Transport, Mobility & Society. 2022; 1:30
doi: 10.56294/tms202230

ORIGINAL

Technical, economic, and financial feasibility study: elevated monorail for the city of Córdoba and its metropolitan área

Estudio de factibilidad técnico, económico y financiero: monorriel elevado para la ciudad de córdoba y zona metropolitana

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Cite as: Bermúdez GR, Robledo W. Technical, economic, and financial feasibility study: elevated monorail for the city of Córdoba and its metropolitan área. Transport, Mobility & Society. 2022; 1:30. https://doi.org/10.56294/tms202230

Submitted: 19-05-2022 **Revised:** 21-07-2022 **Accepted:** 14-12-2022 **Published:** 15-12-2022

Editor: Prof. Emanuel Maldonado

ABSTRACT

The study focused on analyzing the technical, economic, and financial feasibility of implementing an elevated monorail system in the city of Córdoba and its metropolitan area as an alternative form of mass transportation in response to growing traffic congestion and the inefficiency of the current bus system. The research was conducted using a mixed approach, combining qualitative and quantitative techniques, through interviews, focus groups, and review of documentary and statistical sources. The results highlighted that the elevated monorail offered significant technical advantages, such as small stations, reduced curve radii, flexible transport capacity, low noise levels, and the possibility of automation. From a financial standpoint, the project had an estimated total cost of $1 007 billion, considerably less than the subway alternative. The economic analysis yielded a positive Net Present Value (NPV) of $97,7 million and an Internal Rate of Return (IRR) of 43,45 %, indicating its viability and profitability. In terms of social impact, it was concluded that the monorail represented an opportunity to improve urban mobility, reduce travel times, decrease environmental pollution, and optimize the quality of life for residents. Likewise, its implementation promoted social inclusion by ensuring accessibility and introducing competition into a transportation market dominated by a few bus companies. The project was considered feasible and beneficial from a technical, financial, and social standpoint.

Keywords: Monorail; Urban Mobility; Accessibility; Financial Feasibility; Public Transportation.

RESUMEN

El estudio se enfocó en analizar la factibilidad técnica, económica y financiera de implementar un sistema de Monorriel Elevado en la ciudad de Córdoba y su área metropolitana, como alternativa de transporte masivo frente a la creciente congestión vehicular y a la ineficiencia del sistema actual de autobuses. La investigación se desarrolló bajo un enfoque mixto, combinando técnicas cualitativas y cuantitativas, a través de entrevistas, grupos focales y revisión de fuentes documentales y estadísticas. En los resultados, se destacó que el Monorriel Elevado ofreció ventajas técnicas significativas, como estaciones de pequeño porte, radios de curva reducidos, capacidad flexible de transporte, bajo nivel de ruido y posibilidad de automatización. Desde el punto de vista financiero, el proyecto presentó un costo total estimado de 1 007 millones de dólares, considerablemente menor que la alternativa del subterráneo. El análisis económico arrojó un Valor Actual Neto (VAN) positivo de 97,7 millones de dólares y una Tasa Interna de Retorno (TIR) del 43,45 %, lo que indicó su viabilidad y rentabilidad. En cuanto al impacto social, se concluyó que el Monorriel representó una oportunidad para mejorar la movilidad urbana, reducir los tiempos de viaje, disminuir la contaminación ambiental y optimizar la calidad de vida de los habitantes. Asimismo, su implementación favoreció la inclusión social al garantizar accesibilidad y al introducir competencia en un mercado de transporte dominado por pocas empresas de buses. El proyecto fue considerado factible y beneficioso desde las dimensiones técnica, financiera y social.

Palabras clave: Monorriel; Movilidad Urbana; Accesibilidad; Factibilidad Financiera; Transporte Público.

INTRODUCTION

Congestion is the visible symptom of a disease affecting large cities due to inefficient planning that affects land use and the location of activities over time.[1,2,3]

Population and urban growth tend to increase motorization, and without adequate urban planning/regulation, this results in a high demand for motorization, which directly impacts the migration of passengers from the mass transit system to alternative means (increase in the number of private vehicles, motorcycles, bicycles, etc.), causing the consequent saturation of the roads. "In the city of Córdoba, fares for bus, taxi, and private car services have increased without a substantial improvement in service quality, particularly for buses.[4] In addition, for several years now, there have been favorable financing conditions for the purchase of cars and motorcycles, which has reinforced the increase in the ownership and use of these vehicles. All of this is contributing to increased levels of urban traffic congestion and the use of an inefficient public transport system."[5]

The particular factors of the city of Córdoba, related to its unlimited extension and expansion, produce the double effect of more cars on the streets and longer trips. A similar situation occurs with the advent of commuter towns (especially Sierras Chicas).[6,7,8,9]

Although various proposals for solutions to transportation and traffic in the city of Córdoba and Greater Córdoba have been implemented over the years, none of them have contributed to achieving the expected results.[10,11,12,13] This is because the capacity of the predominant mode of transportation, the bus, has been exceeded for decades.[14,15,16,17] It is imperative for the city and its metropolitan area to have medium- to high-capacity transportation, as is the case in cities with more than one million inhabitants similar to Córdoba.[18,19,20] This research analyzes and details the impact of adding a new mobility initiative to the current mass passenger transportation system, which has major operational shortcomings.[21,22] It is also an opportunity to move towards the implementation of other means of transport that have already been tested in various cities around the world and in the region, facilitating economic and social development with better standards of living for its inhabitants once it is adopted.[23]

As an example, the construction of the monorail in the city of São Paulo since 2014 has brought, among other benefits, a reduction in traffic jams during rush hour due to the decrease in private cars, the connection of the four municipalities with the highest population density in the region (São Paulo, São Caetano do Sul, São Andrés, and São Bernardo do Campo), a decrease in environmental pollution, and optimization of travel times for users.[24]

The following presentation is based on case studies with theoretical support.

To what extent can the implementation of an elevated monorail system improve the efficiency of public transport, reduce traffic congestion, and improve the quality of life of the inhabitants of the city of Córdoba and its metropolitan area?

Objective

To analyze the feasibility of implementing an elevated monorail system in the city of Córdoba and its metropolitan area as an alternative form of mass transportation, with the aim of reducing traffic congestion, improving the quality of urban mobility services, and contributing to the economic and social development of the region.

METHOD

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

The sources of information will be:

Primary: in-depth interviews with key actors: 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.
- Key aspects of process management.

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 strengths and weaknesses.
Mention at least two opportunities for improvement.

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

Technical, economic, and financial analysis for the implementation of the Elevated Monorail.
The purpose of the Elevated Monorail Proposal is:

- To provide public transport users with a modern, efficient, fast, comfortable, accessible, and environmentally sustainable means of transport.
- To provide a better quality of life for the city's inhabitants by reducing traffic congestion, shortening travel times, and improving air quality.

This chapter will focus on the technical analysis of the Elevated Monorail and the study of its financial aspects.
Technical Analysis - Physical Components of the Elevated Monorail
A transportation system consists of three physical elements:
Vehicle, Infrastructure, Transportation network Vehicle

For this project, we will analyze the "Hitachi Small" vehicle, considering the company that produces it, Hitachi Rail Systems Co, which has more than a century of experience in the development, manufacture, and implementation of railway systems, offering various modalities that adapt to the needs of each city. This company is taken as a reference because there is no other alternative that meets the necessary characteristics for what is needed in the city of Córdoba, as it allows for a distinction to be made between civil works (which can be carried out by local suppliers) and the supply of the necessary technology (rolling stock, know-how, signaling system, etc.).

Hitachi Rail Systems Co currently provides transportation assistance in Brazil (Porto Alegre, São Paulo, and Rio de Janeiro) and Panama (under construction); these monorails are approved by the Japanese railway system.

This vehicle has been selected due to:

1. It requires small stations.
2. Small curve radii, allowing it to better adapt to urban layouts.
3. It can handle gradients of up to 6 %.
4. Flexible capacity, can carry 2 to 4 cars, allowing for better adaptation to demand.
5. Rubber wheels reduce noise and provide better traction, allowing it to tackle gradients of up to 6 %.
6. They can be fully automated, eliminating the need for a driver.

Características	
Peso (en toneladas)	11
Configuración	4 carros
Capacidad Nominal	415 pasajeros / tren - Sentados: 177 - Parados: 238
Capacidad Planificada	692 pasajeros
Capacidad Máxima	966 pasajeros
Velocidad Maxima (Km/hr.)	60
Velocidad Media (Km/hr.)	36
Radio de Curva Minimo (Mts)	40
Pendiente Maxima Admitida (%)	6

Figure 1. Technical characteristics of the long model monorail

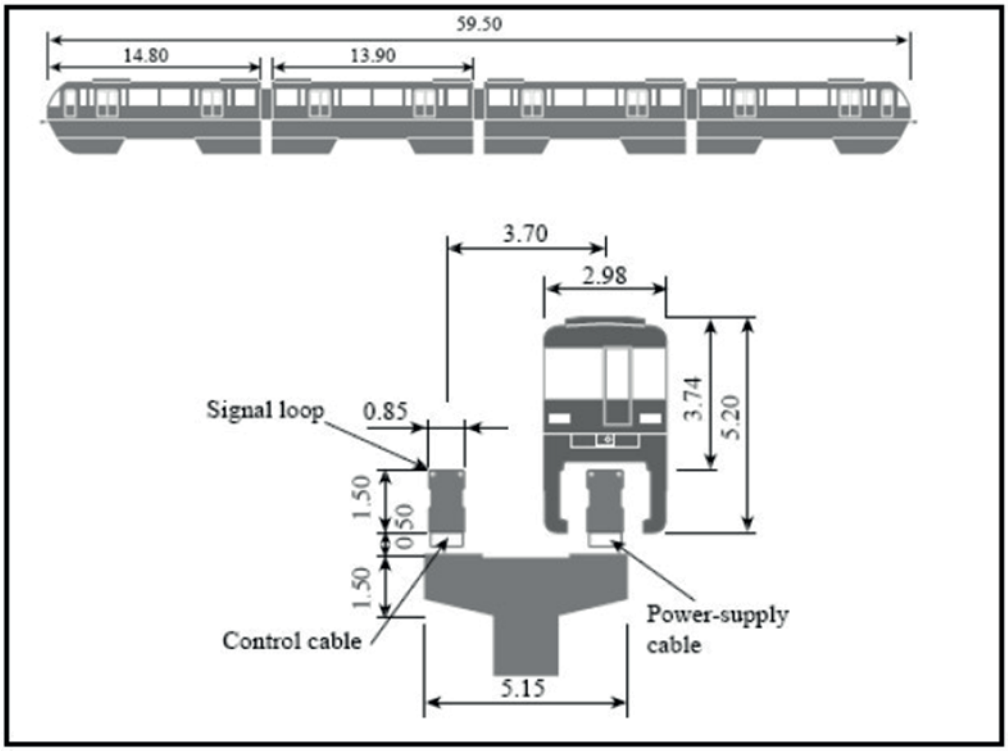

Figure 2. Four-car unit and support structure

Infrastructure

This section details the type of right-of-way on which this transport system operates, stops and/or stations, maintenance workshops, monitoring and control systems, and power supply system.

The elevated monorail operates on an exclusive right-of-way, completely separate from other modes of transport, achieving high operational performance (greater capacity, speed, reliability, and safety), obtaining optimal service levels, and reducing operating costs per unit of capacity.

As for the number of stops, it has already been mentioned that there will be 45 in total, distributed along each line with a distance of 700 to 800 meters between them. Like the lines, the stations will be elevated with vertical circulation for users to enter and exit via stairs (traditional and/or mechanical) and elevators to ensure that people with reduced mobility can use the service. Each line will have its maintenance workshop at the ends of the lines (other than those that terminate in the city center).

Below is a model stop for the elevated monorail system:

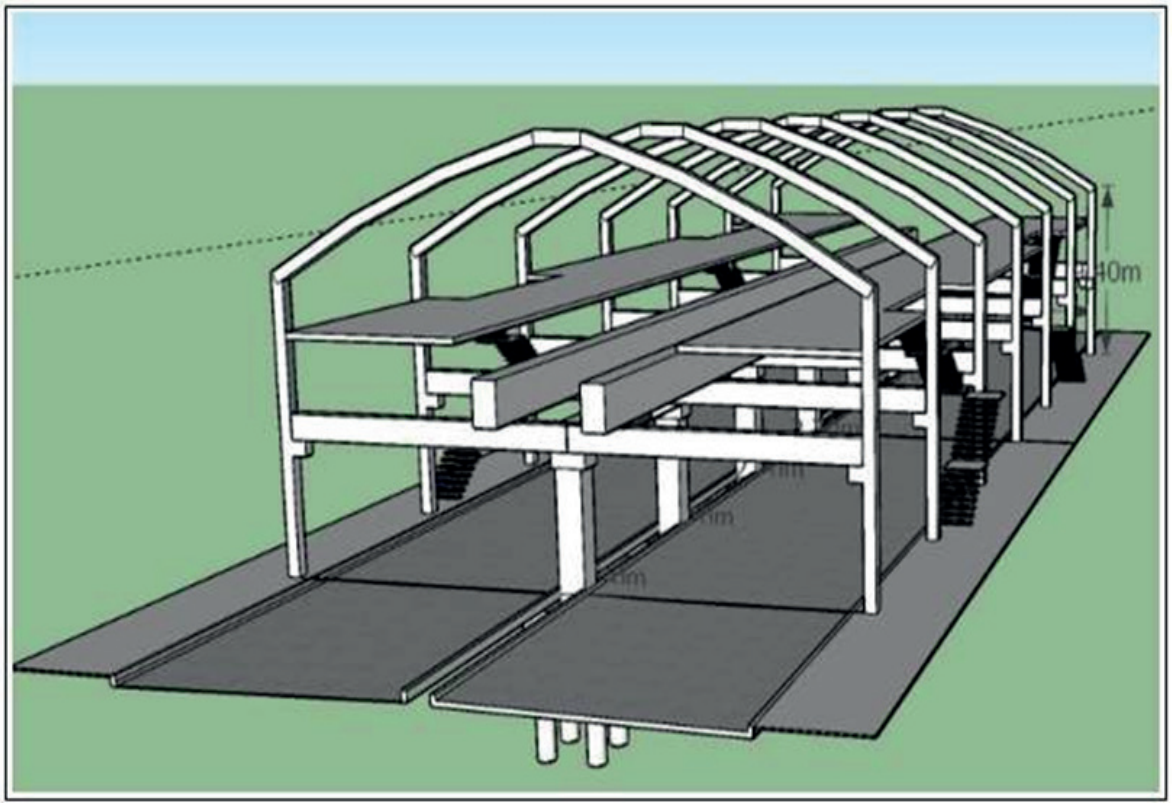

Figure 3. Model stop

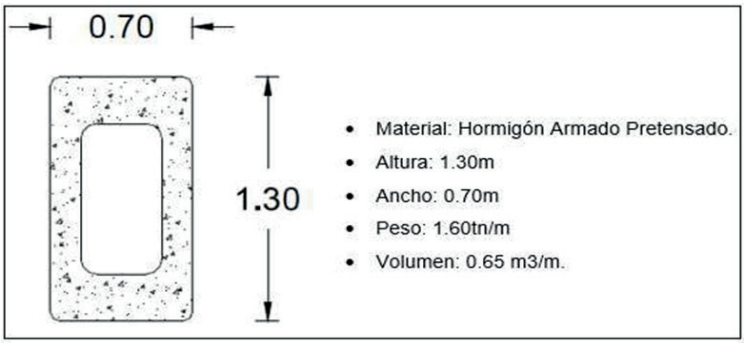

Figure 4. Cross-section of beam

Characteristics of the Model Station:

- Length: 35 meters
- Width: 11,35 meters
- Covered area: 600 square meters (including the boarding mezzanine, roof, and adjoining areas such as ticket offices, restrooms, and stairways)

With regard to the track infrastructure, it should be noted that the elevated monorail will run on a reinforced concrete beam, which will be gripped by the tires. The beam is supported by Y-shaped reinforced concrete columns. Illustrations of the beam and pillars.

Monitoring and control systems will be operated from a central office, which may be located in the new bus terminal using the facilities of the Operations Control Center (Cecop) of the Córdoba Province Transportation Secretariat.

Power will be supplied through the installation of new substations and, where possible, the substations currently used by trolleybuses will be repowered.

The monorail requires a distribution of 750 V (DC). There are currently facilities provided by EPEC that have equipped the surrounding area with a large amount of power for the activities detailed above and those planned for the future. Therefore, the energy supply for this development currently exists, and only minimal installations are required to connect the monorail system to the EPEC distribution network.

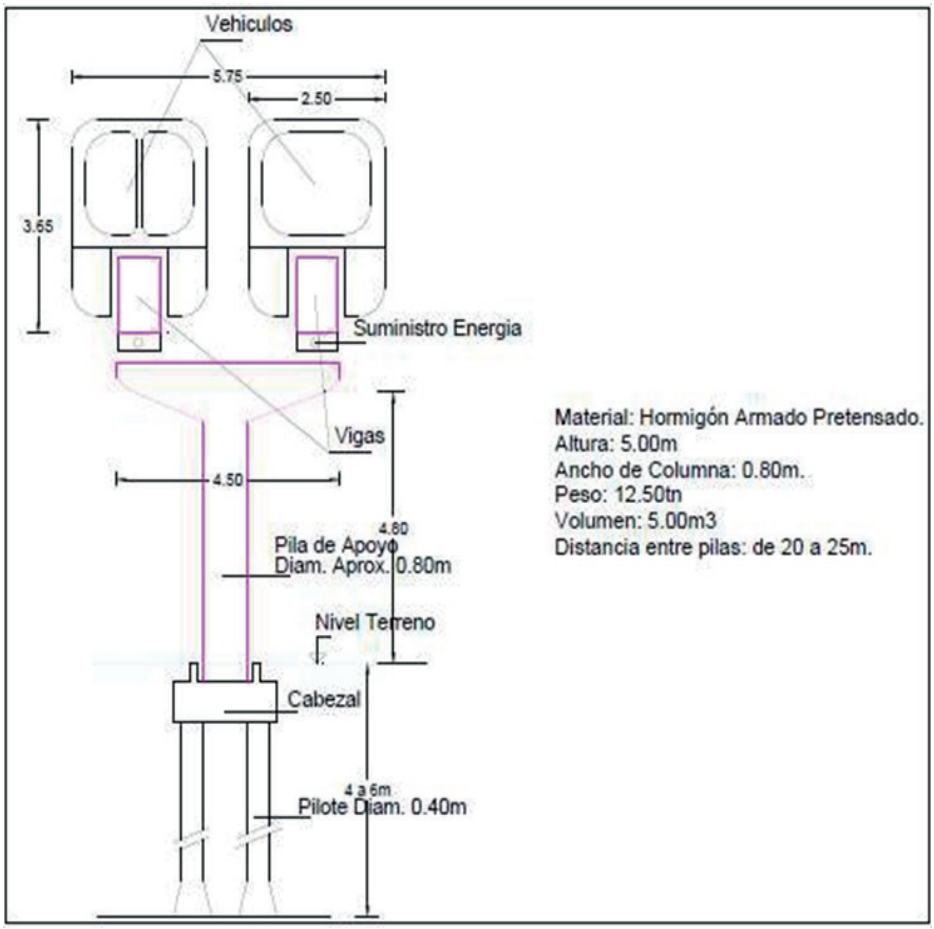

Figure 5. Cross-section of support structure

Transportation Network

As mentioned above, the length of the lines are as follows:

- Line A: 22,58 kilometers (19 km + 3,58 km).
- Line B: 12,8 kilometers.
- Line C: 10,4 kilometers.
- Total length: 45,78 kilometers.

Line A is based on a postgraduate thesis and has a two-way trunk route (19 km) and a one-way branch line (3,58 km). The expansion of the urban area to the northwest of the city makes it essential to plan a branch line that can meet the unmet demand from this sector to the city of Córdoba. The route of the 19-km trunk line includes the following landmarks: Villa Allende, Donato Álvarez Avenue, Blas Pascal, the Train of the Sierras railway airspace, passing through Orpheus,, Dinosaurio Mall, Hyper Liberty, Neonatal Hospital, Alta Córdoba neighborhood, and General Paz Square. The 3,58 km branch line begins at Av. Bodereau and Av. Ricardo Rojas, Blas Pascal University (where it joins the main line).

Line B (12,8 km) runs along the city's main road axis in a west-east direction. It will also provide service to the Chateau Carreras educational and sports center, as well as the neighborhood of the same name. This line can attract potential public transport users who live in the Valle Escondido neighborhood. This will be possible through a bus line that will feed the monorail. In turn, private car users will be able to use the Mario Alberto Kempes stadium parking lots as park-and-ride facilities, thus limiting car traffic in the city center. This branch line starts at the Mario Alberto Kempes Stadium, runs along the east collector road to Avenida Colón, and then reaches the Civic Center.

Finally, Line C (10,4 km) runs along one of the major development axes in the south of the city, passing through important centers that generate and attract travel, such as the Catholic University of Córdoba and the CPC in Villa El Libertador. It also has the potential to capture demand from the Villa El Libertador neighborhood (with a bus system connecting the neighborhood to the transfer center), the private hospital, the Ministry of Social Development's Pablo Pizzurno building, and the University City. The route runs from Vélez Sarsfield and Boulevard San Juan to Plaza of the Americas, from there along the median strip of Friuli Street to Cruz Roja

Argentina Avenue, then west along the NCA railway tracks to Río Negro Street to take the branch line to Renault Argentina, turning south over the Anizacate Street drainage channel to cross the ring road and take Armada Argentina Avenue to the Catholic University of Córdoba.

Economic-Financial Analysis

The economic-financial study of this proposal is of vital importance in order to analyze its attractiveness in economic terms and to evaluate the feasibility of its implementation.

The ultimate objective of the economic-financial analysis will be to analyze two important indicators: the Net Present Value (NPV) and the Internal Rate of Return (IRR), with the aim of classifying the project as a profitable and attractive investment proposal. Likewise, work will be done on preparing the cash flow for this proposal.

Next, a detailed study will be carried out of those items that must be considered when preparing the cash flow for the Base Project, in order to analyze the economic and financial profitability of the proposal.

Project life

Taking into account the scale of the project and using other similar transport plans as a reference, the useful life adopted for the project will be 40 years, while the loan repayment period will be 30 years, as will the amortization of the rolling stock.

It should also be noted that the timeline begins at the start of construction, with the eight-year execution phase included in the 40-year useful life. In other words, construction will take place from year 0 to year 8 inclusive, and only from year 9 onwards will the system enter into full operation (three lines in operation).

Investment plan (general)

The investment mechanism for this project could involve credit participation between the State (Municipal and/or Provincial) and a banking institution, in this case possibly the Central Bank of Japan, as this project has been declared to be of "national interest" by the Japanese Government. This type of private loan would be repaid through a system of fixed annual payments (French amortization system) with constant interest applied to the remaining debt, which is usually between 3 % and 6 %.

For this type of transportation investment, the State (Municipal and/or Provincial) would participate as the main shareholder in the project and grant the concession for the operation, administration, management, and implementation of the system to a concessionaire, which would also be responsible for maintenance, security, and other issues inherent to the system. The State (municipal and/or provincial) will ensure the repayment of the borrowed capital through an annual discount rate applied to the gross profit generated by the concessionaire operating the project, thus covering the risk assumed in exchange for this annual commission, while also expecting to benefit from the social profitability of the project. This rate will be referred to as the "Public Discount Rate" and will be a fixed annual percentage (2 %) applied to the net annual profit received by the concessionaire.

INVERSION			
DESCRIPCION	MONTO	UNIDAD	% DE LA INVERSION TOTAL
OBRA			
Infraestructura (columnas, pilares, etc.) + Fundaciones	$ 4.004.000	USD/KM	18,20%
Estaciones y Facilidades para ascenso / Descenso de pasajeros	$ 1.100.000	USD/KM	5,00%
Galpones de Mantenimiento y Centro de Control de Operaciones	$ 440.000	USD/KM	2,00%
Tasas y Contingencias	$ 462.000	USD/KM	2,1%
Total Obra	$ 6.006.000	USD/KM	**27,3%**
FLOTA			
Material Rodante	$ 990.000	USD/KM	4,5%
Sistemas de implementación	$ 15.004.000	USD/KM	68,2%
Total Flota	$ 15.994.000	USD/KM	**72,7%**
Monto total por kilometro	$ 22.000.000	USD	
MONTO TOTAL INVERSION	**$ 1.007.160.000**	**USD**	

Figure 6. General investment plan: amounts and percentages. Base Project

It is worth noting that the total estimated cost of 1 007 160 000 is 2,7 times lower than the estimated cost of the underground transport system, which was previously considered and presented, an aspect that definitely justifies discarding it and working on the monorail project.

The cost is analyzed per kilometer, as this allows for the apportionment of both the civil works cost and the technology implementation cost.

Public Investment

The investment of $1 007 160 000 will be made effective through a schedule of expenditures over the eight years planned for the construction of the three lines of the transport system. Disbursements must be scheduled according to the funding requirements for each of the eight years of the project's duration, eliminating the option of distributing them equally in eight equal sub-amounts, based on the timing, requirements, and tasks inherent to the work, as a preliminary stage to the system's implementation.

The conditions of the investment to be made by the State (Municipal and/or Provincial) are detailed below, together with the investment schedule:

- Total investment: USD 1 007 160 000 (dollars)
- Discount rate or public commission: 2 % per annum and constant, applied to the net annual profit received by the concessionaire throughout the useful life and operation of the project
- Term: 40 years (project lifetime)
- Payment method: Annual
- Investment schedule: 8 disbursements, one per year, for the first 8 years of the project, which is the construction phase. The amounts are detailed below:
    1. First year: USD 140 800 000 (13,98 % of the total investment).
    2. Second year: USD 140 800 000 (13,98 % of total investment).
    3. Third year: USD 114 400 000 (11,36 % of the total investment).
    4. Fourth year: USD 114 400 000 (11,36 % of the total investment).
    5. Fifth year: USD 124 190 000 (12,33 % of total investment).
    6. Sixth year: USD 124 190 000 (12,33 % of total investment).
    7. Seventh year: USD 124 190 000 (12,33 % of total investment).
    8. Eighth year: USD 124 190 000 (12,33 % of total investment).

Below is a breakdown of how the loan would be taken out by the State (Municipal and/or Provincial) to carry out this mobility project:

- Lending institution: Bank of Japan
- Type of loan: French system
- Total amount: USD 1 007 160 000 (dollars)
- Term: 30 years from the start of the project
- Interest rate: 3,2 % per annum
- Grace period: 8 years (duration of the project, during which no principal is paid, but interest on the debt is paid)
- Payment method and loan disbursement method:
    1. Interest: Paid from the outset on actual disbursements.
    2. Principal: Repayment begins in year 9.
    3. Disbursement: Annual staggered.

Special clarification is warranted regarding the entity that would grant the loan, as it mentions the Bank of Japan, which has expressed interest in financing the project if Hitachi Rail Systems Co. is the supplier of both the vehicles and the technology. The details of the repayment of the loan requested by the State (Municipal and/or Provincial).

Operation and maintenance (O&M) costs

The cost is analyzed per kilometer, as this allows both the cost of civil works and the implementation of technology to be apportioned.

Special mention should be made of the calculation of rolling stock depreciation. Production unit assets are depreciated using the straight-line method.

Año	Intereses	Amortización	Cuota total	Saldo
2021	$ 4.568.177,78	$ -	$ 4.568.177,78	$ 1.007.160.000,00
2022	$ 9.136.355,56	$ -	$ 9.136.355,56	$ 1.007.160.000,00
2023	$ 12.848.000,00	$ -	$ 12.848.000,00	$ 1.007.160.000,00
2024	$ 16.605.013,33	$ -	$ 16.605.013,33	$ 1.007.160.000,00
2025	$ 20.588.920,00	$ -	$ 20.588.920,00	$ 1.007.160.000,00
2026	$ 24.618.195,56	$ -	$ 24.618.195,56	$ 1.007.160.000,00
2027	$ 28.647.471,11	$ -	$ 28.647.471,11	$ 1.007.160.000,00
2028	$ 32.766.272,00	$ -	$ 32.766.272,00	$ 1.007.160.000,00
2029	$ 32.614.168,89	$ 4.507.190,95	$ 37.121.359,83	$ 1.002.652.809,05
2030	$ 32.407.361,00	$ 9.158.612,00	$ 41.565.973,00	$ 993.494.197,05
2031	$ 32.063.440,97	$ 13.113.780,23	$ 45.177.221,20	$ 980.380.416,83
2032	$ 31.637.112,01	$ 17.195.513,84	$ 48.832.625,84	$ 963.184.902,99
2033	$ 30.987.503,56	$ 21.721.253,54	$ 52.708.757,11	$ 941.463.649,44
2034	$ 30.237.227,89	$ 26.391.816,92	$ 56.629.044,82	$ 915.071.832,52
2035	$ 29.337.494,20	$ 31.211.838,33	$ 60.549.332,52	$ 883.859.994,19
2036	$ 28.283.519,81	$ 36.186.100,42	$ 64.469.620,23	$ 847.673.893,78
2037	$ 27.125.564,60	$ 37.344.055,63	$ 64.469.620,23	$ 810.329.838,15
2038	$ 25.930.554,82	$ 38.539.065,41	$ 64.469.620,23	$ 771.790.772,74
2039	$ 24.697.304,73	$ 39.772.315,50	$ 64.469.620,23	$ 732.018.457,23
2040	$ 23.424.590,63	$ 41.045.029,60	$ 64.469.620,23	$ 690.973.427,63
2041	$ 22.111.149,68	$ 42.358.470,55	$ 64.469.620,23	$ 648.614.957,09
2042	$ 20.755.678,63	$ 43.713.941,60	$ 64.469.620,23	$ 604.901.015,48
2043	$ 19.356.832,50	$ 45.112.787,74	$ 64.469.620,23	$ 559.788.227,75
2044	$ 17.913.223,29	$ 46.556.396,94	$ 64.469.620,23	$ 513.231.830,80
2045	$ 16.423.418,59	$ 48.046.201,65	$ 64.469.620,23	$ 465.185.629,16
2046	$ 14.885.940,13	$ 49.583.680,10	$ 64.469.620,23	$ 415.601.949,06
2047	$ 13.299.262,37	$ 51.170.357,86	$ 64.469.620,23	$ 364.431.591,20
2048	$ 11.661.810,92	$ 52.807.809,31	$ 64.469.620,23	$ 311.623.781,89
2049	$ 9.971.961,02	$ 54.497.659,21	$ 64.469.620,23	$ 257.126.122,68
2050	$ 8.228.035,93	$ 56.241.584,31	$ 64.469.620,23	$ 200.884.538,37
2051	$ 6.428.305,23	$ 49.028.524,06	$ 55.456.829,29	$ 151.856.014,31
2052	$ 4.859.392,46	$ 41.584.645,88	$ 46.444.038,34	$ 110.271.368,43
2053	$ 3.528.683,79	$ 35.592.461,91	$ 39.121.145,70	$ 74.678.906,52
2054	$ 2.389.725,01	$ 29.408.528,05	$ 31.798.253,05	$ 45.270.378,48
2055	$ 1.448.652,11	$ 22.400.037,68	$ 23.848.689,79	$ 22.870.340,80
2056	$ 731.850,91	$ 15.167.275,62	$ 15.899.126,53	$ 7.703.065,18
2057	$ 246.498,09	$ 7.703.065,18	$ 7.949.563,26	-$ 0,00
Total	**$ 672.764.669,08**	**$ 1.007.160.000,00**	**$ 1.679.924.669,08**	

Figure 7. Loan repayment schedule (amortization and interest)

COSTOS DE OPERACIÓN			
DESCRIPCION	MONTO	UNIDAD	% DEL COSTO TOTAL
Sueldos (Personal y Operarios)	7.452.984	USD / AÑO	41,23%
Mantenimiento & Gtos de Oficina & Administrativos	2.215.752	USD / AÑO	12,26%
Energia & Materiales & Diversos	5.035.800	USD / AÑO	27,86%
Impuestos	251.790	USD / AÑO	1,39%
Gtos Financieros	1.309.308	USD / AÑO	7,24%
Publicidad	100.716	USD / AÑO	0,56%
Mantenimiento Material Rodante	201.432	USD / AÑO	1,11%
Depreciacion Material Rodante	1.510.740	USD / AÑO	8,36%
TOTAL COSTOS POR AÑO	**18.078.522**	**USD / AÑO**	**100%**
TOTAL COSTOS POR MES	**1.506.544**	**USD / MES**	**100%**

Figure 8. Operation and maintenance (O&M) costs

$$D = (Vi) / VU$$

Donde:

D = Depreciación

Vi = Valor Inicial (Valor de Mercado del Bien)

VU = Vida Útil (30 años)

The calculation of annual depreciation for the project is shown in the following figure:

Descripción	45 unidades
Valor Inicial (usd)	$ 45.322.200,00
Vida Útil (años)	30
Depreciación Anual (usd)	$ 1.510.740,00

Figure 9. Annual depreciation of rolling stock

Revenue

Assumptions and general considerations

The project is scheduled to begin operations in 2023 with the inauguration of Line B, connecting the Kempes Stadium with the Civic Center. In 2025, Line C will begin operating, connecting the Catholic University of Córdoba with the city center, and in 2029, the system will be completed with the launch of Line A, linking the northern sector of the city with its central area.

Lineas A + B + C				
Año	% de cap. max.	Ingr. por vtas (usd)	Ingr. por publicidad (usd)	Total Ingr. (usd)
2021	0%	0	0	0
2022	0%	0	0	0
2023	70%	20.540.923	18.000	20.558.923
2024	80%	23.475.340	18.000	23.493.340
2025	90%	39.617.830	36.000	39.653.830
2026	95%	42.971.906	36.000	43.007.906
2027	95%	44.858.774	36.000	44.894.774
2028	95%	45.802.208	36.000	45.838.208
2029	95%	64.040.053	54.000	64.094.053
2030	95%	66.645.460	54.000	66.699.460
2031	95%	81.674.627	54.000	81.728.627
2032	95%	83.200.582	54.000	83.254.582
2033	95%	83.200.582	54.000	83.254.582
2034	95%	83.200.582	54.000	83.254.582
2035	95%	83.200.582	54.000	83.254.582
2036	95%	83.200.582	54.000	83.254.582
2037	95%	83.200.582	54.000	83.254.582
2038	95%	83.200.582	54.000	83.254.582
2039	95%	83.200.582	54.000	83.254.582
2040	95%	83.200.582	54.000	83.254.582
2041	95%	97.344.861	54.000	97.398.861
2042	95%	97.344.861	54.000	97.398.861
2043	95%	97.344.861	54.000	97.398.861
2044	95%	97.344.861	54.000	97.398.861
2045	95%	97.344.861	54.000	97.398.861
2046	95%	97.344.861	54.000	97.398.861
2047	95%	97.344.861	54.000	97.398.861
2048	95%	97.344.861	54.000	97.398.861
2049	95%	97.344.861	54.000	97.398.861
2050	95%	97.344.861	54.000	97.398.861
2051	95%	114.232.280	54.000	114.286.280
2052	95%	114.232.280	54.000	114.286.280
2053	95%	114.232.280	54.000	114.286.280
2054	95%	114.232.280	54.000	114.286.280
2055	95%	114.232.280	54.000	114.286.280
2056	95%	114.232.280	54.000	114.286.280
2057	95%	114.232.280	54.000	114.286.280
2058	95%	114.232.280	54.000	114.286.280
2059	95%	114.232.280	54.000	114.286.280
2060	95%	114.232.280	54.000	114.286.280

Figure 10. Revenue projection

Taking this as an example, the base project would initially have 14 cars (Line B) with a total maximum capacity to transport 80,395 passengers per day in each direction. This value is arrived at by multiplying the total maximum daily capacity to be transported by the 18-hour service time slot (with an assumed constant frequency from 6 a.m. to midnight). The service would operate on Saturdays, Sundays, and holidays, with reduced frequency compared to weekdays. Multiplying the maximum possible daily passenger capacity by 365 days per year gives a maximum annual capacity of 29 344 175 passengers per year. It should be noted that the highest ticket sales revenues would not be achieved in the first years of the project's life, so it is estimated that under normal economic and operating conditions, the monorail would operate at 95 % of its maximum installed capacity. Each line would start with 70 % of its maximum installed capacity in the first year of operation, 80 % in the second year, 90 % in the third year, and 95 % from the fourth year until the end of the project's useful life.

Projected Revenue

The ticket price is estimated to be USD 1; advertising revenue is also expected, which may be external or internal.

For this study, the service user will pay 100 % of the ticket price; it is up to the state to decide whether to subsidize part of this so that the cost to the passenger is lower.

Below is an estimate of projected revenue over 40 years, taking into account the start of operation of each line and its occupancy rate.

As can be seen in Table 6 and as indicated above, revenue (from sales and advertising) will begin to be received from 2023 onwards in the cash flow, the year in which Line B begins to operate.

Cash Flow

Cash flow refers to the movement of cash inflows and outflows over a given period. Cash flow is the net accumulation of liquid assets over a given period and is therefore an indicator of the liquidity of a company or project.

The study of cash flows can be used to:

- Analyze the viability of investment projects: calculating the Net Present Value (NPV) and the Internal Rate of Return (IRR).
- Analyze the profitability and growth of a business or project.
- Identify liquidity problems: cash flow analysis allows cash balances to be anticipated.

Using figure 11 as a reference, the cash flow for the 40-year life of the project is prepared.

Analysis of indicators for the project

NPV (Net Present Value) and IRR (Internal Rate of Return) are two financial indicators widely used in the economic and financial evaluation of projects, which ultimately allow the profitability of an investment project to be assessed.

Net Present Value (NPV)

Net Present Value (NPV) analysis is a tool that allows the present value of a given number of future cash flows, previously generated by an investment, to be calculated.

NPV also helps to determine which project is the most profitable among several investment options.

This financial evaluation tool makes it possible to determine whether the project generates a rate of return higher than a predetermined rate used to update cash flows. If not, the investment will have a negative NPV and the project should be rejected from a financial point of view.

The methodology consists of discounting all future cash flows from the project to the present (discounting at a discount rate). The initial investment is subtracted from this value, so that the value obtained is the net present value of the project.

The discount rate (k) used to update the projected cash flows is the opportunity cost, return, or minimum profitability expected to be earned. For this project, it is assumed that the opportunity rate will be 5 %, the standard nominal value for investments in dollars at the regional level.

If the NPV is greater than 0, the investment would yield a profit, so the project could be accepted. If the result of this indicator is less than 0, the investment would not yield a profit, so the project could be rejected. If the NPV is equal to zero, the investment would produce neither profit nor loss, so the decision to accept or reject a project should be based on other criteria (social profitability, etc.).

The total estimated investment for the monorail is USD 1 007 160 000, which is 2,7 times less than the investment related to the subway system, which was previously considered and presented. This is an important aspect that justifies choosing the monorail project.

Based on the information in the preceding tables and the available information, the NPV calculation for the

Elevated Monorail Project is: NPV: USD 97 699 063

The project in question, according to the acceptance criteria for NPV outlined above, can be accepted.

Lineas A + B + C			
Año	Ingr. por vtas (usd)	Ingr. por publicidad (usd)	Total de Ingr.(usd)
2021	0	0	0
2022	0	0	0
2023	20.540.923	18.000	20.558.923
2024	23.475.340	18.000	23.493.340
2025	39.617.830	36.000	39.653.830
2026	42.971.906	36.000	43.007.906
2027	44.858.774	36.000	44.894.774
2028	45.802.208	36.000	45.838.208
2029	64.040.053	54.000	64.094.053
2030	66.645.460	54.000	66.699.460
2031	81.674.627	54.000	81.728.627
2032	83.200.582	54.000	83.254.582
2033	83.200.582	54.000	83.254.582
2034	83.200.582	54.000	83.254.582
2035	83.200.582	54.000	83.254.582
2036	83.200.582	54.000	83.254.582
2037	83.200.582	54.000	83.254.582
2038	83.200.582	54.000	83.254.582
2039	83.200.582	54.000	83.254.582
2040	83.200.582	54.000	83.254.582
2041	97.344.861	54.000	97.398.861
2042	97.344.861	54.000	97.398.861
2043	97.344.861	54.000	97.398.861
2044	97.344.861	54.000	97.398.861
2045	97.344.861	54.000	97.398.861
2046	97.344.861	54.000	97.398.861
2047	97.344.861	54.000	97.398.861
2048	97.344.861	54.000	97.398.861
2049	97.344.861	54.000	97.398.861
2050	97.344.861	54.000	97.398.861
2051	114.232.280	54.000	114.286.280
2052	114.232.280	54.000	114.286.280
2053	114.232.280	54.000	114.286.280
2054	114.232.280	54.000	114.286.280
2055	114.232.280	54.000	114.286.280
2056	114.232.280	54.000	114.286.280
2057	114.232.280	54.000	114.286.280
2058	114.232.280	54.000	114.286.280
2059	114.232.280	54.000	114.286.280
2060	114.232.280	54.000	114.286.280

Figure 11. Cash flow - projected income in dollars

Egresos Netos (Usd)						
Año	Préstamo recibido	Inversiones	Costos totales (O&M)	Intereses Préstamo	Amortización Préstamo	Total Egresos
2021	-$ 140.800.000,00	$ 140.800.000,00	$ -	$ 4.568.177,78	$ -	$ 4.568.177,78
2022	-$ 140.800.000,00	$ 140.800.000,00	$ -	$ 9.136.355,56	$ -	$ 9.136.355,56
2023	-$ 114.400.000,00	$ 114.400.000,00	$ 5.054.720,00	$ 12.848.000,00	$ -	$ 17.902.720,00
2024	-$ 114.400.000,00	$ 114.400.000,00	$ 5.054.720,00	$ 16.605.013,33	$ -	$ 21.659.733,33
2025	-$ 124.190.000,00	$ 124.190.000,00	$ 9.161.680,00	$ 20.588.920,00	$ -	$ 29.750.600,00
2026	-$ 124.190.000,00	$ 124.190.000,00	$ 9.161.680,00	$ 24.618.195,56	$ -	$ 33.779.875,56
2027	-$ 124.190.000,00	$ 124.190.000,00	$ 9.161.680,00	$ 28.647.471,11	$ -	$ 37.809.151,11
2028	-$ 124.190.000,00	$ 124.190.000,00	$ 9.161.680,00	$ 32.766.272,00	$ -	$ 41.927.952,00
2029			$ 18.078.522,00	$ 32.614.168,89	$ 4.507.190,95	$ 55.199.881,83
2030			$ 18.078.522,00	$ 32.407.361,00	$ 9.158.612,00	$ 59.644.495,00
2031			$ 18.078.522,00	$ 32.063.440,97	$ 13.113.780,23	$ 63.255.743,20
2032			$ 18.078.522,00	$ 31.637.112,01	$ 17.195.513,84	$ 66.911.147,84
2033			$ 18.078.522,00	$ 30.987.503,56	$ 21.721.253,54	$ 70.787.279,11
2034			$ 18.078.522,00	$ 30.237.227,89	$ 26.391.816,92	$ 74.707.566,82
2035			$ 18.078.522,00	$ 29.337.494,20	$ 31.211.838,33	$ 78.627.854,52
2036			$ 18.078.522,00	$ 28.283.519,81	$ 36.186.100,42	$ 82.548.142,23
2037			$ 18.078.522,00	$ 27.125.564,60	$ 37.344.055,63	$ 82.548.142,23
2038			$ 18.078.522,00	$ 25.930.554,82	$ 38.539.065,41	$ 82.548.142,23
2039			$ 18.078.522,00	$ 24.697.304,73	$ 39.772.315,50	$ 82.548.142,23
2040			$ 18.078.522,00	$ 23.424.590,63	$ 41.045.029,60	$ 82.548.142,23
2041			$ 18.078.522,00	$ 22.111.149,68	$ 42.358.470,55	$ 82.548.142,23
2042			$ 18.078.522,00	$ 20.755.678,63	$ 43.713.941,60	$ 82.548.142,23
2043			$ 18.078.522,00	$ 19.356.832,50	$ 45.112.787,74	$ 82.548.142,23
2044			$ 18.078.522,00	$ 17.913.223,29	$ 46.556.396,94	$ 82.548.142,23
2045			$ 18.078.522,00	$ 16.423.418,59	$ 48.046.201,65	$ 82.548.142,23
2046			$ 18.078.522,00	$ 14.885.940,13	$ 49.583.680,10	$ 82.548.142,23
2047			$ 18.078.522,00	$ 13.299.262,37	$ 51.170.357,86	$ 82.548.142,23
2048			$ 18.078.522,00	$ 11.661.810,92	$ 52.807.809,31	$ 82.548.142,23
2049			$ 18.078.522,00	$ 9.971.961,02	$ 54.497.659,21	$ 82.548.142,23
2050			$ 18.078.522,00	$ 8.228.035,93	$ 56.241.584,31	$ 82.548.142,23
2051			$ 16.567.782,00	$ 6.428.305,23	$ 49.028.524,06	$ 72.024.611,29
2052			$ 16.567.782,00	$ 4.859.392,46	$ 41.584.645,88	$ 63.011.820,34
2053			$ 16.567.782,00	$ 3.528.683,79	$ 35.592.461,91	$ 55.688.927,70
2054			$ 16.567.782,00	$ 2.389.725,01	$ 29.408.528,05	$ 48.366.035,05
2055			$ 16.567.782,00	$ 1.448.652,11	$ 22.400.037,68	$ 40.416.471,79
2056			$ 16.567.782,00	$ 731.850,91	$ 15.167.275,62	$ 32.466.908,53
2057			$ 16.567.782,00	$ 246.498,09	$ 7.703.065,18	$ 24.517.345,26
2058			$ 16.567.782,00			$ 16.567.782,00
2059			$ 16.567.782,00			$ 16.567.782,00
2060			$ 16.567.782,00			$ 16.567.782,00

Figure 12. Cash flow - projected expenses in dollars

https://doi.org/10.56294/tms202230 ISSN: 3072-8398

Año	Total Egresos	Total de Ingr.	Flujo de Fondo Bruto
2021	$ 4.568.177,78	$ -	-$ 4.568.177,78
2022	$ 9.136.355,56	$ -	-$ 9.136.355,56
2023	$ 17.902.720,00	$ 20.558.922,50	$ 2.656.202,50
2024	$ 21.659.733,33	$ 23.493.340,00	$ 1.833.606,67
2025	$ 29.750.600,00	$ 39.653.830,00	$ 9.903.230,00
2026	$ 33.779.875,56	$ 43.007.906,25	$ 9.228.030,69
2027	$ 37.809.151,11	$ 44.894.773,75	$ 7.085.622,64
2028	$ 41.927.952,00	$ 45.838.207,50	$ 3.910.255,50
2029	$ 55.199.881,83	$ 64.094.053,00	$ 8.894.171,17
2030	$ 59.644.495,00	$ 66.699.459,50	$ 7.054.964,50
2031	$ 63.255.743,20	$ 81.728.626,50	$ 18.472.883,30
2032	$ 66.911.147,84	$ 83.254.582,00	$ 16.343.434,16
2033	$ 70.787.279,11	$ 83.254.582,00	$ 12.467.302,89
2034	$ 74.707.566,82	$ 83.254.582,00	$ 8.547.015,18
2035	$ 78.627.854,52	$ 83.254.582,00	$ 4.626.727,48
2036	$ 82.548.142,23	$ 83.254.582,00	$ 706.439,77
2037	$ 82.548.142,23	$ 83.254.582,00	$ 706.439,77
2038	$ 82.548.142,23	$ 83.254.582,00	$ 706.439,77
2039	$ 82.548.142,23	$ 83.254.582,00	$ 706.439,77
2040	$ 82.548.142,23	$ 83.254.582,00	$ 706.439,77
2041	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2042	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2043	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2044	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2045	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2046	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2047	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2048	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2049	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2050	$ 82.548.142,23	$ 97.398.861,25	$ 14.850.719,02
2051	$ 72.024.611,29	$ 114.286.279,75	$ 42.261.668,46
2052	$ 63.011.820,34	$ 114.286.279,75	$ 51.274.459,41
2053	$ 55.688.927,70	$ 114.286.279,75	$ 58.597.352,05
2054	$ 48.366.035,05	$ 114.286.279,75	$ 65.920.244,70
2055	$ 40.416.471,79	$ 114.286.279,75	$ 73.869.807,96
2056	$ 32.466.908,53	$ 114.286.279,75	$ 81.819.371,22
2057	$ 24.517.345,26	$ 114.286.279,75	$ 89.768.934,49
2058	$ 16.567.782,00	$ 114.286.279,75	$ 97.718.497,75
2059	$ 16.567.782,00	$ 114.286.279,75	$ 97.718.497,75
2060	$ 16.567.782,00	$ 114.286.279,75	$ 97.718.497,75

Figure 13. Gross fund flow in dollars

The formula for calculating gross cash flow is as follows:

$$FFB = Ti - Te$$

Donde:

FFB = Utilidad Bruta

Ti = Total de ingresos

Te = Total de egresos

The formula for obtaining the NPV of a project is:

$$\text{VAN} = \sum_{t=1}^{n} \frac{V_t}{(1+k)^t} - I_0$$

Siendo:

Vt = Monto Neto del Flujo de Caja en período t

Io = Monto de la Inversión Inicial (Pública + Privada)

k = Tasa de Descuento

n = 30 años, la vida útil del proyecto

t = Año, período de evaluación

Internal Rate of Return (IRR)

The IRR is the discount rate that eliminates the difference between the present value of the net cash flow and the initial investment. In short, it is the discount rate at which the NPV is equal to zero.

The Internal Rate of Return (IRR) of a project is a reliable indicator of its profitability. In other words, the higher the IRR, the higher the profitability.

The IRR is calculated using the following formula:

$$VAN = \sum_{t=1}^{n} \frac{V_F t}{(1+TIR)^t} - Io = 0$$

Donde:

VFt = Monto del Flujo de Caja en el período t

Io = Monto de la Inversión Inicial (Pública + Privada)

n = 30 años, la vida útil del proyecto

t = Año, período de evaluación

Solving for IRR in the equation gives its value, which must be compared with the assumed discount rate (k), or opportunity cost rate. The general criterion for determining whether a project is worthwhile is as follows:

If the IRR is greater than or equal to the discount rate, the project should be accepted. The reason is that the project provides a higher return than the minimum required return (the opportunity cost).

If the IRR is less than or equal to the discount rate, the project should be rejected. The reason is that the project provides a lower return than the minimum required return.

The results of the IRR indicator for the Elevated Monorail Project are detailed below: IRR: 43,45 %

The project in question can be accepted according to the IRR acceptance criteria outlined above.

Sensitivity Analysis

The parameters used to calculate the project's future cash flow are very sensitive and have a significant financial impact on the projections made, the economic and financial analysis carried out, and the decisions to be made about the monorail project formulated in this thesis.

All this without taking into account other important variables (environmental, social, better services to the population, etc.) that have a positive impact if the investment project formulated in this thesis is implemented.

Performing a financial sensitivity analysis on the project's future cash flow, modifying the sensitive variables that impact the projections made at once, the following emerges:

Table 1. Reduction in ticket price from USD 1 to USD 0,85

Cost of Capital Rate	5,00 %
NPV	-20 546 479
IRR	3,12 %
Public discount rate	2,00
Loan rate received	3,20

In this case, according to the acceptance criteria outlined above, the investment project would show a negative NPV of USD –20,5 million, meaning that from a purely financial standpoint, this project would not be viable.

Table 2. Increase in the cost of capital rate from 5 % per annum to 43,45 % per annum

Cost of capital rate	43,45 %
NPV	-0
IRR	43,45 %
Public Discount Rate	2,00
Loan rate received	3,20

In this case, since the investment project has a cost of capital rate of 43,45 % per annum, equivalent to the IRR, and in accordance with the acceptance criteria set out above, it would show a NPV equal to zero, which would be at the financial break-even point.

Table 3. Sharp increase in the public discount rate from 2 % per annum to 26 % per annum

Cost of Capital Rate	5,00 %
NPV	265 475
IRR	19,71 %
Public Discount Rate	26,00 %
Interest rate on loan received	3,20 %

In this case, since the Investment Project has a Public Discount Rate of 26 % per annum, which is 13 times higher than the rate presented in the thesis, according to the acceptance criteria set out above, it would show a slightly positive NPV of USD 0,27 million. Therefore, this project is strongly affected and, from a purely financial point of view, would be barely viable.

Table 4. Increase in the loan rate received from 3,20 % per annum to 4,60 % per annum

Rate Cost of Capital	5,00 %
NPV	-4 669 851
IRR	4,69
Public Discount Rate	2,00
Loan rate received	4,60

In this case, since the investment project has a loan rate of 4,60 % per annum (i.e., 44 % higher than the loan rate set out in the thesis), according to the acceptance criteria set out above, it would show a negative NPV of USD –4,7 million. Therefore, from a purely financial point of view, this project would not be viable.

CONCLUSIONS

In terms of infrastructure, it can be inferred that the elevated monorail does not have a significant impact on the city's normal activities during its construction phase. Similarly, the effects or externalities of the system's operation are not negative for the urban environment in which it is located.

With regard to the economic and financial aspects, this project is completely viable from a financial point of view, even if an international loan has to be taken out (with a term of thirty years—after an eight-year grace period—considering the year in which each part of the financing is received), seeking to ensure that the monorail, through the value of the ticket, can cover both its construction costs and its operating and financing costs.

The NPV of the Monorail project is positive at USD 97 699 063, adding value to the total investment of USD 1 007 160 000. Therefore, from a financial standpoint, the project should be accepted.

The IRR of the Monorail project is 43,45 %, which is higher than its cost of capital. Therefore, in line with the NPV criterion, the project should be accepted from a financial standpoint, as it generates a higher return than that required by investors.

From a commercial standpoint, the entry of the monorail into the public transport market will bring about a

change from the current monopolistic bus system (with three companies operating 100 % of the market) to an oligopolistic system, due to the incorporation of this alternative and complementary system.

The concentration of the current urban passenger system with three service providers discourages the possible entry of new competitors into the market, with unclear rules of operation by the enforcement authority, thus raising barriers to entry.

Therefore, the incorporation of the monorail into part of the routes currently served by buses will gradually reduce the current lack of commercial competition, as these bus companies are assigned different routes and do not compete with each other.

The introduction of the monorail will, over time, bring improvements to the urban passenger transport system, with more options for users, shorter travel and waiting times, better service, and, in the future, lower relative ticket costs due to competition between the two urban transport systems, which demand itself will refine, all regardless of the subsidy scheme in place to finance transport.

In conclusion, as mentioned in the article "Conceptualization of social profitability in the field of public transport," the importance of having a quality public transport system cannot be analyzed solely from an economic and financial perspective, but also from a social perspective when it is stated that "The social mission of public transport makes the analysis of the social profitability linked to its investments of significant interest, not only as a justification for the amount of resources allocated to finance them, but also in terms of the interest in assessing and quantifying the fulfillment of that social mission."

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FINANCING

None.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

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