International Yearbook

2024

Urban and Railway Transport Studies

Mastère Spécialisé®
de l'École nationale des ponts et chaussées

Systèmes de Transports
Ferroviaires et Urbains

École nationale des PONTS et CHAUSSÉES
IP PARIS

URBAN AND RAILWAY TRANSPORT STUDIES' INTERNATIONAL YEARBOOK 2024

Encadrante à l'École nationale des ponts et chaussées
Françoise MANDERSCHEID

Experts
Antoine CHÈVRE (AFD), en collaboration avec l'AFD

Écoles partenaires

Remerciements
Le MS® STFU remercie chaleureusement Alstom, Keolis, SNCF, RATP, Siemens et Hitachi Rail, les partenaires de la formation.

Avertissement

Warning

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ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES
IP PARIS

Édito

Editorial

DEPUIS sa création en 1747, l'École nationale des ponts et chaussées a toujours donné une place de choix aux infrastructures et a ainsi formé des générations d'ingénieurs qui ont participé à la réalisation des grands projets ferroviaires du monde entier, tels que Fulgence Bienvenüe, père du métro parisien, François Lacôte, un des pionniers du TGV au sein de la SNCF et d'Alstom, ainsi que Jean-Marie Duthilleul, architecte des gares. Cette tradition demeure très vivante aujourd'hui puisque l'École accueille plusieurs formations dédiées aux transports et à la mobilité comme le Mastère Spécialisé® Systèmes de transports ferroviaires et urbains, créé en 2008. La qualité et l'intérêt des travaux de nos étudiants, qui ne se démentent pas année après année, nous ont conduits à les réunir dans un Yearbook pour vous les faire partager.

SINCE *its creation in 1747, École nationale des ponts et chaussées has always put infrastructure first, thus training generations of engineers who went on to be part of major railway projects all around the world—such as Fulgence Bienvenüe, father of the Paris metro; François Lacôte, one of the pioneers of TGV within SNCF and Alstom; and Jean-Marie Duthilleul, the architect of numerous train stations. This tradition is still very much alive today, as the school offers several training courses dedicated to transport and mobility, such as the Railway and Urban Transport System Engineering Advanced Master®, created in 2008. Year after year, the quality and relevance of our students'– projects never waver, inspiring us to collect them in a Yearbook in order to share them with you.*

Anthony Briant

Anthony BRIANT

Directeur de l'École nationale des ponts et chaussées

Headmaster of the École nationale des ponts et chaussées

L'édito de l'équipe MS®

C'EST dans le cadre du Mastère Spécialisé® Systèmes de transports ferroviaires et urbains que les étudiants réalisent depuis plus de 15 ans un projet de transport dans une ville étrangère. Il s'agit d'une étude de faisabilité, similaire aux études amont en phase d'émergence réalisées par les grands bureaux d'études. Ce travail collaboratif, réalisé dans le cadre du module « Conception d'un système de transport ferroviaire et urbain à l'international » (C3), faisant jouer les complémentarités des savoir faire, prend la forme d'un mini mémoire.

Cette étude porte sur un projet nouveau qui n'a pas déjà été étudié par le passé. Ainsi, les sujets sont choisis depuis 9 ans en collaboration avec l'Agence française de développement (AFD) et concernent des transports de masse dans les grandes mégapoles en voie de développement ou des pays que la Banque mondiale et les autres bailleurs de fonds accompagnent dans leur reconstruction. Toutefois, les étudiants ne se rendent pas sur place. Ils sollicitent le vaste réseau des experts, des ambassades, des institutions financières, utilisent au maximum des ressources documentaires sur le web et… leur débrouillardise.

Pour la promotion 2024, l'AFD nous a proposé des projets situés en Afrique, en Amérique du Sud et en Asie. Deux groupes ont travaillé sur des liaisons ferroviaires à l'échelle inter régionale : l'une entre Valparaiso, Santiago et Puerto Montt, au Chili, l'autre entre Java et Sumatra, en Indonésie. Les autres projets proposent des solutions de transport en milieux urbains : la création d'un métro à Khartoum (Soudan), d'une ou de plusieurs lignes à Vadodara (Inde) ; et la restructuration des transports publics à Bichkek (Kirghizistan). Du fait de leur qualité indéniable, certains de ces projets seront même présentés par Antoine Chèvre, expert transport auprès de l'AFD, aux agences des pays concernés.

Vous pourrez en parcourir les résumés dans ce Urban and Railway Transport Studies' Yearbook. Nous espérons que, tout comme les ambassades, les villes et les gouvernements qui nous demandent la diffusion de ces études, vous serez sensibles à la qualité de ces travaux. En vous souhaitant bonne lecture et bon voyage entre Valparaiso, Santiago et Puerto Montt, Java et Sumatra, Khartoum, Vadodara et Bishkek…

Federico ANTONIAZZI

Directeur du Mastère Spécialisé® Systèmes des transports ferroviaires et urbains

Director of the Railway and Urban Transport System Engineering Advanced Master®

A word from the AM® Team

It is for the Railway and Urban Transport System Engineering Advanced Master® that students have been designing a transport project in a foreign city for over 15 years. That project consists of a feasibility study, similar to those performed in the design stage of a project by offices such as Systra or Parsons. This collective study, made within the framework of the C3 module ("Design railway and urban transport system worldwide") and allowing students to complement one another with their different savoir-faire, is carried out in the form of a short thesis.

This study seeks to develop a new project that has never been studied before. This is why, for the past 8 years, topics have been chosen together with the Agence française de développement (AFD) and focused on mass-transit in megacities of developing countries or countries the World Bank helps rebuild. But the students don't go to the places they study. They make use of a large network of experts, embassies and financial institutions, online resources and… their own resourcefulness.

For the 2024 class, together with the AFD, we have selected projects spanning three continents: Africa, South America and Asia. Two groups worked on inter-regional or city-to-city rail links: one between Valparaiso, Santiago and Puerto Montt in Chile, the other between Java and Sumatra in Indonesia. Other projects offer transport solutions in urban areas: the creation of a metro in Khartoum (Sudan), one or more lines in Vadodara (India) and the restructuring of public transport in Bishkek (Kyrgyzstan). Due to their undeniable quality, some of these projects will even be presented to agencies from the relevant countries by Antoine Chèvre.

Their summaries are at your disposal in this Urban and Railway Transport Studies' Yearbook. We hope that, just like the embassies, cities and governments asking us to spread these studies, you will see just how interesting they are. We wish you a pleasant read and a good trip to Valparaiso, Santiago and Puerto Montt, Java and Sumatra, Khartoum, Vadodara et Bishkek…

Federico Antoniazzi
Françoise Manderscheid

Françoise MANDERSCHEID
Responsable du module C3
C3 module teacher

Il était une fois le Mastère Spécialisé® Systèmes de transports ferroviaires et urbains

Le mastère a été créé en 2008 pour pallier la pénurie d'experts ferroviaires pour la RATP, la SNCF, Alstom, Siemens, *etc*. Cette formation propose une vision d'ensemble du système ferroviaire et urbain, selon une approche multidisciplinaire, intégrant les aspects techniques, économiques et règlementaires. Elle s'adresse à des professionnels ayant déjà plusieurs années d'expérience en transport ou à des jeunes qui souhaitent se spécialiser dans ce domaine. Les étudiants y apprennent à concevoir, exploiter et maintenir les différents transports guidés, qu'il s'agisse de trains, de métros, de tramways ou de *Bus Rapid Transit* (BRT), leurs infrastructures, ainsi que le *mass-transit*, dans un contexte où l'urbanisation galopante rend indispensable le recours à des modes de transport fortement capacitaires pour faire face à la congestion et à la pollution.

Près de 160 professionnels participent à l'enseignement et encadrent les étudiants sur des projets collectifs. En effet, l'enseignement du mastère s'appuie sur plusieurs projets en équipe, comme le tracé d'une infrastructure, la conception d'un plan de signalisation ou d'un matériel roulant. Tout au long de l'année, les étudiants préparent aussi un projet de conception d'un nouveau système de transport à l'international, dont vous pouvez lire les résumés dans le présent ouvrage.

Le diplôme confère aux élèves le titre d'« experts internationaux en systèmes de transports ferroviaires et urbains » reconnu par le Registre national des compétences professionnelles (RNCP). Se côtoient dans une même promotion ingénieurs de conception ou de maintenance, experts en exploitation ou en signalisation, ingénieurs système, économistes, chefs de projet. Aujourd'hui, les anciens élèves du mastère constituent un réseau de quelques 400 alumni présents dans plus de 20 pays. La richesse du réseau réside dans la variété des profils et des expériences des étudiants. Beaucoup d'entre eux s'impliquent dans l'enseignement et l'organisation de visites ou de voyages d'études qui participent aussi à la vitalité de la formation et à sa notoriété internationale.

Once upon a time, there was the Railway and Urban Transport System Engineering Advanced Master®

THE *Advanced Master® was created in 2008 to make up for the shortage of railway experts for societies such as RATP, SNCF, Alstom, Siemens, etc. This training course provides an overview of the railway and urban system, using a multidisciplinary approach with technical, economic and regulatory angles. It is aimed at professionals with several years of experience in the field of transport. Students learn how to design, operate and maintain a variety of guided transport systems, including trains, subways, trams and BRT, as well as their infrastructure. A particular emphasis is put on mass-transit, since rapid urbanization means that high-capacity transportation becomes essential to cope with congestion and pollution.*

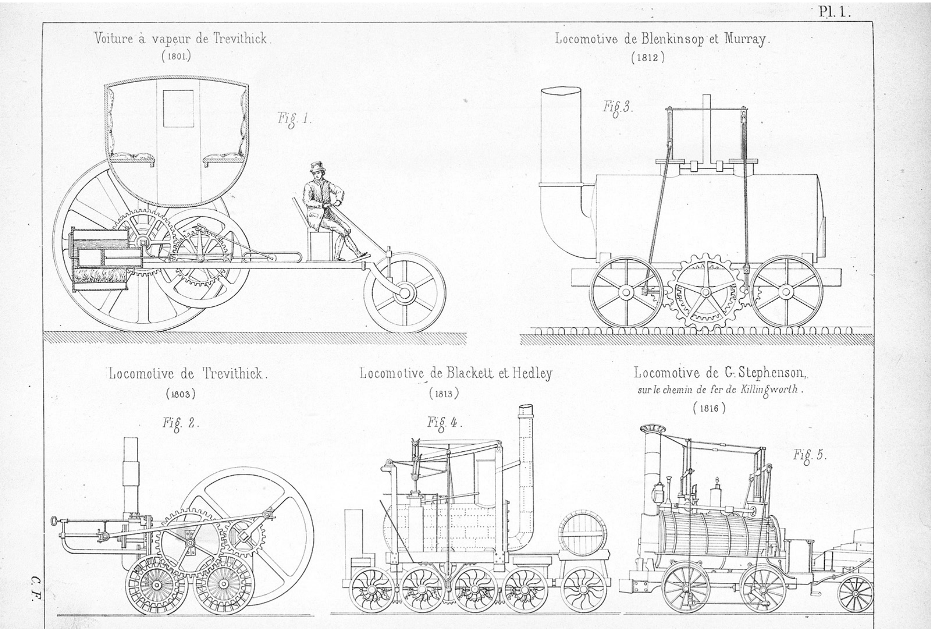
Nearly 160 professionals teach and supervise students on collective projects. The training course relies heavily on those: the design of an infrastructure, of a signalling plan or of rolling stock. Moreover, the students work along the year on a new transport system in a foreign country; the summary of these studies can be read in this very publication.

The Advanced Master® gives students the recognized title of "International Experts in Railway and Urban Transport Systems". In the same class, there are design or maintenance engineers, operating or signalling experts, system engineers, economists, project managers… Today, the alumni form a network of about 400 students in more than 20 countries. The value of this network lies in the variety of student profiles and experiences. Many of them are involved in teaching and organizing visits or study tours which also contribute to the vitality of the Advanced Master® and its international reputation.

Enseigner le ferroviaire à l’École

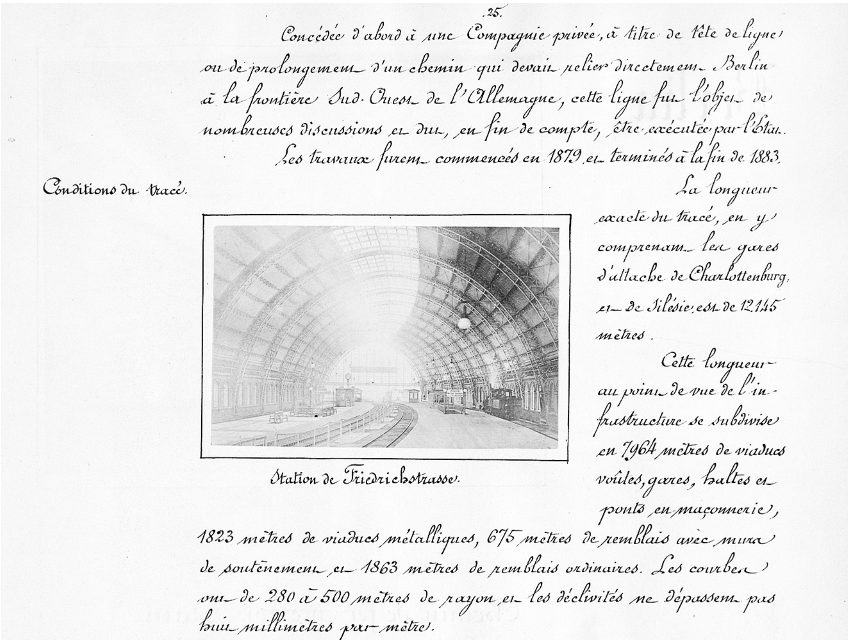
Railway classes at the École

	1832	Charles-Joseph MINARD
Amédée BOMMART	**1842**	
	1852	Jacques MANIEL
	1855	
François JACQMIN	**1867**	Pierre Dominique BAZAINE-VASSEUR
Louis-Charles SEVENE	**1873**	
	1880	Jules MARTIN
Charles BRICKA	**1891**	
	1899	Désiré FOUAN
Albert DESCUBES	**1918**	
	1927	André MARTINET
Louis CAMBOURNAC	**1940**	
	1951	Georges CHAN
Charles FEYRABEND	**1961**	
	1968	Robert BIAIS
Jean ALIAS	**1972**	
	1985	Philippe ROUMEGUERE
Pascal LUPO	**2003**	
	2008	**Création du Mastère Spécialisé®** Systèmes de transports ferroviaires et urbains *Birth of the Advanced Master®*
Paul BOUVAREL	**2013**	Françoise MANDERSCHEID
	2021	Federico ANTONIAZZI



Extrait du *Cours de chemins de fer* de Pierre Dominique Bazaine-Vasseur de 1873. École nationale des ponts et chaussées, 4°23037, en ligne. Disponible sur : https://heritage.ecoledesponts.fr.

Page from Pierre Dominique Bazaine-Vasseur from 1873.



.25.

Concédée d'abord à une Compagnie privée, à titre de tête de ligne ou de prolongement d'un chemin qui devait relier directement Berlin à la frontière Sud-Ouest de l'Allemagne, cette ligne fut l'objet de nombreuses discussions et dut, en fin de compte, être exécutée par l'État.

Les travaux furent commencés en 1879 et terminés à la fin de 1883.

Conditions du tracé.

La longueur exacte du tracé, en y comprenant les gares d'attache de Charlottenburg et de Silésie, est de 12.145 mètres.

Station de Friedrichstrasse.

Cette longueur au point de vue de l'infrastructure se subdivise en 7964 mètres de viaducs voûtés, gares, haltes et ponts en maçonnerie, 1823 mètres de viaducs métalliques, 675 mètres de remblais avec murs de soutènement et 1863 mètres de remblais ordinaires. Les courbes ont de 280 à 500 mètres de rayon et les déclivités ne dépassent pas huit millimètres par mètre.

Extrait du *Journal de mission en Allemagne* d'Albert Petsche, Ferdinand Connesson et Louis Goury du Roslan, 1884. École nationale des ponts et chaussées, Ms. 3153, en ligne. Disponible sur : https://heritage.ecoledesponts.fr.

Page from a 19th century students' project journal.

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Creation of a public transportation system in Bishkek

Amine KORICHE
Mehdi BEN MAHMOUD
Mihai BARBALATA
Wiam ALI FDAL
Mohammed ESSADEQ

ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES
IP PARIS

Cette étude s'intéresse à la création d'une liaison interurbaine sur l'île principale des Philippines, dans un objectif de report modal face aux transports existants fortement carbonés. Le choix est de construire une nouvelle infrastructure, permettant de créer des relations grande vitesse entre les villes majeures du pays. Celle-ci serait concurrentielle et complémentaire avec les transports existants, et permettrait le développement de trafics marchandise et régional. L'exploitation est structurée autour d'une entreprise intégrée pour renforcer la culture ferroviaire. Sous la forme de concession, cette structure associant les industriels et exploitants comme parties prenantes sera en charge dès les prémices du projet de la construction de l'infrastructure, décomposée en 5 phases de San Fernando à Legazpi. Le projet contribuera fortement au développement durable en choisissant une électrification totale et surtout la production en propre de l'énergie de traction dont le surplus bénéficiera à la population locale.

Mots-clés : bus à haut niveau de service, corridors, heure creuse, heure de pointe, personnes par heure par direction, transport en commun sur site propre, valeur actualisée nette socioéconomique

Bishkek, the capital of Kyrgyzstan, faces a significant challenge in improving its public transportation system. With a population exceeding one million inhabitants, the city is struggling with growing urban mobility issues. Rapid population expansion and an increase in individual vehicles have led to persistent problems (road congestion, air pollution, etc.). In this context, France aims to explore a diplomatic approach by promoting a public transportation system in Bishkek. The goal is to develop urban public transportation and position it as a flagship initiative for French companies. This project aims to provide a viable transportation solution for the Kyrgyz capital. Given events in 2023, including the French president's tour of Central Asia to promote industry, advocating for French railway actors is far from fantasy, it is a strategic opportunity!

Keywords: Bus Rapid Transit, Corridors, Person Per Hour Per Direction (PPHPD), Peak Hour, Public transportation system, Off-peak Hour, Socioeconomic Net Present Value

1. The current situation

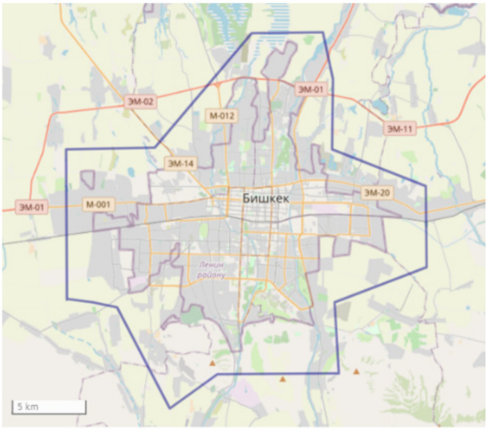

Figure 1. Scope of the study @ OpenStreetMap contributors. Source: openstreetmap.org, 2021.

1.1. Political Context

Being a former Soviet Socialist Republic, Kyrgyzstan appears to have retained certain administrative and institutional practices from the Soviet era. This is evident not only in its territorial divisions but also in the country's administration, which must navigate and unite traditional, local, and national institutions at various decision-making levels. This is naturally reflected in the organization of public transportation: the city's mayor is responsible for urban planning, including transport infrastructure. The mayor oversees transportation development projects and traffic-related policies within the city. Bichkek's governance structure includes a locally elected parliament, the mayor, and their administrative office. The elected official also has a permanent transportation office.

The deputy mayors are responsible for supervising the authorities and transport companies concerned. However, their responsibilities are spread thinly, which creates administrative complexity and ultimately limits decision-making on viable public transport solutions.

2.1. Socio-Economic Context

With a population of over 6.5 million and a GDP of almost $11 billion (2022), Kyrgyzstan is ranked in the second tier of the world's most productive countries. Not only has annual GDP been unstable in recent years, but it also shows the fragility of the country's economic system and a certain downward trend in the medium term:

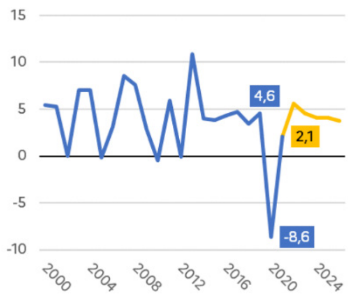

Figure 2. Real GDP growth. Source: The economic and financial situation in Kyrgyzstan, Direction Générale du Trésor (economie.gouv.fr)

With no access to the sea, Kyrgyzstan has no choice but to trade with neighboring countries (Russia and China, for instance). This geographical configuration partly explains the low level of domestic production (and the depletion of the country's resources).

The issue of public debt is also a constant source of concern. As a result of counter-cyclical spending linked to the pandemic, coupled with a fall in activity, public debt has risen sharply, from 51.6% to 68% of GDP, while the IMF predicts that it will remain stable at around 60% of GDP in the future. Overall foreign debt rose significantly in 2020, from 94.9% to 112.8% of GDP, and international reserves stood at just over $3 billion, equivalent to 8 months' imports.

1.3. State of the public transport in the capital

Bishkek's public transport system consists mainly of buses, minibuses and trolleybuses. As a result, demand for these 'cheap' means of transport is high due to the low (or non-existent) supply of affordable private transport, not to mention an underdeveloped road network.

The capital's network comprises around 180 buses operating on 12 routes across the city. Most buses in Bishkek are conventional diesel or petrol-powered vehicles, while the compressed natural gas (CNG) fleet comprises 60 buses. These buses carry around 15% of the city's public transport passengers, with fares of 8 Kyrgyz soms (around €0.08) per journey. The average age of the fleet is estimated at 10 years.

Trolleybuses carry around 18% of the city's public transport passengers, covering 11 routes. The fleet consists of 170 vehicles that have been in service since the days of the Soviet Union. As with the buses, the ageing trolleybus fleet is still in use despite having exceeded its useful life.

Last but not least, minibuses play an essential role in the city, providing services between residential areas and the city center itself. They are considered to be more flexible than buses and trolleybuses, with routes offering more choice to users, who account for 67% of public transport passengers. There are around 4,000 minibuses covering 109 routes and operated by 43 private companies. Since 2020, the minimum fare for minibuses has been 10 Kyrgyz soms (around €0.10). However, minibuses are generally poorly maintained, which means that passenger safety has deteriorated considerably.

All these means of road transport need to be considered in an urban environment where the car also has a fairly significant presence.

This means that we need to find a solution for public transport that can relieve passengers of road constraints and offer them a safer transport system.

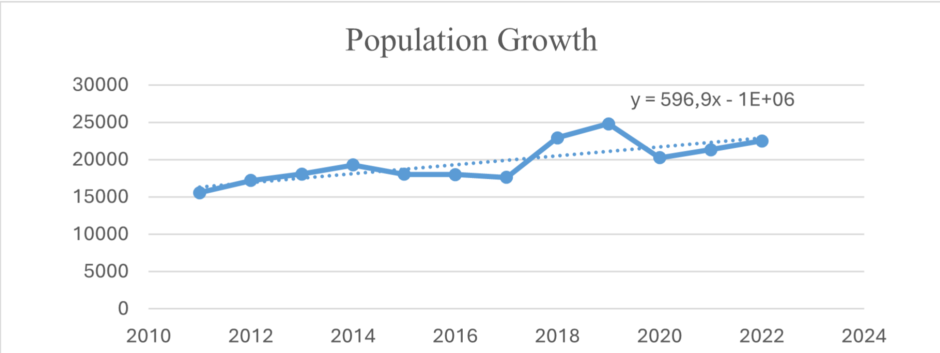

Figure 3. Population Growth in Bishkek since 2011 © MBM

Looking now at the employment data, the trend seems to be heading downwards, and Bishkek has fallen below the national unemployment rate curve.

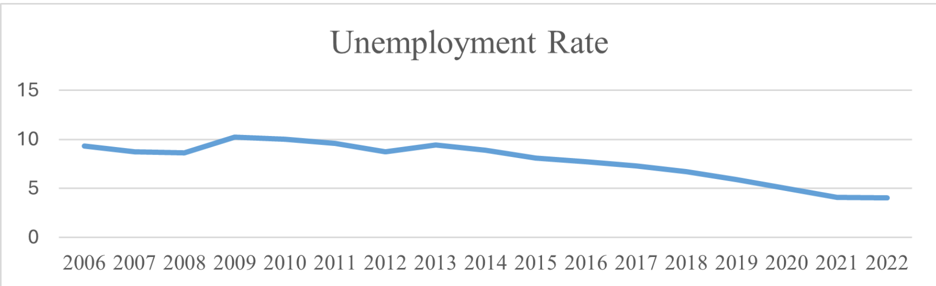

Figure 4. Unemployment Rate in Bishkek © MBM

Although Bishkek contributes significantly to the country's overall unemployment rate, it is interesting to note the encouraging figures and, coupled with the population statistics, we have come to the conclusion that there will be a growing demand for transport over the next ten years. In order to address this issue, the study plan was to carry out a multi-criteria analysis of the different types of dedicated-lane public transport. Here is the result:

	Metro	Tramway	BRT
Average cost km project	40 / 150 M€	5 / 20 M€	15 / 50 M€
PPHPD	VAL: 6 000 – 18 000 Heavy: 40 000 – 100 000	2 000 – 8 000	1 000 – 5 000
Service life of rolling stock	40 y	30 – 40 y	15 – 20 y
Average commercial speed	30 Km/h	20 Km/h	17 Km/h
Inter-station	700 m	500 m	450 m
Operating costs	12 € / Km	8€ / Km	6€ / Km
Average line length	Light: 16.6 Km Heavy: 8.5 Km	12 Km	22.5 Km
Line extension	Complex	Medium	Easy

Capacity demand is the decisive criterion in the choice of transport system. With an estimated PPHPD of 7,000 in 2034 on the busiest avenue in downtown Bishkek, it is on the borderline between the capacities of a tramway and a metro, and far from those of a BRT (which would very quickly find itself undersized), especially as the PPHPD will change every year.

In terms of cost, although a BRT project is slightly less expensive than a tram, the cost of maintaining the rolling stock may influence the decision. This is all the more true given that a BRT will have to be renewed after 15 years, so over a study period of 30 to 40 years, the BRT fleet will have to be completely renewed (costs to be considered), whereas the tram fleet is just reaching the end of its life (and will probably be able to extend its life by around twenty years at most).

Finally, the metro may seem an interesting solution if we think about the estimated long-term PPHPD, but the totex (capex and opex combined) is so high that an economic city like Bishkek cannot bear such costs. This is evidenced by the comments of the mayor of Bishkek, interviewed in 2020, who said that "the construction of the metro was too expensive and is therefore no longer planned".

In the light of the criteria studied above, the choice of a tram system is not only the most judicious and consistent with the current situation in Bishkek, but also an attractive choice for the medium and long term.

3. A tram system tailored for Bishkek

3.1. Bishkek East-West tram line

Once the major West-East corridor had been identified, the challenge was to determine the best route to serve the capital's most difficult points. A 500-metre radius of travel from a tram station is assumed, in order to estimate an average journey time on foot from the outer edge of the circle. In this way, we can compare the influence of our system on the corridor defined above according to the distance thresholds required to change people's behavior in favor of public transport. This gives us, in correlation with the stations identified, the following final route:

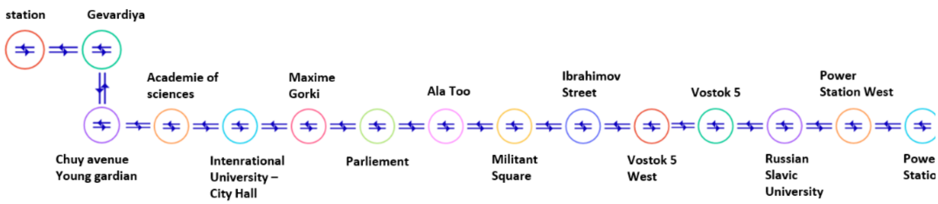

Figure 5. Bishkek East-West tram line © MBM

3.2. Rolling stock solution

Taking into account certain constraints of the rubber-tyred tram, the various advantages/disadvantages of the power supply solution and the configuration of the ends, it was decided to use an iron-wheel type tram to avoid problems due to weather conditions; with two cabins (one at each end) to allow greater modularity; and a catenary power supply to reduce the costs of implementing the solution.

At the same time, to ensure adequate capacity according to the estimated PPHPD (7000), the use of a tramway approximately 30 meters long with MU (multiple unit) configuration was chosen.

Following the market study to identify the best solution to meet Bishkek's transport needs, the rolling stock produced by Alstom was identified, a 5th generation Citadis tramway (X5), namely the Citadis 305 with a nominal length of 30m, which will be used in a double unit configuration.

The modularity of the rolling stock will allow trains to be disconnected outside peak times for maintenance, cleaning and so on.

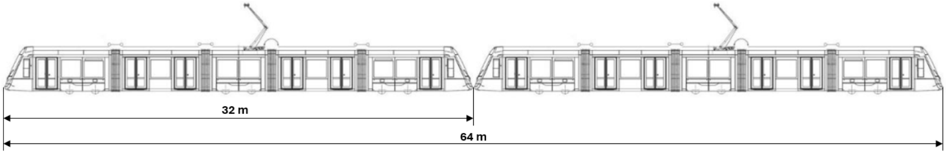

Figure 6. Citadis 305 in double units © Alstom Catalogue

According to the technical specifications, the maximum capacity of the tramway is 238 seats (seated + standing) in single configuration. In order to achieve this capacity, but also to improve passenger flow at peak times, Alstom will be asked to configure the interior so that all the seats are arranged sideways, facing each other:

- Bearing in mind that the city of Bishkek will have a tramway for the first time, it is assumed that the population will need some time to adapt, which is why it would be wise to choose a lower commercial speed than that existing in France, the commercial speed will therefore be 19 km/h.
- Journey time on the line is estimated at around 30 minutes.
- Lastly, the minimum fleet required is 38 units (i.e. 19 double units). If we add an operational reserve train and with 10% of the fleet tied up in maintenance, we obtain a total fleet of 43 units.

Figure 7. Citadis 305 exterior - single configuration © tc-infos.fr

Figure 8. Example of seat configuration for Bishkek © tc-infos.fr

3.3. Infrastructure and civil works

The construction of a tram line is a major project, involving large-scale works. As a result, it is crucial to anticipate and assess the impact of any disruption caused by the works in advance.

The phasing of the works begins with the coordination of multiple diversions (electricity, water, gas, etc.). In the second phase, the boulevards will be redeveloped across their entire width (renovation of the street furniture and planting of new trees on the pavements and most of the station platforms). At the same time, the tracks, platform surfacing, and station platforms are installed.

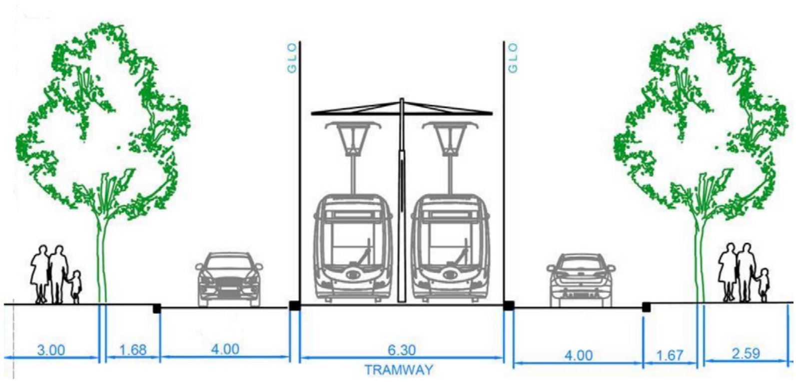

Figure 9. Axial insertion with reduced roadways © Schéma de principe IdFM

Technical tests begin as soon as work on the platform is completed, to assess the operation of the electrical equipment and train the drivers. These trials are concluded by test periods during which the trains run empty before being opened to the public. Different types of surfacing can be used, such as concrete, asphalt, grass, gravel or cobblestones:

Figure 10. Types of surfacing for tramway platforms © Transport urbain

The future trams that will run in Bishkek will be supplied with 750 V DC voltage via an overhead contact line, rather than ground power, in order to reduce installation and maintenance costs.

The power will be supplied by 5 substations, fed by the 10 kV and 6 kV high-voltage electricity network provided by the state-owned operator Tunduk Elektr. The voltage will be transformed into 750 volts direct current and then transmitted to the catenary.

Alstom will also be called upon to supply the signaling and telecommunications solution. This solution is strengthened by the fact that Alstom already offers the ATP system integrated with the chosen rolling stock, which would reduce investment costs. This system helps to ensure compliance with speed limits or traffic lights, enabling high levels of traffic and improved management of driver behavior. It is compact and very easy to install on existing or new interlocking systems. It also requires very little hardware and simple interfaces with the edge and ground.

The project also includes an operations and maintenance center, which will provide:

- Storage of rolling stock
- Train maintenance (and cleaning)
- Hosting of maintenance vehicles for overhaul system equipment (catenary, rails, etc.)
- Operation and management of lineworks.

Figure 11. Rendering of the multi-purpose center © Google Maps

3.4. Maintenance and training plan

Preventive maintenance activities must be planned according to the intervals specified by the manufacturer, considering the operating environment of trams in Bishkek. These activities may involve a variety of tasks, including electrical and mechanical measurements and adjustments, routine maintenance of wiring and checking of fuses, lubrication operations, regular adjustments, alignment and tightening procedures, as well as inspections to detect leaks or torque loads.

The urban tramway system avoids a number of onerous maintenance constraints (compared with a rail system). The main points to check are:

- **Overhead contact lines and electric traction installations**: Training and awareness for this type of action will have to be taken into account (use of maintenance equipment, safe behavior, etc.);
- **Signaling and telecommunications network**: Signaling in a tramway system includes light signals, traffic signs and road markings (for pedestrian safety). Their maintenance ensures the safety and flow of the overall traffic;
- **Rails and switches and crossings:** The aim is to carry out regular visual surveillance operations in order to detect potential anomalies or damage to the track (rails, switches) and the platform. It is important to fix broken rails and replace them if necessary.

The project proposes a driver training support program over two or three years to establish a transfer of skills. This program will combine theory with case studies and practical workshops, enabling stakeholders to familiarize themselves with all kinds of constraints (related to MR and infrastructure). Sharing feedback is essential to prepare all staff to respond effectively to the day- to-day and exceptional challenges encountered in operating a tramway, and these types of training can be a form of partnership with French operating players, who have fundamental feedback on the system.

Similarly, the training of maintenance staff could be performed in collaboration with public transport companies, or the manufacturer associated with future tram systems.

3.5. Operating targets

To adapt our service to fluctuations in passenger numbers, we have defined three distinct intervals:

- Peak hours: Commitment to a 4-minute interval between trams in order to respond effectively to the massive flow of passengers.
- Rush hour: Commitment to a 5-minute interval between trams in order to maintain a fluid and efficient flow of traffic while meeting the needs of users.
- Off-peak hours: Commitment to a 10-minute interval between trams, allowing optimum use of resources while ensuring a sufficient service for passengers.

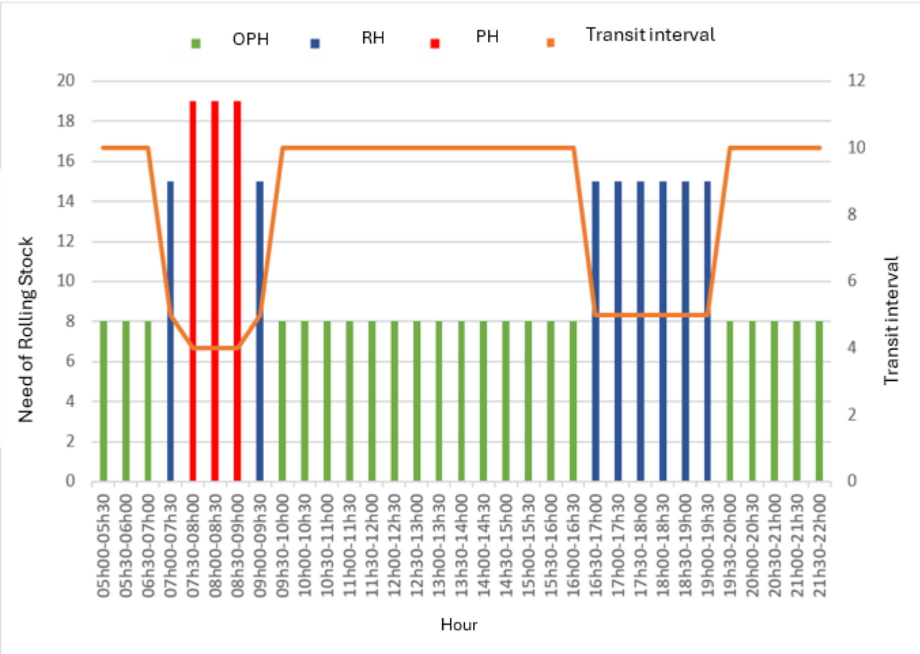

Figure 12. Estimated RS requirements based on the time slots of the working day © MBM

On the basis of the parameters we chose in this study for the design of the tramway (speed, intervals, etc.), it has been possible to generate a time-space graph that simulates the operation of the tramway:

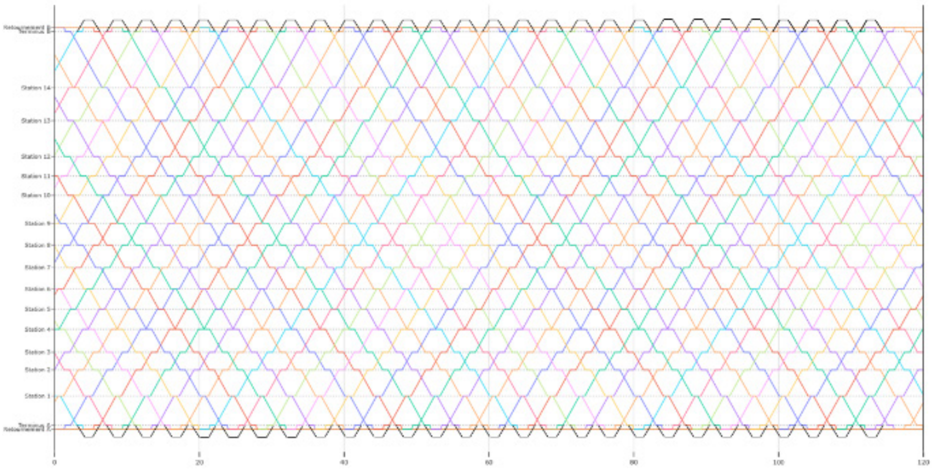

Figure 13. Space-time graph over 120 minutes © Vincent Julliard

3.6. Economic and financial assessment

The creation of this new line requires a fairly high investment cost, as everything has to be created (the platform, rolling stock, operations centre, etc.). Cerema recommends breaking down the initial investment costs of a tramway project into 19 expenditure items, here is the result:

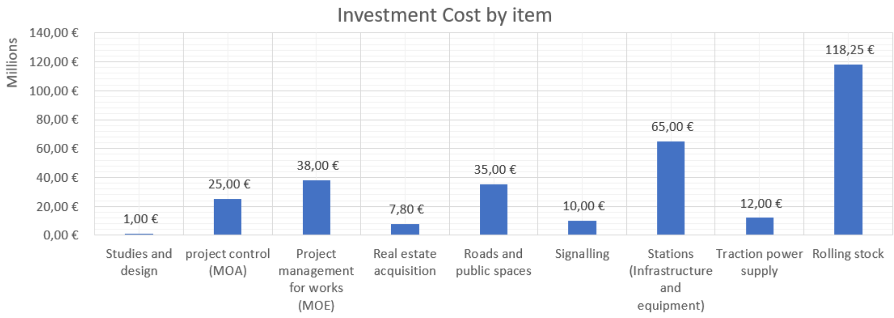

Figure 14. Investment cost by project item © AK

The total cost needed for the initial investment, including 10% of contingency reserve, reaches a substantial €343.25 M.

An estimation of operating costs can only be made by making various assumptions:

- **Estimated Cost/Km**: €8/Km travelled (€18 M/y, in accordance with the following assumption);
- **Average Distance Travelled by Train**: 50,000 Km/y, (total of 2.2 Mkm covered by the 43 trains);
- **Average Salary in Bishkek**: 20,000 soms (equivalent to €210);
- **Annual Infrastructure Maintenance Cost**: approximately 0.7% of the estimated capital expenditure (€2.5 M/y);
- **Average Daily Passengers**: On an average day, there will be 160,000 passengers (approximately 50 million passengers/year).

For a study period of 40 years (the loan repayment period and the nominal lifespan of the trams before renewal), the operating balance averages a negative value of €8.544 M/y. This is primarily due to a low forecast of operating revenues, which could be explained by an intention to encourage a modal shift toward this future public transportation system.

Indeed, it is crucial to consider the socio-economic balance of this study. This involves assessing the overall benefits to the population, including gains in time, safety, and reductions in noise pollution and environmental impact. By summing up all these externalities, the net present value of socio-economic benefits (NPV) amounts to +€210.38 M over the 40-year study period.

The project for a tramway in Bishkek is indeed profitable. It will represent a major advancement in urban transportation for the population and significantly boost the capital's economy.

Regarding financing, several options are available to the country:

- European Grants: The Investment Facility for Central Asia (IFCA) which supports investments in Asia, providing access to essential infrastructure and services;
- Public-Private Partnerships (PPPs): Collaborations between public and private sectors;
- International Loans: Borrowing funds from international sources.

Conclusion

This study aimed to determine the most suitable public transportation system for creating a major public transport network in the heart of Bishkek, with planned infrastructure development over the next decade.

The government's objective is to promote modal shift toward public transport, enhance efficiency, and address climate-related challenges. For the Bishkek municipality, the new transport system must also handle additional traffic resulting from regional population growth.

The tram system, considered realistic, was selected. Subsystems related to rolling stock, infrastructure, operations, and personnel training were considered and compared. The tram system emerges as the most relevant option for future transport network development, offering advantages such as technological maturity, reliability, and a positive image for a city committed to sustainable and low-emission transportation.

This study positions the creation of the tram system as a flagship project for French companies within the framework of France's diplomacy, whether in rolling stock acquisition, operational expertise, or public-private partnerships.

Opportunity study: rehabilitation and modernization of Valparaiso-Santiago-Puerto Montt railway line

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ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES
IP PARIS

Le Chili possède un réseau ferroviaire historique de 6 782 km, qui a connu un long déclin dans les années 1970, entraînant la fermeture de certaines lignes. Dans une logique de réduction des émissions DES, le gouvernement relance son réseau ferré afin de dynamiser le ferroviaire qui est crucial pour atteindre la carboneutralité, décongestionner les routes et concurrencer l'aérien. Le rapport étudie la réhabilitation et la modernisation de la ligne Valparaíso-Santiago-Puerto Montt pour améliorer la capacité, la vitesse et la sécurité selon les standards actuels. L'étude diagnostic approfondie guideront le choix d'un scénario de modernisation et les solutions techniques associées en tenant compte de la faisabilité technique et économique. L'exploitation prévoit un choc d'offre en proposant les nouvelles liaisons. Un partenariat public privé est envisagé pour relever les différents défis. Le projet démontre une rentabilité socioéconomique, soulignant l'importance du développement ferroviaire..

Mots-clés : carboneutralité, choc d'offre, décongestion, modernisation du réseau ferroviaire, partenariat public privé, réhabilitation, rentabilité socio-économique, report modal

Chile owns an historic railway network of 6782 km, which suffered a long decline in the 1970s leading to the closure of some lines. With the ambition to reduce emissions, the government is revitalising its rail network in order to boost rail transportations, which is crucial to achieving carbon neutrality, relieving congestion on the roads and competing with air transport. The report examines the rehabilitation and modernisation of the Valparaíso-Santiago-Puerto Montt line to improve capacity, speed and upgrade safety up to current standards. The in-depth diagnostic study will guide the choice of a modernisation scenario and the associated technical solutions, taking into account technical and economic feasibility. The operation of the new services will result in a significant increase in service. A public-private partnership is envisaged to meet the various challenges. The project demonstrates socio-economic profitability, underlining the importance of rail development.

Keywords: carbon neutrality, decongestion, rehabilitation, modal shift, modernisation of the rail network, public-private partnership, socio-economic profitability, supply shock

Introduction

Chile owns a 6782-km railway network that was opened in 1864 but that faced difficulties in the 1970s under Pinochet dictatorship, leading to the permanent closure of most passenger lines. In the 1990s the government again prioritized rail transport, linking it to its political measures. Therefore, upon request by the Chilean government, this report studies the opportunity of reopening and upgrading the Valparaiso-Santiago-Puerto Montt railway line in order to increase capacity, speed and improve safety to meet the latest railway standards. The study looks at freight and passenger trains as well as the territory changes linked to the upgrade.

1. Assessment

1.1. Economy

Chile stands out as the most developed economy in Latin America: it has the highest growth rates in the region, 2.7% in 2022, and the lowest poverty rates with only 4.8% of its population living on less than $6.85 per day. This success is explained by the neoliberal economic model developed since the 1970s.

The Chilian GDP relies mainly on mining, agricultural and commercial sectors. China and the United States are the main trading partners of Chile.

Despite significant economic advancement, Chile is not able to share wealth equitably, being one of the most unequal countries in the world according to OECD reports.

1.2. Geography

Chile is the longest country in the world (4265km long and 180km wide), characterized by intense meteorological and topographical variety, with very favorable conditions in the central zone constituting the area under study, which is home to 85% of the population concentrated mainly around the country's metropolises: Santiago, Valparaiso and Concepcion. Note that the Chile has a total population of 20M with a low growth rate of 0.57%.

Because of its location at the boundary between two tectonic plates, the Nazca Ocean and the South American continent, Chile experiences earthquakes with a magnitude between 7 and 8 on the Richter scale every 10 years on average. The country also faces risks of volcanic eruptions and tsunamis.

1.3. Projects

As part of environmental measures applied by the government, the President of the Republic, Gabriel Boric, announced the "Trenes Para Chile" aka "Trains for Chile" plan which aims to triple the number of passengers and to double the volume of freight transported by the national railway network.

The following projects are currently planned for the central zone:

- New Santiago Valparaiso service: start of work by 2026, in operation by the end of 2032 and investment estimated at $3,000;
- "Puerto Exterior San Antonio" rail corridor and intermodal center: start of work by 2026, in operation by the end of 2032 and investment still under evaluation;
- The "Estacion Central-Quinta Normal" connection: start of work in 2028, in operation by the end of 2030 and investment estimated at $175M.

2. Current situation of the studied area and technical choices made

An important part of the report was to identify the specificities of the infrastructure along the tracks under study. This understanding dictated technical choices for the upgrade of the network.

2.1. Tracks, Electrification and signaling

Current situation	Technical choices
• Ballasted track • 1676-mm gauge • Vignole" type rails in normal bars • One-piece concrete or wooden sleepers • 42% of the line is electrified at 3kV CC • Various signaling systems with two traffic control centers in Alameda and Concepcion	• Ballasted track • 1676-mm gauge • Using CWR rails • One-piece concrete sleepers • Equipping the non-electrified parts of the line with 3kV CC • Installing ERTMS L2 and interconnecting command and control systems

Figures 1, 2. MCurrent state of the line, Google Earth

2.2. Train stations, level crossing, pedestrian crossing and infrastructure

Current situation	Technical choices
• Functional and abandoned stations all along the line • Level crossings exist only on parts open to passenger transport and unsecured pedestrian crossings • Most tunnels and bridges are adapted to a single track	• Stations located in single track/non electrified areas will be upgraded • Valparaiso station will be restructured and Santiago station transformed into an underground grossing station • Automation of existing SAL0 LX and upgrading with barriers • Replacement of pedestrian crossings with footbridges in highly frequented areas • Restructuration/construction of neces-sary tunnels and bridges

Figures 3, 4. Current state of the infrastructure, Google Earth

2.3. Rolling stock

Current situation	Technical choices
• Lots of trains with different lengths and max speed not suited to the commercial speed required for the project	• Launch tenders to order suitable trains

2.4. Maintenance centers

Current situation	Technical choices
• Loading/unloading areas and maintenance depots are distributed regularly on the line	• The new Chillán maintenance center will be used for the maintenance of the new rolling stock • Recently created work centers will be transformed for track maintenance • Maintenance centers located in single track/non-electrified areas will be modernized

3. Challenges and objectives

After a thorough analysis of risks and opportunities, we aim to achieve significant improvements in the following six areas:

1. **Improvement in efficiency**: Increase the transport capacity and reduce travel time. For example: reduce the current 5-hour trip to 3 hours and 40 minutes for the Santiago-Chillán route after the modernization of the line (SYSTRA, 2023);
2. **Regional development**: Extend the network to remote regions, alleviate road congestion and facilitate commercial exchanges connecting the most populated urban areas of the country, such as Valparaiso – Santiago or Santiago and Concepción;
3. **Sustainable mobility**: Rail transport projects aim to promote more sustainable modes of transportation by reducing dependence on private vehicles and decreasing greenhouse gas emissions;
4. **Connectivity:** Improving the rail network would enhance connectivity between different cities and regions of Chile, thus facilitating travel for work, study, and tourism;
5. **Safety and Comfort:** Modernize and maintain infrastructure to ensure the safety and comfort of passengers (15 deaths/100,000 inhabitants in Chile in 2019 (World Bank, 2023/24;
6. **Accessibility:** Develop a rail transport system that is accessible to everyone (20% of people with reduced mobility (PRM) in Chile, and more than 30% of transport currently not accessible (www.ecologie.gouv.fr, Accessibility in OECD Member Countries, 2023/2024).

4. Definition of modernization scenarios and sub-scenarios

Figure 5. Compared scenarios © Authors, with Google Maps

The studied line is 2140 km long; We therefore compared 3 scenarios. A multicriteria analysis defined scenario 2 as the modernization scenario to follow.

Sub scenarios were formulated to outline the work required, such as the laying of a second track with or without electrification, track renewal, electrification of the existing line and signaling works.

Three sub scenarios were then formulated, and the "total modernization" scenario was chosen after a multi criteria analysis. The aim of this scenario is to upgrade the yellow and orange electrified double-track sections in the same way as the green sections, keeping in mind that the green sections are in very good condition.

The multi-criteria analysis of the three scenarios was based on quantifiable criteria such as the number of km of new track laid, km of electrification, km of track regenerated, the homogeneity of the network and the reduction in greenhouse gases; but also on non-quantifiable criteria such as the improvement in operating performance, the possibility of access to Conception, the ease of passenger and freight co-operation and future needs.

Sous scénario dit « Modernisation totale »

Portion du réseau	Kilomètre linéaire	Pose d'une 2ème voie non électrifiée	Pose d'une 2ème voie électrifiée	RVB	Electrification voie existante
Valparaiso - Limache	44				
Limache - Santiago	141		✓	✓	✓
Santiago - San Fernando	135				
San Fernando - Chillán	267		✓		
Chillán - Victoria	228		✓	✓	✓
San Rosendo – Hualqui	52		✓	✓	
Hualqui - Concepción	18				
Victoria - Temuco	65		✓	✓	

Figure 6. "Total modernization" sub-scenario © Authors, with Google Maps

5. Technical and technological solutions for modernization

Two technical solutions are proposed for network rehabilitation. The sections highlighted in red are those with a large linear kilometer and no passenger service, whereas passenger service is present on the blue sections but only over a short distance.

On the red sections, the decision was made to carry out work using the Hors Suite (HS) method, as the absence of passenger services means that the track can be completely neutralized for the duration of the work. On the blue sections, however, the decision was made to carry out work using the Suite Rapide (SR) method, in order to maintain existing commercial traffic. SR requires the track to be closed only for the duration of the works; commercial traffic can resume as soon as the works are completed, which generally takes place overnight. At the same time, the cost per kilometer of both work is also considered. HS work is generally less expensive than SR work, and HS work saves on the investment cost of the project in the case of the rehabilitation of a long linear kilometer.

Figure 7. Rehabilitation © Authors, with Wikipedia

In terms of modernization technologies, generally all types of work require equipment such as road-rail excavators, ballast wagons, transport wagons and measuring equipment. More specifically, there are contact wire unwinding trains, lifting equipment and railway cranes for electrification work, and equipment such as sleeper and rail replacement trains, rail collection trains and stripping trains for SR work.

The design and location of work centers are important. A detailed analysis of these two aspects enables better coordination, flexibility and management of flows, logistical optimization, and facilitates the transport of personnel, equipment and materials from the work center to the site. These factors indirectly influence the successful completion of the works on site.

The work centers also have a strategic role to play in the future operations and maintenance of the line, as they could eventually be transformed into infrastructure maintenance centers, rolling stock maintenance centers or even siding terminal facilities.

Figure 8. Work center locations © Authors, with Wikipedia

6. Railway operations

Defining operations remains essential to size the proposed service, the rolling stock fleet, and both operational and maintenance schedules. It must be done in collaboration to create the most realistic and robust operational environment possible. The objectives of our scenario are:

1. **To provide a clear ambition to meet the need for modernizing the network**: this enhanced offer is justified by a strong proposal to connect the country's two largest urban areas with a direct link between Santiago and Concepción;
2. **To create new opportunities in the railway market by prioritizing the long-distance services as well as commuter services;**
3. **To stimulate the region by offering new, cross-cutting services while facilitating the creation of new hubs.**

Table 1. Origin-destinations of interest

Part of the network	Linear Kilometers	Cumulative Population at both terminus cities (agglomerations)	Offer / day	Travel time
Valparaiso - Santiago	186 km	7,580,545	40	1h15
Santiago - Concepción	760 km	7,614,279	20	4h30
Concepción - Chillán	171 km	1,180,070	12	1h05
Concepción - Temuco	261 km	1,263,570	10	1h40
Concepción - Valparaiso	759 km	2,012,806	6	4h45
Temuco - Chillán	293 km	397,100	36	1h50
Temuco - Santiago	695 km	6,747,809	16	4h20
Valparaiso – Chillán	588 km	427,000	6	3h40

Table 2. Challenged existing origin-destinations

Origins-Destinations	Linear Kilometers	Cumulative Population	Travel time (HP/HC)
Nos (San Bernardo) - Santiago	20.8 km	5,181,300	6 min HP ; 12 min HC
Chillán - Santiago	398 km	1,180,070	Assumed existing
Rancagua - Santiago	134 km	6,813,150	15 min HP
Talcahuano - Laja	87.3 km	169,513	500,000 passengers/year

With an increase in the service across the territory, highlighted by four new key destinations, this expansion requires an increase in the rolling stock fleet.

Figure 9. New services © Authors

In an effort to optimize costs, all through-services will use a train originating commercially corresponding to the preceding section. Taking the example of Valparaiso Chillán, these six trains will be extensions of those already in operation on the Valparaiso Santiago route. Thus, in detail, we have:

Line	Offer/day	Travel time	Nb of trains
Valparaiso Santiago	40	1h15	20
Valparaiso Chillán	6	3h40	
Concepción Chillán	12	1h05	15
Concepción Temuco	10	1h40	
Concepción Valparaiso	6	4h45	
Temuco Chillán	36	1h50	25
Temuco Santiago	16	4h20	
Santiago Concepción	20	4H30	

Therefore, we can anticipate ordering additional 70 trains to support the maximum daily service levels we aim to achieve. Additionally, we add a reserve margin of five extra trains for rolling stock needs. Indeed, in designing the service offering in harmony with maintenance requirements, it is essential to plan spare trains to avoid service disruptions due to maintenance needs. Train unavailability due to equipment issues is highly intolerable to customers, highlighting operational inefficiencies and lack of agility on the operator's part.

Thus, a total of 75 trains are required to align with our modal shift objectives while creating new business opportunities. Given the relatively short travel distances, each train can complete a full rotation within a day, and even multiple rotations for desired shuttle services on the Valparaiso – Santiago and Temuco – Chillán routes. The short travel times enable increased rotations, thereby minimizing costs by maximizing commercial runs with the same equipment.

7. Economic and financial feasibility

7.1. Cost evaluation

The project cost was calculated from our chosen scenario and the defined construction works. Our estimations lead to €17.9 billion split between tools/technologies, cost of renewal of the tracks, cost of creation of new tracks, infrastructure adjustments, safety and electrification of the tracks, purchase of the necessary rolling stock.

Domaine	Cout prévisionnel Scénario 2	(Valparaiso)-Limache-Santiago	(Santiago)-San Fernando-Talca-Chillán-Laja (San Rosendo)-Concepción	Laja-Victoria-Temuco
Prestations & outillage	3 Milliards d'€	**141 km** à moderniser	**438 km** à moderniser	**127 km** à moderniser
Infrastructure	11,4 Milliards d'€			
Bâtiments	*0,9 Milliards d'€*	**185 km** à équiper en ERTMS L2	**552,2 km** à équiper en ERTMS L2	**192 km** à équiper en ERTMS L2
Voie ferrée	*1,7 Milliards d'€*			
Ouvrages d'art	*3,9 Milliards d'€*			
Sécurité du périmètre	*2,2 Milliards d'€*	Travaux Gare centrale de Santiago	Travaux gares de Chillan et Laja	Travaux gare de Temuco
Electrification	*2,4 Milliards d'€*			
Signalisation/ERTMS	*0,3 Milliards d'€*			
Matériel roulant	1 Milliards d'€	**3 km** de tunnel	**3 km** de pont	**2,5 km** de pont
Provision pour Risque	2,3 Milliards d'€			
TOTAL	**17,9 Milliards d'€**	**3,9 Milliards d'€**	**7,5 Milliards d'€**	**5,4 Milliards d'€**

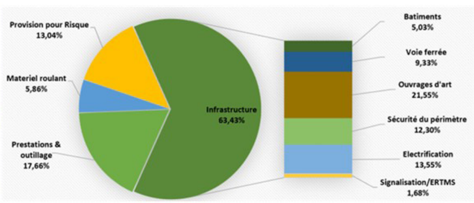

Figure 10. Cost evaluation © Authors, with Google Maps

7.2. Planning

The complete duration of the project is 25 years and 3 months. Construction work is executed by sections, priority is given to sections with the greatest frequency.

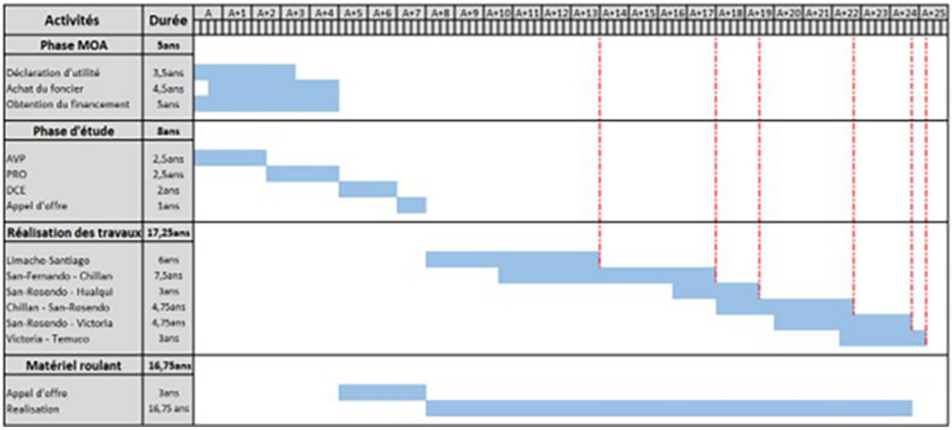

Figure 11. Chile project schedule © Authors

7.3. Financial statement and socio economic evaluation

The operational balance sheet of the project was constructed following the operational scheme of our current study, referring to the table extracted from the course "Economic Model in the Collective Transport Sector: Financial Issues and Operational Balances". The cost per kilometer of a regional train in France, which is €20.70, was adapted to the economic situation of Chile, adjusted according to the GDP per capita, resulting in a cost of €7.60 per kilometer of train. The monthly subscription rate was deliberately set at an attractive price of €3.70 per trip, competitive against bus offers and advantageous in terms of travel time, aiming to triple the number of passengers by 2030. Currently, out of the annual 50 million railway passengers, 12 million are travelling intercity due to limited urban transport options. With these goals, we aim to reach 36 million intercity travelers.

The modernization of the line is expected to result in a positive operational balance, attracting investors and fostering public-private partnerships (PPP), as outlined in the operational setup study.

The financial profitability analysis of the project focuses on its societal impact. Initial financial profitability evaluation considers investment costs for infrastructure, rolling stock acquisition, and additional operational costs related to the new line. Revenue will mainly come from operating income. Regarding ticket prices, a 10% increase post-modernization is proposed to enhance revenue generation. Adjusting the ticket price by €1.90 and aiming for an annual ridership increase of 100 million passengers could lead to a revenue increase of €285 million. These revenues need to be compared with operating costs to estimate the net benefit for the operator.

	Distance	Amplitude	HP	HC	NB FRÉQUENCE HP	NB FRÉQUENCE HC	KM PARCOURU	Fréquentation
Valparaiso <-> Santiago	186	16	4	12	4	2	7 440	25 000
Santiago <-> Concepción	760	16	4	12	4	1	21 280	25 000
Concepción <-> Chillan	171	12	0	12	0	1	2 052	6000
Concepción <-> Temuco	261	12	0	12	0	1	3 132	5000
Concepción <-> Valparaiso	759	12	0	12	0	1	9 108	2 500
Temuco <-> Chillan	293	16	4	12	4	2	11 720	22 500
Temuco <-> Santiago	695	16	0	16	0	1	11 120	11 500
Valparaiso <-> Chillan	588	12	0	12	0	1	7 056	2 500
Somme Réseau	3125						72908	100000
Somme réseau total	3125						72 908	100000
Coefficient jour/année	360							
Km train parcourus / an	26 246 880							
Vide Voyageurs	10%							
km Réseau parcourus /an	28 871 568							
	Cout unitaire/km							
Coût d'exploitation train /km/an	7,60	219 423 917						
Cout d'exploitation /an		219 423 917						
Fréquentation voyage/ jour	100 000							
Fréquentation voyage/an	36 000 000							
Répartition clientèle	Répartition clientèle	Recette / voyage	Recettes tarifaires	Compensations tarif sociaux	Compensation tarifaires			
Ticket unité	25%	20,7	186 030 000	0				
Abonnement mensuel	75%	3,7	99 900 000	0				
Total	100%		285 930 000		-			
Recettes	285 930 000							
Charges d'exploitation	219 423 917							
Résultat d'exploitation	66 506 083							
R/D	1,303							
Recette / voyage	7,943							
Cout d'exploitation /voyage	6,095							
Résultat d'exploitation	66 506 083							
Compensation tarifaires	-							
Subvention d'exploitation	66 506 083							
Charges exceptionnelles	3 789 500							
Subvention d'équilibre	62 716 583							

Figure 12. Project operating results © Authors

The socio-economic evaluation of the project is crucial, considering both quantitative and qualitative impacts on society and the environment.

The analysis aims to quantify and monetize the benefits offered by the project over a 50-year period, comparing them with the incurred costs. The project is deemed socio-economically beneficial if the total benefits outweigh the costs during the study period. Non-monetizable gains include improvement of social cohesion, enhanced quality of life, increased accessibility, tourism development, innovation promotion, job creation, and stronger regional equality.

The socio-economic balance sheet shows a positive value, indicating the project's socio-economic profitability.

$$\text{VAN SE} = -21100 + \sum_{1}^{50} \frac{202+123+928+24{,}5+236+94+285-221}{(1+0{,}075)^{\wedge}t} = \mathbf{+\ 587\ millions\ d'€}$$

The operational and financial setup for project implementation and operation suggests a public-private partnership (PPP) as the best financing option.

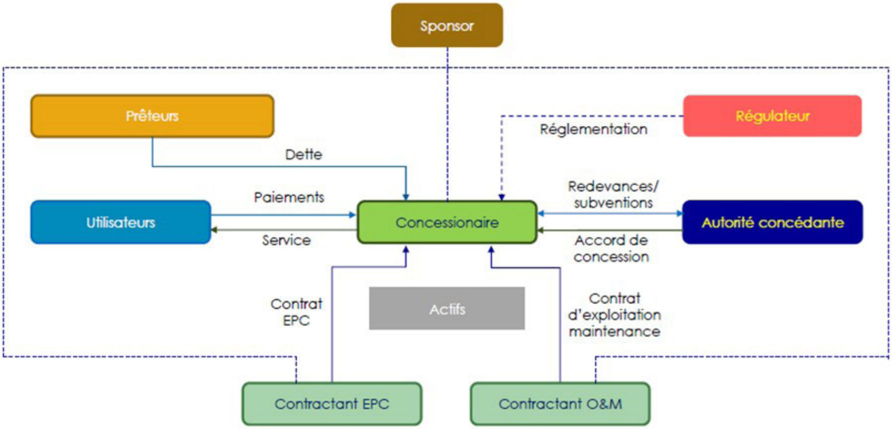

Figure 13. Partnership of project © Authors

The concession contract should outline the responsibilities, financing, revenues, service quality standards, and dispute resolution mechanisms. The proposed financing plan includes a mix of private and public funding sources to ensure the project's successful execution. Legal prerequisites and conditions for the concession contract, including duration, responsibilities, financing, revenues, service quality, price setting, dispute resolution and legal framework, are essential for a robust contractual framework.

Conclusion

Railway transportation is key to the development of Chile. A precise assessment of the zone, linked to the analysis of scenarios consolidated our choice of technical solutions, leading to satisfactory fulfilment of the necessary activities and budget.

The new offer includes four new key destinations, extending the service across the territory and creating the need for new rolling stock to mitigate significant operational challenges that could lead to service disruptions.

The modernization of the Chilean railway line between Valparaiso and Concepción presents significant socio-economic benefits and requires a well-structured operational and financial setup to ensure its success and sustainability.

Railway Connection between Java and Sumatra (Indonesia)

Daming SONG
Maxime CHAHINE
Jérôme BENAZET
Crédo POCANAM
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ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES
IP PARIS

Notre projet vise à établir une liaison ferroviaire entre Palembang à Sumatra et Jakarta à Java, Indonésie. Après avoir étudié plusieurs scénarios, nous avons opté pour un tunnel ferroviaire sous le détroit de la Sonde comme meilleure option. Ce projet rencontre divers défis, notamment la construction d'une infrastructure lourde et la nécessité d'obtenir l'acceptation culturelle, le détroit étant une zone protégée avec plusieurs réserves maritimes stratégiques pour les échanges en Asie du Sud-Est et en Océanie. Notre approche s'inspire des succès du projet Eurotunnel et du tunnel reliant le Danemark à la Suède. Nous visons à améliorer le transport de passagers et de marchandises, cette dernière représentant une part importante des échanges entre les îles, en raison notamment des mines de charbon et autres minerais présents. Cependant, le projet comporte des risques liés aux conditions climatiques régionales et à la nécessité d'électrifier les lignes ferroviaires. Pour assurer son succès, un partenariat public-privé est essentiel pour sécuriser le financement et mobiliser les compétences techniques nécessaires, tant publiques que privées.

Mots-clés : environnement, socio-économie, ferroviaire, transports frets, transports voyageurs, tunnel, Indonésie

Our project aims to establish a railway linking Palembang in Sumatra to Jakarta in Java, Indonesia. After considering various scenarios, we have chosen a railway tunnel under the Sunda Strait as the optimal option. Challenges include heavy infrastructure construction and obtaining cultural acceptance, given the protected status of the area and its strategic importance for maritime trade. Inspired by projects like the Eurotunnel and the Denmark-Sweden link, our goal is to enhance passenger and freight transport, with significant freight flows due to coal mines and other minerals. However, the project faces risks from regional climate conditions and the need for railway electrification. A public-private partnership is essential for securing funding and accessing necessary technical expertise..

Keywords: Environment, Freight Transportation, Passenger Transportation, Railway, Socioeconomic, Tunnel, Indonesia

1. Assessment

1.1. Indonesia: Sumatra and Java

1.1.1. Territorial assessment

Indonesia, a vast archipelago in Southeast Asia with over 17,000 islands, spans from the Indian Ocean to the Pacific Ocean. With a population exceeding 275 million (2022), its major cities are concentrated on Java and Sumatra, highlighting the need for inter-island connectivity. Situated within the Pacific Ring of Fire, Indonesia experiences frequent seismic and volcanic activity, especially on islands like Sumatra and Java. The country hosts about 10% of the world's coral reefs (covering 2.4 million hectares) and 20% of global mangroves (spanning 3.3 million hectares), vital for biodiversity and carbon storage, notably in marine protected areas around the Sunda Strait.

As ASEAN's largest economy and the 16th largest globally, Indonesia recorded a GDP of $1,182 billion USD in 2021, with a GDP per capita of $4,396 USD, reflecting a growing middle class. Concerns such as overpopulation, flooding, and land subsidence in Jakarta have prompted plans to relocate the capital to Borneo, with the aim of easing urban pressures and enhancing sustainability. Transport infrastructure remains critical in ongoing developmental plans.

1.1.2. Existing transportation analysis

According to statistical analysis on transportation modes within the country, a predominance by maritime transport (boats, ferries), used by approximately 80% of travelers, can be observed. In terms of public transportation, airplanes and buses follow (used by around 45% of travelers), with trains accounting for just over 30% of travelers. When it comes to freight transportation, major import and export activities are facilitated through international maritime ports. Domestic transfers are also facilitated by maritime transport (between islands) and road transport (within islands).

1.2. Railway connection project between Java and Sumatra

The analysis highlights strong potential for freight transport between Java and Sumatra, especially through improved port connectivity. Tourism also supports regional passenger transport, bolstered by the East Java-Jakarta high-speed rail line and its proposed extension.

To ensure project success, key technical and social criteria must be met: securing and planning the railway line across the Sunda Strait, accommodating rolling stock standards, and integrating harmoniously with the environment while respecting protected areas and cultural sensitivities. Additionally, alignment with a comprehensive master plan, including electrification and modernization of railway infrastructure, is essential for sustainable development of the Java-Sumatra railway network, addressing long-term economic, social, and environmental needs.

1.2.1. Different technologies for connection

- Scenario 1: Bridge

A bridge, approximately 30 kilometers long depending on the chosen route, will connect the islands of Java and Sumatra. This solution would potentially include a wide deck to accommodate both rail and road transport.

- Scenario 2: Tunnel

A tunnel of similar length to the bridge in the first scenario will also connect the islands of Java and Sumatra. This project will not include a road connection.

- Scenario 3: Ferry connection

This scenario involves connecting the islands by ferry. A ferry, designed to carry passengers and goods, will transport railway vehicles (cargo or passengers) directly across the Sunda Strait.

1.2.2. Scenario choice

To select the most appropriate scenario for the project, which best meets needs and expectations while considering various constraints, a multi-criteria analysis was conducted. Sensitivity tests were also performed to verify the relevance of this analysis (evaluations with different weightings were carried out).

Based on the analysis, the first scenario with the option of a bridge scores significantly lower compared to the other two, thus ruling it out. This leaves us with Scenario 2 and Scenario 3, both closely scored overall, but Scenario 2 slightly outperforms Scenario 3. To make a definitive choice, we need to weigh key criteria such as construction costs, economic factors, operational efficiency, and maintenance requirements. When these factors are considered together, Scenario 2 emerges as the preferred option. In conclusion, constructing a tunnel provides a more reliable, secure, and sustainable solution for connecting Java and Sumatra, offering superior capacity and safety compared to ferries.

Table 1. Multi-criteria analysis.

Pr	Criterion Weight A	Criterion Weight B	Criterion Weight C	Criterion Weight D	Criterion Weight E	Critère	Criterion weight	Scenario 1 Bridge	Scenario 2 Tunnel	Scenario 3 Ferry boat
						Length of the crossing		2	3	4
ECONOMY	40%	50%	25%	30%	25%	- Construction cost		2	2	4
						- Maintenance cost		2	2	3
						- Economic relevance for passengers		3	3	1
						- Economic relevance for goods		3	3	1
						- Dismantling cost		1	4	3
						- Land acquisition costs		4	3	1
						Total		15	17	13
HSE	10%	10%	50%	10%	10%	- Competence of local actors		2	2	4
						- Required training		2	2	4
						- Health / Safety		2	3	4
						- Waste management		3	2	4
						- Prevention of accidental pollution and noise nuisances		2	3	1
						- Impact on navigation		2	4	1
						- Impact on GHG (Greenhouse Gases)		1	1	3
						- Expropriations		3	2	4
						Total		17	19	25
CONSTRUCTION	30%	25%	15%	50%	15%	- Completion time		3	2	4
						- Complementary infrastructure		3	2	1
						- Impact of the size on infrastructure		3	2	4
						- Climatic constraints of construction		2	3	4
						- Feasibility: Pre-existence of similar studies in Indonesia		3	2	4
						Total		14	11	17
OPERATION AND MAINTENANCE	20%	15%	10%	10%	50%	- Maintenance of works		2	3	4
						- Operational safety		2	3	2
						- Infrastructure security		3	4	3
						- Modal sharing: Facilitating integration of road transport		4	2	2
						- Tonnage limit		4	4	1
						- pphpd limit (passengers per hour per direction)				
						- Power supply mode		2	2	1
						- Exposure to climatic hazards		1	4	2
						- Accident rate (at interfaces: external causes)		3	4	2
						- Climatic maintenance constraints (bridge support apparatus, pillar, water infiltration tunnel, tunnel ventilation)		2	3	4
						Total		23	29	21

2. Scale Hypothesis

2.1. Estimation of transportation needs

Estimates for the South Sumatra - Java connection project were derived based on 2022 statistical analyses of passenger and freight flows across air, land, and sea transport, and considering modal shift assumptions. A modal shift from air and maritime modes is anticipated.

The graph below outlines preliminary estimates of passenger and freight flows for the connection project (highlighted in red). This estimation reflects total annual flows in both directions. Freight transport may be uneven due to differences in industrial and mining activities between the islands.

Figure 1. Estimation of transportation needs for connection project. © Daming Song/MyMaps, Google

Based on previous estimation, there is a total of 6 million travelers per year in both directions for the crossing. The main reasons for travel are tourism, visiting family, and business. Therefore, we anticipate an equal flow of travelers in both directions across the crossing. The frequency of passenger trains for the crossing is defined as follows:

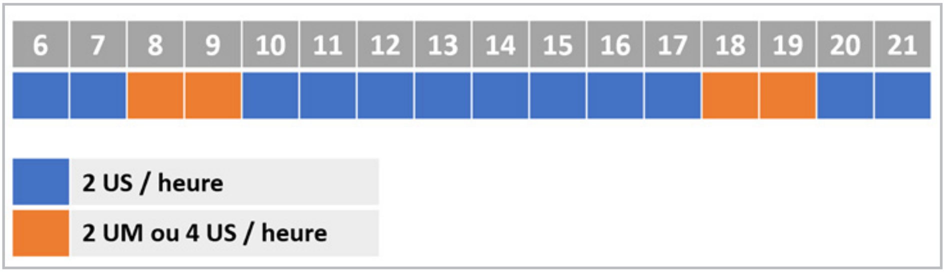

Figure 2. Passenger train frequency. © Daming Song

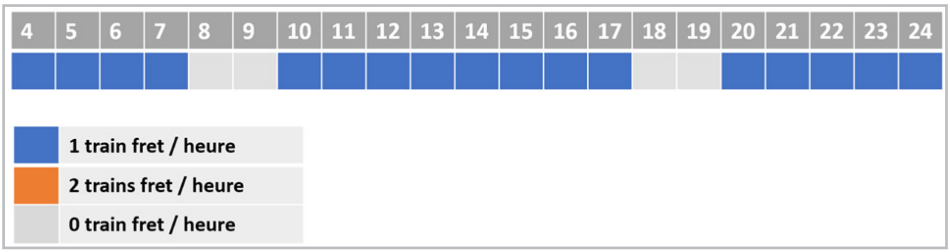

Figure 3. Freight Train. © Daming Song

For freight transport, we estimate 12 million tons of goods annually between Java and Sumatra. This flow is uneven due to mining on Sumatra and industrial activities on Java. A split of 40/60 imbalance is used for estimation, which led to a schedule of 17 freight trains per day for system sizing.

These capacity estimates were then validated through a preliminary space-time grid, taking into account infrastructure and operational assumptions.

2.2. Network Technical Characteristics

The project aims to find a regional railway transport solution, utilizing existing infrastructure and laying new tracks parallel to the current network. Specifically, this railway connection project will span approximately 611 km, including a 33 km tunnel section between Jakarta and Palembang.

Figure 4. Future Java-Sumatra Connection Network © MyMaps, Google

Table 2. Technical Specifications of the Jakarta-Palembang Line

Characteristics	Chosen values
Number of tracks	2 (double track)
Track type	Ballasted
Track gauge	1435 mm (Standard gauge)
Passenger train speed	160 km/h
Freight train speed	100 km/h
Maximum gradients	35‰
Electrification	Overhead catenary 25 kv 50 Hz
Signaling	ERTMS/ITCS level 2

2.3. Infrastructure

The proposed Nusantara Tunnel linking Java and Sumatra has sparked interest among 80% of Indonesia's diverse population. It aims to integrate natural resources between the islands, unlocking national potential. Yet, significant geographical, geological, and ecological constraints challenge its feasibility and scope.

The 33 km underground tunnel, located at a minimum depth of 40 meters beneath the seabed, will connect Java and Sumatra. It has been chosen for geological stability, accommodating electric trains for passengers and freight. The tunnel offers lower capital costs and increased safety. It will also support high-power transmission and telecommunications infrastructure.

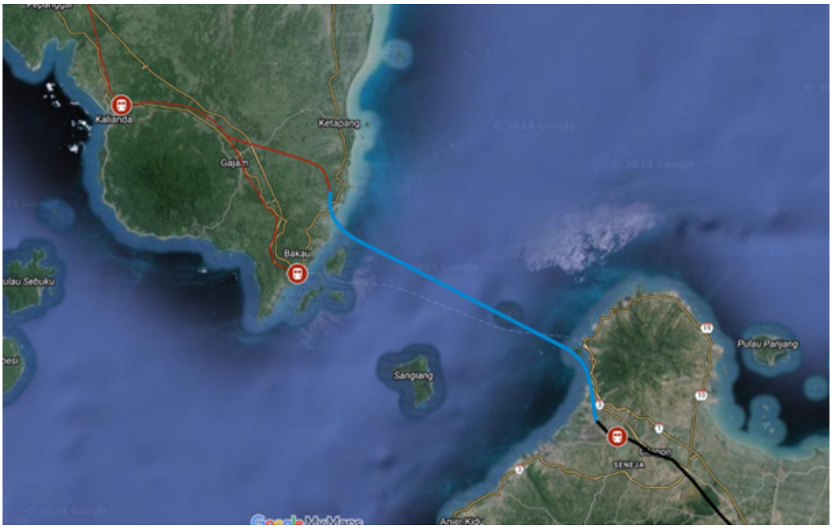

Figure 5. Plan view of the tunnel © MyMaps, Google

The Nusantara Tunnel spans about 33 km, with 26 km (80%) underwater, at a depth of at least 40 meters below the seabed. It resembles the Channel Tunnel, with a maximum water depth of 70 meters above it. The tunnel's maximum gradient is 2% and it maintains a minimum horizontal curve radius of 3000 meters. In the diagram, the surface of Sunda Strait is depicted in blue, the seabed in green, and the tunnel in red.

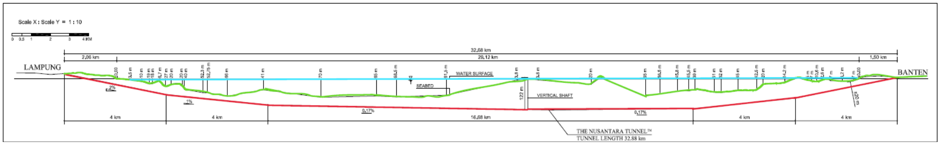

Figure 6. Longitudinal profile of Nusantara tunnel. Source: Sindur P. Mangkoesoebroto, "The Nusantara Tunnele development of an integrated linkage system between Java and Sumatra islands in Indonesia", Tunnelling and Underground Space Technology, *vol. 20, n°6, 7 November 2005.*

We suggest constructing a twin-tube tunnel with a diameter of 7.6 meters, along with an interconnected service tunnel of 4.5 meters, similar to the Channel Tunnel. The decision to use a twin-tube tunnel is aimed at minimizing the effects of pressure waves resulting from pressure differentials within the tunnel.

The service tunnel plays a crucial role by providing access for maintenance and security operations, as well as facilitating passenger evacuation in case of incidents. It also serves as an access point for the ventilation system throughout the structure.

To ensure optimal safety, the service tunnel is maintained at a slight air overpressure, protecting it from smoke in the event of a fire in one of the adjacent railway tunnels.

Figure 7. Example of cut-view tunnel design Source: Eurotunnel

2.4. *Fixed Electric Traction Installations*

Choice of Electrification Type

Indonesia appears to have sufficient energy resources to support electrification of the future railway line linking Java and Sumatra. Opting for 25 kV at 50 Hz electrification is a logical decision, especially if it aligns with existing high-speed rail projects. With a power transmission capacity of 16 MW through the overhead wires, this configuration should enable efficient operation of the line while meeting the increasing transportation needs between the two islands. In case of a failure at one of the two substations, it will be possible to maintain operations while awaiting maintenance.

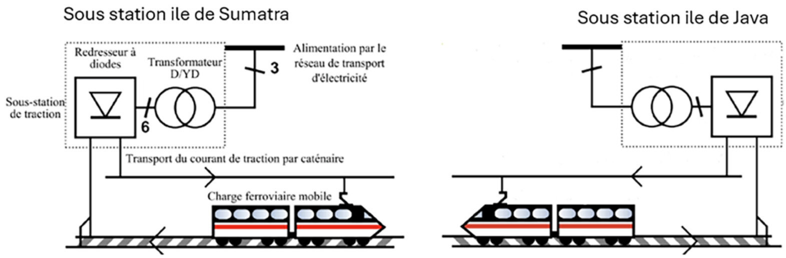

Figure 8. Electrical Substation Power Supply Diagram. Source: Mounir Bensalah, Building Information Modeling *pour des applications ferroviaires : conception d'une sous-station de tramway, thesis defended in July 2018, modified by Crédo Pocanam.*

Java will have 3 substations: one in Jakarta, one in Rangkasbitung, and one at the tunnel entrance. Sumatra will have 11 substations: one at the tunnel entrance, one in Rasahtukuid, one in Lampung, and 7 spaced 40 km apart between Lampung and Palembang.

2.5. *Railway Signaling*

To maintain consistency with the existing High-Speed Rail (HSR) system deployed on the Jakarta-Bandung line, which uses a Chinese variant of ERTMS known as CTCS, we choose to deploy an ECTS Level 2 system.

3. Rolling Stock

3.1. Rolling Stock Composition

Given the construction of the mainline following European standard requirements, we rely on existing products from industrial manufacturers for cost estimation references. The track characteristics, such as gauge, gradient, curve radius, and superelevation, are standard, allowing us to choose catalog products to achieve better cost competitiveness for rolling stock.

The costing basis for passenger trains is the Coradia Stream 6 Cars type of regional trains and Double Coco type locomotive for each freight train. The quantity of rolling stock required to maintain the service level will be detailed further in the operation section.

3.2. Rolling Stock Maintenance

To minimize operational costs, the strategic design and placement of railway maintenance facilities is crucial for optimizing rolling stock durability. Our project includes:

- A central main maintenance workshop
- Storage and in-service monitoring areas
- End-of-line light maintenance stations

Integration with existing railway network facilities on each island must be considered in workshop design. Establishing robust maintenance infrastructure for the Sumatra-Java railway connection ensures safety, reliability and service availability, supporting economic and social development in the regions.

4. Operation

4.1. Timetable

Based on simulations showing an estimated travel time of 6 hours and 10 minutes for freight trains and 4 hours and 20 minutes for passenger trains, and factoring in a target turnaround time of 30 minutes with a train ready on each side, it is possible to establish a typical timetable. This timetable, presented in a space-time graph, needs to account for the performance limitations of both passenger and freight trains. Additionally, it should adhere to allocated time margins for travel slots, which allow approximately 4.5 minutes per 100 km traveled to maintain operational efficiency and scheduling reliability.

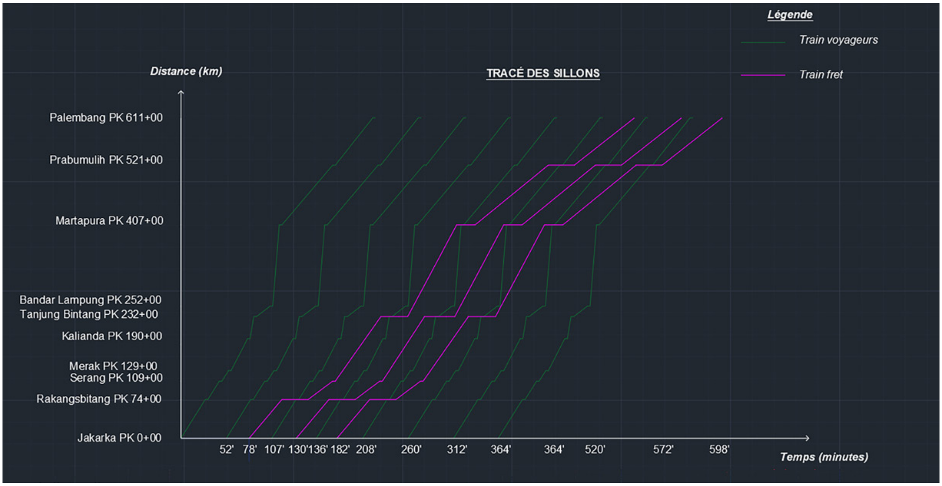

Figure 9. Space-time diagram in the Jakarta - Palembang direction. © Crédo Pocanam

By graphically integrating freight trains, we observe the need to plan crossing points with passenger trains at four stations to avoid compromising their travel times. A more detailed analysis will be necessary to assess the relevance of these crossings at these stations, taking into account railway signaling aspects and examining the track occupancy diagram to ensure smooth and safe network operation.

4.2. Designing the rolling stock rotations

The rolling stock rotation can be defined based on earlier assumptions. During peak hours, multiple units will be coupled to increase capacity and availability for passenger trains. With a 30-minute turnaround time and 10 minutes allocated for cleaning, efficient route planning can minimize the fleet.

Similarly, considering a longer turnaround time set at 1 hour and 40 minutes to allow for technical maneuvers such as coupling wagons and locomotives, the following hourly schedule is obtained for freight trains. Technical maneuvers and preparation times are not represented in these rolling stock rotations.

4.3. Fleet sizing

Taking into account the assumptions made regarding passenger and freight flows, as well as rolling stock maintenance requirements, we have determined that a fleet of 17 multiple units and 30 locomotives would be necessary to effectively meet demand and ensure optimal operation of the railway network.

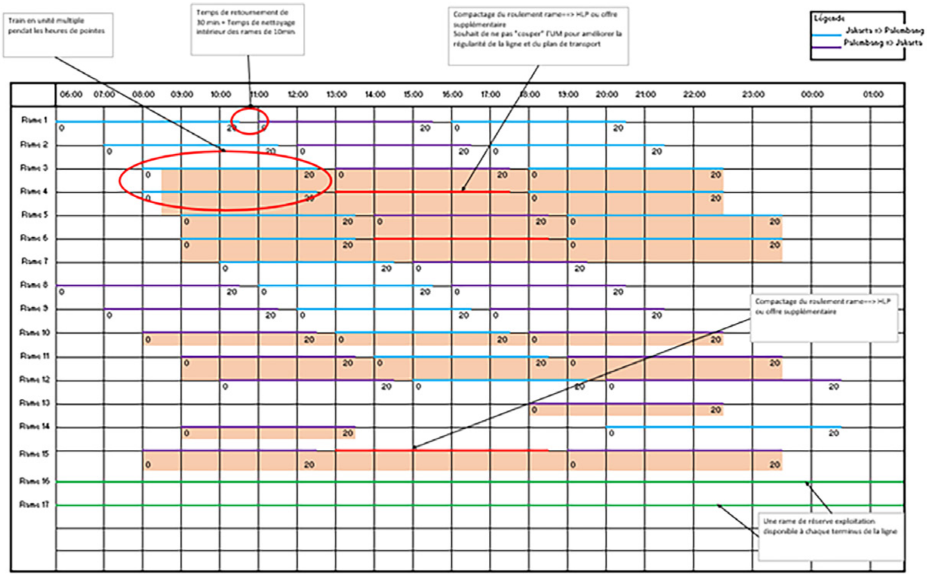

Figure 10. Rolling stock rotation diagram – passenger trains © Jérôme Benazet

5. Financial statement

5.1. CAPEX

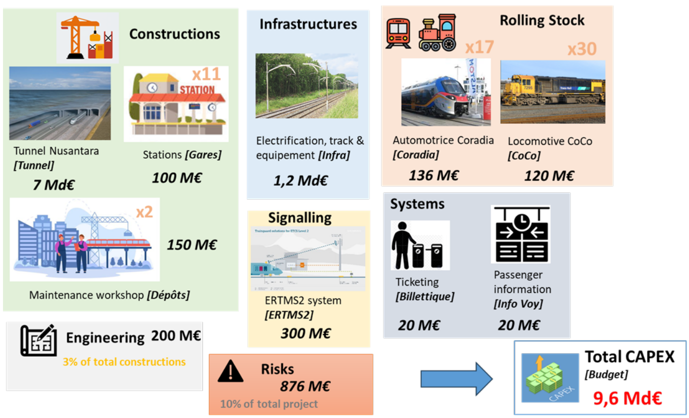

Figure 11. Capital Expenditures (CAPEX) © Julien Tin

5.2. OPEX

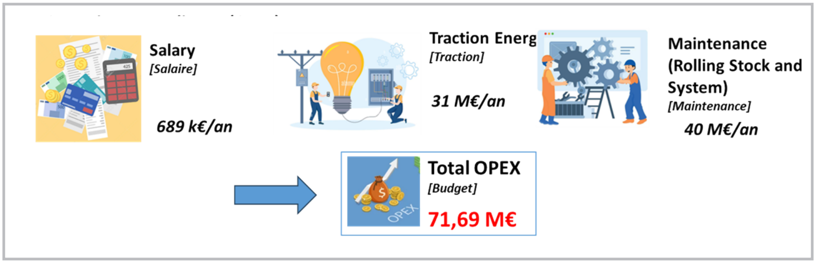

Figure 12. Operation Expenditures (OPEX) © Julien Tin

5.3. Operating Revenue

Operating revenue generated on the Java-Palembang line will primarily come from ticketing revenue. We estimate this revenue to be around €322 million per year.

5.4. Financial Report

We propose then to calculate the Net Present Value (NPV) of the project, assuming a project lifespan of 40 years and a discount rate of 5%. The financial NPV obtained is -€3.25 billion over 40 years. Next, we will consider externalities to assess the overall socio-economic factors affecting the project's overall value. However, by incorporating socio-economic factors into this purely financial statement, we can present a more holistic and positive outlook. Significant benefits can be anticipated from environmental and public safety perspectives.

6. Project Structure

We propose to establish a public project company under a PPP (Public-Private Partnership) Build-Own-Operate model for the implementation of the project. This company will have the capacity to initiate and oversee the procurement and execution of contracts for studies, construction, systems, and the delivery of rolling stock. Subsequently, it will assume responsibility for operating and maintaining the transportation system components under its jurisdiction.

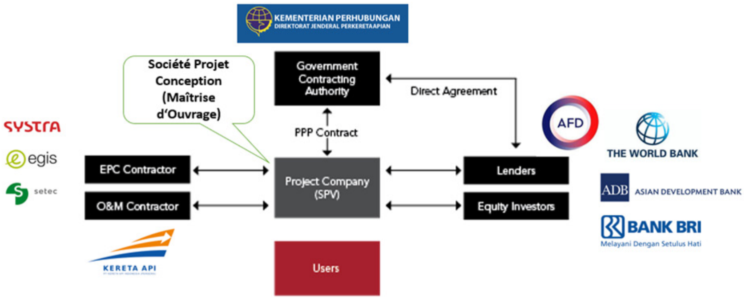

Figure 13. Organizational chart of the project © JICA, 2015, modified by TIN

7. Project Planning

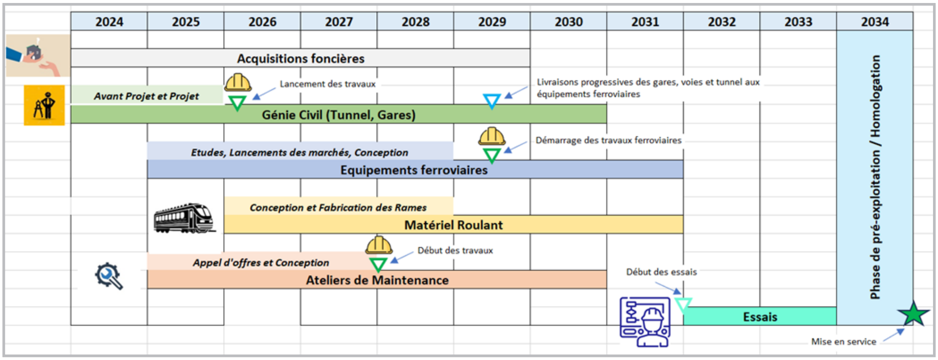

Figure 14. Project planning. © Julien Tin

Conclusion

The project to connect the islands of Java and Sumatra through an underwater tunnel, akin to the renowned Channel Tunnel, represents a bold yet promising solution. This major infrastructure aims to enhance economic integration, facilitate trade, and improve mobility of people and goods between these significant Indonesian islands. The underwater tunnel project linking Java and Sumatra promises to enhance economic integration and mobility between these key Indonesian islands. Chosen for its safety, minimal environmental impact and proven technology, the project reflects Indonesia's commitment to large-scale infrastructure. Despite significant technical and financial challenges, the anticipated benefits in connectivity and regional development justify the investment. Moving forward, detailed planning and risk assessment will be crucial as Indonesia embarks on this ambitious project to bolster its national and international profile.

Creation of a Suburban Rail Service in Khartoum

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Cette étude porte sur la création d'une desserte suburbaine à Khartoum au Soudan. La concentration des points d'intérêts au centre-ville et la décentralisation de la population croissante dans les banlieues, rendent nécessaire une nouvelle solution de transport. Ce rapport présente un diagnostic complet de la situation, suivi d'une analyse multicritère permettant de choisir une solution. Cette solution est ensuite dimensionnée, et sa mise en œuvre est détaillée, en termes d'infrastructures, matériel roulant et exploitation. Finalement, un bilan socio-économique de la solution est réalisé, incluant une analyse de risque détaillée. Le résultat est une réhabilitation complète de la ligne ferroviaire existante. La nouvelle desserte proposera des trains fréquents, avec des matériels roulants hybrides neufs. Tous les équipements seront prévus pour permettre une augmentation progressive des flux de passagers, anticipant ainsi l'adoption croissante par la population de la solution ferroviaire..

Mots-clés : analyse multicritères mobilité, desserte ferroviaire, évaluation socio-économique, matériel roulant hybride, report modal, Khartoum

This study focuses on the creation of a suburban service in Khartoum, Sudan. The concentration of points of interest in the city center and the decentralization of the growing population in the suburbs make a new transportation solution necessary. This report presents a comprehensive diagnosis of the situation, followed by a multi-criteria analysis to choose a solution. This solution is then sized, and its implementation is detailed in terms of infrastructure, rolling stock, and operation. Finally, a socio-economic assessment of the solution is carried out, including a detailed risk analysis. The result is a complete rehabilitation of the existing railway line. The new service will offer frequent trains with new hybrid rolling stock. All equipment will be designed to allow a gradual increase in passenger flows, thus anticipating the population's growing adoption of the new rail solution.

Keywords: hybrid rolling stock, mobility, modal report, multi-criteria analysis, rail service, socio-economic analysis, Khartoum

1. Context of the study

1.1. General Context

Home to almost 48 million inhabitants, Sudan is, at the time of this study, in the midst of a violent civil war. This study places itself in the context of the end of the war and considers the development of a new railway service in and around Khartoum as part as the economic redevelopment of the country.

Even though the Sudan has had an extensive railway network since the end of the 19th century, this network is now in a derelict state. At the country level, improving the railway system is a strategic lever to help the economic situation. Indeed, Sudan has large reserves of oil and ore, which a good transportation system will help exploit and connect with the country harbors.

1.2. Mobility Needs in Khartoum

Khartoum is the capital city of Sudan, and also its most densely populated region. As its population keeps growing, it also expands in the suburban areas around the city center, in a radius reaching over 20km. Most of the service and work areas being in the city center, this generates high levels of congestion on the streets during rush hour.

The main current modes of transportation are the minibus, the personal car and people traveling by foot. Minibus services are not organized, they don't follow specific routes and stop on demand. This also contributes to traffic issues in the capital.

A railway line already exists in the region, traversing the city from South to North and stopping at three stations in the city. However, it is not used anymore on most of its length, due to the lack of maintenance on the infrastructure.

2. Choice and Scaling of the Solution

2.1. Multi-criteria Analysis

A multi-criteria analysis was carried out to select a transport solution and a route. The choice of transport solution was based six main criteria, all centered around sustainable mobility.

2.1.1. Choice of transport solution

Four solutions were compared to select the one best suited to Khartoum's needs:

- Shared Bus Rapid Transit (BRT) line;
- Khartoum Metro Line;
- Tramway line in Khartoum;
- Regional Express Railway Line in Khartoum.

Given the country's financial limitations, the best transport capacity/investment/ robustness ratio was a priority.

Following this analysis, the following conclusions were reached:

- The rail system offers the greatest transport capacity;
- The pre-existence of the infrastructure will significantly reduce the cost of acquisition and the time required to set up the target transport system;
- The positioning of the existing stations ensures spatial coverage of the service points and is consistent with a possible extension.

2.1.2. Choice of route

As the rail solution better meets Khartoum's mobility needs, three potential solutions for getting to and/or from the city center have been considered:

- Route 1: Rail link from the center of Khartoum to the west.
- Route 2: Rail link from the center of Khartoum to the north.
- Route 3: Route for a rail link between South and Central Khartoum

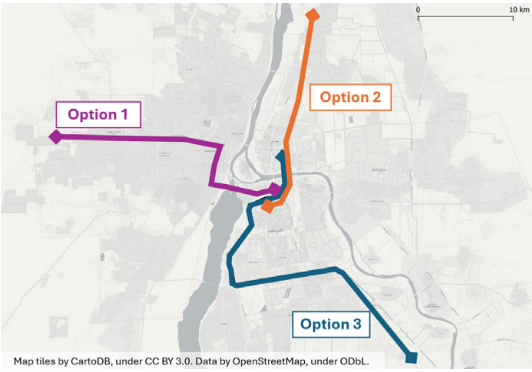

Figure 1. Three routes studied. © Personal creation with map tiles by CartoDB

The descriptions and main constraints associated with each of these routes are set out in the table below:

	Route 1	Route 2	Route 3
Description	Center of Khartoum to the West	Center of Khartoum to North	South and Center of Khartoum
Main Constraints	-No existing railway line -Taking the train over the Nile branch & building a bridge	- Low population density covered - Along a main road & Illegal level crossings slightly below 80	-High population density covered -Coverage of several business areas -86 level crossings -Easy access to Khartoum Airport

Based on this analysis, the solution chosen is a railway service along route 3, providing access to the city center and the south of the city. The solution will be called "KER: Khartoum Express Railways".

2.2. Scale of the Main Variables

2.2.1. PPHPD

The main variable that will help determine the size of the service is the number of passengers per hour per direction, or PPHPD.

A PPHPD ranging from 3750 to 10000 can be estimated based on the number of trips between the suburbs and the city center per day (2 million) and the hypothesis made on the expected modal shift.

Of this range, it was decided to consider the lower bound to avoid over-sizing the solution. This is taking into account a progressive modal shift. However, the fixed infrastructure and system will be sized to allow for PPHPD growth in the future without needing any major change.

2.2.2. Interval

The proposed initial interval is 15 minutes. It is short enough to guarantee a frequent service, and corresponds to an easy-to-remember schedule.

2.2.3. Max speed

The track infrastructure will be designed to allow a maximum speed of 80km/h. Even though initially the operating speeds will be slower, this speed of 80km/h will allow an increased PPHPD in the future and doesn't require restraining the rolling stock below its full capacity.

2.2.4. Number of tracks

The existing line has only one single track. As part of this study, it was decided to upgrade the line to a double track. This will ease the operations and hopefully lower the number of incidents and delays. The operation will also be more robust, as an issue on one track should not stop the service in the other direction.

3. Implementation of the Solution

3.1. Systems and Infrastructure

3.1.1. Tracks

The line will keep the current Cape gauge of 1.067m, as this line is part of the national network. The tracks will be laid on sleepers and ballast, as a concrete slab solution would be too expensive and challenging to maintain. Ballast will also help with draining water, as the region is prone to flooding.

The minimum bending radius is calculated at 472 m, to allow a maximum speed of 80 km/h.

3.1.2. Stations

On top of the three stations already existing, it is proposed to create eight new stops along the line. One major stop at the southern terminus will also include a new rolling stock maintenance facility.

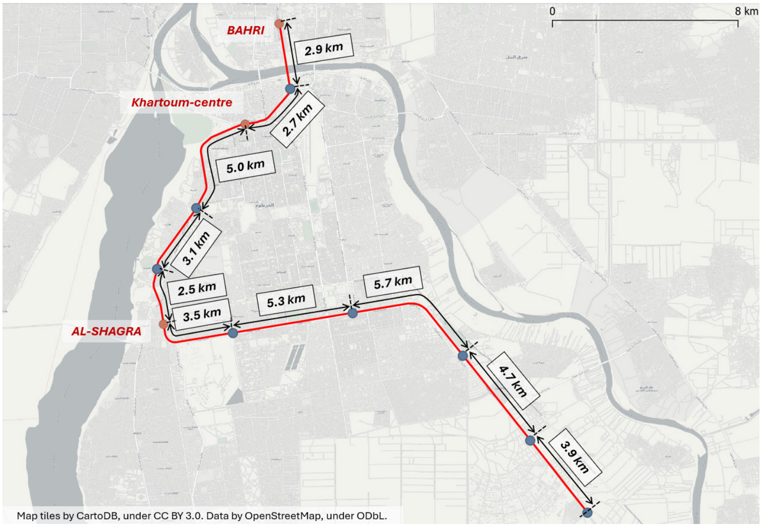

Figure 2. Station locations © Personal creation with map tiles by Carto DB

3.1.3. Bridges and Crossings

As the line is currently unused, it is crossed by streets in over 86 places.

As part of the line renewal, it is proposed to drastically reduce the number of crossings, so that the trains can operate smoothly. Four new bridges will be constructed on the main street crossings, and only twenty level crossings will be kept.

3.1.4. Signaling Systems

The choice of signaling system falls on the automatic three-way light block, which is a relatively simple and reliable solution.

Signals will be placed at least every 1500 m, which, at 80km/h, allows a minimum interval of 149s, which is well below the initial 15 minutes considered.

3.1.5. Maintenance

A large maintenance facility already exists next to Khartoum central station. It will probably need to be renovated, but it is a large space available to store trains, with more than 20 side tracks available. As part of this new suburban service project, a new 1Ha maintenance facility will also be built at the south terminus station.

3.2. Rolling Stock

Given the poor electrical power production in SUDAN, and using a benchmark on projects in similar environments, like the TER in Dakar, we are able to choose the appropriate kind of equipment and its size.

The rolling stock that best meets our needs is called "Régiolis Hybrid Train series B 83500", from the Coradia family made by the French manufacturer Alstom. Initially a dual-mode train (catenary / diesel), modifications which were made to the train consist of replacing two of the four diesel engines (4*300kW) with lithium-ion batteries which allow a range up to 30 km thanks to batteries and 1,000 km with diesel and battery combined. These batteries can recycle 90% of the braking energy.

The self-propelled train chosen is a low-floor peri-urban model with two doors per side on each vehicle, and offering carrying total capacity of 470 passengers per railcar.

To cover our peak hour transport needs, i.e. 938 passengers, the train will be made up of 2 trainsets with a total length of 72m x 2 = 144m which will be parked on 200m long station platforms.

3.3. Operations and Maintenance

The existing railway line traversing Khartoum from north to south accommodates increasing travel demand, driven by rapid urbanization, particularly in the suburban areas. The previous gradual abandonment of this railway line makes modal shift complex. Therefore, this shift cannot occur without genuine attractiveness, both in terms of fare pricing and the service offered.

3.3.1. Passenger Service

To best meet the mobility needs of Khartoum's residents, a daily service from Sunday to Thursday between 05:00 and 22:00 will be provided, with three different headways based on the expected passenger traffic, as follows:

Table 1. Headway based on time slot

Headway (min)	Time Slots	
15	from 6:30 am to 12:00 pm	from 2:00 pm to 5:00 pm
20	from 12:00 pm to 2:00 pm	from 5:00 pm to 8:00 pm
30	from 5:00 am to 6:30 am	from 8:00 pm to 10:00 pm

To ensure better take-up of the service, an omnibus service is preferred. Regular scheduling will be an advantage compared to the long waits observed at bus stations.

3.3.2. Operation

The travel time between the two termini is 57 minutes during peak hours. The total distance is 39.5 km, and the chosen commercial speed is 41.5 km/h. We estimate the turnaround time, including buffer time, to be 25 minutes per terminus. Therefore, a complete loop will take 2 hours and 20 minutes.

To facilitate the inevitable transfer breaks, intermodal hubs must be organized. The current locations of mini-bus clusters partly dictated the positioning of the railway stations.

- Rolling Stock

Based on the interval during peak hours and the total travel time, the following formula calculates the number of trains needed during peak hours, resulting in a requirement of 9.27 trains.

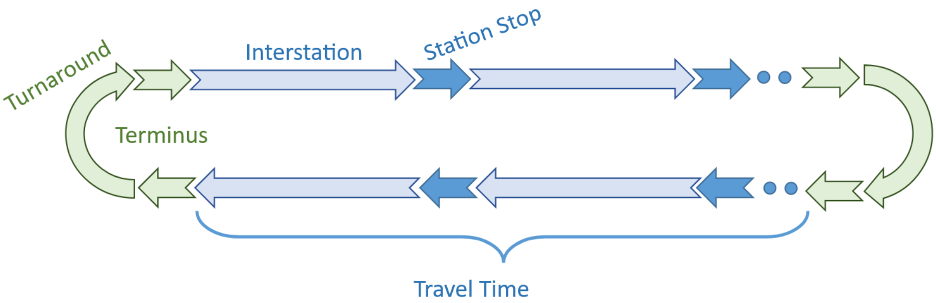

Figure 3. Schematic representation of variables for calculating the number of trains © Myriam Essafi

Applying a 25% maintenance ratio and provisioning an additional vehicle to address operational incidents, the total number of trains required is 13.

- Maintenance

Maintenance will primarily be conducted at night, but a daytime team will be necessary for more extensive maintenance tasks and to address daily operational contingencies.

- Timetable

Based on the distances between stations and the acceleration and braking capabilities of the rolling stock, we achieve an average inter-station speed of 60 km/h. From this, we can derive the following space-time graph for peak hours:

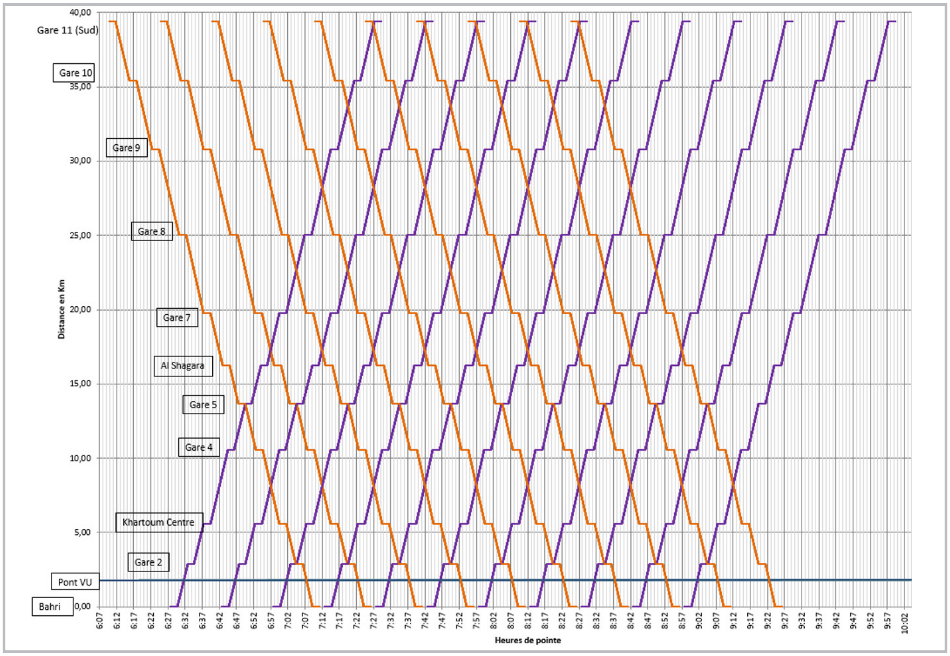

Figure 4. Timetable during peak hours © Myriam Essafi

The main challenge is ensuring that no two trains are scheduled simultaneously on the Blue Nile Bridge section, which consists of a single track. This area is represented on the space-time graph by the line labeled "Pont VU," where it is evident that no two trains ever cross paths.

- Rolling Stock Rotation

The rotation schedules for the rolling stock have been designed to cover all trips in the timetable. The trains will complete their rotations at the station where they need to start the following day. Therefore, no empty trips will be necessary. The driver rotations will also be optimized for passenger service.

3.3.3. Stations

The main stations are through stations. Their organization is simplified as they are equipped with double tracks, allowing dedicated directions of travel under normal conditions. The two terminal stations already have the infrastructure to store trains and enough space for expanding a maintenance center. They will be considered terminal stations where trains will turn around.

3.3.4. Fares and ticketing

The choice of ticket price will be crucial for the service's attractiveness. It will be calculated considering the current fares of other public transportation modes. A flat fare will be preferred across the entire line. To attract frequent travelers with daily commuting needs, weekly, monthly, and even annual subscriptions should be offered at suitable rates. Similarly, student fares should be part of the offering.

The main motivation for maintaining a low fare is that it is essential for encouraging modal shift. It could be beneficial to offer a combined ticket that allows a journey by train and mini bus. However, this reduced revenue will inevitably impact the operational balance.

3.4. *Solution deployment schedule*

The estimated schedule from pre-studies phase to commissioning is 5 years, including selection of foreign stakeholders which should be the major challenge for this project in addition to funding.

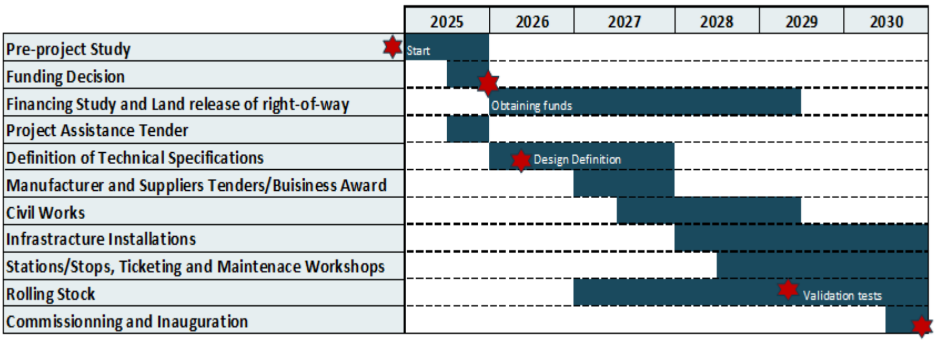

Figure 5. Project Planning

4. Socio-Economic Evaluation

4.1. Financial Analysis

Following the breakdown for all associated costs, an investment of €1.6 bn is the overall budget covering the project steps from studies to the launch of the commercial service.

In order to maintain operational services, an allocated package of €89 M is necessary as a yearly expense.

Total CAPEX costs are around €40 M/km and €2.2 M/km/year.

Table 2. Total Financial Package

	Cost (EUR)	Cost per km (EUR)
CAPEX	€1, 612,254,767	€40,306,369
OPEX/year	€88,740,000	€2,218,500

The total budget is split as follows for each cost center:

Table 3. Budget Breakdown

Cost Center	Cost (€M)	%
Infrastructure	603	35.46%
Civil Works	506	29.73%
Rolling Stock	172	10.12%
Stations/Stops, Ticketing	150	8.82%
Construction Supervision Services	77	4.53%
Risk provisions	71	4.12%
Operation	56	3.29%
Project Assistance	43	2.47%
CSR impact for modal report/ Environmental File	21	1.24%
Services	3	0.20%
Land and release of right-of-way	0.21	0.01%
Total CAPEX/OPEX	**€1.8 bn**	**100%**

Based on the hypothesis of €200 M funding provided by AFD for this project, there will be a €1.4 bn shortfall in achieving the total amount; therefore, another financial backer should be involved.

The World Bank would be the best option considering the amount of funding needed, the socio-political situation of Sudan, and also the collaboration with AFD.

Table 4. Financial Funds

AFD Funding	€200,000,000	12%
Financial backer (to be defined)	€1,412,254,767	88%

For the economic viability of the project, the results of net present value are significantly negative considering an amortization over 50 years.

Table 5. Project economic viability

Initial investment (€)	€1,612,254,767
Duration (years)	50
Actualisation rate/ year	4.5%
Public Subvention/ year	20%
Wear rate / year	3%
Annual incomes	€48,960,000
Annual costs	€88,740,000
VAN	-€781 425 875

However, numerous externalities are identified as having an impact on the propulsion of the development of socio-economic conditions of Khartoum's population, especially since the motorization rate in Sudan is around 4%, and that the more vulnerable citizens depend on public transport to access essential services and workplaces.

4.2. Risk analysis

The implementation of any new project involves risks It is essential to identify, evaluate, and propose means of managing these risks and implementing and prevention actions. The starting hypothesis of this project is the end of the current war in the country. This topic will not be included in the risks considered.

4.3. Risk management plan

After identifying up to 21 risks and classifying them according to their criticality (C), calculated using the formula *C = F x G x D*, a full risk management plan was established.

The three most critical risks retained, and the associated action plans are as follows:

Risk	C	Actions Planned
Insufficient funding	25	-Improve monitoring of the management of funds -Involve public and/or private actors in financing -Diversify financial partners
Personal accidents	25	-Increase awareness-raising actions among local populations -Install fences along the line, over its entire length or on specific sections
Collision with obstacles	20	-Awareness-raising actions among local populations -Passage of the track into a protected area via fences

Conclusion

The Present pre-opportunity project proposes the creation of a suburban rail service in Khartoum to improve urban mobility and respond to increasing urbanization.

The "KER - Khartoum Express Railways" project aims to reinstate 39 km of railway tracks, create 11 stations and offer 4 trains per hour in each direction with Régiolis Hybrid Diesel/battery type rolling stock. The estimated cost is in the order of 40 million euros per km, including rehabilitation, construction of new stations and acquisition of rolling stock.

The expected benefits include a reduction in road congestion, improved accessibility and a positive impact on the local economy and the environment. Additionally, the rail solution helps to significantly reduce the city's carbon footprint, aligning the project with environmental sustainability goals.

To ensure the success of this initiative, it will be crucial to maintain a high level of coordination between government actors, international donors and local partners. Collaboration with existing public transport companies and minibus unions and a strategic approach to intermodality will be essential to ensure a smooth transition to the new transport system.

The suburban service project in Khartoum represents an important step towards more efficient and sustainable urban mobility. For the following steps, it is recommended to continue detailed technical studies, consolidate financial partnerships, and implement more refined and robust risk management plans to ensure successful implementation of the project. By anticipating challenges and exploiting opportunities, the "KER Khartoum Express Railways" service can establish an efficient and adaptable urban mobility model, capable of meeting the demands of a growing metropolis.

Designing one or more tramway lines for the city of Vadodara (India)

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ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES
IP PARIS

Vadodara, ville dynamique et culturellement riche, est la troisième ville la plus peuplée du Gujarat, en Inde. L'objectif principal de notre étude est d'évaluer la faisabilité et la pertinence de la mise en place d'une ou plusieurs lignes de tramway. La solution proposée vise à offrir un système de transport urbain efficace, compétitif et accessible. Les piliers de notre conception sont fondés sur l'attractivité de l'offre, avec un accent sur la priorité des temps de trajet et la fiabilité, ainsi que la sécurité, considérée comme cruciale. Nous proposons un système de tramway évolutif à double voie (deux lignes : l'une nord-sud et l'autre est-ouest) pour augmenter l'attractivité de Vadodara, attirer de nouveaux investissements et améliorer la qualité de vie grâce à la viabilité socio-économique. Il est selon nous réaliste d'envisager que les deux lignes soient opérationnelles d'ici 2033. Des options de phasage sont possibles, et privilégient la construction initiale de la ligne 1, suivie de la ligne 2, la ligne 1 pouvant être opérationnelle d'ici 2031, coïncidant avec les élections municipales pour démontrer les avantages locaux.

Mots-clés : étude, choix du système de transport, exploitation, modélisation de la demande de transport, système de transport urbain, tramway, transports en commun, Inde, Vadodara

Vadodara, a dynamic and culturally rich city, is the third most populated one in the state of Gujarat, India. The primary objective of our study is to assess the feasibility and the coherence of implementing one or more tram lines. The proposed solution aims to provide an efficient, competitive and accessible urban transport system. Key pillars of our design include attractiveness, with a focus on prioritizing travel time and reliability and safety, which is considered crucial. We propose a scalable, dual-track tram system (two lines: one running North-South and one East-West) to elevate the city's profile, attract new investment, and improve quality of life through socio-economic viability. We consider realistic to propose that both lines could be operational by 2033. Phasing options are possible: the initial construction of Line 1 is prioritized, followed by Line 2, with Line 1 potentially becoming operational by 2031, coinciding with municipal elections to showcase local benefits.

Keywords: choice of transport system, modelling transport demand, operation, public transport, study, tramway, urban transport, India, Vadodara

Introduction

The primary objective of our study is to evaluate the feasibility of implementing one or more tram lines in Vadodara, a city with 2.373 million residents in Gujarat, India. The challenge lies in proposing a solution of urban transport enhancing the daily life of the population by providing simpler, more efficient, competitive and faster transportation, while ensuring it remains financially accessible to all residents (Figure 1)..

Figure 1. Pillars of the project. Source: Authors of the executive summary

1. Vadodara: a growing city

Vadodara is a dynamic and culturally rich city, the third most populated city in Gujarat, recognized as the cultural capital of the state (Figure 2). As of early 2024, the city's population is 2.373 million, ranking it the 25th among Indian cities of over a million residents. Classified as a Tier-3 city, similar to about 40 other Indian cities, the success of a public transportation project here could significantly enhance France's reputation in India regarding urban planning and transportation. Vadodara's example could encourage other cities to invest in similar infrastructure projects, ultimately contributing to India's overall economic development.

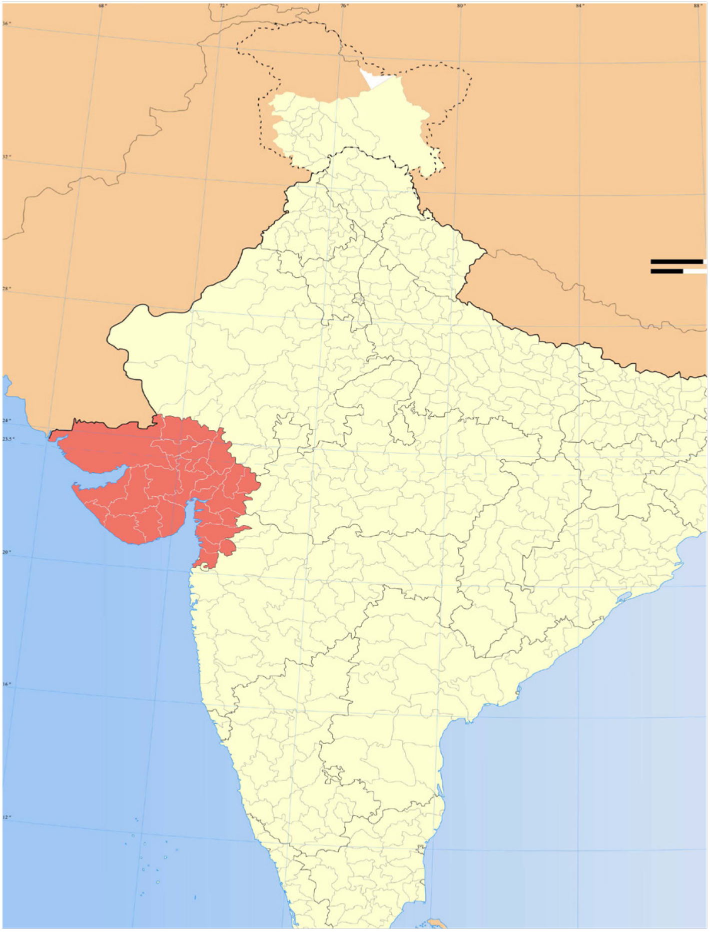

Figure 2. Map showing location of district in Gujarat in India.
Source: Wikimedia Commons © CC by sa PlaneMad/Wikimedia

Vadodara is characterized by a significantly lower illiteracy rate (22%) compared to the national average, which has fostered a strong economic base in the petrochemical and pharmaceutical industries. The city is not only

known for its refineries but also for manufacturing electrical equipment, railway wagons and defence aircraft. Moreover, the information technology sector is rapidly expanding in Vadodara. This has positioned the city as a major industrial, cultural and educational hub in western India, hosting several institutions of national and regional importance. A significant portion of Vadodara's workforce is employed in the tertiary sector, making them prime candidates as users of a public transportation system. However, Vadodara's location between the major growth centres of Ahmedabad and Surat puts it at a disadvantage in attracting investments. The city's economy has slowed down due to increasing global market competition, highlighting the need for infrastructure development, particularly in transportation, to drive growth.

The Vadodara Municipal Corporation (VMC) strategy underscores two key points:

1. Consolidating the city's industrial position.
2. Promoting the city's cultural heritage to boost tourism. Developing urban transportation is crucial to achieve both objectives.

Based on our analysis of Vadodara's current mobility and future projections, the new public transport system must appeal to users who heavily rely on private motorized vehicles. To be attractive, the system must prioritize travel time and reliability, unlike the current bus service. We need to offer frequent service with priority at intersections to ensure optimized and competitive travel times against the city's daily congestion. Our goal is to provide a comprehensive service that aligns with Vadodara's urban development goals, proposing a multimodal system integrated with the existing bus service, which the municipality plans to expand. For the transport system to encourage a shift from private to public transportation, it must be safe and secure. We have identified two key areas:

- Operational security: whether it's a closed system like a metro or an open system like a tramway, it must safely coexist with other urban transport modes.
- Passenger safety: the system must ensure the safety of passengers and their belongings to encourage daily use.

Given India's significant income disparities, the wealthiest are unlikely to use public transport, while the poorest may not be able to afford it. Thus, our primary target demographic is the middle class.

2. Design choices

2.1. Routes selection

Transport corridors in Vadodara have been defined considering:

- Population distribution within the city.
- City points of interest (transportation hubs, main workplaces, educational centres, hospitals, cultural sites
- with potential for tourism...).
- Existing constraints (Vishwamitri river, railroads crossing, presence of heritage gates ...).
- Existing infrastructure (bridges, viaduct, bus lines and stops ...).

Our final proposal consists in the creation of two routes that cover the city from North to South and from West to Est (Figure 3). During the 1st stage of the project, lines 1 and 2 will respectively feature 13 stations on 9.3 km and 15 stations on 11.3 km. A connecting station is present at Sur Sagar Lake, close to the historic centre. Based on projections in terms of urban growth, future extensions can be foreseen towards Old Chhani for Line 1 and towards Makarpura railway station for Line 2.

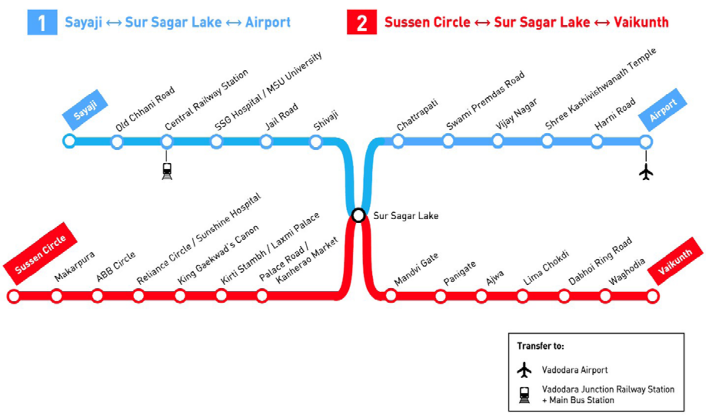

Figure 3. Schematic map of the proposed lines. Source: Authors of the executive summary

2.2. Transportation system selection

Overview of Vadodara highlighted the need for an efficient public transport system. Three alternatives can be foreseen considering city population and traffic projections in 2034: the Bus Rapid Transit (BRT) in dedicated lines, the tramway in dedicated lines and the elevated metro.

A comparative analysis based on 23 criteria was carried out to select preferred option. A score ranging from 1 to 3 and increasing with system performance was attributed to each criteria. Following this analysis, tramway appears to be the best alternative. On the one hand, this system is a good compromise between BRT and elevated metro in terms of investment/operating costs and quality of service.

On the other hand, the tramway project represents the greater opportunity for all stakeholders:

- Vadodara would be able to completely re-think its urban design and to offer the first tramway system in India, thus standing out of other cities that propose buses, BRTs or metro systems.
- As the pilot project succeeds, Indian government could think about deploying tramway solution in all third-tier cities, leading to the development of new competencies and generating new opportunities across the country.
- France, through the support of AFD (Agence Française de Développement), would be able to offer its tramway system that include the rolling stock, the infrastructure but also a complete reconfiguration of the urban space.

2.3. Design choices and technical verifications

2.3.1. Civil works

In order to reduce project costs, decision was taken to avoid tunnel creation and to reuse existing bridges and viaducts. In this preliminary study, we assume that the strength of these structures is sufficient to support a tramway system..

However, this assumption shall be thoroughly assessed during pre-project studies. The heights under the bridges are compatible with the integration of a low catenary system. Verification of the longitudinal profile showed that no gradient exceeds 8%, which is the allowable limit for a tramway system with steel wheels.

Therefore, there is no need to create additional infrastructure to soften the longitudinal profile (Figure 4).

Figure 4. Verification of the longitudinal profile on a section of line 2.
Source: Authors of the executive summary using Google Earth Pro

2.3.2. Railway tracks and electrical supply

Tramway lines are supposed to be exclusively integrated in the urban environment, thus the project team selected the concrete track with grooved rail to enable road sharing with other mobility. Sharp curves were adopted at some intersections to minimize the need for land acquisition, always respecting a minimum radius of 25m.

Vibration and noise levels near homes will be handled through anti vibration insulation or floating slab installation. Given the severe weather conditions faced by the city during monsoon, drainage function will be provided in the hollows of the vertical profile, ideally every 40 to 50 meters. The resilience of the tramway system will also be conditioned by the installation of storm drains in eastern and northern parts of the city.

Project team selected the 750VDC overhead contact line as the preferred power solution for Vadodara tram network given its 85% energy efficiency. Presence of high-voltage lines and 25kV-50 Hz railway tracks in the city corroborated this possibility. Electrical substations will be provided every 2 km, footprint being used as contractor's site facilities during work execution. Alternative power supply is foreseen in areas of interest, narrow streets and complex intersections to enhance urban integration.

Given the risk of flooding and dust presence in Vadodara, ground-level power supply and ground-based static charging solutions were discarded in favor of battery integration on rolling stock. Autonomy sections were dimensioned no greaterthan 1.5 km and are spaced apart sufficiently.

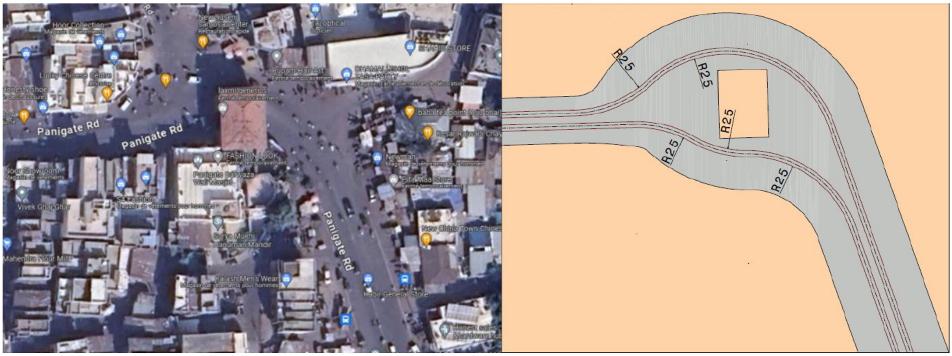

Figure 5. Verification of the land area around Panigate.
Source: Authors of the executive summary, using Google Maps and Catia V5

2.3.3. Stations

System performance will be enhanced by the 750 meters average distance between stops and by ticket validation in the stations. Proposal is to create platforms on existing bus stops locations while ensuring accessibility for people with reduced mobility (straight line integration, lateral access ramps, tactile warning strips, reduced horizontal/vertical gaps with trainset…). Shelters will be integrated to protect users and equipment from weathering.

Different types of platforms can be built depending on streets width and expected passenger flows :

- Double platforms integrated on both sides of the tracks (dimensions : 50 m x 3 m)
- Single central platform with slightly extended width (dimensions : 50 m x 4 m)
- Staggered central platform with double length (dimensions : 100 m x 3 m).

3. Operation

3.1. Rolling stock choice

Based on calculated PPHPD and defined interval, we can estimate the required capacity for the rolling stock.

Cn = 293 passengers

Project team has opted for the ALSTOM Citadis 305® tramway, which offers a 289 passenger capacity in its 2.40 meters wide version with double doors behind the cabins. The Citadis platform is present all around the world, including in Asia with Songjiang (China) and Kaohsiung (Taiwan), thus Vadodara Municipality would benefit from a proven solution while controlled costs and delivery times. Customization of the train will mainly be done through the interior arrangement and the cabin front end. If the tramway system succeeds, an extension to Citadis 405® can be foreseen (Figure 6). Platforms were already dimensioned assuming the 45m length of this material.

Figure 6.: Extension of a Citadis 305 train to a Citadis 405.
Source: Alstom Media Library

3.2. Timetables and operation

We have measured road congestion in Vadodara on weekdays and have concluded that the peak hours are 10.30 am - 1.30 pm and 6.30 pm - 8.30 pm. Based on that data, the tram will be running from 6 am to 11 pm. The typical tram headway ranges between 3 to 5 minutes during peak hours. Following the definition of peak hours in Vadodara, the project team proposes headway of:

- 4 minutes during peak hours.
- 8 minutes during off-peak hours.

The project team believes that frequent service is essential to encourage a shift towards tram use, thereby reducing road congestion. A 3-minute headway provides additional capacity, allowing trams to operate as frequently as every 2 minutes. However, during peak hours with dispersed passenger flows, a 8-minute headway is recommended, considered an acceptable waiting time for passengers.

Prioritizing trams at intersections is crucial for maintaining service quality. To manage interactions with other transport modes and ensure compliance, a 75% priority at intersections for both tram lines in Vadodara is proposed, aiming to reduce delays.

A commercial speed of 20 km/h is targeted, achievable through intersection priority. With a 20 km/h speed, a 4- minute interval, a 6-minute turnaround time, and 30-second station stops, round-trip travel times are estimated at 80 minutes for Line 1 and 94 minutes for Line 2. The projected fleet requirement is 48 units, plus an additional 10% for maintenance and contingencies.

A summary of reference values for tramway operation is presented in Figure 7.

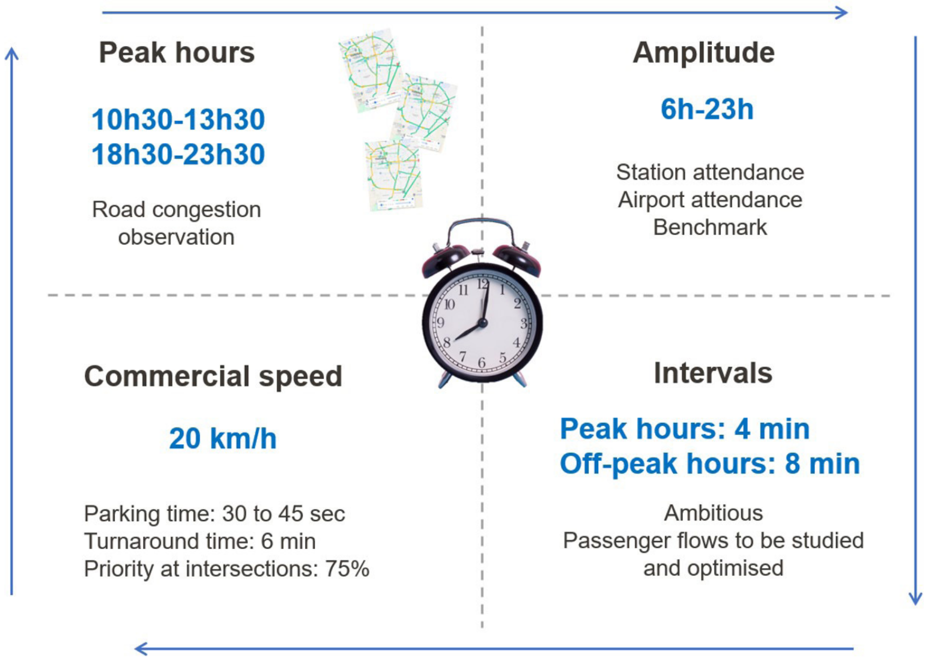

Figure 7. Summary of reference values for tram operation. Source: Authors of the executive summary

The project team proposes customizing tram designs in India's national colours for Vadodara, emphasizing its pioneering status in the state. The tram will predominantly feature green with orange accents on the front and sides (Figure 8).

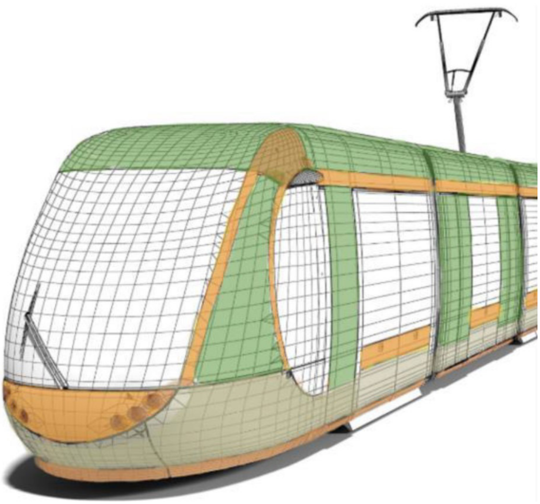

Figure 8. Model of a Citadis train planned for Vadodara (non-contractual image).
Source: Authors of the executive summary using Befunky

4. Project management

4.1. Planning

The planning for tramway construction emphasizes on logistical efficiency and community minimization during the construction period. Key considerations include optimizing material delivery to reduce transport costs, strategically locating storage facilities and implementing effective waste management. Coordination with local authorities aims to mitigate disruptions such as traffic impacts, aligning with environmental regulations. Stakeholder engagement is integral, addressing urban mobility governance and the challenge of increasing two- wheeler usage.

Dialogue with territories, financiers and the community ensures project alignment with local needs for acceptance. The proposed timeline (Figure 9) begins with two years for studies, administrative processes and community consultations.

Construction, including delivery of 48 tram units over four years, starts promptly, accounting for local climate challenges during the monsoon season. One year is dedicated to preparation of commercial operation. Revenue service of the 2 lines is foreseen for 2033.

Phasing options prioritize Line 1 construction initially, followed by Line 2, with Line 1 revenue service by 2031 potentially coinciding with municipal elections to showcase local benefits.

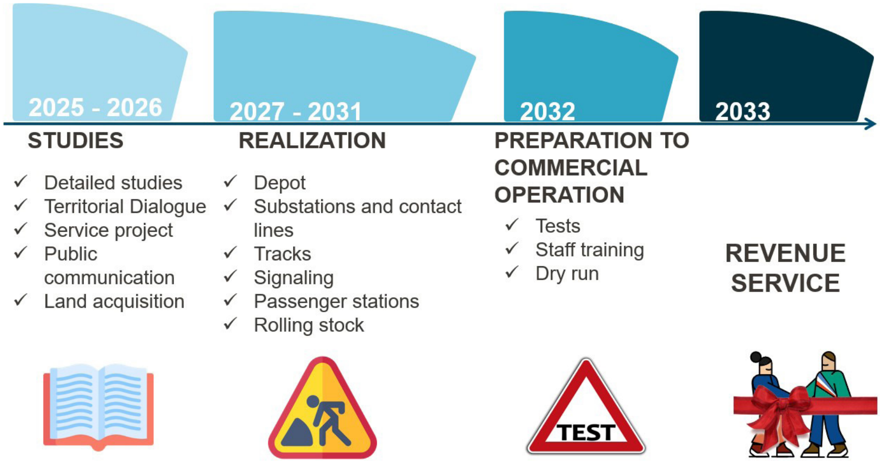

Figure 9. Schedule for the building of the new lines. Source: Authors of the executive summary

4.2. Financial and economic analysis

The project team estimated investment costs based on French tramway average values. Detailed studies will refine these estimates in a later stage of the project. The CAPEX covers subsystems like double tracks, electrical installations, signaling, stations, depots and urban enhancements (e.g., drainage). Total investment is around 440M€, with 30% for rolling stock, 23% for transport systems and 38% for infrastructure (Figure 10). Cost per km, including rolling stock, is approximately 21.35M€, comparable to existing French tramway projects.

Operational cost (OPEX) assumptions for the tram project include 150k€/km annually for double-track maintenance. Rolling stock operation is estimated at €6/vehicle*km, projecting 19.7M€ annually for 3,290,232 km. Personnel needs involve 30 drivers for Line 1, 35 for Line 2, plus 12 controllers, 20 maintainers and

30 administrative/support staff, costing 355k€ annually. Total first-year operational cost is estimated at 23.19M€, with detailed breakdown in Figure 10.

In estimating annual revenues for the tram project, ticket sales are projected as the primary income source. Annual ridership is forecasted at 43,860,000 based on ridership per hour per direction (PPHPD), operating hours and days. A ticket price of the equivalent of €0.30 is proposed, considering affordability and competitive pricing compared to local alternatives. Monthly passes are set at €7.5, with a discounted rate of €6 for students. Additional revenue estimates include €0.15 per journey for special passes, totalling 10.3M€ annually. Advertising revenue, estimated at 10% of total income, could add 1.03M€ annually. Property development revenue assumptions were not included due to data constraints, requiring further municipal consultation. Total projected revenues, fare compensations and advertising income to 550M€, over a period of 40 years.

Externalities and social benefits (time saved, reduced traffic congestion, air and noise pollution) have been considered for Net Present Value (NPV) analysis: a positive NPV of 17,6M€ over a period of 40 years is calculated.

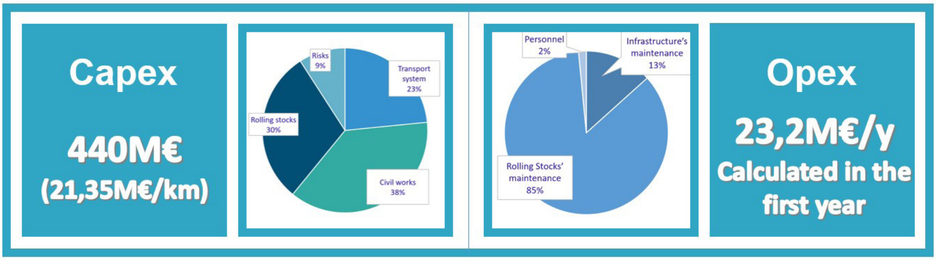

Figure 10. Economic performance of the tramway project estimated by the project team.
Source: Authors of the executive summary

Conclusion

Vadodara's diagnostic study highlighted inadequate public transport. Proposed solution by the project team is a dual-track tram system phased for financial and political feasibility. Focus is on scalability and performance to elevate city profile and attract investors. Cost-effective design and community-focused enhancements aim to improve quality of life, supported by socio-economic viability analysis.

La promotion 2023-2024

The students

ALI FDAL Wiam
EGIS Rail

AMER Hassna
HITACHI Rail

ARHAZZAL Ihssane
AKIEM

BARBALATA Mihai
ALSTOM

BARON Romain
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BEN MAHMOUD Mehdi
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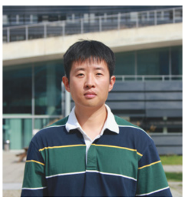
ESSAFI Myriam
SNCF



FU Guojie
Transalp Renouvelement

SOURIS Laurent
ALSTOM

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Informations valables en octobre 2024

HOGUET Quentin
RATP

KORICHE
Sidi Mohamed
HITACHI Rail

LORENZO Alessandra
ALSTOM

SONG Daming
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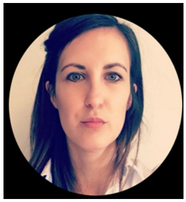
MAPETO MUANAMBELO Christian
SNCF Réseau



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POCANAM Crédo
SETEC

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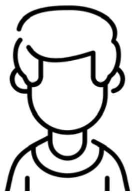
ALSTOM



TIN Julien
KEOLIS

Le voyage d'études en Suisse

The study trip in Switzerland

Du 13 au 17 mai 2024, les élèves de la 16e promotion (2023-2024) du Mastère Spécialisé® Systèmes de transports ferroviaires et urbains se sont rendus en Suisse dans le cadre de leur voyage d'étude ferroviaire. L'objectif de ce voyage était de découvrir le système ferroviaire et urbain suisse. Ils étaient accompagnés par M. Federico Antoniazzi, directeur du Mastère Spécialisé® et Mme. Nivalath Nearith, inspectrice des études.

Après un trajet en TGV Lyria de Paris jusqu'à Lausanne, la promotion a visité le lendemain le siège social et l'atelier de fabrication de MATISA : ue constructeur de machines d'entretien et de travaux ferroviaires. La visite a consisté en une présentation de l'entreprise, de ses ambitions et de l'atelier de construction étaient au programme. La journée s'est poursuivie avec la visite du principal dépôt et siège social des Transports lausannois (TL). Situé en périphérie de Lausanne, le site comporte les fonctions supports de l'entreprise, un atelier de maintenance bus/trolleybus et le poste de commande centralisé de l'ensemble du réseau TL : bus et métro. Le directeur des grands projets et du développement de l'offre aux TL, Christophe Jamelin, a présenté à la promotion le projet du futur tramway lausannois, en construction au moment de la visite et les échanges se sont orientés vers le futur des mobilités sur le territoire avec les grands projets structurants pour les 10 à 15 prochaines années sur le territoire. La journée s'est terminée par la visite de la station Lausanne-Gare sur la ligne M2 du métro qui traverse la ville du nord au sud en conduite automatique et qui possède des pentes jusqu'à 120‰.

Le lendemain, un voyage panoramique d'une heure entre Lausanne et Fribourg, sur la ligne *Intercity 1*, a conduit les étudiants au centre de maintenance et d'exploitation principal des Transports Publics Fribourgeois (TPF). Après une présentation générale de l'entreprise et du fonctionnement des transports urbains en Suisse et plus particulièrement des opérateurs locaux et régionaux, la promotion a visité les ateliers de maintenances des bus et des trains régionaux à voie normale. La journée s'est poursuivie avec un déjeuner à bord d'une automotrice historique de 1922 autour d'une fondue. Une expérience insolite qui a été conviviale et appréciée par l'ensemble des étudiants ! La journée s'est terminée par la visite du centre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MOB
SBB CFF FFS

de maintenance des trains à voie métrique des TPF puis par un retour à Lausanne via Montreux grâce à la ligne à voie métrique du Montreux Oberland Bernois (MOB) avec en bonus une vue panoramique sur le lac Léman.

Le troisième jour, l'excursion s'est poursuivie à Villeneuve, dans le canton de Vaud, sur un site d'Alstom. Auparavant uniquement dédiée à la construction des trains *FV-Dosto* pour les chemins de fer fédéraux (CFF), la fin de la production de ce type de matériel roulant a forcé une reconversion des activités de ce site. Il assure à présent des services de maintenance pour divers clients européens.

Les étudiants ont par la suite visité le Centre d'Exploitation Ouest des CFF à Lausanne qui supervise l'ensemble du trafic ferroviaire de Suisse Romande et ont assisté à une conférence qui leur a donné un aperçu général de l'organisation du réseau des CFF et du site de Lausanne, en soulignant les faits suivants :

- Près de 3 200 km de lignes sur le réseau CFF ;
- Plus de 400 collaborateurs au centre d'exploitation de Lausanne.

Après quoi, ils ont par la suite pris la direction de Zürich. Pour le trajet de Lausanne à Zürich, les étudiants ont emprunté plusieurs trains régionaux de différentes compagnies via Neuchâtel et Berne. Au cours du parcours, Elie Arnal, responsable France chez SMA – une entreprise indépendante de consulting dans le domaine des systèmes ferroviaires –, a pu allier théorique et pratique de manière instantanée en évoquant différents sujets de conception et d'exploitation des infrastructures de transport en Suisse, notamment le cadencement, en passant des gares aux trains, sans oublier les infrastructures fixes. L'aspect de multimodalité, qui occupe une place centrale en Suisse, a également été abordé au cours du voyage.

Enfin, le dernier jour, la visite du centre de maintenance CFF de Zürich Herdern mettait un point final à ce formidable voyage en Suisse. Les étudiants ont pu assister à une présentation du site, mais aussi des principales caractéristiques et innovations du principal matériel roulant entretenu sur ce site : les automotrices *FV-Dosto* d'Alstom. La promotion est rentrée à Paris, enrichie par une expérience pédagogique internationale.

F**ROM** *the 13th to 17th of May 2024, students in the 16th year (2023-2024) of the Executive Master in Railway and Urban Transport System Engineering travelled to Switzerland as part of their rail study trip. The aim of the trip was to discover the Swiss rail and urban system, accompanied by Mr Federico Antoniazzi, director of the Executive Master, and Ms Nivalath Nearith, studies inspector.*

After a trip on TGV Lyria from Paris to Lausanne, the following day the class visited the head office and production workshop of MATISA: a manufacturer of maintenance and railway work machines. The visit included a presentation of the company, its ambitions and the construction workshop.


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The day continued with a visit to the main depot and head office of Transports Lausannois (TL). Located on the outskirts of Lausanne, the site houses the company's support functions, a bus/trolleybus maintenance workshop and the central control room for the entire TL network: bus and metro. Christophe Jamelin, TL's Director of Major Projects and Service Development gave a presentation on the future Lausanne tramway project, which was under construction at the time of the visit. Discussions then turned to the future of transport in the region, with the major structural projects for the next 10 to 15 years. The day ended with a visit to the "Lausanne Gare" station on line M2 of the metro, which crosses the city from north to south with automatic driving and has gradients of up to 120‰.

The following day, a one-hour panoramic trip between Lausanne and Fribourg on the Intercity 1 line took the students to the main maintenance and operations centre of Transports Publics Fribourgeois (TPF). After a general presentation of the company and how urban transport works in Switzerland, and more specifically of local and regional operators, the class visited the maintenance workshops for buses and standard-gauge regional trains. The day continued with a fondue lunch on board a historic 1922 railcar. It was an unusual experience that all the students enjoyed! The day ended with a visit to the TPF metre-gauge train maintenance centre, followed by a return journey to Lausanne via Montreux on the Montreux-Oberland-Bernois (MOB) metre-gauge line, with the added bonus of a panoramic view of Lake Geneva.

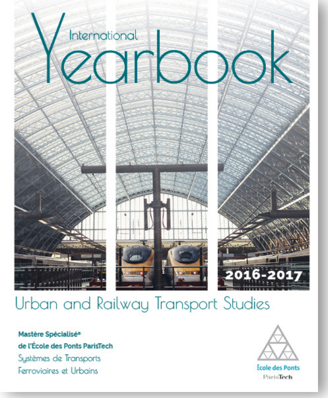
On the third day, the trip continued to Villeneuve, in the canton of Vaud, to an Alstom site. Previously dedicated exclusively to the assembly of FV-Dosto *trains for the Swiss Federal Railways (SBB), the end of production of this type of rolling stock has forced a reconversion of the site's activities. It now provides maintenance services for various European customers.*

The students then visited SBB's centre d'exploitation ouest (Operations Control Centre) in Lausanne, which monitors all rail traffic in the French part of Switzerland, and listened to a speech that gave them a general overview of the organisation of SBB's network and the Lausanne site, highlighting the following facts:

- *Nearly 3,200 km of lines on the SBB network;*
- *More than 400 employees at the Lausanne Operations Centre.*

Along the way, Elie ARNAL, Head of France at SMA - an independent consulting company specialised in railway systems - was able to combine theory and practice in an instant by talking about various aspects of the design and operation of transport infrastructure in Switzerland, in particular interval timetabling, from stations to trains, not *forgetting fixed infrastructure. The multimodal aspect, which occupies a central place in Switzerland, was also addressed during the trip.*

Finally, on the last day, a visit to the SBB service centre in Zürich Herdern completed this remarkable trip through Switzerland. The students were given a presentation about the site, as well as the main features and innovations of the primary rolling stock maintained at this facility: Alstom's FV-Dosto *railcars. The class returned to Paris enriched by this international educational experience.*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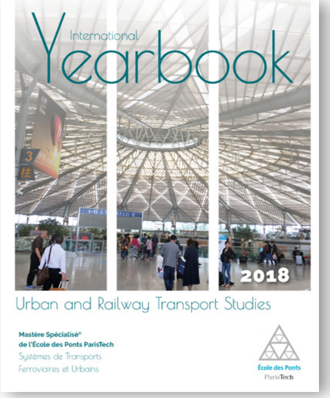
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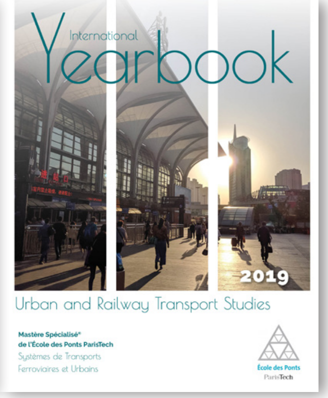
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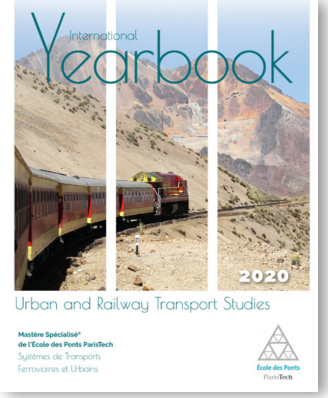
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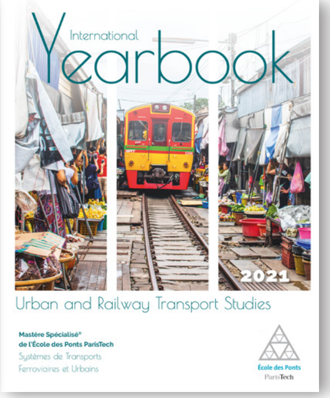
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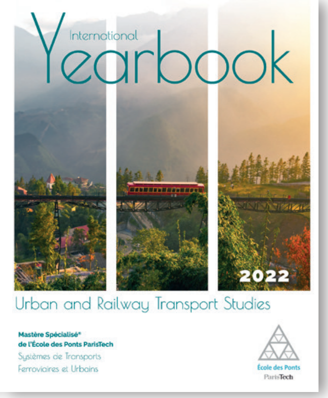
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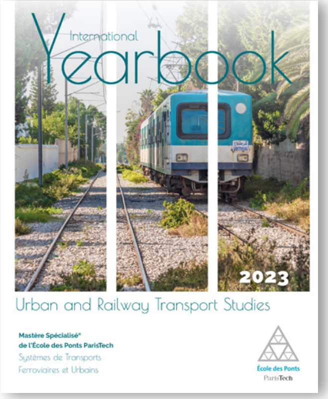
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Yearbook 2016-2017

- Personal Rapid Transit (PRT) in Dubai
- Creation of a transport system in Port Said, Egypt
- Creation of a tramway line for the city of Qom in the Republic of Iran
- Bus Rapid Transport (BRT) in Touba, Senegal
- A metrocable system in Antananarivo, Madagascar
- A regional and urban railway network system in Mauritius island

Yearbook 2018

- Improving the Ankara-Tehran Rail Link
- A Bus Rapid Transit (BRT) in Hyderabad, Pakistan
- Design of a mass transportation system in Semarang, Java (Indonesia)
- Feasibility study of Taguig MRT, Philippines
- Implementing a Bus Rapid Transit system in Lusaka, Zambia
- Reopening of a railway service between Chile and Argentina

Yearbook 2019

- Creation of an Abidjan-Lagos Railway Line
- Dhaka Suburban Railay Line, Bangladesh
- Bus Rapid Transit (BRT) in Cúcuta, Colombia
- Creation of a tramway line in Djibouti City, Djibouti

Yearbook 2020

- TransPeru: creation of a rail connection between Peru and Ecuador
- The first Tramway line in Ashgabat, Turkmenistan
- Lubumbashi suburban railway line (DRC)
- Creating a rail link between Addis Abeba (Ethiopia) and Nairobi (Kenya)
- Design of an aerial cableway between Cotonou and Abomey-Calavi (Benin)

Yearbook 2021

- Creation of a Santiago de Cali (Colombia) Metro line
- Accra-Tema suburban railway line
- India-Sri Lanka Railway line
- New Railway line in Indochina
- Designing a ropeway between the airport and the business district in Metro Cebu (Philippines)

Yearbook 2022

- Development of a Tram-Train Line in Albania and extension of rail lines to Tirana
- The new Thailand-Myanmar railway
- Project of a railway link between Bujumbura and Lubumbashi
- Design of a reserved-lane public transport system in Chişinău (Moldova)
- Rehabilitation of the Puebla-Cholula (Mexico) touristic train line
- Ropeway as vector of mobility and urban planning in Cần Thơ City (Vietnam)

Yearbook 2023

- Rehabilitation of rail transport in Cuba
- Extension of the Sahel Metro in tram-train mode in the conurbation of Sousse (Tunisia)
- Extension of light metro tram Line 2 line towards Ennasr (Tunisia)
- Creation of a metro line in Khulna, Bangladesh
- High-speed railway connection between Legazpi and San Fernando in the Philippines

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La Source, diffuseur de savoirs

La Source, spreading knowledge

Ce *Yearbook* a été réalisé par la Direction de la documentation, des archives et du patrimoine de l'École nationale des ponts et chaussées, en collaboration avec Federico Antoniazzi et Françoise Manderscheid. Ce travail d'édition s'inscrit dans la continuité des missions de conservation et de diffusion des savoirs de l'École.

La Direction de la documentation, des archives et du patrimoine met à disposition des étudiants un espace de 800 m², dénommé La Source, comptant 2 salles de lecture et 6 espaces projets équipés pour le travail en groupe (tableau blanc numérique connecté, écran tactile, visioconférence, *etc*.).

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Véritable outil au service de l'enseignement et de l'apprentissage, La Source offre un accès à un large panel d'informations. On y vient pour se former et s'informer, pour préparer un projet, mais également, pour travailler en groupe, partager des idées, des expériences et des savoirs.

This Yearbook *was made by the Department of Documentation, Archives and Heritage of the École nationale des ponts et chaussées, in close collaboration with Federico Antoniazzi and Françoise Manderscheid. This editorial work is a way of fulfilling the school's mission to conserve and disseminate knowledge.*

The Department of Documentation, Archives and Heritage provides students with an 800 m² space, named La Source. It comprises 2 reading rooms and 6 project rooms equipped for group work (digital whiteboard, touch screens, videoconference equipment, etc.*)*

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Conception et réalisation • *Publishing team*

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En bref

Chaque année, les étudiants du Mastère Spécialisé® Systèmes de transports ferroviaires et urbains sont confrontés à un défi : imaginer une ligne de transport dans une ville ou un espace situé sur un autre continent. Par petits groupes, ils étudient le terrain économique, géographique et même social, afin de faire émerger la solution de mobilité la plus adaptée. Ils achèvent leur étude par des éléments concrets de mise en œuvre : maintenance, mais aussi, financement et planification.

Les résumés des travaux de la promotion 2024 ont été regroupés dans cet ouvrage afin de donner un aperçu de leur qualité et de leur technicité. Cette année, deux groupes se penche sur les problématiques d'une liaison ferroviaire à l'échelle inter régionale, au Chili et en Indonésie. Trois autres groupes proposent une solution de transport innovante et adaptée à l'échelle d'une ville (Khartoum au Soudan, Bichkek au Kirghizistan, Vadodara, en Inde). À travers la multiplicité de ces contextes et de ces lieux les contours des mobilités futures s'esquissent ainsi dans ce Yearbook : laissez vous embarquer au cœur des réflexions et des innovations du monde de demain.

Each year, students from the Railway and Urban Transport System Engineering Advanced Master® have to take on a challenge: to invent a transport line for a city or any place in another continent. In small groups, they study the economic, geographical and even social contexts in order to find the most suitable traffic solution. They end their study with the more practical aspects of implementation: maintenance, but also funding and planning.

Summaries of the 2024 studies have been gathered in this book to give an overview of their quality and technicality. This year, two groups are looking at the problems of an inter-regional rail link, in Chile and Indonesia. Three other groups are proposing an innovative transport solution adapted to the scale of a city (Khartoum in Sudan, Bishkek in Kyrgyzstan and Vadodara in India). Beyond the diversity of these contexts and places, it is thus the future of our own mobility we can discern in this Yearbook: embark on a journey to the heart of thinking and innovation in the world of tomorrow.

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