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Estudio de alternativas para la implantación de un sistema de tren-tranvía en el área metropolitana de Santander

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Resumen

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Las urbes de tamaño mediano se enfrentan a retos de movilidad que exigen soluciones innovadoras y eficientes. En este sentido, los sistemas de tren-tranvía representan una solución que podría dar respuesta a estos problemas, especialmente en aquellos territorios en los que la infraestructura ferroviaria existente presenta un desarrollo importante y puede servir como punto de partida. El proyecto de tren-tranvía en Santander ilustra cómo esta fórmula puede transformar el transporte público en una región en la que la infraestructura ferroviaria actual, si bien con una cobertura geográfica amplia a nivel regional, no presta un servicio adecuado a zonas urbanas densamente pobladas y a otras áreas de interés claves. El objetivo principal de este estudio es evaluar la capacidad de los trenes-tranvía para aumentar significativamente el número de usuarios de los modos ferroviarios y mejorar la cuota modal del transporte público en áreas metropolitanas de tamaño intermedio.

El estudio examina varias alternativas de trazado y escenarios operativos para integrar un sistema de tren-tranvía en la red de transporte metropolitano de Santander. Utilizando una metodología exhaustiva, que incluye una encuesta de preferencias declaradas y la modelización en PTV Visum para estimar la demanda potencial del nuevo modo, se analizaron varios escenarios en una evaluación multicriterio en términos de requisitos de infraestructura, atractividad del nuevo modo, sostenibilidad medioambiental y financiera, e impacto social y urbano, para determinar la solución más conveniente.

La alternativa propuesta incluye la construcción de un nuevo trazado tranviario conectado con la línea ferroviaria Santander-Oviedo en las inmediaciones del Parque Tecnológico y Científico de Cantabria (PCTCAN) y que se extendería hasta el campus de Las Llamas de la Universidad de Cantabria, a la altura del Edificio Interfacultativo. El ramal, de 7,015 kilómetros de vía doble, daría servicio además a los barrios de El Alisal, La Albericia y el eje de la Avenida de los Castros. Adicionalmente, esta solución contempla la implementación de un ramal en vía única entre la línea Santander-Bilbao y el Aeropuerto Severiano Ballesteros, de 1,201 kilómetros, y un baipás entre las dos líneas ferroviarias de ancho métrico mencionadas previamente.

Los resultados muestran que los trenes-tranvía ofrecen una oportunidad alentadora para impulsar el uso del transporte público en núcleos urbanos medianos, con inversiones de capital mucho menores que las necesarias para soluciones de mayor capacidad, como un sistema de metro. Al mismo tiempo, los trenes-tranvía contribuyen a la descarbonización del transporte y a la reducción de la congestión de la red de carreteras, con reducciones previstas del tráfico rodado que oscilan entre el 0,5% y el 4,1%, según el escenario, y aumentos del uso del transporte público que van del 7,7% al 57,8%.

Por último, el estudio destaca la importancia de una buena planificación en el diseño de las infraestructuras para maximizar la penetración geográfica y el acceso a los centros de empleo y servicios. Con una adecuada tarificación, los trenes-tranvía similares a esta propuesta para Santander pueden alcanzar tasas de recuperación de costes superiores al 40%, claramente por encima de las cifras del servicio ferroviario actual, facilitando la sostenibilidad financiera a largo plazo.

Abstract

Title:	Study of alternatives for the implementation of a tram-train system in the metropolitan area of Santander
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Medium-sized urban areas face mobility challenges that require innovative and efficient solutions. In this regard, tram-train systems represent a potential solution to these problems, especially in those territories where the existing railway infrastructure is significantly developed and can thus serve as a starting point. This tram-train project in Santander illustrates how this approach can transform public transport in a region where the existing railway infrastructure, although with a vast geographic coverage at the metropolitan level, does not provide adequate service to densely populated urban areas and other key areas of interest. The primary objective of this study is to evaluate the capacity of tram-trains to significantly increase the ridership of rail-based modes and improve public transport's modal share in intermediate metropolitan areas.

The study examines various alignment alternatives and operational scenarios for integrating a tram-train system into Santander's metropolitan transport network. Using a comprehensive methodology, including a stated-preference survey and modeling in PTV Visum to estimate potential tram-train demand, several scenarios were evaluated in a multi-criteria analysis in terms of infrastructure requirements, mode attractiveness, environmental and financial sustainability, and social and urban impact, to determine the most convenient solution.

The proposal involves the construction of a new tramway section connecting with the Santander-Oviedo railway line in the vicinity of the *Parque Tecnológico y Científico de Cantabria* (PCTCAN) and extending to the University of Cantabria's Las Llamas campus, near the *Interfacultativo* Building. Additionally, this solution contemplates the implementation of a 1.201-kilometer single-track branch between the Santander-Bilbao railway line and the Severiano Ballesteros Airport, and a bypass between the two metric gauge railway lines mentioned above.

The results show that tram-trains offer a promising opportunity to boost public transport use in intermediate urban areas, with much lower capital investments than those required for higher capacity solutions, such a metro system. In addition, tram-trains contribute to the decarbonization of transport and the reduction of road congestion, with expected reductions in car traffic ranging from 0.5% to 4.1%, depending on the scenario, and increases in public transport use ranging from 7.7% to 57.8%.

Finally, the study highlights the importance of well-planned infrastructure design to maximize geographic coverage and access to employment and service centers. With proper fare planning, tram-trains similar to this proposal for Santander can achieve cost recovery rates above 40%, facilitating financial sustainability in the long term.

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1. Introduction

The city of Santander, in northern Spain, is surrounded to the north, east and south by the Cantabrian Sea. This feature, combined with the complex topography over which the city is erected, explains why the metropolitan area's high-capacity transport network –which includes the suburban railway network, the suburban bus network, and the S-10, S-20, S-30 and A-67 highways, covering a population of over 300,000– only reaches the city's south-western neighborhoods, leaving aside Santander's Ensanche, eastern and northern districts.

In fact, those who get to Santander from the surrounding towns by public transport find that all routes end in the surroundings of the Plaza de las Estaciones. A few meters from the City Hall, this area is certainly close to the city center. However, it is several kilometers from major attractors and generators of trips: educational facilities such as the University of Cantabria, tourist areas such as the Sardinero beach, residential areas such as Valdenoja or Avenida de los Castros, or sports venues such as the Campos de Sport or the Palacio de Deportes. When heading to one of these areas, one almost inevitably must take a second transportation mode, often the municipal bus service, to reach their final destination.

In a metropolitan area of this scale, the fact of having to make transfers in public transport is quite penalizing since, unless perfectly coordinated, this will imply a substantial increase in travel time with respect to the total travel time by private vehicle. For instance, a 7-minute transfer (including walking and waiting times), which is quite realistic or even ambitious in the case of Santander, for a journey that takes 15 minutes by car, makes public transport a much less attractive option.

Given this situation, most of the trips between the metropolitan area and the city are made in private vehicles. This, combined with the poor road network configuration, leads to frequent congestion during peak hours at the main accesses and exits of the city. As in the case of public transport, the high-capacity road network only serves the areas to the south and west of the city, with just two main accesses (S-20 to the west and S-10 to the southwest). Such lack of redundancy means that, at the slightest incident in the network, kilometric traffic jams are produced, which affect thousands of citizens.

The solution is to take metropolitan public transport routes to where those arriving from outside the city actually travel, whether they are residents of neighboring cities (more than 110,000 on the Santander-Torrelavega corridor and more than 50,000 on the Santander Bay corridor) or tourists arriving from the airport (more than 1.24 million in 2023). Allowing people to get directly to their destination without the need to transfer to another line will make public transport a much more attractive option. In fact, public transport's modal share in Santander was 10% in 2015, which leaves enough room for improvement.

One of the backbones of the existing metropolitan transport system is the commuter rail network, which comprises three lines (one in Iberian gauge and two in metric gauge). This network is reasonably well developed, with stations in the main urban centers of the metropolitan area, including several in the southwest neighborhoods of Santander (4 stations in the case of the metric-gauge network, 3 stations in the case of the Iberian-gauge network).

Regarding metric gauge lines, this network is structured around two lines that serve the region's most dynamic axes: Santander-Santa Cruz de Bezana-Torrelavega and Santander-Camargo-Astillero. This circumstance, combined with the fact that the metric gauge allows for easier integration into the urban landscape (smaller train dimensions, tighter permitted radii, etc.), represents a major opportunity for the creation of a tram-train system based on the existing metric-gauge network.

In addition, the regional airport, which handled over 1.2 million passengers in 2023, is served by a single bus line connecting it to the city's main bus and train station. It has no direct connection to the rail network, even though the Santander-Astillero-Liérganes line is only 800 meters from the airport. The tram-train could help resolve this situation by creating a branch line to serve the airport.

Overall, Santander's metropolitan transport network has one major shortcoming: the disconnection of the north and east of the city from the rest of the metropolitan area, including the regional airport. In the case of public transport, this network reaches only as far as the *Plaza de las Estaciones* (Stations Square), located near the city's south-western gateway, far from the residential areas in the north and east of the city and more than 3-4 km from the main focal points, such as the Sardinero beaches, the eponymous stadium and the university, among others; in the case of private transport, the high-capacity highways are even further away from the city's main hubs. The aim of this project is therefore to provide a high-capacity mass transit solution capable of putting an end to this problem, in the form of a tram-train.

In order to develop a solution, it is first necessary to propose a series of alternatives for the tramway layout in the city of Santander. To this end, the main areas of interest, potential generators and attractors of displacements were analyzed: offices, commercial areas, tourist centers, etc. Based on the urban structure and these zones of interest, three route alternatives were defined.

To define the potential for attracting travelers to each of these alternatives, a Visum PTV model of the Santander metropolitan area was utilized. For each route alternative, a series of scenarios were proposed in which tram-train lines, fares and services varied. The modal split was calculated based on a Logit utility model for car, bus and tram-train modes. This model was obtained from a stated preference survey, which received responses from a sample of 208 people.

Since a total of 27 scenarios were simulated, a first filtering of the scenarios was conducted. The most efficient scenarios in terms of passenger attraction were selected, i.e., those that generated the highest number of tram-train users in relation to the cost they entailed. For this calculation, infrastructure investment, rolling stock acquisition cost, and operating costs were considered.

Finally, to determine the most appropriate solution to improve the transportation system of the Santander metropolitan area, a multi-criteria analysis was carried out. This assessment included indicators related to the tram-train system's alignment, the new mode's attractiveness, its demand and environmental sustainability, financial sustainability, and social and urban impact.

The solution identified as the most appropriate is the following: (i) in terms of infrastructure, it involves the construction of a tramway section in the city of Santander from the Santander-Cabezón de la Sal line –in the vicinity of the PCTCAN– to the intersection of Avenida de los Castros with Calle Honduras next to the Interfacultativo building, a tramway branch from Valle Real station –on the Santander-Liérganes line– to the Airport, and a bypass between the Santander-Cabezón and Santander-Liérganes lines; (ii) in terms of service operation, the network would have 4 types of service –Santander-Bezana-Cabezón, Santander-Airport-Maliaño-Liérganes, Interfacultativo-Bezana-Cabezón and Interfacultativo-Maliaño-Liérganes– each with a 60-minute frequency.

This proposal has an estimated potential demand ranging between 7,003 (for a 1.65€ fare) and 8,393 (for a 0.66€ fare) daily tram-train passengers. It requires an investment in infrastructure of approximately 151,716,513€ and a total cost over the first 30 years of operation of 571,471,565€. It is the option with the lowest total cost and the highest cost recovery ratio –between 20.1% and 41.9%, depending on the fare– of those evaluated. It is therefore a proposal capable of attracting a significant number of daily trips to public transport despite having the lowest total cost and the best cost recovery ratios, which is critical to ensure the sustainability of the service in the long term.

2. Methodology

The methodology followed consists of 5 main stages: (i) study of the existing railway infrastructure and urban environment, (ii) definition of route alternatives for the new infrastructure, (iii) development of a stated-preference survey to obtain a utility model, (iv) modeling in PTV Visum of different tram-train operation scenarios for each route alternative to estimate their potential passenger demand, (v) pre-filtering of scenarios and subsequent multi-criteria evaluation to determine the most appropriate solution.

The main challenge encountered corresponds to the PTV Visum tram-train system modeling stage and is directly related to the inherent nature of the system. The versatility of this transport mode lies in the combination of tramway sections in urban environments and rail sections in interurban areas. Macroscopic modeling thus requires a differentiated treatment of these two types of environments to avoid an excessive computational burden and to prevent operating on an overly complex model, which would otherwise have an unnecessarily high level of detail in a regional-scale geographic extension.

In this regard, a model with a zoning and transport network codification at the highest level of detail in the city of Santander and adjacent areas adjacent to the airport, which are the locations where new infrastructures are proposed, has been utilized. Moving away from the city along the two existing narrow-gauge railway corridors, the zoning is organized into larger partitions, structured around the main transport axes (highways A-67, S-10, etc.) and the transport network is coded at a lower level of detail. From the stations of Bezana (Santander-Cabezón line) and Maliaño (Santander-Liérganes), all the transport demand corresponding to the rest of the two corridors is respectively consolidated in two nodes, as external zones.

Consequently, the use of the utility model developed from the stated-preference survey, which includes variables such as access time to the public transport stop, is restricted to the geographic area modeled with a higher level of detail. In the remaining zones, a simplified impedance model is applied. Although its accuracy has been verified by cross-checking it the baseline scenario with actual ridership data, it is not sensitive to variations in the fare, which, it should be mentioned, partially affects the results obtained.

Moreover, the origin-destination matrices available as input data at the time of modeling did not specify the mode breakdown of public transport trips. Therefore, all public transport trips within the city of Santander in the OD matrices were considered as bus trips and all external public transport trips were considered as tram-train trips. This assumption was also verified by comparing the baseline scenario with actual ridership data.

Several additional considerations are shown below.

- The existing urban bus lines have not been modified, as this was considered beyond the scope of the study.
- When, in subsequent sections, the terms Bezana line and Maliaño line are used, it is because the network coding in PTV Visum only extends to those two stations, but the tram-train services would run all the way to Cabezón de la Sal and Liérganes, respectively.
- Operating costs are calculated considering the operation of 300 working days, as an approximation to consider a lower frequency on weekends and holidays, since the demand modeling has been conducted for an average business day.

3. Tram-train

A tram-train is a light rail vehicle which can operate on conventional railway tracks –especially in interurban areas– and tramway sections –mainly in urban zones. It uses vehicles that are an intermediate between a tram and a train, capable of traveling on both types of tracks. They thus have the advantage of combining the great urban accessibility of tramways with the higher travel speeds of conventional trains.

As a result of this hybrid approach, passengers can travel from urban centers directly to suburban areas without the need to change modes of transport. This improves passenger experience and reduces travel time. By being able to partially use existing rail infrastructure, typically on interurban sections, tram-train systems can reduce the need to build new infrastructure, which saves costs and minimizes transport disruption.

On the one hand, tram-trains have a higher passenger capacity than traditional tramways and can run at higher speeds, which makes them attractive for longer journeys. On the other hand, compared to conventional commuter trains, they can negotiate sharper curves and steeper gradients typical of urban settings. This, together with their smaller vehicle dimensions, allows them to penetrate city centers more efficiently than conventional trains.

Since the opening of the Karlsruhe Stadtbahn (Germany) in 1992 (Naegeli, Weidmann, & Nash, 2012) (Novales, Orro, & Rodríguez Bugarin, 2002), the number of tram-train systems in operation has been steadily increasing. Most tram-train systems in Europe have been implemented in cities ranging between 100,000 and 350,000 inhabitants (Metelka, 2023). Santander, with 172,726 inhabitants in 2023 (INE, 2023), is clearly within the typical population range for this type of transport system.

In the case of Spain, the example *par excellence* is the Alicante Tram, inaugurated in 2003. Initially, it was opened using the old metric gauge network of Ferrocarrils de la Generalitat Valenciana. Subsequently, it lost its "pure" tram-train characteristic (i.e., tracks shared with conventional trains) as a result of the evolution of the railway network. However, the system continues to operate in a quasi-tram-train manner, as the tram-train runs partly on railway tracks with a railway signaling system and other railway equipment (Novales, Cerezo, & Ortega, 2013). In fact, it currently combines tramway-type, railway-type and even a quasi-subway-type section in the center of Alicante.

Since then, new systems of this type have been proposed in other cities. The only case in which it came into service is the Metropolitan Tramway of the Bay of Cadiz, which started operations in 2022. It uses tramway sections in the cities of Chiclana de la Frontera and San Fernando, which are combined with the railway section linking the latter city with Cadiz, where it shares the route with commuter, medium and long-distance trains, including freight.

Although experience already shows numerous success stories, tram-train remains a mode with a limited number of networks in operation. Differences in track gauge, safety and signaling systems, electrification, shock resistance and driving conditions between rail and tram networks are well known, making the implementation of tram-train networks, which have to combine both, more complicated (Gurri et al., 2023). It is therefore important to develop an unambiguous regulation that reconciles both systems to implement networks of this kind.

Figure 1: Tranvía Metropolitano de la Bahía de Cádiz (Diario de Cádiz, 2023)

4. Study of route alternatives

4.1. Existing infrastructure

The proposed new tram-train service will partially use the metric gauge rail network currently managed by Administrador de Infraestructuras Ferroviarias and operated by Renfe Operadora. The two metric gauge lines are the C-2 (Santander-Cabezón de la Sal) and C-3 (Santander-Liérganes) of Renfe Cercanías. Both originate at the Santander terminal station and are fully electrified.

The first, 45.6 km long and comprising 23 stations, is double track for the first 26 km and single track for the rest of the route. It connects the regional capital with the most important municipalities to the west, including Torrelavega (51,361 inhabitants), Piélagos (26,605 inhabitants) and Santa Cruz de Bezana (13,689 inhabitants), among others. The second, of 26.9 km and 14 stations, serves the municipalities south of the arc of the Bay of Santander, including Camargo (30,349 inhabitants) El Astillero (18,220 inhabitants) and Medio Cudeyo (7,696 inhabitants).

Most of the stations in both cases are located close to the centers of the urban areas they serve, so it is not considered necessary to adapt the existing network beyond the renovation of the railway superstructure, which in many cases is obsolete. In this regard, a large proportion of the citizens in the metropolitan area's municipalities live and/or work within walking distance of a railway station, which facilitates the goal sought with the tram-train system. Therefore, it would only be necessary to ensure that this transport system allows them to reach their final destination quickly and comfortably, which is oftentimes not the case currently.

Figure 2: Existing narrow-gauge commuter train lines (Santander-Cabezón in green, Santander-Liérganes in blue)

Therefore, in order to allow commuters living or working in these corridors to take full advantage of the existing rail infrastructure in the metropolitan region, it would be sufficient to extend the network in tram mode into the city of Santander. In the following sub-section, the most appropriate routes for this purpose will be studied. In addition, the opportunity of creating this new mode of transport can be used to implement other small extensions to the rail network, such as a branch line to the airport, located just 800 meters from the Santander-Liérganes line. The layout of the existing metric gauge commuter lines with all their stations is shown in Figure 3.

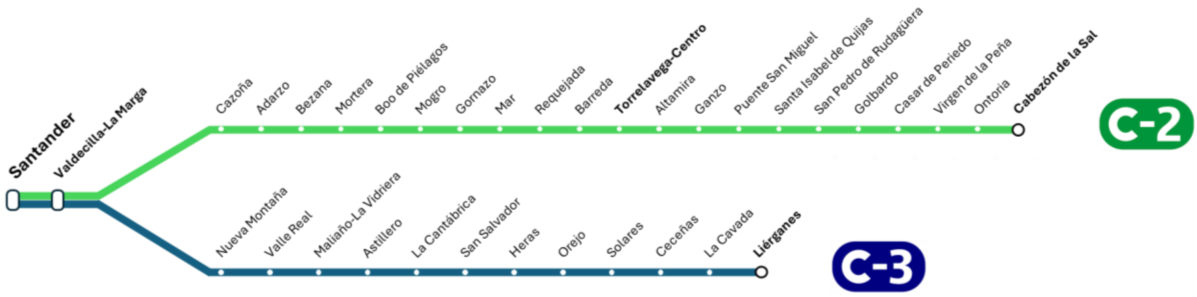

Figure 3: Existing narrow-gauge commuter lines diagram

4.2. Urban analysis

The main points of interest have been studied, which are considered to be trip generators and receptors, in order to design the most appropriate route alternatives for the tramway section in the city of Santander. For this purpose, the following types of establishments and facilities have been analyzed:

- Educational centers
- Health centers
- Offices over 150 m^2
- Stores of more than 500 m^2

- Culture and entertainment
- Sports facilities of more than 500 m^2
- Hotels

The following figure shows a pattern with a higher concentration of points of interest in the city center, along the axes of (i) San Fernando Street, to the west, (ii) Marqués de la Hermida and Castilla Streets, to the south-west, and (iii) Paseo Pereda and Puerto Chico, to the east. Outside the city center, there are strong concentrations in the Parque Científico y Tecnológico de Cantabria (PCTCAN), to the west; the Candina and Nueva Montaña industrial complexes, to the south; the La Albericia and La Tejera areas, to the northwest; the university area, to the north; and the Sardinero area, to the east.

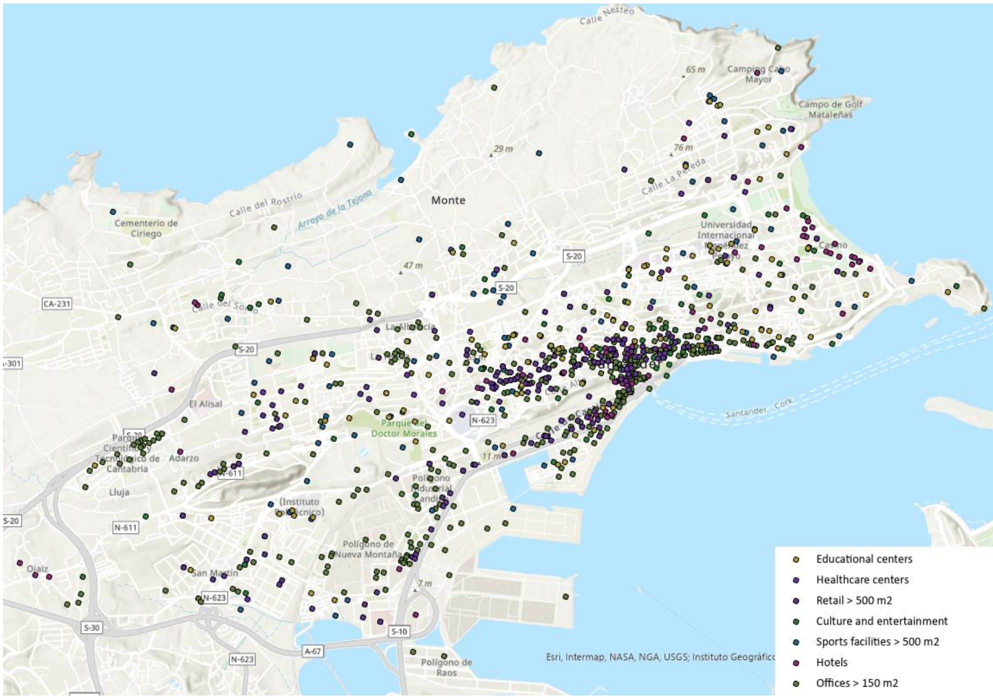

Figure 4: Points of interest in Santander

It is then necessary to analyze the geographical coverage of these areas of interest by the existing metric gauge railway network, to find out which are the sectors that present a shortfall in transportation links with the metropolitan area. For this purpose, the areas within 500 meters of a metric gauge railway station in Santander are shown in Figure 5. The city currently has 5 stations in operation. Santander (Plaza de las Estaciones' terminal station) and Valdecilla-La Marga are served by the C-2 and C-3 lines; Cazoña and Adarzo are served by the C-2 line; and the Nueva Montaña station is served by the C-3 line.

It can be observed that the existing stations cover a considerable area of the southern and western zones of the city, and part of the city center, serving a large number of points of interest, especially in the case of the terminal station and, to a lesser extent, Valdecilla-La Marga. However, there are still important uncovered areas, as can be seen below. These areas are: (1) part of the San Fernando Street axis, (2) Puerto Chico, (3) the PCTCAN, (4) the Nueva Montaña industrial area, (5) La Albericia/La Tejera, (6) the university campus and (7) the Sardinero. A brief analysis of each of them is then carried out:

1. San Fernando Street: this area is dominated by retail stores and, in second place, by offices. There is also a health center and some educational establishments. However, it is located only 400 meters from the existing railway line, far enough from the Santander and Valdecilla-La

Marga stations to be out of their catchment range, but close enough so that creating a new station in this area would be too clearly overlapping with these other two stations.

2. Puerto Chico: offices clearly predominate in this zone, followed by retail and cultural and entertainment establishments. This area is the natural continuation of the railway line from the Plaza de las Estaciones; in fact, until a few decades ago the tracks extended through this area.
3. PCTCAN: given the nature of the sector, offices prevail, and the presence of the Universidad Europea del Atlántico also stands out. It is relatively close to the C-2 commuter train line, with no nearby stations and poor street connections.
4. Nueva Montaña industrial area: the area is characterized by job centers and commercial areas; there are also some hotels and cultural and entertainment venues. However, the area is confined, surrounded by the port and the S-10 and A-67 highways, so it is not considered feasible to extend the network to this area.
5. La Albericia/La Tejera: this zone has a great diversity of activities, with offices, health, sports and educational centers. The presence of the Faculty of Medicine of the University of Cantabria stands out.
6. University: in this case, educational centers stand out, with 3 schools and multiple faculties and technical schools of the University of Cantabria, as well as the Menéndez Pelayo International University. Next in importance are offices, sports centers, hotels, and retail stores.
7. Sardinero: hotels predominate in the area, followed by offices, educational and sports centers. This is a district with a strongly seasonal demand fluctuation.

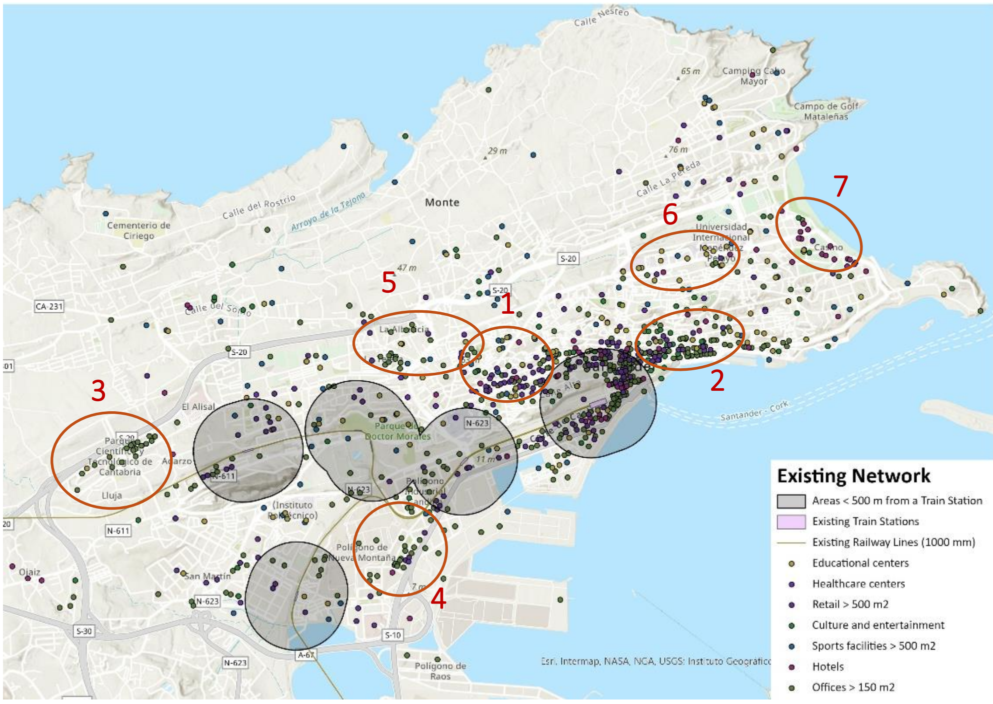

Figure 5: Areas of interest and existing narrow-gauge railway network

4.3. Proposed alternatives

Based on the preceding section, the following route alternatives have been defined for the tramway section in the city of Santander. For the definition of these alternatives, an attempt has been made to connect in each alternative several of the areas of concentration of points of interest previously mentioned. Therefore, not only the potential demand has been considered, but also geographical aspects. All alternatives include the creation of a 1.2 km long branch line between the Valle Real shopping center station and Santander airport, given the geographic proximity between the latter and the existing railway line and its capacity to bring tourist and business users to the tram-train system.

Alternative 1 for the tramway alignment begins a few meters before the platform area of the existing Santander terminal station, where it stops in a new platform area, turning slightly to the north to continue past the passenger building. It crosses the Plaza de las Estaciones on its south side and continues along Calderón de la Barca Street to Alfonso XIII Square, where it makes the first new stop (*Jardines de Pereda*) next to the Botín Center.

It continues east along Paseo de Pereda, making its second stop (*Puerto Chico*) just after the intersection with Gándara Street. It then continues north along Casimiro Sainz and San Emeterio Street, making its third stop (*Tetuán*) at the entrance to the tunnel of the same name. The Tetuán tunnel currently has a sidewalk on its west side, one lane in each direction for motor vehicles in the center, and a bicycle lane on its east side. To allow the tram-train to pass through and ensure the reliability of the service, the tunnel would be closed to private vehicle traffic and would remain open to pedestrians, bicycles, buses and tram-train.

At the northern mouth of the tunnel, a fourth stop is made (*Simón Cabarga*), just before turning left onto Avenida de los Castros, along which it continues to the intersection with Honduras Street, making stops in front of the School of Civil Engineering (*UIMP*) and in front of the Inter-faculty building (*Interfacultativo*).

Figure 6: Alternative 1 layout

Alternative 1 would require the construction of a 3,465-meter-long double-track tramway section in the city of Santander and a 1,201-meter-long single-track branch line to the airport.

Streets layout would be as follows (all existing sidewalks and bicycle lanes will remain unchanged):

- Calderón de la Barca: one parking lane, one lane for private vehicles circulation and double tram-train track.
- Paseo Pereda (Alfonso XIII Square-Muelle de Calderón section): two lanes for private vehicles and one lane for bus and tram-train in the eastbound direction; one lane for private vehicles and one lane for bus and tram-train in the westbound direction.
- Paseo Pereda (Muelle de Calderón-Casimiro Sainz section): two lanes for private vehicles, one lane for bus and tram-train, and one parking lane in each direction.
- Casimiro Sainz and San Emeterio: one lane for private vehicles in each direction and double tram-train track in the center.
- Tetuán Tunnel: double tram-train track in the center.
- Avenida de los Castros: one lane for private vehicles in each direction and double tram-train track in the south side.

Alternative 2 for the tramway alignment starts on the existing Santander-Cabezón de la Sal line, between the Adarzo and Bezana stations, near the S-30 highway overpass. At that point, it heads northeast, re-entering the urban fabric at the west end of Albert Einstein Street, making its first stop (*PCTCAN-UNEAT*) approximately 200 meters after that point. It continues along this street, making its second stop (*PCTCAN-Adarzo*) between the intersections with Severo Ochoa and Rucandial streets. Afterwards, it takes Joaquín Rodrigo Street, where it stops in front of the El Alisal shopping center (*El Alisal-Luz de Albar*). The route proceeds eastward along Julio Jaurena Street; Los Ciruelos Street, where it makes its fourth stop (*El Alisal-La Albericia*); and José María de Cossio Street, where the tram-train stops at Plaza Acebo (*Los Acebos*) and at the east end of the street (*Gutiérrez Solana*).

After entering the Avenida de los Castros at its western end, the tram-train makes its seventh stop (*Facultad de Medicina*), in a location close to multiple industrial, commercial, educational and sports areas. Alternative 2 continues for the next 2.7 km until the end of its route along this avenue. Its last stops are the following: *Los Castros-Miguel de Unamuno*, next to the intersection with the homonymous street; *Los Olivos*, next to Los Olivos Park; *Los Castros-General Dávila*, past the intersection with Poeta Matilde Camus Street; *Facultad de Derecho* and *Interfacultativo*, next to these two University of Cantabria buildings, respectively.

Additionally, Alternative 2 would require the construction of a bypass between Santander-Liérganes and Santander-Cabezón de la Sal railway lines, to allow services to run between the airport and the new urban tramway route.

Streets layout would be as follows (all existing sidewalks and bicycle lanes will remain unchanged):

- Albert Einstein, Joaquín Rodrigo and Julio Jaurena: one lane for private vehicles and one lane for tram-train and bus in each direction.
- Los Ciruelos: one lane for private vehicles and one parking lane in each direction, and double tram-train track in the center.
- José María de Cossío and Gutiérrez Solana: one lane for private vehicles in each direction, one parking lane on its north side, and double tram-train track in the center.
- Avenida Los Castros: from its west end to Camilo Alonso Vega Street, one lane for private vehicles and one parking lane in each direction, and double tram-train track in the center; from Camilo Alonso Vega Street to Alternative 2 east end, one lane for private vehicles in each direction and double tram-train track in the south side.

Figure 7: Alternative 2 layout

Alternative 2 would require the construction of a 7,015-meter-long double-track tramway section in the city of Santander, a 290-meter-long single-track bypass connecting the two existing narrow-gauge railway lines, and a 1,201-meter-long single-track branch line to the airport.

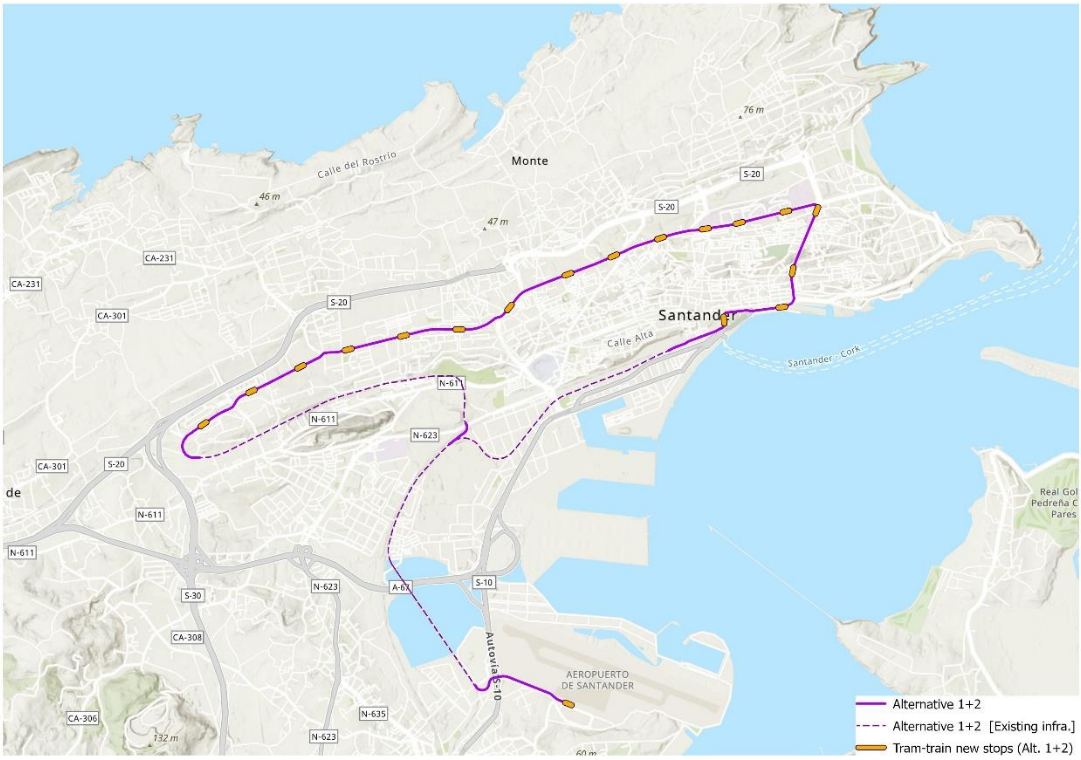

Figure 8: Alternative 1+2 layout

The third alternative would consist of a combination of Alternatives 1 and 2. It will therefore be referred to as **Alternative 1+2**. It makes a loop that, from the airport, enters the city through the existing terminal station at Plaza de las Estaciones and passes through Puerto Chico, the University, the axis of the Avenida de los Castros, La Albericia, El Alisal and the PCTCAN, or vice versa, making the same route in the opposite direction.

Alternative 1+2 would thus require the construction of a 10,412-meter-long double-track tramway section in the city of Santander, a 290-meter-long single-track bypass connecting the two existing narrow-gauge railway lines, and a 1,201-meter-long single-track branch line to the airport.

The share of all points of interest in Santander that would be within 500 meters of a new tram-train station for each of the alternatives is shown below. For comparative purposes, it can also be seen what this percentage is for the 5 narrow-gauge railway stations currently in service in Santander. The figures shown only refer to stops on the proposed new tramway routes.

	Existing network	Alternative 1	Alternative 2	Alternative 1+2
Education Centers	17%	29%	33%	50%
Health Centers	21%	21%	33%	46%
Retail Stores	37%	28%	15%	43%
Culture and Entertainment	11%	41%	23%	59%
Sports centers	14%	16%	38%	48%
Hotels	27%	28%	7%	34%
Offices	35%	38%	16%	52%

Table 1: Points of interest within 500 meters of a train (existing network) or tram-train stop (Alternatives 1, 2, 1+2)

In most cases, with the proposed new tramway routes alone, the current number of points of interest within 500 meters of a station is exceeded. It shall be noted that each of the alternatives also uses the existing railway network, so the number of points of interest covered by the entire tram-train system would be significantly higher considering the stations on the railway section.

In the case of Alternative 1, the most significant increases are in the case of cultural and entertainment centers (41% would be less than 500 meters from a tram-train stop, compared to 11% currently) and educational centers (29% vs. 17% currently). It presents more modest results in the case of sports centers, which tend to be located in large facilities in lower density areas than those served by this alternative, mainly located in the center of the city.

In the case of Alternative 2, the growth in the case of sports centers (38% vs. current 14%) and educational centers (33% vs. current 17%) is remarkable. It is worth mentioning the low coverage percentage in the case of hotels, as it does not go across or near the most popular tourist areas, the Sardinero and the city center. The relatively low percentages for stores and offices may be surprising. This is due to the fact that Alternative 2 passes through areas with large commercial zones and bigger offices, where each office and store employs and attracts a greater number of people.

Finally, the best percentages are found in Alternative 1+2 at all levels, as is to be expected, with the best records for cultural and entertainment centers (59% would be within 500 meters of a tram-train stop), offices (52%) and educational centers (50%).

5. Stated preference survey

To model the potential demand for the tram-train route alternatives in the Santander metropolitan area, it is necessary, among other steps, to determine the utility model that characterizes the area's commuters. This utility model will have a utility formula for each of the transport modes considered (car, bus and tram-train, in this case). The utility value of each mode will depend on their attributes. When the utility value of mode *a* is higher than mode *b*'s utility, the user will prefer using mode *a*. To define the utility functions for Santander metropolitan area transport modes, a stated preference survey was conducted using the efficient survey design, divided into a pilot phase and a final phase, as described below.

5.1. Efficient survey design

A duly conducted stated preference survey, in which different scenarios are presented for a proposed transport mode, requires three phases for its design (Dell'Olio, Ibeas, & Cecin, 2011).

First, based on knowledge of the characteristics of the system under study (in this case, the transport system of the Santander metropolitan area) and a definition of the characteristics of the new mode to be integrated into such system, a series of values are defined for each of the parameters to be studied. In this case, four parameters are studied for the bus and tram-train modes (travel time, access time, waiting time and fare) and two parameters for the car mode (travel time and travel cost). For each of these parameters, three possible values were defined, which were eventually used to determine the combinations that resulted in the scenarios proposed in the survey.

Thereafter, a pilot survey is prepared. To this end, the NGENE software is used to find, given a preliminary utility model, the scenarios in which the values of the parameters are combined in such a way that the necessary survey sample size is minimized. This software provides, for a given utility model, multiple iterations with a set of scenarios each, which are calculated as the program seeks to minimize a particular variable (in this case, the S-estimate or minimum sample size). Having minimized the S-estimate, the scenarios of that last iteration are selected, and the pilot survey is prepared. This survey must be completed by –at least– the number of participants defined by the S-estimate. Once this minimum number of responses has been collected, the NLOGIT software is used to obtain a new utility model, more accurate than the preliminary model used at the outset of the process. The program uses the respondents' choices to define several possible new utility models, which can be selected based on their log likelihood function, standard error or significance levels.

Lastly, the final survey is elaborated. Having selected a utility model –from those proposed by NLOGIT– that presents acceptable values for the previously mentioned statistical variables, a new set of scenarios is retrieved in NGENE. These scenarios present different values for each of the parameters, being this time more coherent because of the calibration based on the pilot survey. On this occasion, the objective is for the final survey to be answered by as many respondents as possible, to obtain better reliability and greater profile diversity in the responses. Once the final survey is closed, the respondents' choices are imported into NLOGIT to obtain the final utility model, which will be used in the PTV Visum model.

5.2. Survey design

The pilot stated preference survey was conducted, and responses were received between April 15 and 25, 2024. The survey included questions to characterize the respondent (gender, age, education level, zip code) and their mobility habits (availability of driving license, transport card and car, public transport use frequency, mobility alternatives available for their regular commute). Finally, 6 mobility scenarios were included, in which a choice was to be made between car, bus and tram-train, showing different characteristics of cost, travel, access and waiting times. Table 2 shows the parameters for each of these variables in every scenario; travel, access and waiting times are expressed in minutes, and costs and fares in euros.

Sce.	Car		Bus				Tram-train			
	Travel time	Cost	Travel time	Access t.	Waiting t.	Fare	Travel time	Access t.	Waiting t.	Fare
1	8	1.80	10	5	3	0.33	16	2	3	0.6
2	22	2.70	30	10	3	1	25	7	9	1.2
3	15	0.90	30	2	11	0.33	25	2	5	1.8
4	22	0.90	20	5	7	1.8	16	12	5	0.6
5	8	1.80	20	2	7	1.8	10	7	9	1.2
6	15	2.70	10	10	11	1	10	12	3	1.8

Table 2: Pilot stated-preferences survey design – Scenarios (times are expressed in minutes, fares in euros)

These scenarios were calculated with the NGENE software, based on the following preliminary utility model:

$$U(Car) = -0.2 \cdot travel_{time} - 0.75 \cdot cost$$

$$U(Bus) = 1.8 - 0.2 \cdot travel_{time} - 0.5 \cdot access_{time} - 0.16 \cdot waiting_{time} - 0.9 \cdot fare$$

$$U(TT) = 2.2 - 0.2 \cdot travel_{time} - 0.5 \cdot access_{time} - 0.16 \cdot waiting_{time} - 0.8 \cdot fare$$

Some deductions can be drawn from this first model: (i) users are less sensitive to cost in the case of the private vehicle and more so in the case of the bus; (ii) access time is more penalizing than waiting and travel times, in which it is not necessary to walk and one can even sit and rest or use that time for other purposes; (iii) the model constant of the tram-train is greater than that of the bus, making it a mode that is *a priori* more attractive.

NGENE defined a S-estimate of 68.405 for this set of scenarios. Consequently, the pilot survey received 69 responses during the time it remained open.

5.3. Final survey and LOGIT model

From the responses obtained in the pilot survey, and through the NLOGIT software, an improved utility model –which is shown below– and new mobility scenarios –which are described in Table 3– were obtained.

$$U(Car) = -0.117 \cdot travel_{time} - 0.847 \cdot cost$$

$$U(Bus) = 0.908 - 0.139 \cdot travel_{time} - 0.102 \cdot access_{time} - 0.063 \cdot waiting_{time} - 1.311 \cdot fare$$

$$U(TT) = 1.0181 - 0.139 \cdot travel_{time} - 0.102 \cdot access_{time} - 0.063 \cdot waiting_{time} - 1.311 \cdot fare$$

Some of the deductions previously made are valid in this second model: (i) car users are still less sensitive to cost than public transport users; (ii) the tram-train constant is still higher than that of the bus, making it an a priori more attractive mode. However, in this model, public transport travel time appears to be more penalizing than access and waiting times, which could be the case for crowded vehicles and more pleasant waiting and access environments. Besides, public transport travel time is more penalizing than car travel time, which is to be expected.

These new scenarios were the ones proposed in the final stated preference survey, which was open to responses between May 9 and June 9, 2024. The structure of the final survey was identical to the pilot survey, except for the scenario parameters, this time more consistent thanks to the NLOGIT calibration, and minor modifications or clarifications based on the comments and suggestions received in the pilot survey.

Sce.	Car		Bus				Tram-train			
	Travel time	Cost	Travel time	Access t.	Waiting t.	Fare	Travel time	Access t.	Waiting t.	Fare
1	22	2.70	30	2	11	1	25	12	3	1.2
2	8	0.90	10	2	3	0.33	25	2	5	1.8
3	8	1.80	30	5	7	1.8	10	2	5	1.2
4	22	2.70	20	10	3	1	16	7	9	1.8
5	15	0.90	10	10	11	0.33	10	7	3	0.6
6	15	1.80	20	5	7	1.8	16	12	9	0.6

Table 3: Final stated-preferences survey - Scenarios (times are expressed in minutes, fares in euros)

The final survey received 208 responses during the time it remained open, well above the 36.077 S-estimate defined by NGENE for this set of scenarios. 53.4% of the responses were from men and 46.6% from women. Regarding their age range, university-age respondents predominated, as the survey was mainly disseminated through that community: 63.9% are between 18-30 years old, 20.2% between 30-55 years old, 8.7% between 55-75 years old, and 7.2% under 18 years old. Similarly, 41.3% have a master's degree or higher, and 38.5% have a bachelor's degree. 75% of the respondents reside in Santander, the remaining respondents corresponding to postal codes in the metropolitan area, with 39600 (Camargo) standing out, accounting for 4.8% of the respondents. A remarkable 23.1% of all responses are from postal code 39005, where the university campus is located. Therefore, it is worth mentioning that the results obtained will inevitably be influenced, at least in part, by the fact that they largely correspond to a specific citizen profile.

In terms of mobility practices, 77.9% possess a driver's license and 65.4% have at least one car. 29.8% use public transport 3 or more days a week, 19.2% 1 or 2 days a week and 39.9% use it but not every week. To make their regular commute (home-work, home-university, etc.), 35.1% only have public transport as an option, while 28.4% can only use their car and 36.5% have both options.

Finally, regarding the possession of transport passes, 63.5% of those surveyed have the Santander municipal bus card (TUS), 25.5% have the regional transport consortium card (valid for urban bus, regional bus and train), 23.6% have the commuter train card and 15.9% do not have any pass at all. 55 respondents have more than one transport pass.

From the survey results, the final utility model was obtained with NLOGIT, which is shown below.

$$U(Car) = -0.037 \cdot travel_{time} - 0.787 \cdot cost$$

$$U(Bus) = 0.444 - 0.107 \cdot travel_{time} - 0.049 \cdot waiting_{time} - 0.612 \cdot fare$$

$$U(TT) = 1.386 - 0.107 \cdot travel_{time} - 0.111 \cdot waiting_{time} - 0.896 \cdot fare$$

Finally, the model resulting from the survey indicates that: (i) access time was not a significant variable, so it was dropped from both public transport utility functions; (ii) the tram-train constant is clearly higher than that of the bus, so the new mode is *a priori* more attractive; (iii) waiting time is more penalizing in the case of the tram-train than in the case of the bus, even more than travel time, which is probably due to an unconscious comparison of future tram-train stops with existing train stations, not very pleasant compared to bus stops; (iv) fare increases are more penalizing in the case of the tram-train than in the case of the bus, which is more firmly established in Santander's local society; (v) travel time by car is much less penalizing than its equivalent by bus or tram-train, which is to be expected due to the greater comfort it provides; (vi) car users are more cost-sensitive than bus users, which is quite surprising since this tends to be the other way around in practice (De Oña, Estévez, & De Oña, 2021).

The presence of correlation between the two public transport modes was checked. A hierarchical model was proposed, but the parameter associated with the public transport “nest” was found to be significantly different from 1, making it virtually similar to a multinomial model. Consequently, it was considered appropriate to adopt a multinomial model instead of a nested one, which allows simplifying the model and its use in PTV Visum.

6. Demand estimation

Once the utility model for the city of Santander was obtained, the potential demand for the new tram-train service was estimated. For this purpose, the proposed route alternatives have been codified on a PTV Visum model of the Santander metropolitan area. For each alternative, different service schemes have been proposed, as well as different public transport fare configurations. In this way, it is possible to determine aspects such as which alternative is capable of attracting the greatest number of passengers to the tram-train or if these new users mostly come from the private vehicle or are current public transport users.

6.1. PTV Visum model

For the purpose of estimating the potential demand for each of the tram-train system alternatives, a PTV Visum model has been used. The model utilizes calibrated origin-destination matrices for private and public transport, so that only the modal split and assignment phases are performed. The model includes the street, road and rail networks within Santander and neighboring areas to the south of the city (the vicinity of the Valle Real shopping center and the airport, in the municipality of Camargo). The infrastructure network is coded from Santander to the following limits: S-10 highway until exit nº 3; Santander-Orejo-Bilbao/Liérganes and Santander-Palencia railway lines until Maliaño station; N-623 road until Muriedas; CA-308 road until Igollo de Camargo; N-611 road and A-67 highway until Santa Cruz de Bezana; Santander-Cabezón de la Sal-Oviedo railway line until Bezana station; and CA-231 until Soto de la Marina.

In addition, demand from and to the rest of the metropolitan area is included in the model through the following 6 external zones:

- Trips to/from the S-10 axis, which enter the model through connectors linking the external zone with this highway and the Santander-Liérganes railway line.
- Trips from/to the N-623 axis, which enter the model through connectors linking the external zone with this road and the Santander-Palencia railway line.
- Trips to/from the southern margin of the S-30 ring road, which enter the model through a connector linking the external zone with the CA-308 road.
- Trips from/to the A-67 axis, which enter the model through connectors linking the external zone with this highway and the Santander-Cabezón railway line.
- Trips to/from the N-611 axis, which enter the model through connectors linking the external zone with this road and the Santander-Cabezón railway line.
- Trips from/to the CA-231 axis, which enter the model through a connector linking the external zone with this road.

The Visum model of the Santander metropolitan area works as follows. It is launched using 24-hour origin-destination matrices provided by the SUMLAB+ department of the University of Cantabria. First, walking trips are assigned for internal trips within the city of Santander by means of Visum's "Bicycle assignment" method, which considers impedance. In this way, the other modes considered in the procedure sequence (car, bus and tram-train) remain to be distributed with the utility model.

The base matrices are only for cars and public transport, without distinction between modes in the latter case. In order to make this separation, the public transport matrix is split in two: trips within the city of Santander (both origin and destination zones inside the city boundaries) are made by urban bus, and the rest (with external origin and/or destination zones) are made by train.

One of the particularities of modeling a tram-train system is the need to work at a double scale: at the urban scale, since there are tramway-type sections, and at the regional scale, given that there are railway-type segments. The unavailability of a Visum model with an appropriate level of detail in terms of transport network and zone coding for the entire study area has required a differentiated analysis for trips inside and outside the city of Santander.

Within the city limits and in the areas of Valle Real and the Airport (both in the municipality of Camargo), the LOGIT model was used, which was obtained from the stated-preferences survey for car, bus and tram-train modes. For external trips, the level of development of the Visum model makes it unfeasible to work with this LOGIT model, which uses variables such as access time to a stop, so a simplified utility model has been adopted, which only uses the impedance of each mode.

The modal split is then calculated for external trips, those with at least one origin or destination outside Santander. This mode choice is calculated based on the following utility functions, which only depend on the impedance of each mode. Outside the city boundaries, the model only considers car and tram-train modes, hence no bus mode is shown in this case.

$$U(Car) = -0.00361 \cdot impedance$$

$$U(TT) = -0.00361 \cdot impedance - 2$$

Impedance is equal to the total travel time in the loaded network.

Once this first external modal split has been made, the modal choice calculation of the internal trips is made, which uses the utility functions calculated from the stated preference survey, as previously explained. The car utility function parameter corresponding to the cost is multiplied by the unit cost per kilometer (MITMA, 2022) and the number of kilometers traveled. In this second mode choice calculation, corresponding to Santander's municipal area, the three modes are considered, since the municipal bus service is available.

$$U(Car) = -0.03705 \cdot travel_{time} - 0.78743 \cdot 0.3588 \cdot distance$$

$$U(Bus) = 0.44383 - 0.10742 \cdot travel_{time} - 0.04908 \cdot waiting_{time} - 0.61167 \cdot fare$$

$$U\ (TT) = 1.3857 - 0.10742 \cdot travel_{time} - 0.11075 \cdot waiting_{time} - 0.89593 \cdot fare$$

Finally, the assignment of car, bus and tram-train trips is performed. The model iterates a maximum of 3 times if the following criterion is met for, at least, one network element.

$$Abs\big(X(n) - X(n-1)\big) > min\big(0.01 \cdot max\big(X(n);\ X(n-1)\big) + 5;\ 10\big)$$

Where X(n) is the value of that element in iteration number n and X(n-1) is the value of that same element in the previous iteration (or iteration number n-1). Once the iteration is finished, the final assignment results are obtained for a 24-hour analysis period.

An outline of the procedure sequence of the Visum PTV model used to estimate the potential demand of the tram-train network is shown below.

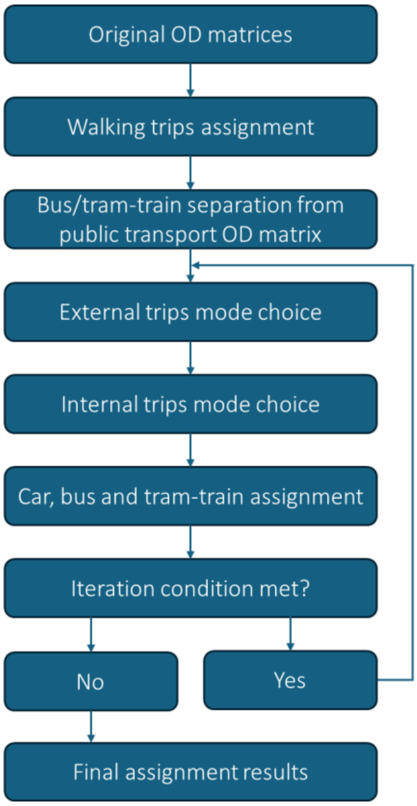

Figure 9: PTV Visum model's procedure sequence summary

In terms of the transportation network, the initially provided network of the Visum model has been maintained, only making the necessary modifications to implement each of the proposed tram-train alternatives. The vast majority of the tramway route uses existing street and avenue lanes, with the following exceptions:

- The branch to the airport (except for the bridge over the S-10 highway).
- The bypass between the Santander-Cabezón and Santander-Liérganes lines.
- The connection of Alternative 1 (and Alternative 1+2) to the existing terminal station next to Plaza de las Estaciones.
- The section of Alternative 1 (and Alternative 1+2) through Jardines de Pereda.
- The connection of Alternative 2 (and Alt. 1+2) to the Santander-Cabezón line near the PCTCAN.

In the Visum model, these sections have been modeled as only open for tram-train mode circulation, with a maximum speed of 50 km/h. In all other cases, lanes currently open to traffic or parking will be closed to be reserved for the tram-train or the existing bus lanes will be used, which will be shared by the tram-train and the bus. Where lanes are closed to traffic, the link's private transport capacity has been reduced in Visum proportionally to the number of lanes closed. For instance, if in an avenue with 4 lanes and a current capacity of 25,000 vehicles per day and direction, two lanes are closed for the tram-train, the capacity has been reduced to 12,500 vehicles per day in each direction.

6.2. Tram-train service scenarios' demand calculation

The estimation of the potential demand for the tram-train system has been calculated through different simulations, in which the route alternative, the service scheme and the fare vary. For alternative 1, two scenarios with different service schemes are proposed; for alternative 2, three; and for alternative 1+2, four. For each of these scenarios, 3 different fares were analyzed: 1.65€ tram-train ticket and 1.30€ bus ticket; 1.30€ ticket for both modes; 0.66€ ticket for both modes. For reference, the current price of a single-zone train ticket is 1.65€, the single bus ticket is 1.30€, and the bus ticket with a pass[1] is 0.66€.

As a result, a total of 27 simulations have been evaluated. Although in the model trains only reach as far as the Bezana and Maliaño stations on the Santander-Cabezón and Santander-Liérganes lines, respectively, it is assumed that they would continue their route beyond these stations, as is currently the case.

Additionally, the PTV Visum model has been run for the baseline scenario, in order to check if the utility model works properly. According to the data provided by SUMLAB+, there are currently 515,053 daily car trips and 38,691 public transport trips in the Santander metropolitan area. Of the latter, 35,654 are internal to the city of Santander and 3,037 are external (origin and/or destination outside the city). If one applies the assumption made on the model's procedure sequence, it can be stated that the number of daily bus users is close to the number of internal public transport trips (3,037) and the number of daily train passengers is similar to the number of external trips (35,654).

The Visum model obtained the following results for the baseline scenario, with a 1,65€ fare for the train mode and 1,30€ for the bus mode. It can be observed that the number of passengers in all modes is close to the real values, so it can be concluded that the model is reliable. The model counts as internal trips only those within zones in the municipality of Santander. However, the neighboring zones of Valle Real shopping center and the airport are considered to be inside the municipality, despite being in Camargo. For this reason, passengers using the train to travel between Santander and Valle Real, one of the most used stations in the network, are internal trips. This explains the relatively high number of current internal train users, given the limited possibilities for train intra-city travel within Santander.

Baseline scenario (Daily trips)	
Internal trips	298,811
External trips	249,963
Car internal trips	266,994
Bus internal trips	31,385
Tram-train internal trips	432
Car external trips	247,004
Tram-train external trips	2,959
Car total trips	513,998
Bus total trips	31,385
Tram-train total trips	3,391

Table 4: Baseline scenario results

[1] The TUS municipal bus card or the Regional Transport Consortium card.

6.2.1. Alternative 1 scenarios

Scenario 1: Extension of existing narrow-gauge lines

In this first scenario, it is proposed to extend lines C-2 (Santander-Cabezón) and C-3 (Santander-Liérganes) from the terminal station to the Interfacultativo stop on Avenida de los Castros, using the tramway route through the city center and the Tetuán tunnel. Trains on the C-3 line would enter the branch line to the airport, having to reverse direction to continue their route. One train every 20 minutes per direction is proposed on each line, so as to achieve an average frequency of 10 minutes on the shared section.

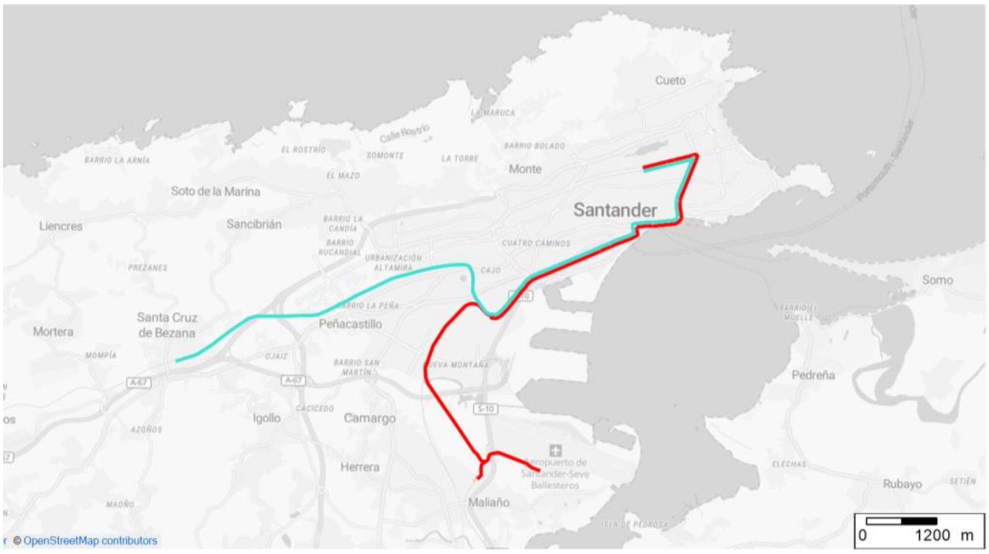

Figure 10: Alternative 1 Scenario 1 (Bezana line in blue, Maliaño line in red)

Therefore, two lines with two types of services have been modeled. These services are the following:

- Maliaño-Airport-Santander. Departures from 6:29 to 22:49, every 20 minutes.
- Santander-Airport-Maliaño. Departures from 7:00 to 23:20, every 20 minutes.
- Bezana-Santander. Departures from 6:23 to 23:03, every 20 minutes.
- Santander-Bezana. Departures from 6:50 to 23:30, every 20 minutes.

The following results were obtained for this scenario:

Alternative 1 - Scenario 1 (Daily Trips)			
Fare	1.65€	1.30€	0.66€
Internal trips	298,631	299,509	298,629
External trips	249,964	249,964	249,964
Car internal	245,312	245,312	245,312
Bus internal	31,425	31,468	41,856
Tram-train internal	2,021	2,534	3,555
Car external	245,312	245,312	245,312
Tram-train external	4,652	4,652	4,652
Car total trips	510,497	510,819	498,530
Bus total trips	31,425	31,468	41,856
Tram-train total trips	6,673	7,186	8,207

Table 5: Alternative 1 Scenario 1 results

Alternative 1 - Scenario 1 (Daily Trips)			
Fare	1.65€	1.30€	0.66€
Tram-train total trips	6,673	7,186	8,207
Bezana line	3,143	3,321	3,659
Maliaño line	4,105	4,420	5,062

Table 6: Alternative 1 Scenario 1 results by tram-train line

Scenario 2: Extension of existing narrow-gauge lines and Airport branch line

In this second scenario, the two lines of the previous scenario are maintained, except that line C-3 would no longer enter the airport. Instead, the airport station would be served by a line that would run between Interfacultativo and Aeropuerto. The 20-minute frequency per line of the previous scenario is reinforced in the shared sections by a service every 30 minutes on the Airport line.

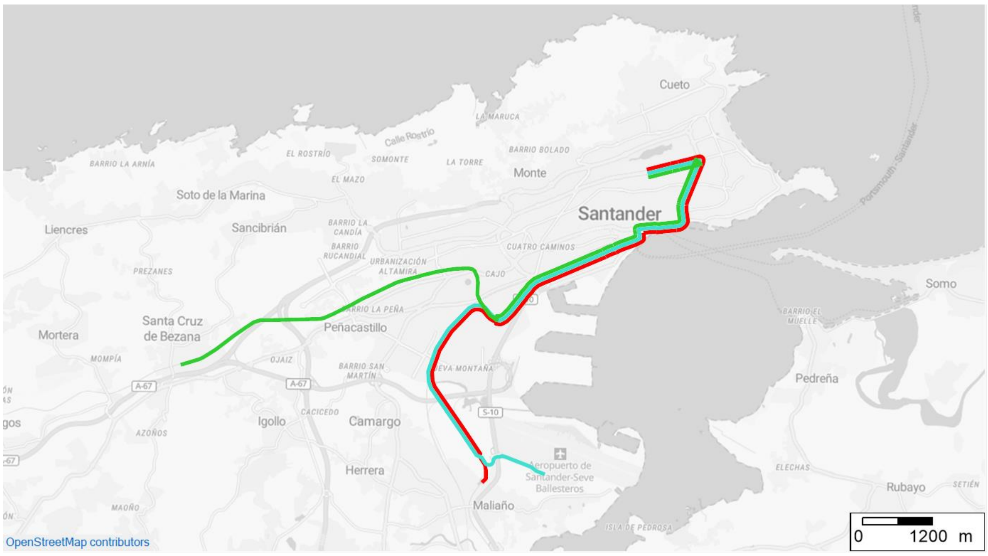

Figure 11: Alternative 1 Scenario 2 (Bezana line in green, Maliaño line in red, Airport line in blue)

Hence, three lines with two types of services have been modeled. These services are listed below:

- Airport-Santander. Departures from 5:20 to 21:20, every 30 minutes.
- Santander-Airport. Departures from 4:46 to 20:46, every 30 minutes.
- Maliaño-Santander. Departures from 6:37 to 22:57, every 20 minutes.
- Santander-Maliaño. Departures from 7:02 to 23:22, every 20 minutes.
- Bezana-Santander. Departures from 6:24 to 23:04, every 20 minutes.
- Santander-Bezana. Departures from 6:51 to 23:31, every 20 minutes.

The results for this second scenario are shown below.

Alternative 1 - Scenario 2 (Daily Trips)			
Fare	1.65€	1.30€	0.66€
Internal trips	298,678	299,565	298,679
External trips	249,963	249,963	249,963
Car internal	245,272	245,272	245,272
Bus internal	31,494	31,562	42,008
Tram-train internal	1,269	1,631	2,407
Car external	265,915	266,372	254,264

Tram-train external	4,691	4,691	4,691
Car total trips	511,187	511,644	499,536
Bus total trips	31,494	31,562	42,008
Tram-train total trips	5,960	6,322	7,098

Table 7: Alternative 1 Scenario 1 results

Alternative 1 - Scenario 2 (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Tram-train total trips	5,960	6,322	7,098
Bezana line	2,748	2,842	3,039
Maliaño line	3,347	3,520	3,893
Airport line	504	579	741

Table 8: Alternative 1 Scenario 1 results by tram-train line

6.2.2. Alternative 2 scenarios

<u>Scenario 1a: Extension and splitting of existing narrow-gauge lines</u>

Alternative 2 scenarios 1a and 1b propose splitting each of the existing commuter train lines (C-2 and C-3) into two. Half of the trains on each line would finish and start at Santander terminus station, as they all do at present, and the other half would do so at the Interfacultativo stop, using the tramway section from the PCTCAN. Both scenarios differ from each other in terms of train frequency. Trains on the C-3 line would enter the branch line to the airport, having to reverse direction to continue their route. There would be no direct connection between the airport and the new tramway route.

Scenario 1a is rather conservative and only includes one train of each service every 60 minutes, so that each line has an average frequency of 30 minutes up to the point where services to the terminal station and Interfacultativo diverge. There is also an average 30-minute frequency on the Valdecilla-Santander and PCTCAN-Interfacultativo sections, where trains from both lines coincide.

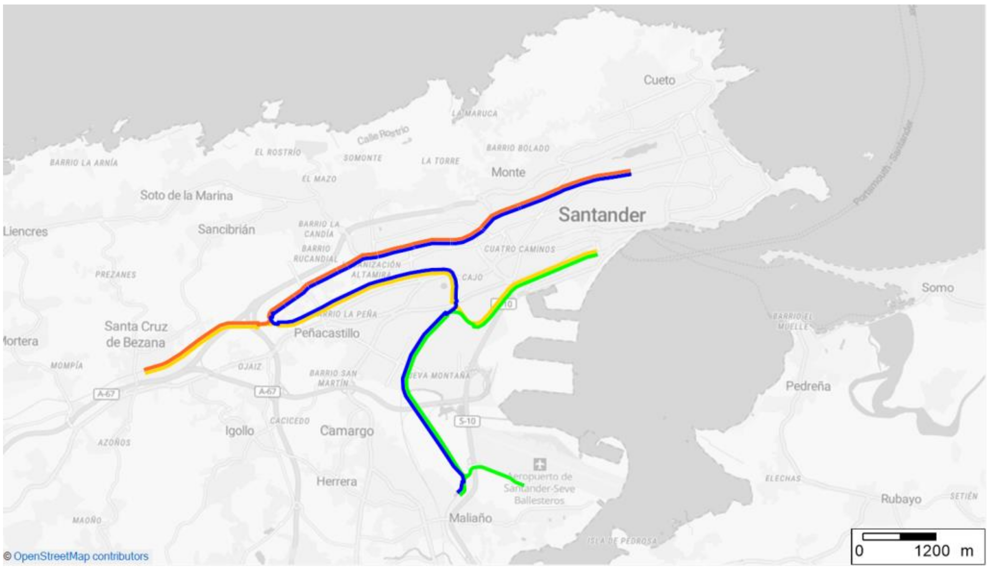

Figure 12: Alternative 2 Scenarios 1a and 1b (Bezana-Interfacultativo in orange, Bezana-Santander in yellow, Maliaño-Interfacultativo in blue and Maliaño-Aeropuerto-Santander in green)

Four lines with two types of services have been modeled. These services are listed below:

- Maliaño-Airport-Santander. Departures from 6:10 to 23:10, every 60 minutes.

- Santander-Airport-Maliaño. Departures from 6:30 to 23:30, every 60 minutes.
- Maliaño-Interfacultativo. Departures from 6:56 to 22:56, every 60 minutes.
- Interfacultativo-Maliaño. Departures from 6:30 to 23:30, every 60 minutes.
- Bezana-Santander. Departures from 6:39 to 22:39, every 60 minutes.
- Santander-Bezana. Departures from 6:15 to 23:15, every 60 minutes.
- Bezana-Interfacultativo. Departures from 6:18 to 23:18, every 60 minutes.
- Interfacultativo-Bezana. Departures from 6:40 to 23:40, every 60 minutes.

The following results have been obtained for Scenario 1a.

Alternative 2 - Scenario 1a (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Internal trips	297,287	298,072	297,286
External trips	249,954	249,954	249,954
Car internal	264,746	265,042	252,979
Bus internal	31,170	31,228	41,540
Tram-train internal	1,371	1,802	2,767
Car external	244,322	244,322	244,323
Tram-train external	5,632	5,632	5,631
Car total trips	509,068	509,364	497,302
Bus total trips	31,170	31,228	41,540
Tram-train total trips	7,003	7,434	8,398

Table 9: Alternative 2 Scenario 1a results

Alternative 2 - Scenario 1a (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Tram-train total trips	7,003	7,434	8,398
Santander-Bezana	1,235	1,242	1,257
Interfacult.-Bezana	2,238	2,388	2,716
Santander-Maliaño	1,320	1,363	1,470
Interfacult.-Maliaño	2,811	3,029	3,505

Table 10: Alternative 2 Scenario 1a results by tram-train line

Scenario 1b: Extension and splitting of existing narrow-gauge lines

Scenario 1b only differs from Scenario 1a in having better frequencies for services to and from the Interfacultativo stop, which are more appropriate for a tramway service. In the case of those connecting Interfacultativo with Maliaño, there are 3 services per hour; those connecting it with Bezana are 2 per hour.

Services are organized in such a way that 5 services per hour and direction run on the tramway section. On the Maliaño/Liérganes line, there is a train approximately every 15 minutes (3 services per hour to/from Interfacultativo and 1 to/from the terminal station). In the case of the Bezana/Cabezón line, there is a train every 30 minutes to/from Interfacultativo and a train every 60 minutes to/from the terminal station. Therefore, there are 2 services per hour and direction on the Valdecilla-Santander section.

As in the previous case, four lines with two types of services have been modeled. All services are listed below:

- Maliaño-Airport-Santander. Departures from 6:25 to 23:25, every 60 minutes.
- Santander-Airport-Maliaño. Departures from 6:45 to 23:45, every 60 minutes.
- Maliaño-Interfacult. Departures from 6:42-6:57-7:12 to 22:42-22:57-23:12, 3 services per hour.
- Interfacultativo-Maliaño. Departures at 6:30; and from 7:15-7:30-7:30-7:45 to 23:15-23:30-23:45, 3 services per hour.
- Bezana-Santander. Departures from 6:42 to 22:42, every 60 minutes.
- Santander-Bezana. Departures from 6:15 to 23:15, every 60 minutes.
- Bezana- Interfacult. Departures from 6:18-6:38 to 22:18-22:38, 2 services per hour; and 23:18.
- Interfacult.-Bezana. Departures from 6:40-7:00 to 22:40-23:00, 2 services per hour; and 23:40.

Scenario 1b yielded the following results.

Alternative 2 - Scenario 1b (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Internal trips	298,073	297,286	298,075
External trips	249,964	249,964	249,964
Car internal	263,725	262,341	251,189
Bus internal	31,104	30,945	41,355
Tram-train internal	3,244	4,000	5,531
Car external	244,293	244,293	244,293
Tram-train external	5,671	5,671	5,671
Car total trips	508,018	506,634	495,482
Bus total trips	31,104	30,945	41,355
Tram-train total trips	8,915	9,671	11,202

Table 11: Alternative 2 Scenario 1b results

Alternative 2 - Scenario 1b (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Tram-train total trips	8,915	9,671	11,202
Santander-Bezana	637	643	656
Interfacult.-Bezana	3,280	3,473	3,843
Santander-Maliaño	584	620	704
Interfacult.-Maliaño	5,423	5,943	7,004

Table 12: Alternative 2 Scenario 1b results by tram-train line

Scenario 2: Extension and splitting of existing narrow-gauge lines and Airport branch line

Scenario 2 proposes a service scheme similar to that of scenarios 1a and 1b, with one main difference: the Maliaño-Santander line would no longer reach the airport, which would be connected by the Interfacultativo-Airport line. The rest of the lines would remain unchanged. This implies that there would be no direct connection between the airport and the city center. Instead, the residential neighborhoods around Avenida de los Castros, La Albericia and El Alisal, and the PCTCAN, among others, would have this direct connection.

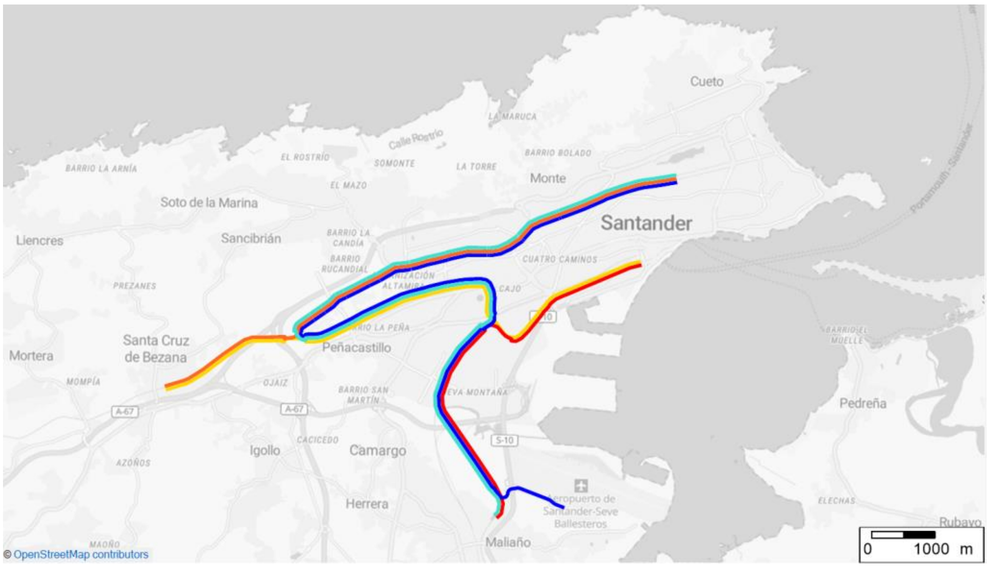

Figure 13: *Alternative 2 Scenario 2 (Bezana-Interfacultativo in orange, Bezana-Santander in yellow, Maliaño-Interfacultativo in light blue, Maliaño-Santander in red, and Aeropuerto-Interfacultativo in dark blue)*

Services have been organized in such a way that both the Maliaño and the Bezana corridors have 3 services per hour (2 to/from the Interfacultativo and the remaining to/from the terminal station). In the case of the Maliaño corridor, there are three types of service (Maliaño-Interfacultativo, Maliaño-Santander and Aeropuerto-Interfacultativo), so that each of them has a 60-minute frequency. In the case of the Bezana corridor, as there are only two types of service (Bezana-Interfacultativo and Bezana-Santander), the first has two services per hour and the second has one train per hour. The PCTCAN-Interfacultativo tramway section will thus have 4 services per hour and direction.

The 4 lines with 2 types of services each are summarized below.

- Airport- Interfacultativo. Departures from 5:25 to 21:25, every 60 minutes.
- Interfacultativo -Airport. Departures from 4:00 to 20:00, every 60 minutes.
- Maliaño-Santander. Departures from 6:11 to 23:11, every 60 minutes.
- Santander-Maliaño. Departures from 6:27 to 23:27, every 60 minutes.
- Maliaño-Interfacultativo. Departures from 6:56 to 22:56, every 60 minutes
- Interfacultativo-Maliaño. Departures from 6:30 to 23:30, every 60 minutes.
- Bezana-Santander. Departures from 6:39 to 23:39, every 60 minutes.
- Santander-Bezana. Departures from 6:15 to 23:15, every 60 minutes.
- Bezana-Interfacultativo. Departures from 6:18-6:38 to 22:18-22:38 (2 per hour); and 23:18.
- Interfacultativo-Bezana. Departures from 6:40-7:00 to 22:40-23:00 (2 per hour); and 23:40.

The following results have been obtained for Scenario 2.

Alternative 2 - Scenario 2 (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Internal trips	298,072	297,285	298,072
External trips	249,964	249,964	249,964
Car internal	265,497	264,434	253,733
Bus internal	31,274	31,151	41,705
Tram-train internal	1,301	1,700	2,634
Car external	244,312	244,312	244,312

Tram-train external	5,652	5,652	5,652
Car total trips	509,809	508,746	498,045
Bus total trips	31,274	31,151	41,705
Tram-train total trips	6,953	7,352	8,286

Table 13: Alternative 2 Scenario 2 results

Alternative 2 - Scenario 2 (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Tram-train total trips	6,953	7,352	8,286
Santander-Bezana	768	777	797
Interfacult.-Bezana	2,668	2,807	3,123
Santander-Maliaño	1,091	1,124	1,204
Interfacult.-Maliaño	2,584	2,695	2,961
Interfacultativo-Airport	718	813	1,039

Table 14: Alternative 2 Scenario 2 results by tram-train line

6.2.3. Alternative 1+2 scenarios

Scenario 1: Extension of existing narrow-gauge lines

The first scenario for Alternative 1+2 proposes the extension of the existing narrow-gauge commuter train lines using the new tramway section. The C-2 line would deviate from the existing line at the PCTCAN and would return to it from the current terminal station, which it would reach through the Tetuán tunnel, eventually ending at the airport. Line C-3 will be extended using the tramway route up to PCTCAN. Therefore, there will be a section shared by both lines between the PCTCAN and Valle Real stations.

A frequency of 20 minutes is proposed for both lines, similar to the current schedule, so that on the shared section there would be a train every 10 minutes.

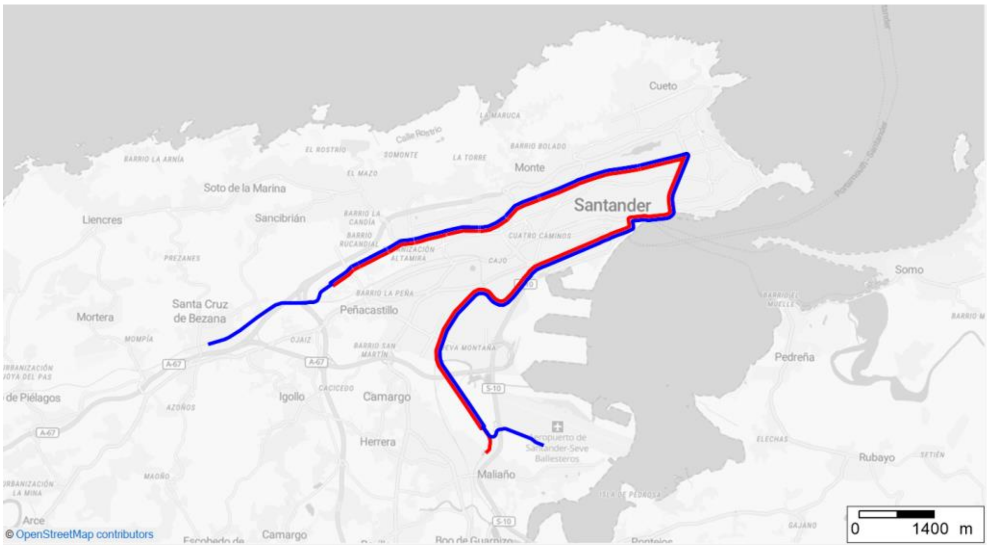

Figure 14: Alternative 1+2 Scenario 1 (Bezana-Aeropuerto in blue, Maliaño-PCTCAN in red)

This scenario therefore includes two lines with two types of services each. These services are listed below.

- PCTCAN-Maliaño. Departures from 6:30 to 23:10, every 20 minutes.

- Maliaño-PCTCAN. Departures from 6:11 to 22:51, every 20 minutes.
- Bezana-Airport. Departures 4:30; and from 5:40 to 23:00 every 20 minutes.
- Airport-Bezana. Departures 5:05; and from 5:59 to 23:19 every 20 minutes.

The following results were obtained for Scenario 1.

Alternative 1+2 - Scenario 1 (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Internal trips	297,819	297,031	297,032
External trips	249,963	249,963	249,963
Car internal	262,611	260,846	248,283
Bus internal	30,937	30,736	40,783
Tram-train internal	4,271	5,449	7,966
Car external	246,431	246,431	246,431
Tram-train external	3,532	3,532	3,532
Car total trips	509,042	507,277	494,714
Bus total trips	30,937	30,736	40,783
Tram-train total trips	7,803	8,981	11,498

Table 15: Alternative 1+2 Scenario 1 results

Alternative 1+2 - Scenario 1 (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Tram-train total trips	7,803	8,981	11,498
Maliaño line	4,966	5,476	6,553
Bezana line	2,658	3,312	4,698

Table 16: Alternative 1+2 Scenario 1 results by tram-train line

Scenario 2: Extension of existing narrow-gauge lines and new circular line

Scenario 1 shows a shortcoming regarding trips within the city limits: those willing to travel from Valdecilla or the city center to the northwest of the city, i.e. the PCTCAN or El Alisal, would have to follow the entire route around Puerto Chico, the Tetuán Tunnel and the university campus. This considerably extends the trip with respect to alternatives by bus or car, making the tram-train unattractive for these internal trips. Fortunately, this can be easily solved with the existing infrastructure, which closes the U-shaped tram route to the southwest, creating a closed loop that could be exploited by a circular line. This is precisely what Scenario 2 proposes, which can be more clearly appreciated in Figure 15.

By keeping the 20-minute frequency for the two existing and extended lines (as in Scenario 1) and incorporating the circular line with a 15-minute frequency, a total of 10 services per hour and direction would be running in the stations of the city of Santander. This would make the tram-train system a very competitive alternative both for trips between the metropolitan area and Santander and within the city itself.

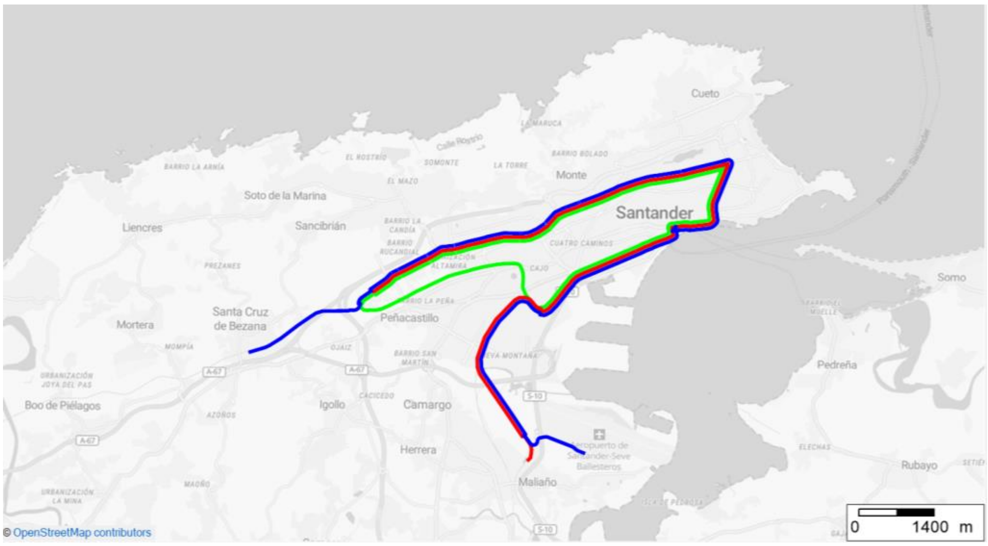

Figure 15: Alternative 1+2 Scenario 2 (Bezana-Aeropuerto in blue, Maliaño-PCTCAN in red, circular line in green)

Accordingly, three lines with two types of services are proposed, as detailed below:

- PCTCAN-Maliaño. Departures from 6:30 to 23:10, every 20 minutes.
- Maliaño-PCTCAN. Departures from 6:11 to 22:51, every 20 minutes.
- Bezana-Airport. Departures at 4:30; and from 5:40 to 23:00, every 20 minutes.
- Airport-Bezana. Departures at 5:05; and from 5:59 to 23:19 every 20 minutes.
- Circular (clockwise). Running through PCTCAN from 6:07 to 23:07, every 15 minutes.
- Circular (counterclockwise). Running through PCTCAN from 6:37 to 23:37, every 15 minutes.

The simulation of Scenario 2 provided the following results.

Alternative 1+2 - Scenario 2 (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Internal trips	297,032	297,818	297,031
External trips	249,964	249,964	249,964
Car internal	261,068	260,495	247,040
Bus internal	30,755	30,729	40,604
Tram-train internal	5,209	6,594	9,387
Car external	246,434	246,434	246,434
Tram-train external	3,530	3,530	3,530
Car total trips	507,502	506,929	493,474
Bus total trips	30,755	30,729	40,604
Tram-train total trips	8,739	10,124	12,917

Table 17: Alternative 1+2 Scenario 2 results

Alternative 1+2 - Scenario 2 (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Tram-train total trips	8,739	10,124	12,917
Maliaño line	4,414	4,779	3,536
Bezana line	2,098	2,603	5,518
Circular line	2,059	2,554	3,536

Table 18: Alternative 1+2 Scenario 2 results by tram-train line

Scenario 3: Loops of existing narrow-gauge lines

Scenario 3 proposes a different approach, aimed at taking users from the metropolitan area to their final destination faster. To this end, there would be only two lines (Cabezón-Bezana-Santander and Liérganes-Maliaño-Santander), as currently. However, each of them would run the entire tramway route, alternating clockwise and counterclockwise directions: for example, at a station such as Valle Real, a given train would pass towards Santander, which will enter the city through the PCTCAN, continuing along El Alisal, Avenida de los Castros, the Tetuán tunnel, Puerto Chico, the center of Santander and eventually passing again through Valle Real towards Maliaño/Liérganes; the next train towards Santander, instead, would enter the city through the central station and run the tramway route in the opposite direction, leaving Santander through the PCTCAN and then returning towards Valle Real, Maliaño and Liérganes.

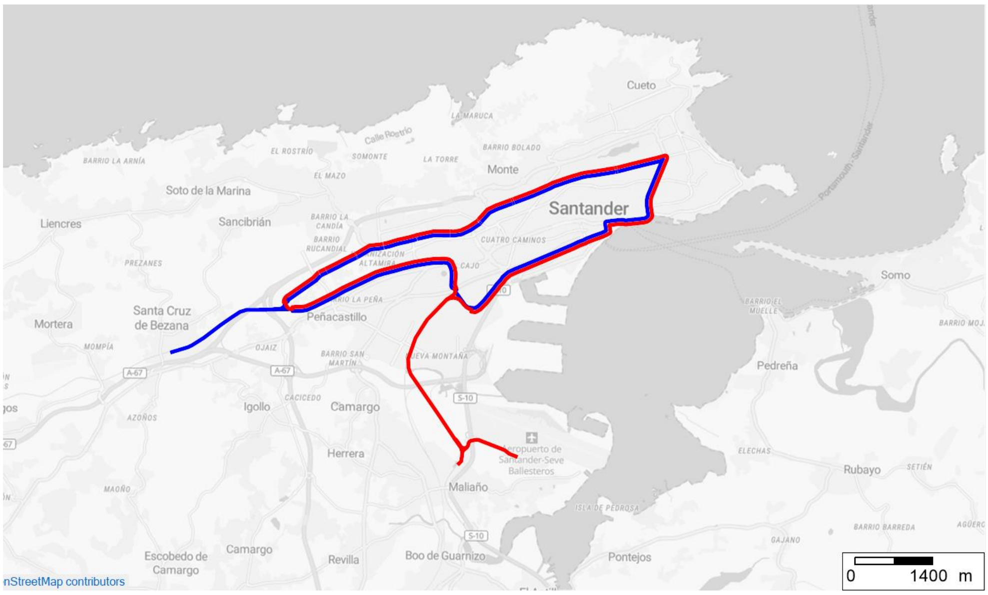

Figure 16: Alternative 1+2 Scenario 3 (Bezana line in blue, Maliaño line in red)

The Aeropuerto stop is served by a train every 30 minutes, since clockwise services only stop there on their way from Santander to Maliaño and the counterclockwise services do so on their way from Maliaño to Santander. In this way, they connect the airport as directly as possible with the city center and the most touristic areas, while avoiding all trains from entering the Airport branch line, thus reducing travel times for other users.

The schedules were coordinated in such a way that a train runs every 15 minutes on the tramway section, i.e., one train of each line every 30 minutes in each direction. More precisely, these are the services proposed in Scenario 3:

- Bezana line (clockwise). Running through PCTCAN from 6:15 to 23:15, every 30 minutes.
- Bezana line (counterclockw.). Running through PCTCAN from 6:30 to 23:30, every 30 minutes.
- Maliaño line (clockwise). Running through PCTCAN from 6:00 to 23:00, every 30 minutes.
- Maliaño line (counterclockw.). Running through PCTCAN from 6:45 to 23:45, every 30 minutes.

The results obtained for Scenario 3 are shown below.

Alternative 1+2 - Scenario 3 (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Internal trips	297,031	297,817	297,031
External trips	249,964	249,964	249,964
Car internal	263,710	263,715	251,124
Bus internal	30,983	31,016	41,146
Tram-train internal	2,338	3,086	4,761
Car external	242,736	242,736	242,736
Tram-train external	7,228	7,228	7,228
Car total trips	506,446	506,451	493,860
Bus total trips	30,983	31,016	41,146
Tram-train total trips	9,566	10,314	11,989

Table 19: Alternative 1+2 Scenario 3 results

Alternative 1+2 - Scenario 3 (Daily Trips)			
Fare	**1.65€**	**1.30€**	**0.66€**
Tram-train total trips	8,739	10,124	12,917
Bezana line	4,602	4,879	5,489
Maliaño line	5,566	6,015	7,032

Table 20: Alternative 1+2 Scenario 3 results by tram-train line

Scenario 4: Loops of existing narrow-gauge lines and circular line

The fourth and last scenario is the most ambitious of all, proposing the best service for travelers from the metropolitan area –the scheme with loops in clockwise and counter-clockwise directions alternating in time, allowing them to reach their destinations more swiftly– and for travelers within the city of Santander –with the circular line also allowing them to travel faster. This is arguably the scenario that maximizes the potential of the new infrastructure, as it could probably only be improved by further increasing frequencies.

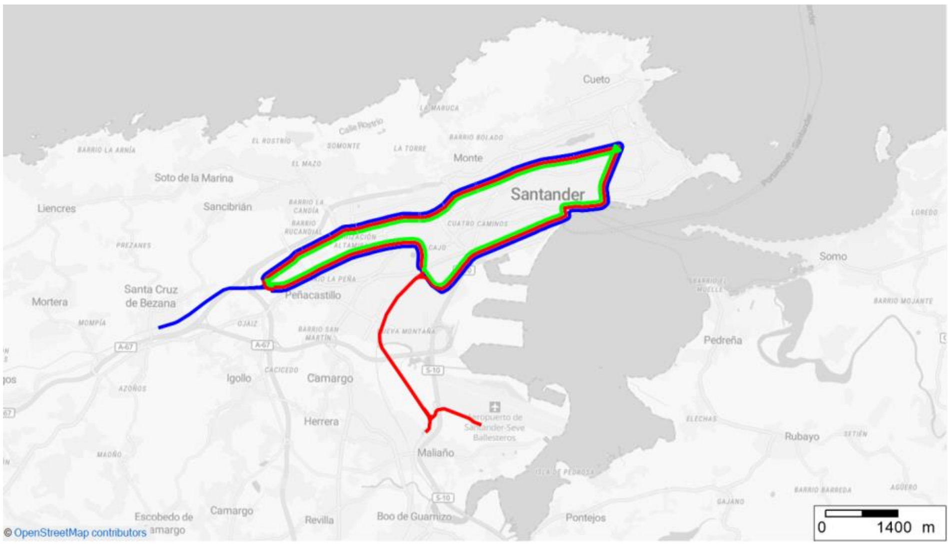

Figure 17: Alternative 1+2 Scenario 4 (Bezana line in blue, Maliaño line in red, circular line in green)

The proposed frequencies for the Bezana and Maliaño lines are the same as in Scenario 3 –one train every 30 minutes for each type of service, resulting in a 15-minute frequency on the shared section– and the same frequency as in Scenario 2 for the circular line –one train every 15 minutes in each direction. Thus, 8 services per hour and direction would run on the section shared by all lines. In the rest of the sections there would be 4 services per hour and direction, except for the Airport, with 2 services per hour and direction –only trains entering or leaving Santander through the central station would stop there, as in Scenario 3.

Below is a detailed list of the three lines –with two types of services each– proposed in Scenario 4.

- Bezana line (clockwise). Running through PCTCAN from 6:15 to 23:15, every 30 minutes.
- Bezana line (counterclockwise). Running through PCTCAN from 6:30 to 7:00, every 30 minutes.
- Maliaño line (clockwise). Running through PCTCAN from 6:00 to 23:00, every 30 minutes.
- Maliaño line (counterclockw.). Running through PCTCAN from 6:45 to 23:45, every 30 minutes.
- Circular (clockwise). Running through PCTCAN from 6:07 to 23:07, every 15 minutes.
- Circular (counterclockwise). Running through PCTCAN from 6:37 to 23:37, every 15 minutes.

Scenario 4 results are shown in Tables 21 and 22.

Alternative 1+2 - Scenario 4 (Daily Trips)			
Fare	1.65€	1.30€	0.66€
Internal trips	297,817	296,831	297,818
External trips	249,966	249,966	249,966
Car internal	263,390	261,800	250,166
Bus internal	30,978	30,806	41,037
Tram-train internal	3,449	4,225	6,615
Car external	242,736	242,736	242,736
Tram-train external	7,230	7,230	7,230
Car total trips	506,126	504,536	492,902
Bus total trips	30,978	30,806	41,037
Tram-train total trips	10,679	11,455	13,845

Table 21: Alternative 1+2 Scenario 4 results

Alternative 1+2 - Scenario 4 (Daily Trips)			
Fare	1.65€	1.30€	0.66€
Tram-train total trips	10,679	11,455	13,845
Bezana line	4,389	4,571	4,975
Maliaño line	5,099	5,428	6,181
Circular line	1,798	2,242	3,228

Table 22: Alternative 1+2 Scenario 3 results by tram-train line

7. Multi-criteria analysis

7.1. Pre-selection of scenarios

The fact that a total of 3 route alternatives, 9 tram-train service scenarios and 3 fares have been proposed makes a pre-selection necessary before carrying out the multi-criteria evaluation to determine which is the best proposal for the transportation system of the metropolitan area of Santander. For this purpose, the number of passengers being attracted to the tram-train system with respect to the baseline scenario will be evaluated with respect to the system's cost. In this way, the less "efficient" solutions are discarded, and the evaluation focuses on those capable of attracting more passengers at a lower investment cost.

The ultimate goal is the search for sustainable solutions (with lower investment, operation and maintenance costs) regarding their ridership and the service provided. The tram-train is a public transport system complementary to the existing public transport network in Santander, which currently relies mainly on buses.

The demand for each scenario having already been calculated, the next step is to calculate the approximate costs. In this case, the cost of infrastructure and rolling stock acquisition, and the operating cost for 30 years were considered.

7.1.1. Infrastructure cost estimation

The first cost that arises when planning the implementation of a new tram-train system is the new infrastructure that must be built and, eventually, the cost of adapting some sections of the existing railway system. This could be either tramway infrastructure, primarily in urban environments or high-density areas, or rail infrastructure, typically in interurban or less densely populated areas.

In the specific case of this tram-train system, the proposed route alternatives require the construction of single-track and double-track tramway type sections, as well as a single-track railway type section for the bypass between Santander-Bezana-Cabezón and Santander-Maliaño-Liérganes lines.

Unit costs of the tramway infrastructure have been estimated based on a 2016 project for the Zaragoza tramway extension (IDOM, 2016), at 13,843,234€/km for double track, updated to 17,189,674€/km in 2024 (the cumulative inflation rate from January 2016 to June 2024 in Spain is 24.2%). In the case of single-track sections, it is assumed that the cost is equivalent to 60% of the double-track cost, based on the proportions of single-track vs. double-track cost in railway (Grande, Torralbo, Lobera, Sánchez-Cambronero, & Castillo, 2018).

The cost of the only rail section that would need to be built, the single-track bypass, was budgeted in July 2020 at €18,744,072.86 (MITMA, 2020). It is not updated for inflation to 2024 prices as some of the projected elements, such as a dead-end track, would not be needed for the tram-train case. The cost of this bypass could therefore be estimated at 18.75 million euros at present.

The new infrastructure requirements for each alternative are shown in Table 23.

Alternative	Double-track tramway	Single-track tramway	Single-track railway
Alternative 1	3,465	1,201	0
Alternative 2	7,015	1,201	290
Alternative 1+2	10,412	1,201	290

Table 23: New infrastructure needs by route alternative (in meters)

After applying the costs described above, Table 24 shows the total infrastructure costs by alternative, which are expressed in euros.

Alternative	Double-track tram.	Single-track tram.	Single-track railw.	Total infrastr. cost (€)
Alternative 1	59,562,219	12,386,879	0	**71,949,098**
Alternative 2	120,585,561	12,386,879	18,744,072	**151,716,513**
Alternative 1+2	178,978,883	12,386,879	18,744,072	**210,109,834**

Table 24: Infrastructure cost by route alternative (in euros)

7.1.2. Rolling stock acquisition cost estimation

To calculate the number of tram-trains required in each scenario, the total line travel time and stopping time at both terminus stops have been considered to estimate the time for a complete cycle. Once the cycle time is known and considering the line frequency, the minimum number of tram-trains can be determined. It has been established, with some exceptions, that the number of trains to be assigned to each line should be 15% higher than the minimum, in order to have a safety margin in case of breakdowns, maintenance needs, etc.

To test this estimation, the number of tram-trains needed to operate the existing narrow-gauge train services was calculated. For simplification purposes, an average frequency of 20 minutes has been considered for each line, and it has been assumed that all services run on the whole line length.

In the case of the C-2 Santander-Bezana-Cabezón line (*Bezana line* in the Visum model), with a travel time of 78 minutes and an approximate 12-minute stop time at each terminus, a cycle time of 180 minutes per train is obtained. Applying the 20-minute frequency, this results in a minimum of 9 trains, which rises to 10.35 (11 trains) when adding the additional 15%. In the case of the C-3 Santander-Liérganes line (*Maliaño line* in the Visum model), the 53-minute travel time and 7-minute stop at each terminus yield a cycle time of 120 minutes per train. With the same frequency, a minimum of 6 trains is obtained, which rises to 6.9 (7 trains) if the safety factor is applied. Thus, a total of 18 trains is obtained. Taking into account that the Santander depot currently has 16 EMUs[2] of the 3800 series and 3 of the 3600 series, it can be concluded that the calculation is very close to reality.

Existing train lines		
Line	C-2 Santander-Bezana-Cabezón	C-3 Santander-Maliaño-Liérganes
Travel time, one-way (min)	78	53
Total terminus stop time (min)	12	7
Total train cycle (min)	**180**	**120**
Line frequency (min)	20	20
Strict min. number of trains	9	6
Minimum number of trains	**9**	**6**
+15%[3]	10.35	6.9
Number of tram-trains	**11**	**7**

Table 25: Estimation of the number of trains required to operate the existing narrow-gauge lines

Therefore, considering the above procedure as valid, the number of tram-trains required for each of the 9 scenarios has been calculated. The results obtained for each of them are shown below.

In the case **of Alternative 1 Scenario 1**, 2 more units would be necessary than in the current scenario for the Santander-Maliaño-Liérganes line, whose route is lengthened not only by the extension in Santander to the Interfacultativo stop, but also by the time of access and exit of the Airport new stop. Therefore, a total of **22 tram-trains** would be required to operate the system.

Alternative 1 Scenario 1		
Line	Bezana line	Maliaño line
Travel time, one-way (min)	88	68
Total terminus stop time (min)	12	9

[2] EMU: Electric Multiple Unit.

[3] Reserve rolling stock for service incidents and maintenance tasks.

Total train cycle (min)	**188**	**145**
Line frequency (min)	20	20
Strict min. number of trains	9.4	7.25
Minimum number of trains	**10**	**8**
+15%	11.5	9.2
Number of tram-trains	**12**	**10**

Table 26: Estimation of the number of trains required to operate Alternative 1 Scenario 1 tram-train lines

For **Alternative 1 Scenario 2**, 12 EMUs are still necessary for the Bezana line, while the number of tram-trains for the Maliaño line is reduced to 9 –since the time spent at the Airport stop is saved–, and 4 EMUs would be needed for the Airport line. The total is, therefore, **25 tram-trains**.

Alternative 1 Scenario 2			
Line	Bezana line	Maliaño line	Airport line
Travel time, one-way (min)	88	63	24
Total terminus stop time (min)	12	9	16
Total train cycle (min)	**188**	**135**	**64**
Line frequency (min)	20	20	30
Strict min. number of trains	9.4	6.75	2.13
Minimum number of trains	**10**	**7**	**3**
+15%	11.5	8.05	3.45
Number of tram-trains	**12**	**9**	**4**

Table 27: Estimation of the number of trains required to operate Alternative 1 Scenario 2 tram-train lines

The scenario that requires the fewest trains is **Alternative 2 Scenario 1a**, since all lines have a 60-minute frequency. Four trains are needed for the operation of each line, **16 tram-trains** to operate its four lines.

Alternative 2 Scenario 1a				
Line	Sant.-Bezana	Interf.-Bezana	Sant.-Maliaño	Interf.-Maliaño
Travel time, one-way (min)	78	82	58	69
Total terminus stop time (min)	16	16	10	10
Total train cycle (min)	**172**	**180**	**126**	**148**
Line frequency (min)	60	60	60	60
Strict min. number of trains	2.87	3	2.1	2.47
Minimum number of trains	**3**	**3**	**3**	**3**
+15%	3.45	3.45	3.45	3.45
Number of tram-trains	**4**	**4**	**4**	**4**

Table 28: Estimation of the number of trains required to operate Alternative 2 Scenario 1a tram-train lines

In **Alternative 2 Scenario 1b**, the lines departing from Santander central station remain unaltered, but the frequencies of those reaching the Interfacultativo stop are improved, resulting in the need for a total of **25 tram-trains**, clearly more than in the previous scenario. The greatest increase comes from Interfacultativo-Maliaño line, having a 20-minute frequency, i.e. 2 more trains per hour and direction.

Alternative 2 Scenario 1b				
Line	Sant.-Bezana	Interf.-Bezana	Sant.-Maliaño	Interf.-Maliaño
Travel time, one-way (min)	78	82	58	69
Total terminus stop time (min)	16	16	10	10
Total train cycle (min)	**172**	**180**	**126**	**148**

Line frequency (min)	60	30	60	20
Strict min. number of trains	2.87	6	2.1	7.4
Minimum number of trains	3	6	3	8
+15%	3.45	6.9	3.45	9.2
Number of tram-trains	4	7	4	10

Table 29: Estimation of the number of trains required to operate Alternative 2 Scenario 1b tram-train lines

Regarding **Alternative 2 Scenario 2**, the number of tram-trains required for the Santander-Maliaño line decreases to 3, since it no longer stops at the Airport, and it drops to 4 in the case of the Interfacultativo-Maliaño line, as is logical, given that its frequency is reduced to one train per hour. The total number of required EMUs is **20 tram-trains**.

Alternative 2 Scenario 2					
Line	Santander-Bezana	Interfacult.-Bezana	Santander-Maliaño	Interfacult.-Maliaño	Interfacult.-Airport
Travel time, one-way (min)	78	82	53	69	33
Total terminus stop time (min)	16	16	10	10	48
Total train cycle (min)	**172**	**180**	**116**	**148**	**114**
Line frequency (min)	60	30	60	60	60
Strict min. number of trains	2.87	6	1.93	2.47	1.9
Minimum number of trains	3	6	2	3	2
+15%	3.45	6.9	2.3	3.45	2.3
Number of tram-trains[4]	4	7	3	4	2

Table 30: Estimation of the number of trains required to operate Alternative 2 Scenario 2 tram-train lines

In **Alternative 1+2 Scenario 1**, the Bezana line increases its travel time by 32 minutes each way with respect to its current journey time, which –slightly reducing the stopping times at the terminals– means that it needs 14 EMUs (3 more than at present). In the case of the Maliaño line, the route is extended by 27 minutes with respect to the current journey time, requiring 11 tram-trains (2 more than now). In this scenario, therefore, **25 tram-trains** are needed.

A 110-minute journey time for the complete Cabezón de la Sal-Bezana-Santander-Airport line may seem excessive for a service of this type, but it is common on narrow-gauge commuter train networks in Spain. For example, Cercanías Asturias C-4 line (Cudillero-Gijón) has services that take more than two hours to complete the journey between the two terminals. Even in commuter train networks with a much higher demand, such as Cercanías Madrid, there are services on the C-2 line (Guadalajara-Cercedilla) that exceed 2 hours and 15 minutes of travel time between terminals.

Alternative 1+2 Scenario 1		
Line	Bezana line	Maliaño line
Travel time, one-way (min)	110	80
Total terminus stop time (min)	20	16
Total train cycle (min)	**240**	**176**
Line frequency (min)	20	20
Strict min. number of trains	12	8.8

[4] In the case of the Airport line, the number of tram-trains it is rounded down given that (i) the long stopping period at the line terminals does not make it necessary to have a back-up train, and (ii) it is considered that the additional trains of the other lines can be used if necessary.

Minimum number of trains	**12**	**9**
+15%	13.8	10.35
Number of tram-trains	**14**	**11**

Table 31: Estimation of the number of trains required to operate Alternative 1+2 Scenario 1 tram-train lines

Concerning **Alternative 1+2 Scenario 2**, it would be necessary to incorporate the 7 tram-trains necessary to operate the circular line. These resulted from a 41-minute travel time to run the entire ring, with a 2-minute margin to compensate for possible delays. In total, **32 tram-trains** are needed.

Alternative 1+2 Scenario 2			
Line	Bezana line	Maliaño line	Circular line
Travel time, one-way (min)	110	80	41
Total terminus stop time (min)	20	16	2
Total train cycle (min)	**240**	**176**	**43**
Line frequency (min)	20	20	15
Strict min. number of trains	12	8.8	5.73
Minimum number of trains	**12**	**9**	**6**
+15%	13.8	10.35	6.9
Number of tram-trains	**14**	**11**	**7**

Table 32: Estimation of the number of trains required to operate Alternative 1+2 Scenario 2 tram-train lines

Alternative 1+2 Scenario 3 (and 4) has the particularity that each line makes a loop in the city of Santander, so that they only have one terminal station. This is why only one travel time and one stop at a terminal station are included in the cycle time calculation, instead of two. In this way, a 15-minute frequency is achieved at all stations with **29 tram-trains**.

Alternative 1+2 Scenario 3		
Line	Bezana line	Maliaño line
Travel time (min)	180	132
Terminus stop time (min)	20	16
Total train cycle (min)	**200**	**148**
Line frequency (min)	15	15
Strict min. number of trains	13.33	9.87
Minimum number of trains	**14**	**10**
+15%	16.1	11.5
Number of tram-trains	**17**	**12**

Table 33: Estimation of the number of trains required to operate Alternative 1+2 Scenario 3 tram-train lines

Finally, **Alternative 1+2 Scenario 4** would need the 29 EMUs of the previous case and the 7 tram-trains for the circular line that are also required in Scenario 2, up to a total of **36 tram-trains**, being the scenario that has the largest number of units. Since only 30 tram-trains would be strictly necessary (14 for Bezana line, 10 for Maliaño line and 6 for the circular line), it would be possible to adopt a less cautious approach and reduce the number of tram-trains to 33 or 34, with a backup tram-train for each line. However, to be consistent with the method followed in the other cases, the 36 units are retained.

Alternative 1+2 Scenario 4			
Line	Bezana line	Maliaño line	Circular line
Travel time (min)	180	132	41
Terminus stop time (min)	20	16	2

Total train cycle (min)	**200**	**148**	**43**
Line frequency (min)	15	15	15
Strict min. number of trains	13.33	9.87	5.73
Minimum number of trains	**14**	**10**	**6**
+15%	16.1	11.5	6.9
Number of tram-trains	17	12	7

Table 34: Estimation of the number of trains required to operate Alternative 1+2 Scenario 4 tram-train lines

Table 35 shows the approximate rolling stock acquisition costs for each of the scenarios considered. An average cost per EMU of 3.725 million euros has been assumed. A tramway unit for the Zaragoza Tram was budgeted at €3 million in 2016 (IDOM, 2016). As previously mentioned, the cumulative inflation rate from January 2016 to June 2024 in Spain is 24.2%, resulting in an approximate present cost of €3,725,215.

Alternative	Scenario	Number of tram-trains	Rolling stock acq. cost (€)
Alternative 1	Scenario 1	22	81,954,730
	Scenario 2	25	93,130,375
Alternative 2	Scenario 1a	16	59,603,440
	Scenario 1b	25	93,130,375
	Scenario 2	20	74,504,300
Alternative 1+2	Scenario 1	25	93,130,375
	Scenario 2	32	119,206,880
	Scenario 3	29	108,031,235
	Scenario 4	36	134,107,740

Table 35: Rolling stock acquisition costs by scenario

7.1.3. Operating cost estimation

In order to calculate the operating costs, it is necessary to estimate the number of kilometers that the vehicles assigned to each line will travel over a given timeframe. For this purpose, a study period of 30 years is considered. The number of annual kilometers travelled is calculated assuming that the annual system operation is equivalent to that of 300 working days.

Therefore, the first step to obtain the operating costs is to determine the annual kilometers traveled in each scenario. For this purpose, the length of each line, the number of daily services (considering both directions), and the number of equivalent days of operation are considered. The calculations are detailed below.

<u>Alternative 1 - Scenario 1</u>

Approximately **2,491,452 km/year** are expected in this first scenario, in which there are 51 daily services per direction on each line. They are distributed by line as follows.

$$Bezana\ line = 49.46 \frac{km}{service} \cdot 102 \frac{services}{day} \cdot 300\ \frac{working\ days}{year} = 1{,}513{,}476 \frac{km}{year}$$

$$Maliaño\ line = 31.96 \frac{km}{service} \cdot 102 \frac{services}{day} \cdot 300\ \frac{working\ days}{year} = 977{,}976 \frac{km}{year}$$

Alternative 1 - Scenario 2

In the second scenario, there would be approximately **2,686,116 km/year**, with 51 services per direction on the Bezana line, 50 on the Liérganes line and 66 on the airport line. The distribution by line is shown hereafter.

$$Bezana\ line = 49.46\frac{km}{service}\cdot 102\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 1{,}513{,}476\frac{km}{year}$$

$$Maliaño\ line = 31.96\frac{km}{service}\cdot 100\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 958{,}800\frac{km}{year}$$

$$Airport\ line = 10.8\frac{km}{service}\cdot 66\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 213{,}840\frac{km}{year}$$

Alternative 2 - Scenario 1a

In this scenario, there would be approximately **1,655,550 km/year**, with 18 daily services per direction on all lines except Maliaño-Interfacultativo, which has 17 services towards Interfacultativo and 18 towards Maliaño. Detailed calculations are provided below.

$$Bezana - Santander = 45.97\frac{km}{service}\cdot 36\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 496{,}476\frac{km}{year}$$

$$Bezana - Interfacultat. = 46.03\frac{km}{service}\cdot 36\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 497{,}124\frac{km}{year}$$

$$Maliaño - Santander = 28.45\frac{km}{service}\cdot 36\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 307{,}260\frac{km}{year}$$

$$Maliaño - Interfacultat. = 33.78\frac{km}{service}\cdot 35\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 354{,}690\frac{km}{year}$$

Alternative 2 - Scenario 1b

In scenario 1b, a total of **2,814,168 km/year** is envisaged, with 18 daily services per direction on the lines with origin or destination at the terminal station, 35 on the Bezana-Interfacultativo line and 51-52 on the Maliaño-Interfacultativo line, depending on the direction. The breakdown by line is shown as follows.

$$Bezana - Santander = 45.97\frac{km}{service}\cdot 36\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 496{,}476\frac{km}{year}$$

$$Bezana - Interfacultat. = 46.03\frac{km}{service}\cdot 70\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 966{,}630\frac{km}{year}$$

$$Maliaño - Santander = 28.45\frac{km}{service}\cdot 36\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 307{,}260\frac{km}{year}$$

$$Maliaño - Interfacult. = 33.78\frac{km}{service}\cdot 103\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 1{,}043{,}802\frac{km}{year}$$

Alternative 2 - Scenario 2

In scenario 2, tram-trains are expected to run **2,252,628 km/year**, with 17-18 daily services per direction on all lines except Bezana-Interfacultativo, which keeps the frequency of the previous scenario. The estimates by line are shown below.

$$Bezana - Santander = 45.97\frac{km}{service}\cdot 36\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 496{,}476\frac{km}{year}$$

$$Bezana - Interfacultat. = 46.03\frac{km}{service}\cdot 70\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 966{,}630\frac{km}{year}$$

$$Maliaño - Santander = 26.19\frac{km}{service}\cdot 36\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 282{,}852\frac{km}{year}$$

$$Maliaño - Interfacultat. = 33.78\frac{km}{service}\cdot 35\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 354{,}690\frac{km}{year}$$

$$Airport - Interfacult. = 14.9\frac{km}{service}\cdot 34\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 151{,}980\frac{km}{year}$$

Alternative 1+2 - Scenario 1

A total of **2,941,380 km/year** are expected in this first scenario, in which there are 54 daily services per direction on the Bezana line, 51 in the case of Maliaño line. The distribution by line is as follows.

$$Bezana\ line = 56.84\frac{km}{service}\cdot 108\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 1{,}841{,}616\frac{km}{year}$$

$$Maliaño\ line = 35.94\frac{km}{service}\cdot 102\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 1{,}099{,}764\frac{km}{year}$$

Alternative 1+2 - Scenario 2

The second scenario presents the same annual kilometers for the Bezana and Maliaño lines as Scenario 1, plus an additional nearly 700,000 km from the 69 daily services per direction of the circular line. The total is therefore **3,632,760 km/year**. The detailed calculations are shown below.

$$Bezana\ line = 56.84\frac{km}{service}\cdot 108\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 1{,}841{,}616\frac{km}{year}$$

$$Maliaño\ line = 35.94\frac{km}{service}\cdot 102\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 1{,}099{,}764\frac{km}{year}$$

$$Circular\ line = 16.7\frac{km}{service}\cdot 138\frac{services}{day}\cdot 300\ \frac{working\ days}{year} = 691{,}380\frac{km}{year}$$

Alternative 1+2 - Scenario 3

In the third scenario it should be noted that the services are considerably longer because, by making a loop in Santander, the outward and return journeys are made in the same service. Both lines have a total of 70 services per day, 35 looping clockwise and 35 counterclockwise. The total number of kilometers traveled is **3,385,410 km/year**. The calculations by line are detailed below.

$$Bezana\ line = 95.49 \frac{km}{service} \cdot 70 \frac{services}{day} \cdot 300\ \frac{working\ days}{year} = 2{,}005{,}290 \frac{km}{year}$$

$$Maliaño\ line = 65.72 \frac{km}{service} \cdot 70 \frac{services}{day} \cdot 300\ \frac{working\ days}{year} = 1{,}380{,}120 \frac{km}{year}$$

Alternative 1+2 - Scenario 4

The fourth scenario, in which the loop remark mentioned in Scenario 3 must also be considered, is the one with the highest total number of kilometers traveled annually, **4,077,790 km/year**. The calculations for each of the three lines are shown hereafter.

$$Bezana\ line = 95.49 \frac{km}{service} \cdot 70 \frac{services}{day} \cdot 300\ \frac{working\ days}{year} = 2{,}005{,}290 \frac{km}{year}$$

$$Maliaño\ line = 65.72 \frac{km}{service} \cdot 70 \frac{services}{day} \cdot 300\ \frac{working\ days}{year} = 1{,}380{,}120 \frac{km}{year}$$

$$Circular\ line = 16.7 \frac{km}{service} \cdot 138 \frac{services}{day} \cdot 300\ \frac{working\ days}{year} = 691{,}380 \frac{km}{year}$$

Table 36 shows the approximate costs of operating the tram-train system, annually and for a 30-year period, for each of the scenarios considered. An average operation cost of 5€/km has been assumed for the first year of operations[5]. The average annual inflation rate in Spain is 2.3% between January 2022 and June 2024. Operating costs for a 30-year period are calculated as shown in the following formula.

$$OC = \frac{Km}{year} \cdot Unit\ Operation\ Cost \cdot \frac{(1 + CPI)^n - 1}{CPI} \cdot (1 + CPI)$$

OC is the total operating cost in euros, CPI is the consumer price index, and n is the number of years. As an example, operating cost for Alternative 1 Scenario 1 is calculated as follows.

$$OC = 2{,}491{,}452 \frac{km}{year} \cdot 5 \frac{€}{km} \cdot \frac{(1 + 0.023)^{30} - 1}{0.023} \cdot (1 + 0.023) = 541{,}995{,}382.09\ €$$

Alternative	Scenario	Annual distance traveled (km)	Years	Operating cost (€)
Alternative 1	Scenario 1	2,491,452	30	541,995,382
	Scenario 2	2,686,116		584,342,973
Alternative 2	Scenario 1a	1,655,550		360,151,612
	Scenario 1b	2,814,168		612,199,657
	Scenario 2	2,252,628		490,041,138
Alternative 1+2	Scenario 1	2,941,380		639,873,607
	Scenario 2	3,632,760		790,277,775
	Scenario 3	3,385,410		736,468,769
	Scenario 4	4,076,790		886,872,937

Table 36: Operating costs for a 30-year period by scenario

[5] Based on data provided by IDOM.

7.1.4. Total estimated costs

Considering infrastructure, rolling stock acquisition and 30-year operating costs, the following total costs are obtained for each scenario.

Alternative	Scenario	Costs (€)			
		Infrastructure	Rolling stock	Operating	Total
Alternative 1	Scenario 1	71,949,098	81,954,730	541,995,382	**695,899,210**
	Scenario 2	71,949,098	93,130,375	584,342,973	**749,422,446**
Alternative 2	Scenario 1a	151,716,513	59,603,440	360,151,612	**571,471,565**
	Scenario 1b	151,716,513	93,130,375	612,199,657	**857,046,545**
	Scenario 2	151,716,513	74,504,300	490,041,138	**716,261,951**
Alternative 1+2	Scenario 1	210,109,834	93,130,375	639,873,607	**943,113,816**
	Scenario 2	210,109,834	119,206,880	790,277,775	**1,119,594,489**
	Scenario 3	210,109,834	108,031,235	736,468,769	**1,054,609,838**
	Scenario 4	210,109,834	134,107,740	886,872,937	**1,231,090,511**

Table 37: Total costs by scenario

7.1.5. Pre-selected scenarios

To pre-select the scenarios on which the multi-criteria evaluation will be made, the tram-train's *total cost per passenger* and the *operating cost recovery* ratios are calculated. For each route alternative (1, 2 and 1+2) and fare, the scenario with the lowest total cost per passenger ratio and the highest operating cost recovery ratio has been selected.

The total cost per passenger ratio is calculated as follows.

$$Cost/Demand\ ratio = \frac{Total\ cost\ (thousand\ €)}{Tram - train\ demand\ (30\ years)}$$

The 30-year tram-train passenger demand has been estimated considering that the annual demand is equivalent to that of 300 business days, which is consistent to the assumption made to calculate the system's operating costs.

As a reminder, each scenario was modeled with three different fare schemes:

- Tram-train ticket at €1.65 (current commuter train single-zone ticket fare) and municipal bus ticket at €1.30 (current bus single ticket fare).
- Tram-train and bus ticket at €1.30 (current bus single ticket fare).
- Tram-train and bus ticket at €0,66 (current bus fare with TUS municipal bus card or Regional Transport Consortium card).

Cost/demand ratio (Tram-train fare = 1.65€)				
Alternative	Scenario	Total cost (€)	Tram-train demand (30 years)	Cost/demand ratio (€/passenger)
Alternative 1	Scenario 1	695,899,210	60,057,000	**11.59**
	Scenario 2	749,422,446	53,640,000	13.97
Alternative 2	Scenario 1a	571,471,565	63,027,000	**9.07**
	Scenario 1b	857,046,545	80,235,000	10.68
	Scenario 2	716,261,951	62,577,000	11.45
Alternative 1+2	Scenario 1	943,113,816	70,227,000	13.43
	Scenario 2	1,119,594,489	78,651,000	14.23

	Scenario 3	1,054,609,838	86,094,000	**12.25**
	Scenario 4	1,231,090,511	96,111,000	12.81

Table 38: Cost/demand ratio by scenario, for a 1.65€ tram-train fare

Cost/demand ratio (Tram-train fare = 1.30€)				
Alternative	Scenario	Total cost (€)	Tram-train demand (30 years)	Cost/demand ratio (€/passenger)
Alternative 1	Scenario 1	695,899,210	64,674,000	**10.76**
	Scenario 2	749,422,446	56,898,000	13.17
Alternative 2	Scenario 1a	571,471,565	66,906,000	**8.54**
	Scenario 1b	857,046,545	87,039,000	9.85
	Scenario 2	716,261,951	66,168,000	10.82
Alternative 1+2	Scenario 1	943,113,816	80,829,000	11.67
	Scenario 2	1,119,594,489	91,116,000	12.29
	Scenario 3	1,054,609,838	92,826,000	**11.36**
	Scenario 4	1,231,090,511	103,095,000	11.94

Table 39: Cost/demand ratio by scenario, for a 1.30€ tram-train fare

Cost/demand ratio (Tram-train fare = 0.66€)				
Alternative	Scenario	Total cost (€)	Tram-train demand (30 years)	Cost/demand ratio (€/passenger)
Alternative 1	Scenario 1	695,899,210	73,863,000	**9.42**
	Scenario 2	749,422,446	63,882,000	11.73
Alternative 2	Scenario 1a	571,471,565	75,582,000	**7.56**
	Scenario 1b	857,046,545	100,818,000	8.50
	Scenario 2	716,261,951	74,574,000	9.60
Alternative 1+2	Scenario 1	943,113,816	103,482,000	**9.11**
	Scenario 2	1,119,594,489	116,253,000	9.63
	Scenario 3	1,054,609,838	107,901,000	9.77
	Scenario 4	1,231,090,511	124,605,000	9.88

Table 40: Cost/demand ratio by scenario, for a 0.66€ tram-train fare

The operating cost recovery ratio (CRR) does not consider infrastructure and rolling stock acquisition costs, it focuses on annual revenue and operating & maintenance costs, and it is obtained as shown below.

$$Cost\ Recovery\ ratio\ (CRR) = \frac{Annual\ ridership \cdot Fare\ (€)}{Annual\ operating\ costs\ (€)}$$

Cost recovery ratio (Tram-train fare = 1.65€)				
Alternative	Scenario	Annual revenue (€)	Annual ope. cost (€)	Cost recovery ratio
Alternative 1	Scenario 1	3,303,135	12,457,260	**0.265**
	Scenario 2	2,950,200	13,430,580	0.220
Alternative 2	Scenario 1a	3,466,485	8,277,750	**0.419**
	Scenario 1b	4,412,925	14,070,840	0.314
	Scenario 2	3,441,735	11,263,140	0.306
Alternative 1+2	Scenario 1	3,862,485	14,706,900	0.263
	Scenario 2	4,325,805	18,163,800	0.238
	Scenario 3	4,735,170	16,927,050	**0.280**
	Scenario 4	5,286,105	20,383,950	0.259

Table 41: Cost recovery ratio by scenario, for a 1.65€ tram-train fare

Cost recovery ratio (Tram-train fare = 1.30€)				
Alternative	Scenario	Annual revenue (€)	Annual ope. cost (€)	Cost recovery ratio
Alternative 1	Scenario 1	2,802,540	12,457,260	**0.225**
	Scenario 2	2,465,580	13,430,580	0.184
Alternative 2	Scenario 1a	2,899,260	8,277,750	**0.350**
	Scenario 1b	3,771,690	14,070,840	0.268
	Scenario 2	2,867,280	11,263,140	0.255
Alternative 1+2	Scenario 1	3,502,590	14,706,900	**0.238**
	Scenario 2	3,948,360	18,163,800	0.217
	Scenario 3	4,022,460	16,927,050	0.238
	Scenario 4	4,467,450	20,383,950	0.219

Table 42: Cost recovery ratio by scenario, for a 1.30€ tram-train fare

Cost recovery ratio (Tram-train fare = 0.66€)				
Alternative	Scenario	Annual revenue (€)	Annual ope. cost (€)	Cost recovery ratio
Alternative 1	Scenario 1	1,624,986	12,457,260	**0.130**
	Scenario 2	1,405,404	13,430,580	0.105
Alternative 2	Scenario 1a	1,662,804	8,277,750	**0.201**
	Scenario 1b	2,217,996	14,070,840	0.158
	Scenario 2	1,640,628	11,263,140	0.146
Alternative 1+2	Scenario 1	2,276,604	14,706,900	**0.155**
	Scenario 2	2,557,566	18,163,800	0.141
	Scenario 3	2,373,822	16,927,050	0.140
	Scenario 4	2,741,310	20,383,950	0.134

Table 43: Cost recovery ratio by scenario, for a 0.66€ tram-train fare

Accordingly, the pre-selected scenarios are:

- Alternative 1 Scenario 1, having the lowest cost/demand ratio and the highest CRR.
- Alternative 2 Scenario 1a, having the lowest cost/demand ratio and the highest CRR.
- Alternative 1+2 Scenario 1, having the lowest cost/demand ratio for a 0.66€ fare and the highest CRR for a 1.33€ and a 0.66€ fare.
- Alternative 1+2 Scenario 3, having the lowest cost/demand ratio for a 1.65€ and a 1.33€ fare and the highest CRR for a 1.65€ fare.

7.2. Final scenario selection

The multi-criteria evaluation to determine the most appropriate solution for the implementation of a tram-train network in the Santander metropolitan area is based on the criteria described below. The weighting is indicated in parentheses next to the name of the indicator. The criteria are grouped in five categories:

- Alignment: those indicators which refer to the characteristics of the new infrastructure layout, which have an impact on the reliability of the service or the operating speeds, among others.
- Mode attractiveness: criteria related to characteristics that may favor a greater demand for the tram-train are included here.
- Demand and environmental sustainability: this category includes indicators obtained from the demand estimates of the Visum PTV model, with a special focus on the modal shift of passengers towards public transport and the reduction of GHG emissions.

- Financial sustainability: financial indicators, which have a lower weighting since they have been taken into account in the pre-selection of scenarios.
- Social and urban impact: criteria concerning the impact that the development of the works and the presence of the tram-train during the operation phase will have on Santander's society and urban layout.

Except for the third category and the "percentage of existing infrastructure" indicator, all indicators refer only to the new tramway alignment to be built.

Indicator	Units	Notes
1 ALIGNMENT *(0.15)*		
Percentage of length of straight alignment *(0.05)*	Percentage	Total sum of length of straight stretches divided by the total length of the line and expressed in a percentage. A high value is preferred to a smaller one.
New infrastructure length *(0.05)*	Km	Total length of the new alignment. A small value is preferred to a higher one. It may vary from the shortest alternative to the longest one.
Percentage of existing infrastructure (0.05)	Percentage	Proportion of the total number of kilometers used by the proposed tram-train service that correspond to the existing railway infrastructure. The infrastructure from Santander to the stations of Bezana and Maliaño is considered, since no network modifications or extensions are proposed outside this geographical area. 1 km of double track section is considered as 2 km of new/existing tracks. A high value is preferred to a smaller one.
Number of intersections with private traffic *(0.025)*	No. of intersections	Total number of points of conflict between the tramway alignment and existing streets and avenues. A small value is preferred to a higher one, to increase service reliability.
2 MODE ATTRACTIVENESS *(0.2)*		
Population coverage along the line *(0.05)*	No. of people	Number of people captured along the lines assuming 500 meters on each side. A higher value is preferred to a smaller one.
Workplaces coverage along the line *(0.075)*	Percentage	Number of offices (>150 m^2) captured along the lines assuming 500 meters on each side. A higher value is preferred to a smaller one.
Other points of interest coverage along the line *(0.05)*	Percentage	Number of points of interest (except for offices) captured along the lines assuming 500 meters on each side. A higher value is preferred to a smaller one.
Number of stations per km *(0.025)*	Ratio	A higher value is preferred to reduce the average walking distance to each station.
3 DEMAND AND ENVIRONMENTAL SUSTAINABILITY *(0.3)*		
Total daily ridership *(0.05)*	No. of passengers	Number of tram-train passengers in one day. A higher value is preferred to a smaller one.

Average daily ridership per newly built station *(0.05)*	Ratio	Number of tram-train passengers in one day divided by the number of newly built stations. A higher value is preferred to a smaller one.
Number of daily car trips attracted to the tram-train *(0.1)*	No. of trips	Decrease in the number of car trips compared to the baseline scenario. A higher value is preferred to a smaller one.
Public transport share of all trips *(0.1)*	Percentage	Percentage of total daily trips that are made by public transport, so as to ensure that trips attracted from the bus are not rewarded. A higher value is preferred to a smaller one.
4 FINANCIAL SUSTAINABILITY *(0.2)*		
Cost/demand ratio *(0.05)*	Ratio	A lower value is preferred to improve the financial sustainability of the tram-train system.
Cost recovery ratio *(0.05)*	Ratio	A higher value is preferred to improve the financial sustainability of the tram-train system.
Total cost *(0.1)*	Millions of euros	A small value is preferred to a higher one.
5 SOCIAL AND URBAN IMPACT *(0.15)*		
Sensitive areas exposed to worksite nuisances *(0.05)*	No. of sensitive areas	Number of healthcare and educational centers located less than 150 meters from the tramway alignment, which could be impacted by worksite nuisances. A lower value is preferred to a higher one.
Length close to the nearest buildings (D<10 m) *(0.075)*	Km	Total sum of the length of stretches where the distance from the edge of the tramway platform to the nearest buildings is smaller than 10 m. A small length is preferred to a bigger one.
Tetuan Tunnel Closure *(0.025)*	Yes/No	Some of the proposed alternatives require the closure of the Tetuán tunnel to private traffic. Due to the impact that the closure of this artery may have on traffic in large sectors of the city, the non-closure of the tunnel is preferable over its closure.

The results for each of the scenarios under evaluation for the indicators described above are shown hereafter, for a 1.30€ fare for both tram-train and bus.

Indicator	Units	Alt 1 S1	Alt 2 S1a	Alt 1+2 S1	Alt 1+2 S3
1 ALIGNMENT *(0.15)*					
Percentage of length of straight alignment *(0.025)*	Percentage	**76.53%**	**65.63%**	**68.19%**	**68.19%**
New railway/tramway track length *(0.05)*	Km	**8.131**	**15.521**	**22.315**	**22.315**

Percentage of existing infrastructure (0.05)	Percentage	79.29%	66.73%	45.57%	58.24%
Number of intersections with private traffic *(0.025)*	No. of intersections	18	20	35	35
2 MODE ATTRACTIVENESS *(0.2)*					
Population coverage along the line *(0.05)*	People	22,169	39,398	57,730	57,730
Workplaces coverage along the line *(0.075)*	Percentage	37.58%	16.20%	52.48%	52.48%
Other points of interest coverage along the line *(0.05)*	Percentage	27.53%	23.14%	46.08%	46.08%
Number of stations per km *(0.025)*	Ratio	0.984	0.838	0.851	0.851
3 DEMAND AND ENVIRONMENTAL SUSTAINABILITY *(0.3)*					
Total daily ridership *(0.05)*	No. of passengers	7,186	7,434	8,981	10,314
Average daily ridership per newly built station *(0.05)*	Ratio	898.25	571.85	472.68	542.84
Number of daily car trips attracted to the tram-train *(0.1)*	No. of trips	3,179	4,634	6,721	7,547
Public transport share of all trips *(0.1)*	Percentage	7.03%	7.05%	7.26%	7.54%
4 FINANCIAL SUSTAINABILITY *(0.2)*					
Cost/demand ratio *(0.05)*	Ratio	10.76	8.54	11.67	11.36
Cost recovery ratio *(0.05)*	Ratio	0.225	0.350	0.238	0.238
Total cost *(0.1)*	Millions of euros	695,899,210.28	571,471,564.82	943,113,816.41	1,054,609,838.41

5 SOCIAL AND URBAN IMPACT *(0.15)*					
Sensitive areas exposed to worksite nuisances *(0.05)*	No. of sensitive areas	12	13	23	23
Length close to the nearest buildings (D<10 m) *(0.075)*	Km	0.520	0.344	0.555	0.555
Tetuan Tunnel Closure *(0.025)*	Yes/No	Yes	No	Yes	Yes

The last step to determine the scores for each scenario is to normalize the values of each indicator. For indicators where a smaller value is preferred over a larger one, the following normalization formula is used.

$$p_{a,i} = \left(\frac{v_{a,i}}{\min\left\{v_{s,i},\ s \in \{a,b,c,d\}\right\}}\right)^{-1}$$

Where $p_{a,i}$ is the score of scenario a for indicator i, $v_{a,i}$ is the value of scenario a for indicator i, and $v_{s,i}$ represents the set of values of all scenarios for indicator *i.*

For indicators where a higher value is preferred over a smaller one, the following normalization formula is used.

$$p_{a,i} = \frac{v_{a,i}}{\max\left\{v_{s,i},\ s \in \{a,b,c,d\}\right\}}$$

In the specific case of the "Tetuan Tunnel Closure" indicator, since it is a Yes/No indicator, a score of 1 is assigned to scenarios that do not require the tunnel to be closed and 0 to those that do need it.

In this manner, scores between 0 and 1 are obtained for each scenario and indicator, which are subsequently multiplied by the weighting coefficients of each indicator. The sum of the scores of a given scenario for all indicators yields the final score for each scenario. The scores for each indicator and scenario are shown below.

Indicator	Alt 1 S1	Alt 2 S1a	Alt 1+2 S1	Alt 1+2 S3
1 ALIGNMENT *(0.15)*				
Percentage of length of straight alignment *(0.025)*	1.00	0.86	0.89	0.89
New railway/tramway track length *(0.05)*	1.00	0.52	0.36	0.36

Percentage of existing infrastructure (0.05)	1.00	0.84	0.57	0.73
Number of intersections with private traffic *(0.025)*	1.00	0.90	0.51	0.51
2 MODE ATTRACTIVENESS *(0.2)*				
Population coverage along the line *(0.05)*	0.38	0.68	1.00	1.00
Workplaces coverage along the line *(0.075)*	0.72	0.31	1.00	1.00
Other points of interest coverage along the line *(0.05)*	0.60	0.50	1.00	1.00
Number of stations per km *(0.025)*	1.00	0.85	0.87	0.87
3 DEMAND AND ENVIRONMENTAL SUSTAINABILITY *(0.3)*				
Total daily ridership *(0.05)*	0.70	0.72	0.87	1.00
Average daily ridership per newly built station *(0.05)*	1.00	0.64	0.53	0.60
Number of daily car trips attracted to the tram-train *(0.1)*	0.42	0.61	0.89	1.00
Public transport share of all trips *(0.1)*	0.93	0.94	0.96	1.00
4 FINANCIAL SUSTAINABILITY *(0.2)*				
Cost/demand ratio *(0.05)*	0.79	1.00	0.73	0.75
Cost recovery ratio *(0.05)*	0.64	1.00	0.68	0.68
Total cost *(0.1)*	0.82	1.00	0.61	0.54

5 SOCIAL AND URBAN IMPACT *(0.15)*				
Sensitive areas exposed to worksite nuisances *(0.05)*	1.00	0.92	0.52	0.52
Length close to the nearest buildings (D<10 m) *(0.075)*	0.07	1.00	0.06	0.06
Tetuan Tunnel Closure *(0.025)*	0.00	1.00	0.00	0.00

After multiplying the scores for each indicator by their corresponding weighting coefficient and summing them, the following total scores are obtained for each scenario, for a 1.30€ fare.

Tram-train fare = 1.30€	
Scenario	Total score
Alternative 1 Scenario 1	0.707
Alternative 2 Scenario 1a	**0.785**
Alternative 1+2 Scenario 1	0.696
Alternative 1+2 Scenario 3	0.723

Table 44: Total score by scenario (Tram-train fare = 1.30€)

The result obtained indicates that the most appropriate alternative, as per the criteria and weightings established, is Alternative 2, and to be more specific its Scenario 1a. As shown in the table below, the highest score is also obtained for this scenario for the other fares proposed.

Total score		
Scenario	Tram-train fare = 1.65€	Tram-train fare = 0.66€
Alternative 1 Scenario 1	0.711	0.742
Alternative 2 Scenario 1a	**0.790**	**0.805**
Alternative 1+2 Scenario 1	0.662	0.722
Alternative 1+2 Scenario 3	0.722	0.726

Table 45: Total score by scenario (Tram-train fares of 1.65€ and 0.66€)

8. Conclusions

The city of Santander and its metropolitan area require a comprehensive enhacement of its public transport system, to improve the connection of the surrounding municipalities with the capital of the Cantabrian region. With the aim of proposing a solution in this regard, this report has (i) carried out a study of the urban environment and railway infrastructure, (ii) presented a series of route alternatives for a tram-train system and several operating scenarios each of them, (iii) developed a stated-preference survey to obtain a utility model that characterizes local mobility patterns, (iv) estimated the potential demand for the tram-train system, and (v) conducted a multi-criteria analysis based on indicators related to the tram-train system's alignment, the new mode's attractiveness, its demand and environmental sustainability, financial sustainability, and social and urban impact.

The tram-train system is a suitable option for the case of the metropolitan area of Santander, which currently has a railway infrastructure that, albeit in need of renovation in some sections, connects most of the main municipalities with the capital. The creation of a tramway alignment in Santander would allow, through its connection with the existing railway network, to improve the transport conditions for thousands of citizens by bringing them much more rapidly and conveniently to their final destinations. In addition, it will increase the capacity of the urban transportation system in the city of Santander.

It is worth mentioning that this would be the first service of its kind operating on the metric gauge network managed by the Spanish railway infrastructure manager (ADIF), following the currently unsuccessful attempt on León's commuter network, which has never been put into service despite all the infrastructure being completed.

Nonetheless, the modeling of this transport mode has posed some particular challenges. Firstly, the application of the utility model obtained from the stated-preference survey was only possible within the municipal area of Santander and some areas of adjacent municipalities. This is due to restrictions inherent to the PTV Visum model that was used, in which the coding of the transport network and zones of trip generation and attraction did not cover the entire study area. For the rest of the study area, a simplified model has been used that only considers the impedance of each mode.

Moreover, the available origin-destination matrices only made a distinction between trips by car and trips by public transport. Therefore, it was necessary to apply the assumption that, for the model to start running, all internal trips within the city of Santander were made by bus and all external trips were made by train. This assumption was proven to work correctly by cross-checking the data obtained in the baseline scenario with the actual modal share data provided by the SUMLAB+ department of the University of Cantabria.

Regarding this last point, it is worth mentioning that the tram-train will operate in two very different environments: urban and interurban. In the urban setting, its main competitors are cars and urban buses. In the interurban zones of Cantabria, however, the bus does not represent a significant rival, as its performance is clearly inferior in most cases.

The total number of combinations of route alternatives, operating schemes and fares came to 27. In order to reduce this number for the multi-criteria analysis, a first pre-selection of 4 scenarios (12 if considering the 3 proposed fares) was made on the basis of cost/demand and cost recovery ratios, calculated from the cost and demand estimations.

The final result obtained, for all the fares under evaluation, indicates that the most appropriate alternative to improve the transport system of Santander's metropolitan area is **Alternative 2** and, more precisely, its operational **Scenario 1a**.

Alternative 2 involves constructing a tramway branch that connects with the *Santander-Cabezón de la Sal* line of the existing railway network near the western boundary of the Cantabria Science and Technology Park (PCTCAN by its Spanish acronym). This alignment extends eastward along the north of Santander along Albert Einstein, Joaquín Rodrigo, Julio Jaurena, Los Ciruelos, Jose María de Cossio, Gutiérrez Solana streets, and Avenida de los Castros, up to the intersection of the latter with Calle Honduras, near the *Interfacultivo* Building of the University of Cantabria. Additionally, like the other alternatives, it includes a second tramway branch from the Valle Real railway station on the *Santander-Liérganes* line, in the municipality of Camargo, to the Seve Ballesteros Airport. Finally, to enable the operation of the system, it is necessary to construct a bypass between the Santander-Cabezón and Santander-Liérganes railway lines to avoid the need for reversals at the Santander terminal station.

Alternative 2 Scenario 1a proposes dividing each of the existing commuter train lines (C-2 and C-3) into two. Half of the trains on each line would arrive at and depart from Santander terminal station, and the other half would do so at the Interfacultativo stop, running along the tramway section from the PCTCAN. Trains on the Santander-Maliaño-Liérganes line would enter the branch section to the airport, having to reverse direction to continue their route. A 60-minute frequency is proposed for each type of service, so that each line has an average frequency of 30 minutes up to the point where services to the terminal station and Interfacultativo diverge. There is also an average 30-minute frequency on the Valdecilla-Santander and PCTCAN-Interfacultativo sections, where trains from both lines coincide.

Figure 18: Proposed tram-train lines diagram

Under this operational scheme, **the daily demand for the tram-train is estimated at 7,003 passengers (with a 1.65€ fare), 7,434 passengers (with a 1.30€ fare), or 8,398 passengers (with a 0.66€ fare).** The implementation of this solution involves an infrastructure investment of some 151,716,513€, the acquisition of 16 new tram-train units at an estimated cost of 59,603,440€, and an operational cost over the first 30 years of 360,151,612€. The total cost for a 30-year horizon is thus 571,471,565€, the lowest of all the scenarios evaluated.

For the highest fare (1.65€), it has a cost/demand ratio of 9.07€ per passenger over a 30-year horizon and a cost recovery rate of 41.9%; for the 1.30€ fare, it has a CDR of 8.54€/passenger and a CRR of 35.0%; and for the lowest fare (0.66€), it has a CDR of 7.56€/passenger and a CRR of 20.1%. **In all cases, it is the scenario with the lowest cost per passenger and the highest cost recovery rate.**

The model was run with these three fares to observe the sensitivity of tram-train demand to changes in ticket price. While there is not a significant difference in ridership when reducing the fare from 1.65€ to 1.30€, it is true that public transport modal share increases notably when setting a 0.66€ fare for both bus and tram-train. In any case, the price of the tram-train service is to be determined by its operator (presumably Renfe Operadora), ideally in collaboration with the Santander City Council and Santander's urban bus service operator (TUS), which should be considered a complementary service to the tram-train in its urban section rather than a competitor.

Therefore, this is an alternative that significantly improves the geographical coverage of the high-capacity public transport system of the metropolitan area, not only emerging as the most beneficial according to the set of indicators from the multicriteria analysis, but also the one with the lowest total cost and the highest cost recovery rate. It is true that this is partly due to the fact that it is the scenario with the poorest service frequencies (30 minutes per direction at all stations except the Airport, 60 minutes per direction for each type of service). However, the proposed option shows a higher tram-train demand than, for instance, all the scenarios of Alternative 1, which have higher costs and lower cost recovery rates. Therefore, it is a proposal that allows attracting a significant number of passengers to the tram-train, with savings in terms of costs and resources that lead to a better financial sustainability, thus facilitating the long-term durability of the service.

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Annex 1. Stated-preference survey

Encuesta de movilidad en el Área Metropolitana de Santander

Este formulario tiene por objetivo estimar el potencial de atracción de viajes de un nuevo sistema de transporte masivo de pasajeros en el área metropolitana de Santander, Cantabria.

El mismo incluye una serie de preguntas con el fin de caracterizar al encuestado, sus opciones de movilidad disponibles y sus hábitos de movilidad actuales. A continuación, se presentarán escenarios con diferentes opciones para efectuar un desplazamiento hipotético. Los mismos han sido creados tras una calibración realizada gracias a las respuestas a la encuesta piloto. La duración aproximada es de 5 minutos.

¡Muchas gracias por vuestro tiempo!

Correo: *Inserte correo válido*

Caracterización del encuestado

Por favor, indique su género:

- Masculino.
- Femenino.
- Otro.

Seleccione su rango de edad:

- Menor de 18 años.
- 18-30 años.
- 30-55 años.
- 55-75 años.
- Más de 75 años.

Indique su nivel de estudios:

- Educación Primaria / E.G.B.
- Educación Secundaria / Graduado Escolar.
- Bachillerato / B.U.P.
- Formación Profesional.
- Estudios Universitarios de Grado.
- Estudios Universitarios de Máster o superiores.

Seleccione el código postal de su vivienda habitual:

- 39001
- 39002
- 39003
- 39004
- 39005
- 39006
- 39007

- 39008
- 39009
- 39010
- 39011
- 39012
- Otro: *Indique cuál*

Movilidad actual

¿Dispone de carnet de conducir?

- Sí.
- No.

¿Dispone de, al menos, un automóvil?

- Sí.
- No.

¿Con qué frecuencia utiliza el transporte público?

- 3 o más días por semana.
- 1-2 días por semana.
- No lo utilizo todas las semanas.
- No lo utilizo nunca.

Para su trayecto habitual (p. ej.: de su domicilio al trabajo o la universidad y viceversa), ¿qué modos de transporte tiene disponibles actualmente?

- Automóvil.
- Transporte público.
- Ambos.

¿Dispone de tarjeta de transporte?

- ☐ Tarjeta Transportes Urbanos de Santander (TUS).
- ☐ Tarjeta Consorcio de Transportes de Cantabria.
- ☐ Tarjeta sin contacto Renfe Cercanías.
- ☐ Ninguna
- ☐ Otro: *Indique cuál*

Escenarios de movilidad

A continuación se muestran una serie de escenarios con diferentes alternativas de transporte para efectuar un desplazamiento entre un punto A y otro punto B.

Para cada escenario, se proponen tres modos de transporte: tren-tranvía, autobús y coche. Para cada modo, se indican un tiempo de viaje, un tiempo de acceso y un tiempo de espera (en minutos), así como un coste monetario (la tarifa en el caso del tren-tranvía y el autobús, y el coste del carburante en el caso del coche, en todos los casos en € por viaje).

A título informativo, un sistema de tren-tranvía es aquel que combina tramos en los que el vehículo se desplaza por una vía ferroviaria convencional (especialmente en tramos interurbanos) con tramos de tipo tranviario (principalmente en zona urbana), y emplea vehículos derivados del tranvía que son capaces de circular por ambos tipos de vía.

Ejemplo de tren-tranvía

Escenario 1. ¿Qué opción de transporte elegiría?

	Tren-tranvía	Autobús	Coche
Tiempo de viaje (min)	25	30	22
Tiempo de acceso (min)	12	2	-
Tiempo de espera (min)	3	11	-
Coste (€)	1,20	1,00	2,70

- Tren-tranvía.
- Autobús.
- Coche.

Escenario 2. ¿Qué opción de transporte elegiría?

	Tren-tranvía	Autobús	Coche
Tiempo de viaje (min)	25	10	8
Tiempo de acceso (min)	2	2	-
Tiempo de espera (min)	5	3	-
Coste (€)	1,80	0,33	0,90

- Tren-tranvía.
- Autobús.
- Coche.

Escenario 3. ¿Qué opción de transporte elegiría?

	Tren-tranvía	Autobús	Coche
Tiempo de viaje (min)	10	30	8
Tiempo de acceso (min)	2	5	-
Tiempo de espera (min)	5	7	-
Coste (€)	1,20	1,80	1,80

- Tren-tranvía.
- Autobús.
- Coche.

Escenario 4. ¿Qué opción de transporte elegiría?

	Tren-tranvía	Autobús	Coche
Tiempo de viaje (min)	16	20	22
Tiempo de acceso (min)	7	10	-
Tiempo de espera (min)	9	3	-
Coste (€)	1,80	1,00	2,70

- Tren-tranvía.
- Autobús.
- Coche.

Escenario 5. ¿Qué opción de transporte elegiría?

	Tren-tranvía	Autobús	Coche
Tiempo de viaje (min)	10	10	15
Tiempo de acceso (min)	7	10	-
Tiempo de espera (min)	3	11	-
Coste (€)	0,60	0,33	0,90

- Tren-tranvía.
- Autobús.
- Coche.

Escenario 6. ¿Qué opción de transporte elegiría?

	Tren-tranvía	Autobús	Coche
Tiempo de viaje (min)	16	20	15
Tiempo de acceso (min)	12	5	-
Tiempo de espera (min)	9	7	-
Coste (€)	0,60	1,80	1,80

- Tren-tranvía.
- Autobús.

- Coche.

Annex 2. NGENE and NLOGIT output

Initial model and NGENE scenarios

```
Design
;alts = Tram, Bus, Car
;rows = 6
;con
;eff = (mnl,s)
;model:
U(Tram) = b1[2.2] + b2[-0.2] * TVt[10,16,25] + b3[-0.5] * TAt[2,7,12]+b4[-0.16]*TEt[3,5,9] + b5[-0.8]*TARt[0.6,1.2,1.8]/
U(Bus) = b6[1.8] + b7[-0.2] * TVb[10,20,30] + b8[-0.5] * TAb[2,5,10]+b9[-0.16]*TEb[3,7,11] + b10[-0.9]*TARb[0.33,1,1.8]/
U(Car) = b11[-0.2] * TVc[8,15,22] + b12[-0.75]*TARc[0.9,1.8,2.7]$
```

Figure 19: First Logit model in NGENE

b1: Tram-train constant; b2: Tram-train travel time; b3: Tram-train access time; b4: Tram-train waiting time; b5: Tram-train fare; b6: Bus constant; b7: Bus travel time; b8: Bus access time; b9: Bus waiting time; b10: Bus fare; b11: Car travel time; b12: Car travel cost.

MNL efficiency measures												
D error	0.779423											
A error	12.643425											
B estimate	20.129292											
S estimate	68.404669											
Prior	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10	b11	b12
Fixed prior value	2.2	-0.2	-0.5	-0.16	-0.8	1.8	-0.2	-0.5	-0.16	-0.9	-0.2	-0.75
Sp estimates	48.037692	43.246857	18.357606	68.404669	67.199183	64.75717	18.536749	27.036205	65.421623	66.923013	40.381585	43.484452
Sp t-ratios	0.282791	0.298043	0.457455	0.236981	0.239097	0.243563	0.455239	0.37695	0.242323	0.23959	0.308436	0.297228
Design												
Choice situation	tram.tvt	tram.tat	tram.tet	tram.tart	bus.tvb	bus.tab	bus.teb	bus.tarb	car.tvc	car.tarc		
1	16	2	3	0.6	10	5	3	0.33	8	1.8		
2	25	7	9	1.2	30	10	3	1	22	2.7		
3	25	2	5	1.8	30	2	11	0.33	15	0.9		
4	16	12	5	0.6	20	5	7	1.8	22	0.9		
5	10	7	9	1.2	20	2	7	1.8	8	1.8		
6	10	12	3	1.8	10	10	11	1	15	2.7		

Figure 20: NGENE output for the first Logit model, with the scenarios for the pilot survey

NLOGIT output based on the pilot survey results

```
|-> DISCRETECHOICE;Lhs=CHOICE;Choices=TT,BUS,CAR;Model:
    U(TT)=ctt+tvtp*TVIAJE+tacceso*TACCESO+tespera*TESPERA+costetp*COSTE/
    U(BUS)=cbus+tvtp*TVIAJE+tacceso*TACCESO+tespera*TESPERA+costetp*COSTE/
    U(CAR)=tvcar*TVIAJE+costecar*COSTE$
Iterative procedure has converged
Normal exit:   6 iterations. Status=0, F=    .3689321D+03

-----------------------------------------------------------------------------
Discrete choice (multinomial logit) model
Dependent variable                Choice
Log likelihood function       -368.93206
Estimation based on N =     414, K =   8
Inf.Cr.AIC  =     753.9 AIC/N =    1.821
---------------------------------------
            Log likelihood R-sqrd R2Adj
Constants only    -430.2487  .1425 .1341
Note: R-sqrd = 1 - logL/Logl(constants)
---------------------------------------
Chi-squared[ 6]          =     122.63325
Prob [ chi squared > value ] =    .00000
Response data are given as ind. choices
Number of obs.=    414, skipped    0 obs
--------+--------------------------------------------------------------------
```

```
        |                  Standard            Prob.      95% Confidence
  CHOICE|  Coefficient       Error       z    |z|>Z*         Interval
--------+--------------------------------------------------------------------
     CTT|   1.01810*        .58882     1.73  .0838     -.13597   2.17218
    TVTP|   -.13948***      .02707    -5.15  .0000     -.19253   -.08642
 TACCESO|   -.10163*        .05724    -1.78  .0758     -.21381    .01056
 TESPERA|   -.06290**       .03114    -2.02  .0434     -.12393   -.00186
 COSTETP|  -1.31128***      .22084    -5.94  .0000    -1.74413   -.87844
    CBUS|    .90763         .59016     1.54  .1241     -.24906   2.06432
   TVCAR|   -.11670***      .03916    -2.98  .0029     -.19345   -.03995
COSTECAR|   -.84654***      .17149    -4.94  .0000    -1.18265   -.51042
--------+--------------------------------------------------------------------
***, **, * ==>  Significance at 1%, 5%, 10% level.
Model was estimated on May 01, 2024 at 10:59:31 AM

-----------------------------------------------------------------------------
```

NGENE scenarios for NLOGIT output model

b1: Tram-train constant; b2: Public transport travel time; b3: Public transport access time; b4: Public transport waiting time; b5: Public transport fare; b6: Bus constant; b7: Car travel time; b8: Car travel cost.

MNL efficiency measures										
D error	0.27918									
A error	3.337654									
B estimate	54.745925									
S estimate	36.077008									
Prior	b1	b2	b3	b4	b5	b6	b7	b8		
Fixed prior value	1.0181	-0.13948	-0.10163	-0.0629	-1.31128	0.90763	-0.1167	-0.84654		
Sp estimates	28.925226	10.88565	21.704882	36.077008	12.750687	33.320426	25.685585	31.106429		
Sp t-ratios	0.364433	0.594058	0.420705	0.326318	0.548895	0.339548	0.386733	0.351424		
Design										
Choice situation	tram.tvt	tram.tat	tram.tet	tram.tart	bus.tvb	bus.tab	bus.teb	bus.tarb	car.tvc	car.tarc
1	25	12	3	1.2	30	2	11	1	22	2.7
2	25	2	5	1.8	10	2	3	0.33	8	0.9
3	10	2	5	1.2	30	5	7	1.8	8	1.8
4	16	7	9	1.8	20	10	3	1	22	2.7
5	10	7	3	0.6	10	10	11	0.33	15	0.9
6	16	12	9	0.6	20	5	7	1.8	15	1.8

Figure 21: NGENE output for NLOGIT's model, with the scenarios for the definitive survey

NLOGIT output based on the final survey results

```
|-> DISCRETECHOICE;Lhs=CHOICE;Choices=TT, BUS, CAR;Model:
    U(TT)=ctt+tviaje*TVIAJE+tesperaT*TESPERA+costeT*COSTE/
    U(BUS)=cbus+tviaje*TVIAJE+tesperaB*TESPERA+costeB*COSTE/
    U(CAR)=tviajeC*TVIAJE+costeC*COSTE$
Iterative procedure has converged
Normal exit:   6 iterations. Status=0, F=    .1187095D+04

-----------------------------------------------------------------------------
--
Discrete choice (multinomial logit) model
Dependent variable               Choice
Log likelihood function     -1187.09534
Estimation based on N =    1248, K =   9
Inf.Cr.AIC  =    2392.2 AIC/N =    1.917
```

```
----------------------------------------
             Log likelihood R-sqrd R2Adj
Constants only  -1346.5863  .1184 .1153
Note: R-sqrd = 1 - logL/Logl(constants)
----------------------------------------
Chi-squared[ 7]          =    318.98200
Prob [ chi squared > value ] =   .00000
Response data are given as ind. choices
Number of obs.=  1248, skipped    0 obs
--------+---------------------------------------------------------------------
--
        |                Standard            Prob.      95% Confidence
  CHOICE|  Coefficient      Error       z    |z|>Z*        Interval
--------+---------------------------------------------------------------------
--
     CTT|    1.38570***      .28928    4.79  .0000      .81872   1.95267
  TVIAJE|    -.10742***      .01413   -7.60  .0000     -.13512   -.07973
TESPERAT|    -.11075***      .02715   -4.08  .0000     -.16396   -.05755
  COSTET|    -.89593***      .16381   -5.47  .0000    -1.21699   -.57488
    CBUS|     .44383**       .22041    2.01  .0440      .01184    .87582
TESPERAB|    -.04908**       .02432   -2.02  .0436     -.09675   -.00140
  COSTEB|    -.61167***      .17671   -3.46  .0005     -.95802   -.26532
 TVIAJEC|    -.03705**       .01779   -2.08  .0372     -.07191   -.00219
  COSTEC|    -.78743***      .15929   -4.94  .0000    -1.09962   -.47523
--------+---------------------------------------------------------------------
--
***, **, * ==>  Significance at 1%, 5%, 10% level.
Model was estimated on Jun 10, 2024 at 04:00:49 PM
------------------------------------------------------------------------------
--
```

ESTUDIO DE ALTERNATIVAS PARA LA IMPLANTACIÓN DE UN SISTEMA DE TREN-TRANVÍA EN EL ÁREA METROPOLITANA DE SANTANDER

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UC | Universidad de Cantabria

ESCUELA DE CAMINOS UNIVERSIDAD DE CANTABRIA

Introducción

- **Las ciudades medianas a menudo enfrentan dificultades para ofrecer un transporte público eficiente**, especialmente en zonas donde los sistemas convencionales de alta capacidad no prestan un servicio adecuado a los núcleos urbanos.
- En este contexto, es fundamental **buscar soluciones de transporte directo**, ya que un transbordo puede implicar tanto tiempo como el trayecto completo en vehículo privado.
- Se deben desarrollar soluciones que no solo aborden estos retos de manera eficaz, sino que también **optimicen la eficiencia de recursos y se mantengan dentro de unos márgenes presupuestarios razonables.**
- **Aprovechar al máximo la infraestructura existente** es una estrategia clave, ya que permite maximizar el impacto de las mejoras de transporte público minimizando los costes.

Objetivos del estudio

- Explorar la idoneidad del tren-tranvía para **hacer frente a los desafíos de movilidad compartidos por las áreas metropolitanas intermedias**, como (i) la congestión vial, (ii) una oferta de transporte público poco competitiva, y (iii) lagunas de conectividad.
- Evaluar su capacidad para **aumentar significativamente la demanda de modos de transporte ferroviarios y mejorar la cuota modal del transporte público** en este contexto.
- Examinar **la sostenibilidad financiera a largo plazo** de la implementación de trenes-tranvía, estimando los costes de inversión, operativos y de mantenimiento, así como los ingresos.
- Determinar **la solución de tren-tranvía más conveniente para Santander** (España), aplicando un marco de evaluación multicriterio.

Caso práctico

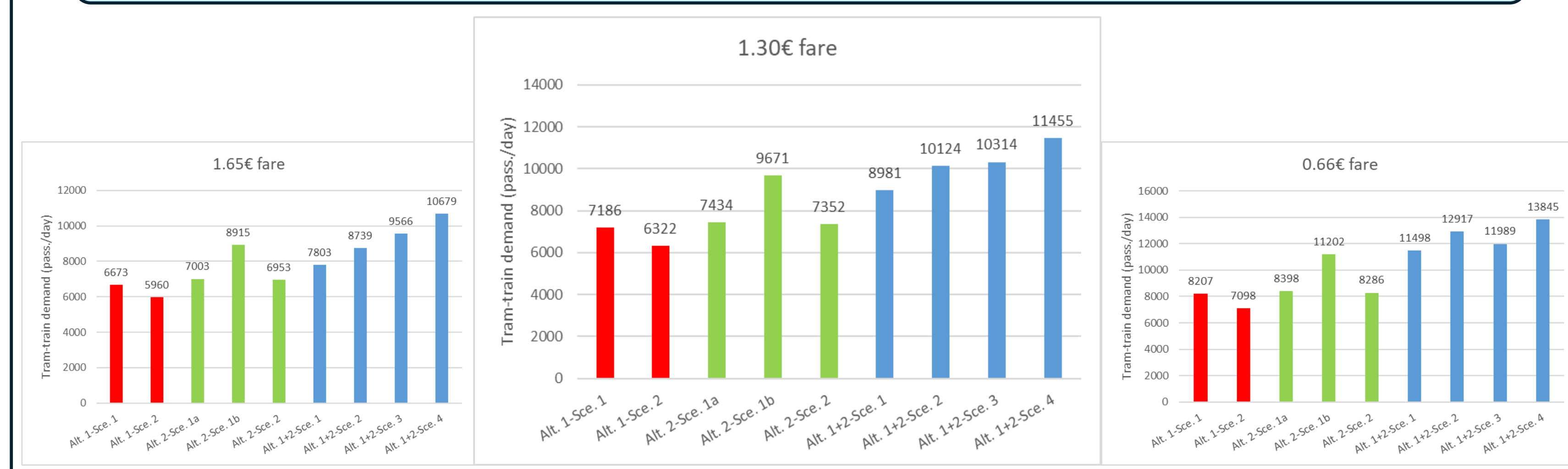
Desarrollo de una red de tren-tranvía en el área metropolitana de Santander, en el norte de España, a partir de la red ferroviaria de ancho métrico existente en la región.

- La **red de transporte alta capacidad** solo alcanza los barrios al sur y oeste de Santander, dejando **sin un servicio adecuado las zonas del Ensanche, este y norte**.
- **Obligando a realizar trasbordos** a los pasajeros del área metropolitana.
- **Se alarga el tiempo de viaje y el transporte público pierde atractividad** frente al vehículo privado, provocando un aumento de la congestión vial en los principales accesos.
- El **desarrollo actual de la red ferroviaria de ancho métrico presenta una gran oportunidad** para crear una red de tren-tranvía que acerque a los viajeros hasta su destino final.

Resultados

Demanda diaria del tren-tranvía: **5.960 a 13.845 pasajeros/día**, según el escenario

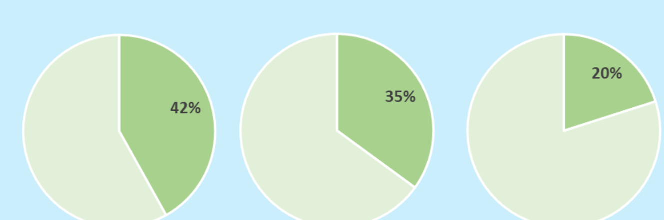
Aumento del **+75.8% al +308% con respecto a la línea de base**, según el escenario



Hasta un **4,1% menos de viajes en coche** (-6,3% en Santander)

Cuota del transporte público entre 6,8% y 10% (sin proyecto: 6,3%)
En Santander: entre 10,9% y 16,8% (sin proyecto: 10,6%)

Tasa de recuperación de costes muy influida por la tarifa



El tren-tranvía

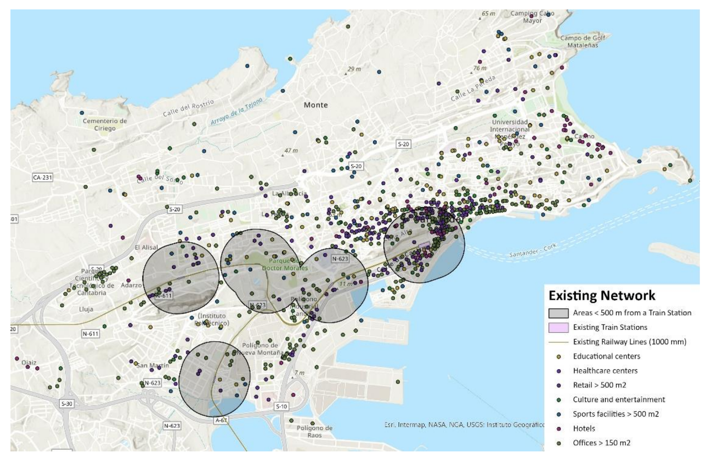
- Vehículo ligero capaz de operar **tanto en vías ferroviarias convencionales**, especialmente en áreas interurbanas, **como en secciones de tranvía** en zonas urbanas.
- **Combina la accesibilidad urbana del tranvía con las mayores velocidades del tren**, y permite a los pasajeros viajar directamente entre centros urbanos y áreas suburbanas.
- **Reduce la necesidad de construir nueva infraestructura** (y el coste de inversión).

(Diario de Cádiz, 2023)

- El primer sistema de este tipo data de 1992, en **Karlsruhe (Alemania).** Desde entonces, su número ha ido creciendo notablemente, destacando los casos de:
  - Mulhouse (Francia)
  - Sheffield (Reino Unido)
  - Alicante (España)
  - Cádiz (España)
- Sigue siendo un modo de transporte limitado por **las diferencias técnicas y de compatibilidad entre las redes ferroviarias y tranviarias** (ancho de vía, electrificación, sistemas de seguridad y señalización).

Metodología

1. ESTUDIO DE LA INFRAESTRUCTURA EXISTENTE Y EL MEDIO URBANO



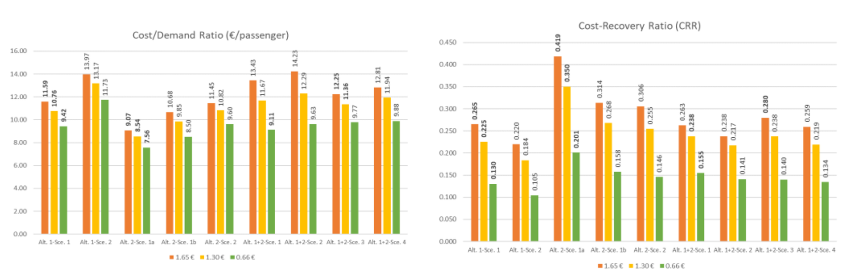
2. DEFINICIÓN DE ALTERNATIVAS DE TRAZADO

3. ENCUESTA Y DEFINICIÓN DE MODELO LOGIT

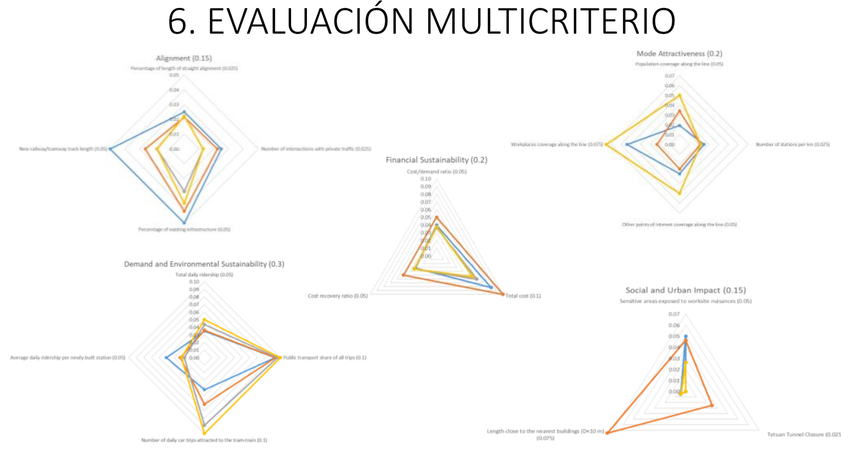
Diseño eficiente de encuestas

4. ESTIMACIÓN DE LA DEMANDA

5. PRESELECCIÓN DE ESCENARIOS



6. EVALUACIÓN MULTICRITERIO



Solución propuesta

Frecuencia

60 mins/sentido en cada línea

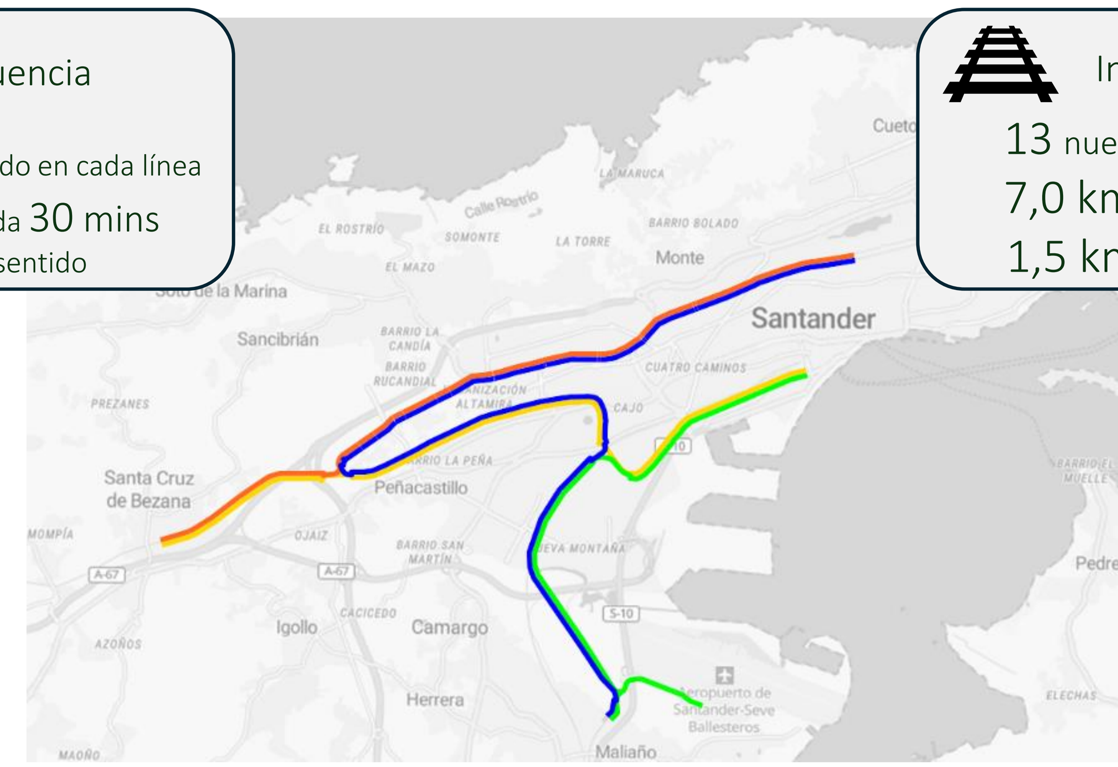
Un servicio cada 30 mins en cada sentido

Infraestructura

13 nuevas estaciones

7,0 km de doble vía

1,5 km de vía única



4 líneas (2 actuales)

Hasta 8400 pax/día (+148%)

Hasta -3.3% viajes en coche

41,9% Recuperación de costes

211M€ CapEx

360M€ OpEx (30 años)