavalleja	9.664	9.901
Lavalleja	Roque Saenz Peña	9.087	9.325
Roque Saenz Peña	Intercambiador Alvear	8.504	8.728
Intercambiador Alvear	Av Sarmiento	7.947	8.174
Av Sarmiento	Intercambiador Mitre	7.081	7.443
Intercambiador Mitre	José Manuel Issasa	5.260	5.604
José Manuel Issasa	Av. Gdor. Amadeo Sabattini	4.354	4.691
Av. Gdor. Amadeo Sabattini	Provincias Vascongadas	3.328	3.518
Provincias Vascongadas	Av Madrid	2.695	2.613
Av Madrid	Ciudad de las Artes	2.104	2.234
Ciudad de las Artes	Intercambiador UNC UTN	1.518	1.600
Intercambiador UNC UTN	Paso de los Andes	682	782
Paso de los Andes	Intercambiador Las Flores	127	132

Source: Study of demand for the urban rail corridor in the city of Córdoba: Herradura Bodereau Project – Flores Station – FINAL REPORT. Higher Institute of Transport Engineering (ISIT)

Figure 16. Load per section per direction. Fast Train. 2020 projection



Source: Study of demand for the urban rail corridor in the city of Córdoba: Herradura Bodereau Project – Flores Station – FINAL REPORT. Higher Institute of Transport Engineering (ISIT)

Figure 17. Stations and areas of influence within a radius of 1200 meters

The following data is taken from the project:

- Total length: 32 km
- First stage: 17,6 km
- Second stage: 14,4 km
- Number of crossings: 63
- Starts at Tristán Narvaja Station and ends at Flores Station
- 24 daily services
- 6 state-of-the-art trains with air conditioning
- Stages:
- First stage:
    1. From Tristán Narvaja Station to Mitre Station
    2. 12 stations – 2 interchanges
    3. Completion date: 2020

- Second Stage:
    1. From Mitre Station to Flores Station
    2. 5 stations – 3 interchanges
    3. Completion date: 2021–2022

- 5 modal interchanges and 17 stations

Source: Córdoba Province Transportation Secretariat
Figure 18. Modal Interchanges and Stations

As indicated in the report prepared by ISIT, "it can be seen that demand on the Northern Branch is five (5) times higher in terms of passengers per kilometer, with only a 20 % increase in network length. This suggests that, to launch a rail transport service, it should be limited to the Northern Branch. The Southern Branch increases the length of the network by 82 %, increasing passenger numbers by only 25 %, which, in terms of investment and operating costs, significantly weakens the economic viability of the service."

There is a third stage, which involves connecting the city with the Metropolitan Area:

- Flores - Malagueño Station.
- Belgrano Station (Alta Córdoba) – Malvinas Argentinas.
- Mitre Station - Juárez Celman / Jesús María.
- Mitre Station - La Calera.

In terms of budget, an estimated investment of $6 million was planned for the first stage, with a total investment of $11 million, and a final execution period of 3 years (2020–2022) for the first two stages.

Elevated Monorail

Congestion is a visible symptom of the problem of not having innovative solutions for urban transport in Córdoba and city traffic, caused by inefficient planning and land use development over time. Likewise, population growth and urbanization tend to increase motorization. Without adequate urban planning/regulation, this causes an increase in the rate of motorization, which directly impacts the migration of passengers from the mass transit system to individual means of transportation, such as private vehicles, motorcycles, bicycles, etc., generating a vicious cycle of transportation that causes the consequent saturation of communication routes.

The particular factors of the city, related to its extensive growth and expansion, produce a double effect: more cars on the streets and longer journeys. A similar situation occurs with the advent of satellite cities (especially Sierras Chicas).

Although various proposals for addressing transportation and traffic issues in the city of Córdoba and its surrounding areas have been implemented over the years, none of them have yielded the expected results.

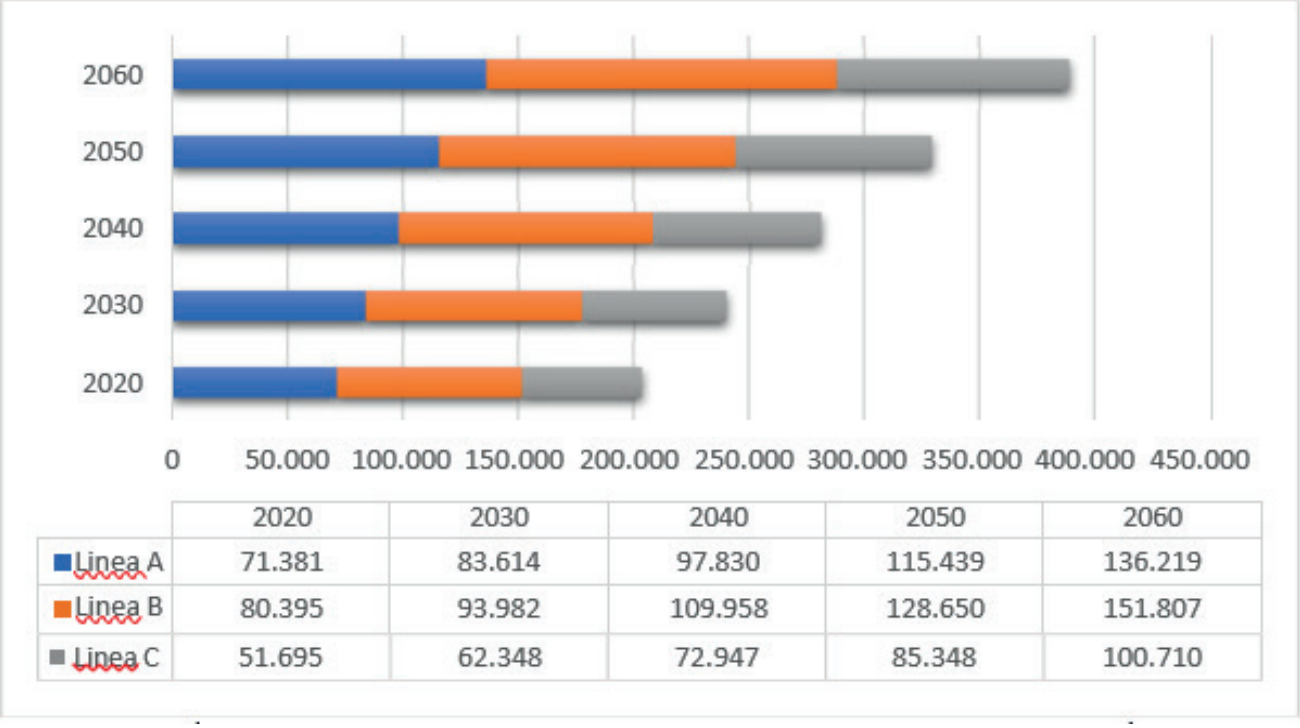
The monorail is an innovative, safe, and environmentally friendly transportation system with a balanced relationship between investment and medium- and long-term benefits.

The city of Córdoba requires an innovative, high-capacity mode of transportation that will help address the challenges of mass passenger transport and its impact on vehicular traffic.

The Secretary of Transportation of the Province of Córdoba has worked on the preliminary draft "Proposal for a Monorail Mass Transportation System for Córdoba and the Metropolitan Area," which is based on route studies conducted by Mgter. Civil Engineer Oscar Milton Dapas, and includes:

Ramal	Longitud	Estaciones	Formaciones	Vagones	Pasajeros por día (por sentido)
Línea A (Villa Allende - Centro de Cba) Subramal (Boderau - Blas Pascal)	19 km + 3,58 km	21	11	2	71.381
Línea B (Estadio Kempes - Centro Cívico)	12,8	14	7	2	80.395
Línea C (UCC - Centro de Cba)	10,4 km	10	3	3	51.695

Figure 19. Relevant data on the Córdoba Elevated Monorail. 2020 projection



	2020	2030	2040	2050	2060
Linea A	71.381	83.614	97.830	115.439	136.219
Linea B	80.395	93.982	109.958	128.650	151.807
Linea C	51.695	62.348	72.947	85.348	100.710

Figure 20. Projected number of passengers per day per direction 2020-2060

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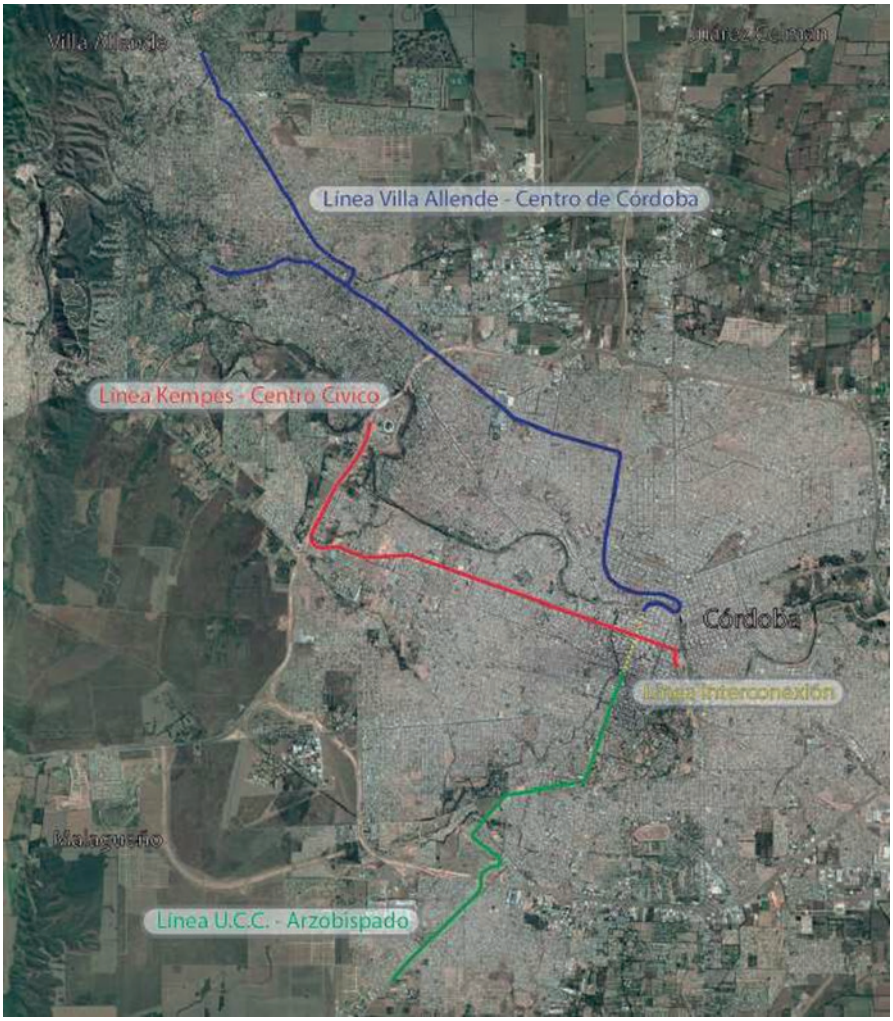
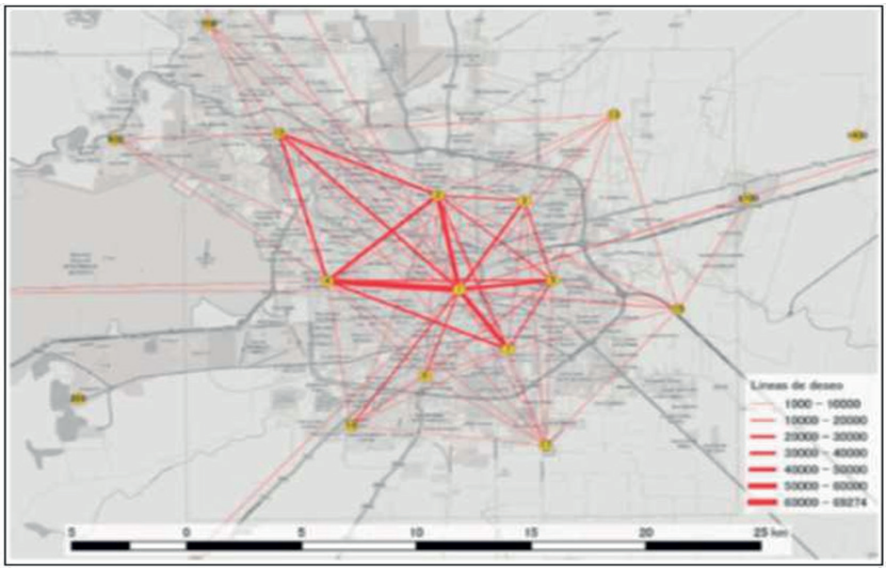


Source: Preliminary draft "Proposal for a Monorail Mass Transit System for Córdoba and the Metropolitan Area." Córdoba Province Transportation Secretariat. 2018

Figure 21. General planimetry of the Córdoba Elevated Monorail lines

Based on demand studies conducted by the consulting firm Nippon Koei, the desired lines, or travel demand taking into account the main areas of the city, are as follows:



Source: Preliminary draft "Proposal for a Monorail Mass Transit System for Córdoba and the Metropolitan Area. Córdoba Province Transportation Secretariat. 2018

Figure 22. Travel demand for the Córdoba Elevated Monorail

https://doi.org/10.56294/tms202245 ISSN: 3072-8398

To carry out the entire project, which comprises three lines with a total length of 45,78 kilometers, the estimated budget is $1 007 160 million, of which 72,7 % corresponds to railway equipment and systems, while the remaining 27,3 % would be applied to everything related to the civil works of the project.

In terms of determining which mode of transport the user would choose, the reference point is Oscar Dapas's postgraduate thesis, which proposes a logit model for determining user choice.

With the monorail running along the bus route, users have the following possibilities for choosing the monorail according to certain attributes; that is, at the same fare for the monorail as for the bus.

	Sector	Tarifa Omn.	Tiempo de espera Omn.	Tiempo de Viaje Omn.	Tarifa Mono	Tiempo de Viaje Mono	Utilidad	Prob. De elegir Monorriel
Opciones	1	1	7,5	13	1	7	0,446359	0,61
	1	1,3	5	13	1,5	7	-0,62899	0,35
	1	1,3	5	13	1,75	7	-1,13909	0,24
	2	1	7,5	35	1	18	1,230799	0,77
	2	1,3	5	35	1,5	18	0,155449	0,54
	2	1,3	5	35	1,75	18	-0,35465	0,41
	3	1	7,5	53	1	28	1,868345	0,87
	3	1,3	5	53	1,5	28	0,792994	0,69
	3	1,3	5	53	1,75	28	0,282893	0,57

Source: Dapas[35]

Figure 23. Demand analysis for an elevated mass transit line in the city of Córdoba

At the same fare, the probability of choosing the monorail over the bus increases depending on the distance to the city center, which is divided into concentric sectors: 1) 1 to 5 km from the center, 2) 5 to 12 km, and 3) 12 km to the municipal boundary.

Choice of system to be analyzed

Below is a summary of the main details of each system analyzed, as well as their strengths, opportunities, weaknesses, and threats.

	Subterráneo	Ferrocarril Urbano	Monorriel elevado
Etapas	3 (líneas)	2 (Norte - Sur)	3 (líneas)
Costo del Kilometro (usd)	$ 120.000.000	$ 343.750	$ 22.000.000
Inversión total del Proyecto (usd)	$ 2.742.000.000	$ 11.000.000	$ 1.007.160.000
Plazos de Construcción (años)	17 (1,35 km por año)	3 (10 km por año)	8 (6 km por año)
Tipo de traza	Troncal	Periférico	Troncal
Traza (kilómetros totales)	22,85	32	45,78
Capacidad de Carga (por hora por Sentido)	55.000	5.000	30.000

Figure 24. Technical specifications by transportation system analyzed

	Subterráneo	Ferrocarril Urbano	Monorriel elevado
Fortalezas	* Medio de transporte rápido y Eficiente. * No posee contaminación visual ni auditiva en superficie. * Elevada capacidad de carga y frecuencia. * No se altera la arquitectura de la ciudad. * Mejora la intermodalidad.	* Menor inversión que los otros medios analizados (solo puesta en valor de la traza existente). * La traza planteada ya se encuentra libre de obstáculos para su utilización (actualmente). * Mejora la conectividad de la ciudad con el área metropolitana. * Mejora la Intermodalidad.	* Medio de transporte rápido y eficiente. * Elevada capacidad de carga y frecuencia. * Rapidez en la construcción de la obra civil. * Modo de transporte Innovador. * Traza mas larga en comparación a las alternativas analizadas. * Mejora la Intermodalidad.

Oportunidades	* Necesidad de la sociedad de contar con alternativas de traslado.	* Necesidad de la sociedad de contar con alternativas de traslado.	* Necesidad de la sociedad de contar con alternativas de traslado. * Posibilidad de tomar prestamos internacionales para su implementación.
Debilidades	* Altos costos de capital inicial. * Medio de construcción lerdo. * Traza mas corta en comparación a las alternativas analizadas.	* Baja capacidad de carga. * Gran cantidad de cruces a paso nivel (63). * Baja velocidad de marcha. * Tiempo de vida limitado para la traza existente. * Perdida de capacidad de carga en traza con pendiente	* Contaminación visual en superficie. * La construcción puede llegar a generar problemas en el transito.
Amenazas	* Imposibilidad de acceder a prestamos internacionales. * Ambiente Polîtico inestable a nivel nacional. * Posibles problemas legales por demoras en la construcción.	* Continuo avance de asentamientos precarios sobre la traza férrea. * Ambiente Polîtico inestable a nivel nacional.	* Ambiente Polîtico inestable a nivel nacional. * Posibles problemas legales por la contaminación visual y auditiva.

Figure 25. SWOT analysis

To define the means of transport to be studied in depth, a quantitative analysis will be carried out in which the different means of transport analyzed in this study will be compared with each other in order to determine a particular transport system. The tools to be used are as follows:

- Factor Weighting Method.
- Traffic Density Indicator.

The objective of the factor weighting method is not to define an optimal mode but rather an acceptable option. To compile the following table, interviews were conducted with leading figures in the private sector (the interview model can be found in the appendix to this study. The interviews were conducted in 2019. A total of 15 people were interviewed) who are linked to the Mass Passenger Transport Service and public officials. Among other questions, they were asked to assign a relative weight to a series of pre-established attributes.

Table 1. Weighting of Factors

Variables		**Alternatives**		
Description	**Relative weight (%)**	**Underground**	**Urban railway**	**Elevated monorail**
Type of route	35	9	5	9
Construction speed	20	2	8	7
Load Capacity	15	9	5	8
Total Number of Kilometers	10	5	7	9
Investment per kilometer (USD)	15	2	9	6
Stages	5	5	5	5
		5,95	6,4	7,8

As shown in table 1, the monorail is the most suitable alternative for developing a new solution to address the mobility problems faced by the city of Córdoba and its metropolitan area.

The variable with the most significant relative weight is the type of route, as it is emphasized that the new transport system to be implemented must be located on the city's most developed axes (trunk lines) to promote intermodality. The Latin American Association of Metros and Subways (ALAMYS), at its 2017 International Conference in Mexico City, concluded in its panel "Applications of intermodal solutions in Ibero-America" that intermodality should be considered as a public policy. No urban development or mobility plan should ignore this concept. There is no point in implementing new transport systems if they operate in isolation from existing systems.

The second most important variable is the speed of construction, as this has an impact on production costs and possible problems with residents and businesses along the route. Another relevant point in relation to this factor is that the transport system allowing for the fastest construction method is the elevated monorail (6 km per year), with the exception that, in the case of the urban railway, the aim is to enhance the value of the existing route. It is not necessary to build new infrastructure, which is why it is not comparable to the other two models studied.

It is essential to note that the impact on regular city activity during the construction period is minimal, unlike the subway, where the open-air construction of stations necessitates the removal and replacement of underground public services, accompanied by large-scale excavation in a densely populated urban area.

In terms of transport capacity, the subway performs best, while the urban railway performs worst.

In terms of investment per kilometer, a similar phenomenon occurs with the variable construction speed, as the train has the lowest cost per kilometer. However, this is because the investment is made to renovate the existing infrastructure, whereas for the other two systems analyzed, the investment must be made in new infrastructure.

The elevated monorail has the longest route, with its three lines exceeding 45 kilometers.

In terms of the number of stages, all the proposals evaluated have three phases; in the cases of the subway and the monorail, these correspond to the three lines stipulated for each case. In the case of the railway, the first two stages

seek to capture the demand of the urban system, while the third stage "metropolizes" the service by extending its routes.

Regarding the Traffic Density Index, Leroy W. Demery Jr., engineer Boris Pushkarev, and others conducted an economic analysis, using traffic level as the primary indicator. Specifically, they employed traffic density expressed in passenger-kilometers per kilometer of line on a weekday. The choice is based on the fact that it is an indicator that reflects benefits and can be reasonably calculated.

The study considered five criteria related to traffic levels for the selection of the threshold:

- Possibility of obtaining an adequate level of service for passengers (space in vehicles and frequencies),
- Possibility of achieving labor cost savings compared to buses,
- Possibility of obtaining energy savings compared to previously used modes,
- Possibility of achieving land use savings compared to previously used modes,
- Level of investment per unit of service offered. It should also be noted that the authors explicitly avoid using the cost-benefit technique to determine the threshold, citing the multiplicity of assumptions that would have to be used and the complexity of determining the necessary equivalence factors.

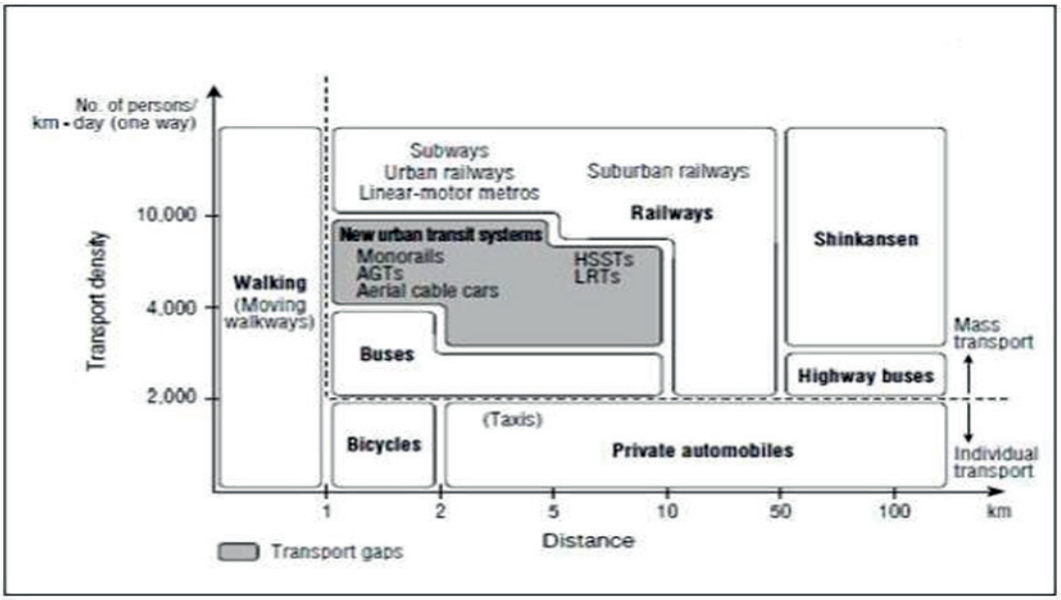
The following equation gives the traffic density indicator:

Density = (Passengers per day x average distance traveled) / length of the line

In 2005, the report "Traffic Density Thresholds for Rail Transit: A Retrospective" established that the minimum traffic density threshold that justifies the implementation of a monorail (in this case, for the states.

The United States has 4000 passengers per weekday per kilometer (in both directions) per kilometer of line.

Akira Nehashi, in his article "New Urban Transit Systems Reconsidered: A Better Transport Environment for the Next Century," analyzed different modes of transportation and identified which would be ideal to implement, using Japanese transportation in the 1990s as an example.



Source: New Urban Transport Systems Reconsidered. Japan Railway & Transport Review. No. 16, June 1998

Figure 26. Field of application for each mode of transport in Japan

In Germany, the engineering subsidiaries of four of the most significant public transport authorities formed an LRT consulting firm (LRTC). "The Handbook published in 1993 (Gerndt et al., 1993) presents thresholds for four categories of light rail; the first three similar to trams and the fourth similar to subways. The thresholds, always in passenger-weekdays per kilometer (in both directions) per kilometer of line, are respectively 4000, 10 000, 20 000, and 30 000." Given this,

possible to estimate the monorail as a means of transport falling between the 20 000 and 30 000 categories, giving a threshold of approximately 25 000 passenger-kilometers per weekday in both directions.

For example, and referencing the work of Oscar Dapas, 42 a threshold of 15 000 passenger-kilometers per day in one direction is adopted. According to this value, said work considers the Villa Allende-Córdoba line viable from 2020, with the following travel projection:

Año	Demanda
2020	71.381
2030	83.614
2035	90.450

Figure 27. Estimated demand for Line A - Villa Allende / Córdoba City Center per day per direction

The traffic density index for the same reference line is:

Año	Densidad
2020	19.828
2030	23.226
2035	25.125

Figure 28. Traffic density - Passenger - weekday per kilometer (one direction) per kilometer of line

It can be concluded that, taking only line A (Villa Allende/Córdoba City Center) as an example to analyze its traffic density, it is 32 % above the established threshold.

These values are justified based on the values of the desired travel lines prepared by the consulting firm Nipon Koei.

It is possible to note that, given the greater number of trips on the Avenida Colon line compared to line A and its significantly shorter length, the traffic index of the Colon line will be much higher than that of line A, according to Dapas[35]—demand analysis for an elevated guided mass transit line in the city of Córdoba.

Consequently, it will be justified with a greater margin than line A for the year 2020.

Why an elevated monorail for Córdoba?:

The choice of monorail is based on various factors that characterize this mode of transport and are fully compatible with a fundamental solution to the city of Córdoba's public transport problems. The following facts mark this proposal:

- The elevated monorail, in its most compact versions, can easily transport 200 to 400 passengers per train. The transport capacity in this version is 9000 to 12 000 passengers per hour and per direction. It should be noted that this means quadrupling the capacity offered by buses.
- The elevated monorail travels above congested roads and is not affected by flooding, road closures due to demonstrations, etc.
- The current high accident rate. The elevated monorail, as global experience shows, poses minimal risk compared to other modes of transport.
- The operating speed of current modes of transport is low due to traffic and the geometric characteristics of the roads. The elevated monorail features a high operating speed, and its track is dedicated exclusively to its use.
- The pollution generated by the current system (buses) is aggravated by the state's inability to control this situation. The elevated monorail is quiet and does not produce polluting emissions.
- The limited technological possibilities of the current system in terms of predicting arrival times at different stops, minute-by-minute tracking of people in the system, automation, etc. The elevated monorail enables the complete automation of the system and allows for online testing of demand conditions.
- The current system is economically inefficient, making it increasingly difficult to attract private sector interest in its operation. Based on international experience, the elevated monorail is highly efficient in this area.

CONCLUSIONS

Throughout this study, the advantages of the elevated monorail have been developed (speed of construction, environmentally friendly, high load capacity, more economical than other alternatives, etc.). However, its main strength is the possibility for users to have a choice and not be prisoners of a single public transport system.

From the point of view of demand, the elevated monorail is the best alternative to meet the transportation needs of people living in the city of Córdoba and its metropolitan area (population density varies throughout its territory).

From a technological perspective, this system has the highest standards of safety, operational flexibility, quality, technical specifications, and reliability, as the chosen supplier has extensive experience in this type of public passenger transport project.

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FINANCING

None.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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