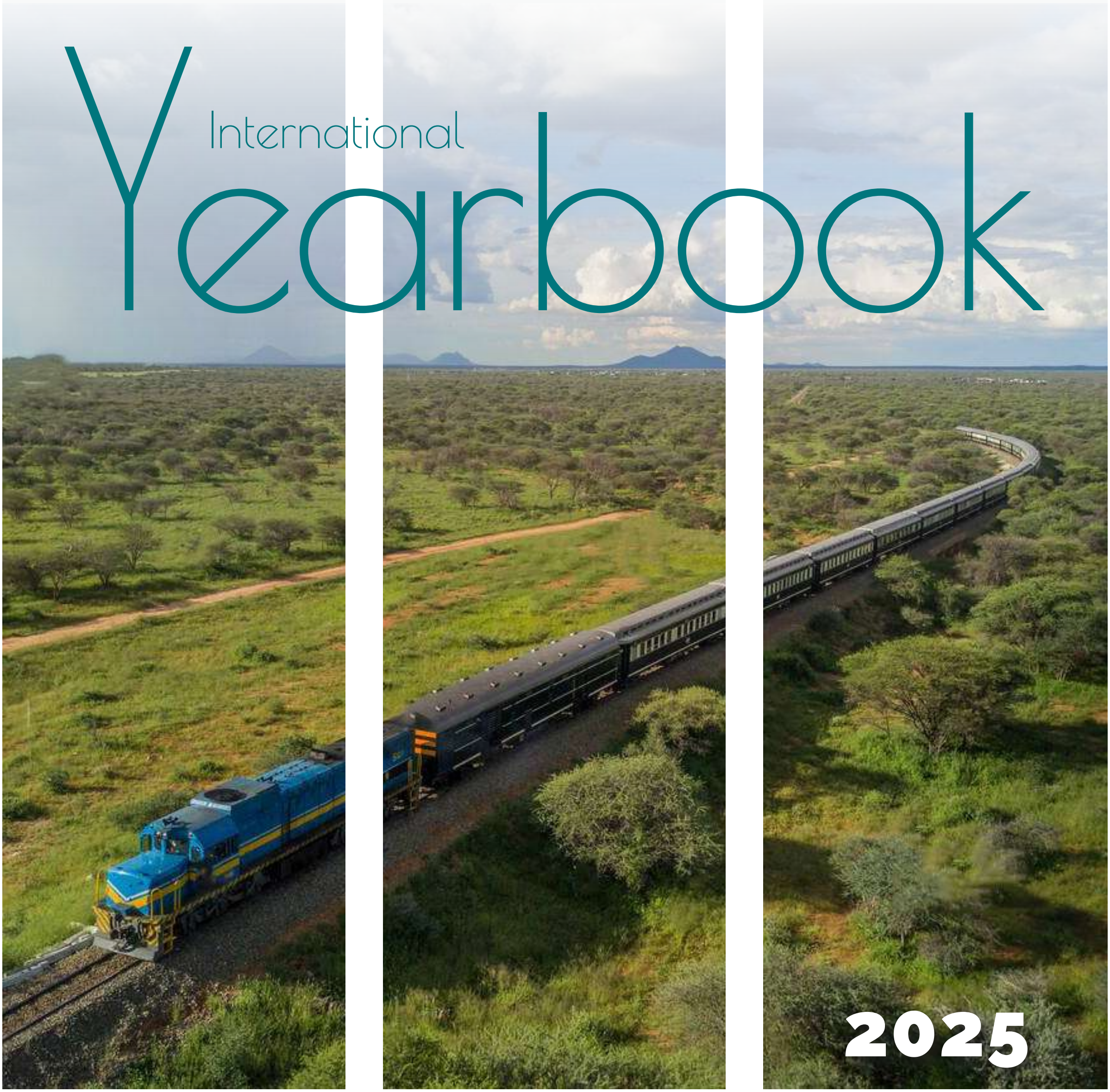
International

Yearbook



2025

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

2025

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

Écoles partenaires

Remerciements
Le MS® STFU remercie chaleureusement Alstom, Keolis, SNCF, RATP, Siemens, CSEE, Transdev, Systra et STRMTG, les partenaires de la formation.

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Urban and Railway Transport Studies' International Yearbook 2025

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

Systèmes de transports ferroviaires et urbains

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®

Dans le cadre du Mastère Spécialisé® Systèmes de transports ferroviaires et urbains, les étudiants réalisent depuis plus de 15 ans un projet de transport à l'international. 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), prend la forme d'un mini-mémoire.

Chaque étude porte sur un projet nouveau qui n'a pas déjà été étudié par le passé. Les sujets touchent aux problématiques du transport de masse dans les grandes mégapoles en voie de développement, du transport interrégional de voyageurs, ou du transport de fret sur longue distance dans des pays que la Banque mondiale, l'Agence française de développement (AFD) ou d'autres bailleurs de fonds accompagnent dans leur développement. Les étudiants ne se rendent toutefois pas sur place. Ils sollicitent un vaste réseau d'experts, d'ambassades, et d'institutions financières, utilisent au maximum des ressources documentaires sur le web et… leur débrouillardise.

Pour la promotion 2025, l'AFD nous a proposé des projets situés dans le Maghreb, en Afrique australe et orientale, en Europe orientale et en Asie du Sud-Est. Trois groupes d'élèves se sont penchés sur le développement de liaisons ferroviaires intra-urbaines: le premier a étudié le développement d'un service de type RER dans la capitale du Zimbabwe (Harare), le second la modernisation du tramway de Lviv en Ukraine, et le dernier le développement d'un tramway à Denpasar (Bali, Indonésie). Deux autres groupes se sont intéressés au développement de nouveaux services ferroviaires de voyageurs (Trans-Tunisie) ou combiné avec du transport de fret minier (Namibie) en appréhendant aussi les besoins en infrastructures et matériels roulants.

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. Nous vous souhaitons bonne lecture !

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

As part of the Railway and Urban Transport System Engineering Advanced Master®, students have been designing a transport project in an international for over 15 years. A project consists of a feasibility study, similar to those prepared in Engineering firms. This is a group project, prepared within the framework of the C3 module ("Design railway and urban transport system worldwide") which allows students to complement one another with their different know-how. The output is in the form of a master-degree level thesis.

Studies seek to develop a brand new project that has never been studied before. Topics cover issues of mass transportation in large developing megacities, interregional passenger transportation, and long-distance freight transportation in countries that are supported by the World Bank, the French Development Agency (AFD), and other donors. However, the students don't actually travel to the countries themselves. They rely on a vast network of experts, embassies, and financial institutions, making maximum use of online data, and… their own resourcefulness.

For the 2025 class, the AFD has proposed projects located in the Maghreb, Southern and Eastern Africa, Eastern Europe, and Southeast Asia. Three groups of students focused on the development of intra-urban rail links: the first group studied the development of an urban mass rapid transit service in the Zimbabwean capital (Harare), the second group studied the modernization of the Lviv tramway in Ukraine, and the last group studied the development of a tramway in Denpasar (Bali, Indonesia). Two other groups focused on the development of new passenger rail services (Trans-Tunisia) or combined rail services with mining freight transport (Namibia), also addressing greenfield/brownfield infrastructure and rolling stock requirements.

You can read the summaries in this Urban and Railway Transport Studies' Yearbook. We hope that, like the embassies, cities, and governments that request the dissemination of these studies, you will appreciate the quality of this work. We hope you enjoy reading.

Federico Antoniazzi
Antoine Kunth

Antoine KUNTH
Responsable du module C3
C3 module teacher

Le Mastère Spécialisé®

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.

The Advanced Master®

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 (1855–1873)

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 (1968–1985) — 1972

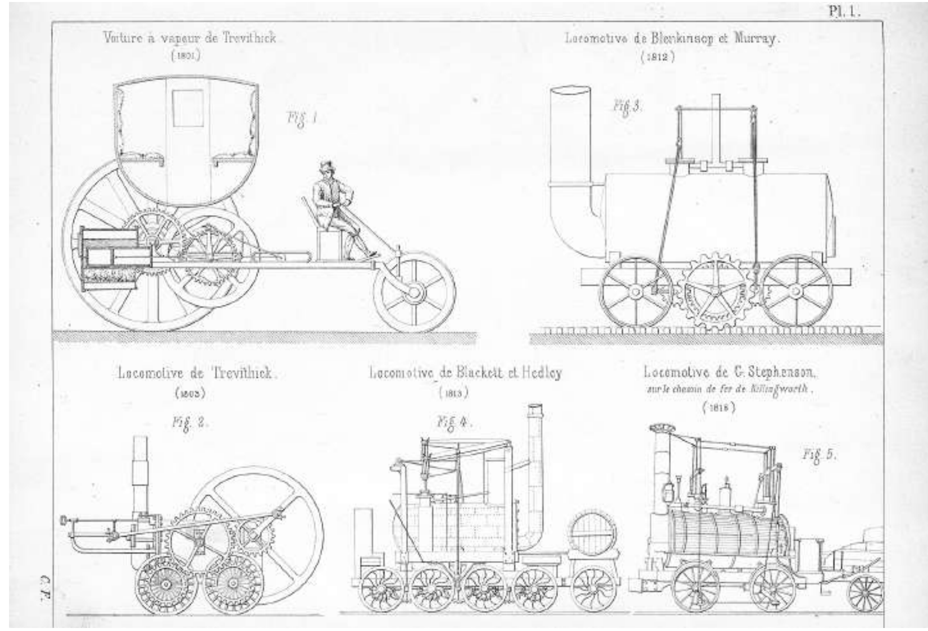
1985 — Philippe ROUMEGUERE

Pascal LUPO — 2003

2008 — **Création du Mastère Spécialisé®** Systèmes de transports ferroviaires et urbains — *Birth of the Advanced Master®*

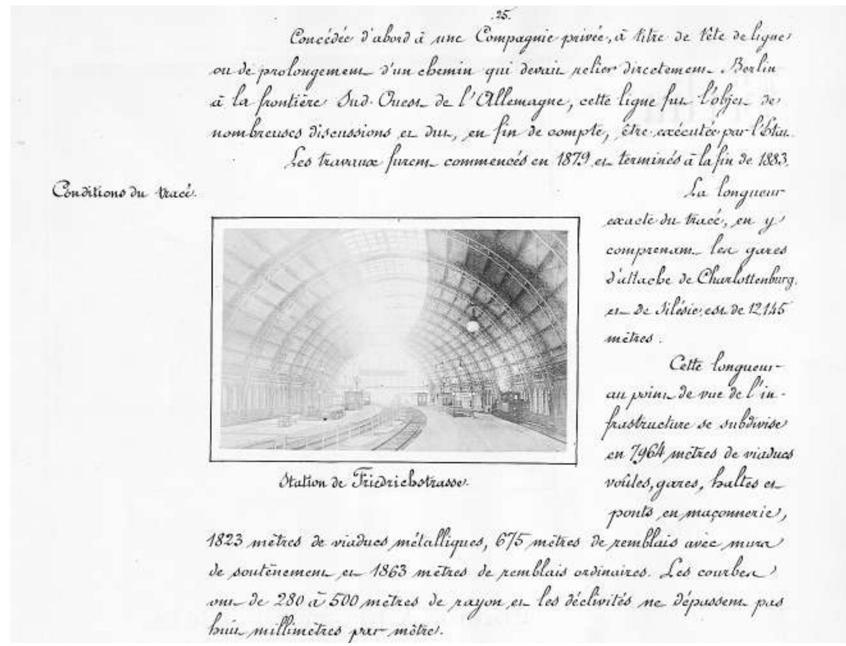
Paul BOUVAREL — 2013 — Françoise MANDERSCHEID (2008–2013)

2021 — Federico ANTONIAZZI (2013–2021)



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 12145 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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Rehabilitation of the Walvis Bay - Karibib mining service

Adélie BUSSON
Victor CHENIN
Fritz Donald NOTIO TAFOMPA
Aurélie GODARD
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École Nationale des Ponts et Chaussées
IP Paris

Dans le cadre de l'initiative européenne « Global Gateway », qui vise à sécuriser les approvisionnements en matières premières critiques à travers des projets d'infrastructure durables, cette étude porte sur la réhabilitation de la liaison ferroviaire entre Walvis Bay et Karibib, en Namibie. Située sur le corridor Maputo–Gaborone–Walvis Bay, cette ligne a un rôle stratégique dans l'exportation de lithium, une ressource essentielle pour la transition énergétique mondiale. La Namibie souhaite capitaliser sur sa position géographique et son accès direct à l'océan Atlantique pour devenir un hub logistique régional. La modernisation de la ligne doit permettre de transporter annuellement 50 000 tonnes de concentré de lithium à une vitesse de 80 km/h, avec une capacité de 18,5 t à l'essieu. Le projet intègre également la construction d'une voie industrielle pour relier directement la mine de Karibib au réseau national, avec une réflexion sur les choix de matériel roulant (diesel ou électrique à batteries), les solutions contre l'ensablement, et les enjeux de gouvernance ferroviaire. Au-delà des bénéfices logistiques, ce projet s'inscrit dans une vision de développement durable et industriel à l'échelle régionale, en réduisant les émissions de CO_2, en structurant une filière minière exportatrice et en envisageant des partenariats public-privé pour renforcer la résilience du système ferroviaire namibien.

Mots-clés : lithium, corridor minier, fret ferroviaire, Installation Terminale Embranchée (ITE), transition énergétique, locomotive à batteries, redynamisation locale, concession, report modal, Valeur Actuelle Nette (VAN)

As part of the European Union's "Global Gateway" initiative—which aims to secure the supply of critical raw materials through sustainable infrastructure projects—this study focuses on the rehabilitation of the railway line between Walvis Bay and Karibib in Namibia. Located on the Maputo–Gaborone–Walvis Bay Corridor, this route is strategically important for the export of lithium, a key component in the global energy transition. Namibia seeks to leverage its coastal position and direct access to the Atlantic Ocean to become a regional logistics hub. The railway's modernization will enable the transport of 50,000 tonsnes of lithium concentrate per year at 80 km/h with an axle load of 18.5 t. The project also includes the construction of an industrial spur line connecting the Karibib mine to the national network, with an assessment of rolling stock options (diesel vs. battery-electric), sand mitigation strategies, and governance models. In addition to logistics, this project supports a broader vision of regional industrial and sustainable development by reducing CO_2 emissions, structuring a lithium export industry, and exploring public-private partnerships to strengthen the resilience of Namibia's railway system.

Keywords: lithium, mining corridor, rail freight, Connected Terminal Installation (CTI), energy transition, battery-powered locomotive, local revitalization, concession, modal shift, Net Present Value (NPV)

Rehabilitation of the Walvis Bay - Karibib mining service

1. Study context

In response to China's New Silk Road initiative, the European Union has implemented the "Global Gateway" strategy. The aim of this policy is to invest in sustainable projects, particularly in Africa around rail corridors, to secure supplies of raw materials and in particular minerals for the energy transition. For its part, Namibia, with its direct access to the sea and its rail network currently operated by TransNamib, seeks to become a regional logistics hub.

The aim of this study is to describe how and under what conditions the rail rehabilitation project between Walvis Bay and Karibib on the Maputo-Gaborone-Walvis Bay corridor can facilitate the transport of minerals that are critical to the energy transition.

In 2024, the EU adopted the regulation on critical raw materials, which were defined as " of high economic importance for the EU and presenting a high risk of supply disruption due to the concentration of their sources and the absence of quality and affordable substitutes." The regularly updated list contains 34 critical raw materials, 17 of which are "strategic", highlighted in yellow.

Figure 1. Critical raw materials identified by the EU. Source: Council of the European Union, Critical raw materials identified by the EU, 2024, https://www.consilium.europa.eu/fr/infographics/critical-raw-materials/

Mining resources, including diamonds, uranium, gold, zinc, lead, and copper, are crucial for Namibia's revenue. Recently, lithium—vital for electric batteries—has been identified in the country. The International Energy Agency forecasts a 42-fold increase in global lithium consumption from 2020 to 2040, with production heavily concentrated in China, raising economic and geopolitical concerns.

The Karibib Project in southeast Namibia contains the seventh largest lithium reserve in Africa, estimated at 950,000 tons, with a 19-year extraction lifespan. Plans are underway to rehabilitate the transport line for at least 50,000 tons of lithium concentrate annually

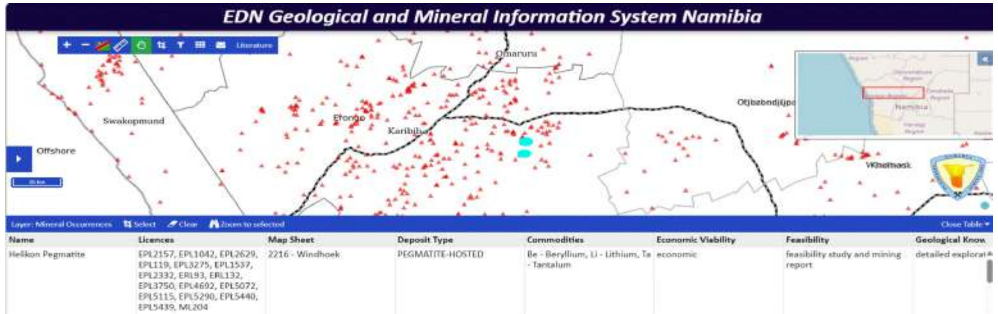

Figure 2. Karibib Project (in blue). Source: Ministry of mines and energy (Namibia), Lithium mines identified for Karibib project, 2024, GMIS Namibia

The west coast's configuration causes interactions between warm continental and cold oceanic air, resulting in thick coastal fog and strong inland winds that shift sand onto road and rail infrastructure. This creates safety risks and increases operating costs for on-site crews.

2. Overview of rail services to Walvis Bay

2.1. Diagnosis

The non-electrified single-track railway from Walvis Bay to Karibib is a key route, managed by TransNamib, extending to the capital Windhoek.

It has a Cape Town gauge of 1,067 mm, featuring a gradual incline with a maximum gradient of 11% and a minimum curve radius of 160 m towards Swakopmund. Walvis Bay station has 20 tracks for cargo operations with two terminals handling 6.6 million tons.

However, infrastructure maintenance is inadequate, limiting operations to a commercial speed of 20 km/h, compounded by slowdowns due to sandstorms. The aging fleet averages 55 years, leading to only two mixed passenger and freight night trains operating between Walvis Bay and Windhoek, with freight tonnage dropping by 10% from 2020 to 2021.

Figure 3. Route of the section of railway line between Walvis Bay and Karibib. © Adélie Busson, Victor Chenin, Aurélie Godard, Arnaud Marville, Fritz Donald Notio Tafompa, 2025. Source for map data: Google Earth.

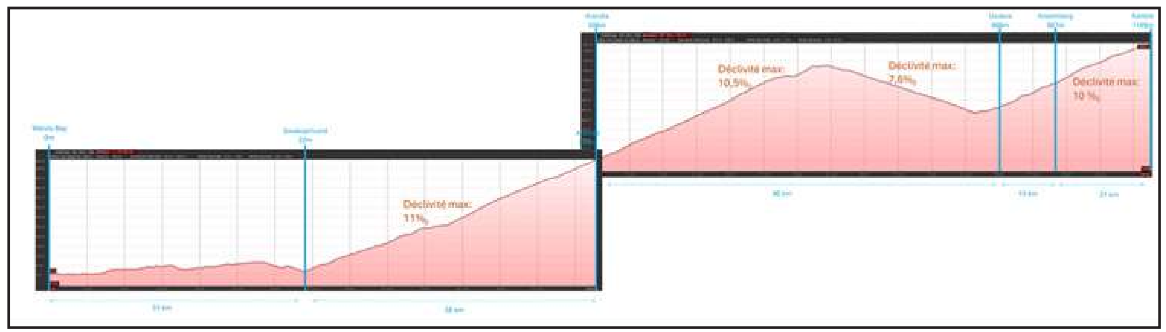

Figure 4. Longitudinal alignment of the existing Walvis Bay line © Adélie Busson, 2025. Source for map data: Google Earth.

2.2. Renovation of the Walvis Bay - Kranzberg line

A modernization project led by a Chinese firm aims to upgrade the line to support 18.5 tons per axle and achieve 80 km/h for freight. The first phase to Arandis was completed in 2023, with the second phase set for 2030, costing an estimated USD 69 million (56% from the Namibian government, 44% from the African Development Bank). A future phase will modernize signaling with automatic train control systems.

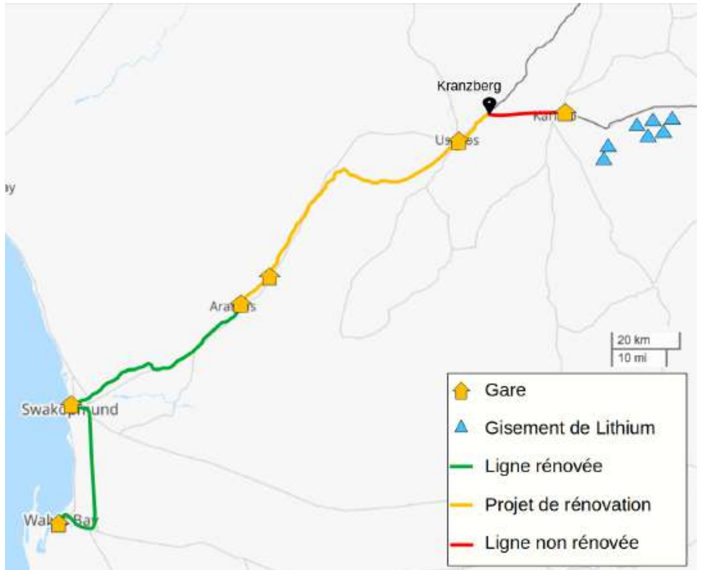

Figure 5. Assumptions for the Karibib - Walvis Bay line © Adélie Busson, Victor Chenin, Aurélie Godard, Arnaud Marville, Fritz Donald Notio Tafompa, 2025. Source for map data: OpenStreetMap.

3. Technical analysis and feasibility

3.1. Lithium mining

Lithium is extracted from rocks using a conventional mining process, with the ore being concentrated on site by means of crushing and flotation. The spodumene concentrate is then shipped (without any special safety precautions) to a refining plant, usually at the port, to produce refined lithium. In Namibia, the 4% LiO_2 lithium concentrate will be transported from Karibib to the port of Walvis Bay and then shipped to the refining plant in Abu Dhabi.

As a benchmark, we studied a similar project that exists in France in the Allier region (EMILI project). Here, the concentrate will be transported by pipeline and then filtered before being loaded onto trains at a rail loading platform and transported to a conversion (refining) plant.

3.2. Upgrading and extending the infrastructure

The 35 km Kranzberg - ITE section will be rehabilitated to support a load capacity of 18.5 tons per axle. The upgrade involves renewing the track with new rails and prestressed concrete sleepers spaced every 60 cm, using 31.5/60 mm caliber ballast. Soil stability will be verified with test pits, and two metal truss bridges will be overhauled. A works base at Kranzberg will store supplies and parking for work trains.

Figure 6. Diagram of the works base © Victor Chenin, 2025. Source for map data: Google Earth.

The team of around 20 will work on two fronts in 8-hour shifts, producing an estimated 100 linear meters per day. Weekend work will allow for 1,400 linear meters of production, totaling 1,800 linear meters weekly over 88 hours. Completion is expected in 20 weeks, plus 3 months for preparation, totaling 8 months.

A 3.22 km industrial spur (ITE) will be created to connect the mine to the main rail network with an average ramp of 16‰, featuring a spur track, a level crossing with traffic signals for crossing the B2 national road, a loading area with hoppers and conveyors, an adjacent siding, and a control station.

Renovating the 35 km rail section is estimated at USD 0.5 million/km (based on the cost of rehabilitating the section between Walvis Bay and Arandis and a benchmark in Cameroon), totaling USD 17.5 million. Constructing the 3.22 km ITE is estimated at USD 1.2 million/km, amounting to USD 3.9 million. Annual maintenance costs are projected at USD 5,000/km based on data published by TransNamib, equivalent to USD 1,356,100 per year.

Figure 7. Route of the Karibib mine ITE connection to the national grid (existing line in red – ITE in blue – siding in green) © Fritz Donald Notio Tafompa, 2025. Source for map data: Google Earth.

3.3. Equipment dedicated to lithium transport

The choice of wagon type is crucial for optimizing loading and unloading. Traditional dumper wagons are commonly used, which can be emptied by shovel or overturning. Although side unloading wagons were tested in France, the more economical dumper option is favored given the existing infrastructure at Walvis Bay.

To transport 50,000 tons of lithium annually, two options are selected: a long train of 20 wagons per week or three shorter trains of seven wagons per week.

The current line is not equipped with a power supply, and the installation of a continuous power supply along the track is not feasible in view of the amount of traffic on the line. Therefore, given the line's favorable profile, a battery-powered locomotive option was explored, based on the Australian "Infinity Train" model, which recharges during downhill stretches. This design allows for operation at 80 km/h with two locomotives and seven wagons, utilizing brake energy recovery and static recharging at stations connected to the 220kV electricity network at Kranzberg and Walvis Bay port. The embedded NMC batteries must supply 2,180 kWh of energy for the return journey.

The rolling stock fleet is sized for a complete convoy to which a maintenance reserve must be added.Expected costs are USD 9,110,000 for the diesel train and USD 16,110,000 for the battery electric train

Figure 8. Gondola wagon for Namibia. Source: CRRC, 2022, https://www.crrcgc.cc/cjen/2013-12/22/article_F15189EE272B44319AED6BA8BBC4ADF4.html

Annual energy costs are slightly higher for the diesel locomotive at USD 92,500 compared to USD 77,800 for the battery option, due to energy recovery.

Recharging infrastructure is estimated at USD 1.5 million per station, based on the existing electrical setup and no charging time constraints.

To address frequent sandstorms that can disrupt operations or pose derailment risks, several solutions were reviewed: acquiring specialized rolling stock for sand removal, installing protective barriers, implementing a "Smart Track: Desert Blocks" solution to reduce sand accumulation, and developing a chemical solution to bind sand to the ground. The multi-criteria analysis demonstrates the utility of low-cost sand barriers, as well as the acquisition of an air blower to remove sand from both lanes and roads, which are subject to the same constraints.

Figure 9. Simplified route considered for the on-board energy feasibility analysis - Karibib - Walvis Bay direction © Adélie Busson, Victor Chenin, Aurélie Godard, Arnaud Marville, Fritz Donald Notio Tafompa, 2025.

3.4. Operating the line

The line between Walvis Bay and the Karibib mine is a single-track line with its operational center at Windhoek. Several passing loops have been set up along the route to allow trains to cross, most of the time with the addition of a second track (800 m long, i.e. generously dimensioned for our trains with a maximum length of 350 m).

Given the Starline timetable for 2019-2020, trains from the Karibib mine will be able to fit in easily during the day without any risk of conflict in a nominal situation. The journey time includes loading/unloading times as well as intermediate recharging time (full diesel or battery) in the return direction at Kranzberg. Based on the TransNamib train model, no trains are scheduled to run on Sundays.

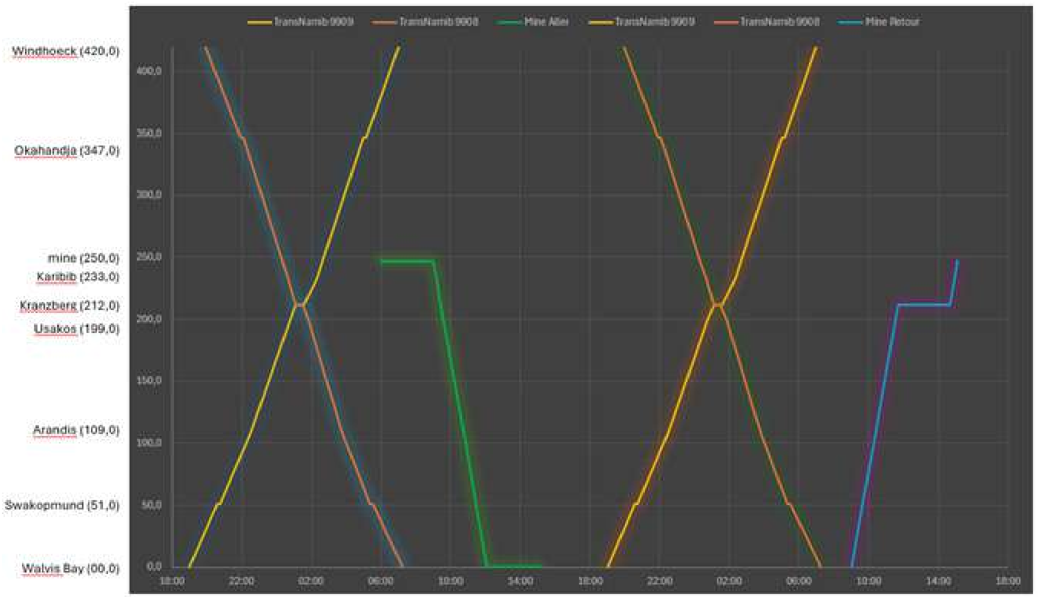

Figure 10. RPM Tech AF1 EVO cold air blower with rail-road system, Source: RPM Tech, 2025, https://grouperpmtech.com/equipements/soufflante-a-air-froid-af1-evo-avec-systeme-rail-route

To operate this transport plan, we require:

- A sedentary agent (on a 2 x 8 hours schedule) working a day shift at the ITE control center
- Drivers to transport the trains over their entire route with an overnight stay away from home planned at Walvis Bay.

Train unloading could be ordered as a port service and therefore invoiced at an hourly rate.

As regards the battery-electric train, the service could be set up with 4 multi-skilled agents (both driving and sedentary agents). The diesel train option could be studied using 3 multi-skilled staff members instead of 4, as only one driver per week is required.

We estimated operating costs based on Namibian rents, average salaries, energy costs and rolling stock maintenance costs, as defined above.

Furthermore, in our study, we consider the possibility of a mining company becoming a new infrastructure manager or new operator in the Namibian rail system. Due to low traffic, offsetting infrastructure maintenance costs with traffic charges is challenging. Toll costs based on French tariffs for freight trains on UIC lines 7 to 9, at a cost of USD 300 per train for electric traffic and USD 385 for diesel traffic are under consideration.

In total, the annual summary of operating costs gives an estimated cost per kilometer of around USD 4/km for the electric train and USD 3/km for the diesel train.

3.5. Impacts of the project on the socioeconomic balance sheet

In our sparsely populated desert context, the only environmental externality considered is the GHG (Greenhouse Gas) emissions balance, with the value of one tonne of CO_2 based on the 2030 value, set at €280 per ton[1]. The reference scenario considered is that of lithium transport by truck via the road network.

	Truck	Diesel train	Electric train
CO2 emissions / year (in T)	1 796	906	109
CO2 value ref. 2030 (280€ / T CO2)	**502 794 €**	**253 548 €**	**30 634 €**
Difference in GHG emissions per year (truck - train)		**249 246 €**	**472 160 €**

Figure 11. Proposed Time-Space graph (over 48 hours) - 1 pattern per week for the diesel train, 3 patterns for the battery train © Aurélie Godard, 2025.

In addition to the positive externalities on CO_2, the Karibib mining project could stimulate the Namibian economy by creating direct and indirect jobs along an industrial chain centered around lithium that could be very extensive and generate more

1. Quinet, Alain (prés.), Riedinger, Nicolas (coord.), *La valeur de l'action pour le climat : Une référence pour évaluer et agir*, France Stratégie, mars 2025. https://www.strategie-plan.gouv.fr/files/files/Publications/2025/2025-03-20%20-%20Valeur%20de%20l%27action%20pour%20le%20climat/FS-2025-RAPPORT%20QUINET_19mars20h-COUV-vdef.pdf

qualified jobs as well as structural, social and environmental transformations. At the very least, we believe it would be useful to study the possibility of establishing a lithium refining plant on Namibian soil or located in one of its neighboring countries, to create more value on African soil and strengthen the resilience of the Namibian economy.

Finally, although we were unable to establish a precise figure using the country's statistics, the rail project will undeniably have a positive effect on safety (both road and health) by limiting the number of trucks on the road.

4. Governance

At present, governance of the Namibian rail system is centralized around TransNamib, a public company in which the State is the sole shareholder, but whose performance record demonstrates the need for major structural reform. Public-private partnership is considered in a country with a strong State culture.

The example of Gabon's rail network could, however, provide some inspiration: The Transgabonais network is used to transport mining and passenger trains. Since 2005, management of the infrastructure has been entrusted to the Société d'Exploitation du Transgabonais, under a concession to manage and maintain the rail infrastructure, organize and ensure the safety of traffic and improve competitiveness to support national economic development.

The governance of the line must be studied in 3 distinct sections:

1. The section between Walvis Bay and Kranzberg, which has already been renovated by the Namibian state, which will retain ownership of the infrastructure. This sector can be considered as a conventional section where TransNamib will charge a traffic fee. However, the introduction of such a system would be unprecedented for Namibia. We therefore believe it would be relevant to propose the assistance of an external consultancy firm to implement this new governance.
2. The section between Kranzberg and the ITE junction needs to be upgraded for our project and several governance options could be considered depending on the immediate funding capacity of the Namibian government and short-term political and economic priorities:
   - If the Namibian government has the funding to carry out the renewal work, a conventional model would be the simplest.
   - If not, a public-private partnership model could be explored. In this scenario, the mining company or another private company would finance the renewal work and provide maintenance for a defined period in return for an annual fee paid by the State.
3. The section of the ITE itself will be built by the mining company, which will be the sole owner and responsible for its administration and maintenance.

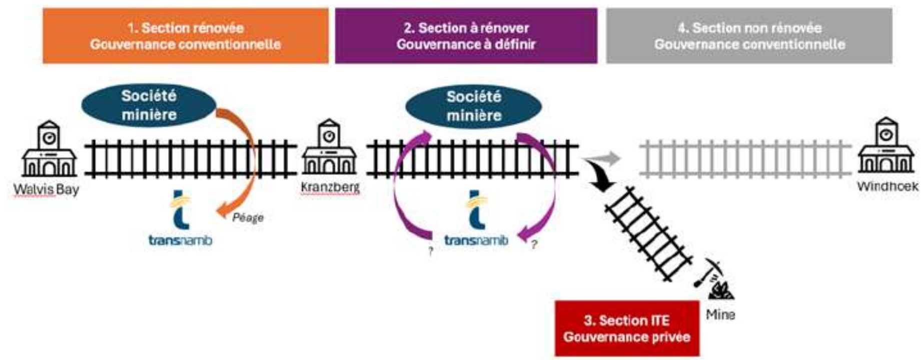

Figure 12. GHG emissions by mode of transport © Aurélie Godard, 2025.

5. Economic and financial analysis

5.1. Summary of project costs

NB: not included:

- solutions to the silting problem
- maintenance costs for the main line (due to an RC in operating costs).

	Cost family	Amount (USD)		Road transport comparison
		Electric train option	Diesel train option	
CAPEX	Infrastructure renovation (existing line)	17 500 000	17 500 000	0
	Infrastructure construction (new ITE)	3 900 000	3 900 000	0
	Investment in rolling stock (locomotive)	16 110 000	9 110 000	0
	Recharging infrastructure (2 stations)	3 000 000	0	0
Total CAPEX		**40 510 000**	**30 510 000**	**0**
OPEX (annual)	Operating costs	320 539	223 913	1 500 000
	ITE maintenance costs	16 100	16 100	0
Total OPEX		**336 639**	**240 013**	**1 500 000**

5.2. Net present value

The reference scenario under consideration is that of a mine in operation and lithium transported by road. The project duration considered for the NPV is 20 years (mine operating life) and the discount rate is 6%, which is recommended for southern African countries.
These results highlight the monetized benefits of choosing to operate the mine using diesel trains (profitability from the thirteenth year of operation).

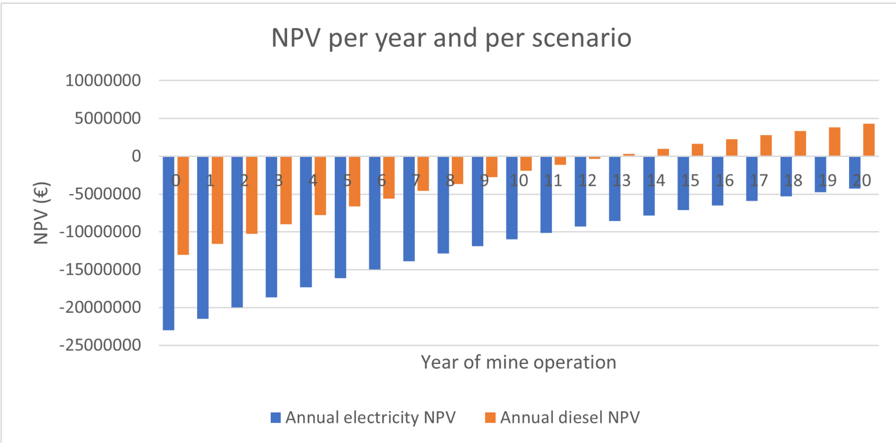

Figure 13. Diagram of the line governance sections © Victor Chenin, 2025.

5.3. Drawing up the financing plan

The total CAPEX cost of the project is estimated at around USD 40.5 million for the electric train option and USD 30.5 million for the diesel train option. Thanks to the financing tools available under the European "Global Gateway" strategy in Africa, it is estimated that there is a potential subsidy of around 50%. To benefit from this, the partner country must adhere to the fundamental values of the EU and implement transparent budgetary control. As far as rolling stock is concerned, we estimate that the rate of funding would only be valid for battery-powered trains.

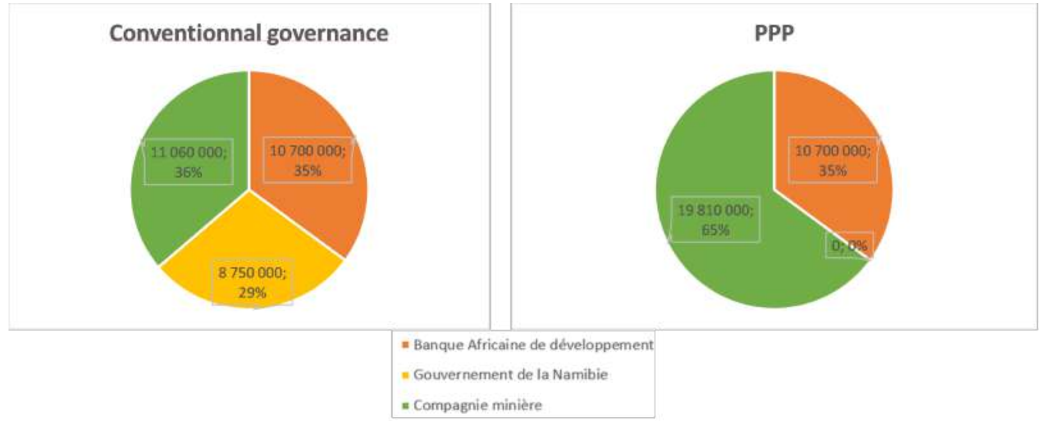

Figure 14. Summary of costs of the different projects envisaged
© Adélie Busson, Aurélie Godard, Arnaud Marville, 2025.

6. Schedule

The main phases are as follows:

- Emergence Phase (6 months): Identification of needs, general feasibility analysis, initial route selection, and regulatory procedures.
- Preliminary Design (AVP) Phase (12 months): Technical and economic studies, topographic and geotechnical surveys, cost estimation, and rolling stock specification.
- Detailed Design (PO) Phase (6 months): Final technical plans, preparation of bidding documents, tendering, contractor selection, and logistics planning.
- Execution Phase (24 months): Infrastructure works, including rehabilitation of the existing line and construction of the new industrial spur (ITE), installation of loading systems, delivery of rolling stock, and staff training.
- Commissioning Phase (12 months): Testing and validation of all systems, including dynamic trials and operational launch of the Karibib–Walvis Bay railway link.

This approach helped identify the critical path, with the minimum estimated project duration set at five years.

7. Conclusion

The project to rehabilitate the Walvis Bay - Karibib rail service is a strategic response to the challenges of supplying critical minerals, and lithium in particular, which are essential to the global energy transition. It is part of the international cooperation drive supported by the EU Global Gateway initiative, while also meeting Namibia's national ambitions to become a regional logistics hub.

The study carried out enabled an in-depth analysis of the technical solutions applicable to the rehabilitation of the existing infrastructure, the construction of a railway spur line (ITE) to the Karibib mine, and the reliable and efficient transport of 50,000 tons of lithium concentrate per year to the port of Walvis Bay. Two technological scenarios were evaluated for powering the rolling stock on this non-electrified line: conventional diesel and battery electric traction. Although the electric solution has environmental advantages, the economic analysis favors the diesel scenario, which guarantees a positive socioeconomic balance in a context of low volumes and controlled investment.

In addition, environmental constraints, in particular the sandstorms that regularly affect the line, have been taken into consideration. The study recommends targeted investment in specific equipment, such as wind barriers and suitable sand removal equipment, to ensure the line's continued operation.

In institutional terms, the project advocates public-private partnership (PPP) governance, a model tried and tested in other African railway contexts and in line with European Union guidelines. This mode of governance implies opening up operations to private operators, which will entail an in-depth restructuring of TransNamib to enable it to become an infrastructure manager and collect fees for access to its network. This change is necessary to guarantee the corridor's economic viability and ramp-up.

To be completed in five years, this project represents much more than a simple infrastructure rehabilitation: it is a structuring opportunity for the economic development of Namibia, for the securing of critical value chains, and for the promotion of sustainable and integrated corridors in Southern Africa.

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Modernization of the Lviv tramway

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Ce projet porte sur la modernisation du réseau de tramway de Lviv, en Ukraine, en s'inspirant du modèle « à la française ». Le tramway de Lviv joue un rôle central dans la mobilité urbaine, en reliant les quartiers et en assurant un service quotidien à des milliers de résidents. Toutefois, face à l'évolution des modes de vie, à l'augmentation des attentes des usagers et aux exigences environnementales actuelles, le réseau montre ses limites. Ce rapport présente un diagnostic complet de l'état actuel du réseau, suivi de l'étude de deux options et d'une analyse multicritère visant à déterminer la solution la plus appropriée. La solution retenue est ensuite détaillée, en tenant compte des différents aspects de sa mise en œuvre. Enfin, une évaluation socio-économique et une analyse des risques de la solution proposée sont réalisées. En conclusion, le projet de modernisation du tramway de Lviv, guidé par des exemples français réussis, présente des avantages significatifs en augmentant la vitesse commerciale et en améliorant l'accessibilité pour une agglomération de près de 750 000 habitants. Cette modernisation renforcera l'attractivité du tramway, facilitera son usage quotidien et contribuera à un service plus fiable.

Mots-clés : modernisation, tramway, Lviv, mobilité, transport public, ferroviaire

This study focuses on the modernization of the tramway network in Lviv, Ukraine, inspired by the "French-style" model. Lviv's tram network plays a central role in urban mobility, connecting neighborhoods and providing daily service to thousands of residents. However, in the face of changing lifestyles, growing user expectations, and current environmental demands, the network is showing its limitations. This report presents a comprehensive diagnosis of the current state of the network, followed by the examination of two options and a multi-criteria analysis to determine the most suitable solution. The chosen solution is then detailed, taking various aspects of its implementation into consideration. Finally, a socioeconomic assessment and risk analysis of the proposed solution are performed. In conclusion, the Lviv tram network modernization project, guided by successful French examples, offers significant benefits by increasing commercial speed and improving accessibility for a metropolitan area of nearly 750,000 inhabitants. This modernization will enhance the tramway's appeal, facilitate daily use, and contribute to more reliable service.

Keywords: modernization, tram network, Lviv, mobility, public transport, railway

Modernization of the French-style tramway

1. Context of the study

General Context

Ukraine, a country located in Eastern Europe, has undergone profound transformations over the past decades, marked by political upheavals, economic challenges, and, more recently, military conflict. Since the 2014 annexation of Crimea and especially in the wake of the full-scale invasion by Russia in 2022, the country has experienced large-scale population displacements and infrastructural damage. Amid these difficulties, certain cities such as Lviv, in the west of the country, have remained relatively well-preserved and have taken on new national roles.

Lviv has become a major logistical, humanitarian, and administrative hub. Its strategic location near the Polish border, coupled with its historical and cultural heritage, has strengthened its role as a gateway between Ukraine and the European Union. As a result, the city's urban infrastructure — and in particular, its public transport system — has been placed under increasing pressure.

In this context, the Lviv tram network is not only a legacy of early modern urbanism but also a critical asset in ensuring resilient, low-carbon mobility. The modernization of this system is part of a broader strategy to reinforce sustainable urban development, maintain functional connectivity during crises, and position Lviv as a model for post conflict recovery and European integration.

Diagnostic

The Lviv tram network is one of the oldest and most iconic public transport systems in Ukraine, located in the historic city of Lviv, in the western part of the country. Established in 1880, the tram system originally operated as a horse-drawn service, later transitioning to electric trams in 1894 — making it one of the first electrified tram systems in Eastern Europe. Its early adoption of electric power coincided with Lviv's hosting of the General National Exhibition, highlighting the city's progressive urban planning.

Today, the tram system in Lviv remains a vital component of the city's public transportation network. Managed by the municipal enterprise Lvivelectrotrans, it serves over 100,000 passengers daily, connecting various districts of the city with the historic center. The system includes 6 main tram lines, covering approximately 34 kilometers of track. Despite aging infrastructure and financial challenges, the tram remains a preferred mode of transport for both residents and tourists due to its affordability and accessibility.

Lviv's tram network is notable for its narrow-gauge track (1,000 mm), which distinguishes it from many other Ukrainian cities that use standard gauge. This contributes to the quaint and historic character of the system, particularly in the UNESCO-listed city center, where trams run along cobbled streets and past historic buildings.

In recent years, efforts have been made to modernize the tram fleet and infrastructure. With the support of international partners such as the European Investment Bank (EIB) and the German Development Bank (KfW), Lviv has acquired refurbished trams from Germany and implemented partial infrastructure upgrades. Projects include new low-floor trams to improve accessibility and investments in track renewal and electrification efficiency.

Despite the ongoing war in Ukraine dating from 2022, Lviv's tram system has continued to operate, albeit under pressure. The city, which has become a refuge for displaced Ukrainians, has relied even more heavily on its public transport, highlighting the tram system's resilience and importance in times of crisis. Lviv authorities have maintained a strong commitment to preserving and enhancing the tram network as part of a broader vision of sustainable urban mobility.

The Lviv tram system remains not only a practical mode of transport but also a cultural symbol of the city. It reflects a blend of history, resilience, and gradual modernization, standing as a testament to Lviv's enduring European identity and its commitment to environmentally friendly transportation solutions.

Possible options and choice of solution

Following an in-depth analysis of the current network and French best practices, two alternative scenarios were developed to modernize Lviv's tram system:

Option 1: Full Network Modernization (Inspired by Nantes)

This scenario aims to bring the entire tram network up to European standards. It includes the conversion to standard gauge (1,435 mm), full renewal of tracks and stations, acquisition of modern low-floor trams, and upgrades to depots and power systems. The goal is to improve speed, reliability, accessibility, and passenger comfort across the city.

Estimated cost: €300–350 million

Impact: Network-wide transformation with long-term benefits

Option 2: Central Segment Renovation (Inspired by Strasbourg and Nice)

Focused on a 3 km stretch in the historic city center, this scenario seeks to enhance urban integration and the passenger experience. Key features include a car-free tram corridor, improved stations, better pedestrian and cycling facilities, and the potential use of catenary-free (hybrid) trams.

Estimated cost: €50–70 million

Impact: Quick, visible improvements in a key urban area

These two scenarios represent complementary approaches, one systemic, one targeted, to shape the future of sustainable mobility in Lviv

Multicriteria Analyses

A multi-criteria analysis was performed. The objective is to identify the solution that offers the best balance between performance, feasibility, impact on urban mobility, and local acceptability.

This analysis will guide decision-making in defining the modernization strategy that is best suited to the specific needs and constraints of the city of Lviv. The choice of solution was based five main categories as follows:

- Temporal Criteria

C9 – Duration of the project

- Environmental Criteria

C6 – Environmental impacts during the works

- Technical Criteria

C1 – Impact of modifications made to the existing system on infrastructure
C2 – Usability of the existing tram fleet
C3 – Evaluation of the capacity to use existing depots and maintenance workshops as part of the modernized new system

- Economic Criteria

C4 – Investment cost
C5 – Availability of funding sources
C10 – Long-term cost/benefit ratio

- Social and User-Oriented Criteria

C7 – Continuity of service during the transition period
C8 – Accessibility and design adapted for people with reduced mobility

Categories	Criteria	Option 1	Option 2
Technical Criteria	C1 – Impact of modifications made to the existing system on infrastructure	2	8
	C2 – Usability of the existing tram fleet	1	8
	C3 – Evaluation of the capacity to use existing depots and maintenance workshops as part of the modernized new system	1	8
	Total	**4**	**24**
Economic Criteria	C4 – Investment cost	1	5
	C5 – Availability of funding sources	1	5
	C10 – Long-term cost/benefit ratio	5	5
	Total	**7**	**15**
Social and User-Oriented Criteria	C7 – Continuity of service during the transition period	3	6
	C8 – Accessibility and design adapted for people with reduced mobility	10	10
	Total	**13**	**16**
Temporal Criteria	C9 – Duration of the project	2	6
	Total	**2**	**6**
Environmental Criteria	C6 – Environmental impacts during the works	1	4
	Total	**1**	**4**

An evaluation and weighting of each of these criteria according to the matrix presented in the table above allows us to obtain the summary table of multi-criteria analyses:

Categories	Weighting	Option 1	Option 2
Technical Criteria	20%	0.4	4.8
Economic Criteria	30%	2.1	4.5
Social and User-Oriented Criteria	20%	2.6	3.2
Temporal Criteria	20%	0.4	1.2
Environmental Criteria	10%	0.1	0.4
Total	100%	5.6	**14.1**

Taking the preceding analysis into consideration, Option 2, which received the highest score, appears to be the most optimal choice for the modernization of Lviv's tram network. Considering the current situation of the city, this option also seems the most realistic and best suited to the priority needs in terms of urban mobility. This preference highlights the importance of a targeted approach, integrating the renovation of the city center, improved accessibility, and the enhancement of public space, while ensuring greater efficiency of the network.

2- Implementation of the Solution

As part of the future modernization of Lviv's tram network, the project is being developed through close coordination between local, national, and international stakeholders. The project ownership involves the City of Lviv, the municipal operator Lvivelectrotrans, and the Ukrainian Ministry of Infrastructure, with backing from European institutions such as the EIB and EBRD. A project management support team has been formed to bring together technical, legal, and financial expertise, with contributions from international consultants specializing in urban mobility.

An international tender will select the contractor responsible for the technical design and execution oversight of key works, including the planned pedestrianization of the central corridor served by lines L1 and L2, the future upgrade of tram stations (including accessibility and urban design improvements), and the gradual renewal of rolling stock. The goal is to achieve both functional efficiency and visual harmony across the central network, while ensuring continuity of service during implementation.

The project is structured into six future phases, starting with technical studies and public consultations, followed by funding mobilization and detailed design development. Procurement procedures and permit applications will then pave the way for the construction phase, which is expected to include infrastructure upgrades, tram fleet delivery, and passenger information systems. The final steps will involve dynamic testing, phased commissioning, and post-deployment monitoring. This long-term initiative reflects Lviv's strong political will to reallocate public space toward sustainable transport and soft mobility modes.

Implementation of the chosen solution

Step 1 - Removal of car traffic

In order to enhance the tram's reliability and improve the urban environment, car traffic will be entirely removed from the shared corridor of lines L1 and L2, located in Lviv's historic city center. This full pedestrianization will reduce traffic pressure, cut noise pollution, and provide a safer space for pedestrians and cyclists. The approach follows the example of successful projects in Strasbourg and Nice.

Step 2 - Development of cycling infrastructure

A 14 km cycling ring will be developed around the new pedestrian zone, with a central path crossing the city core. The project includes secured lanes, bicycle parking, repair points, and shared zones with trams and pedestrians. The objective is to promote active mobility and support intermodal connections.

Step 3 – Modernization of power supply

Overhead power lines will be removed from a 3 km stretch in the historic center to preserve the UNESCO-listed urban landscape. Trams will be fitted with onboard batteries, and automatically recharged at terminal stations using a ground-based system (SRS). This ensures silent, clean and autonomous operations in the heart of the city.

Step 4 – Station upgrades and accessibility

Five major stops on the corridor will be upgraded to meet universal accessibility standards: raised platforms (21 cm), tactile ground indicators, visual contrast, modern shelters, real-time information systems, and adapted urban furniture. The reference model for this redesign is the Dijon tramway.

Step 5 – Rolling stock renewal

The fleet will be renewed with Alstom Citadis X05 trams compatible with the narrow gauge. These low-floor vehicles will carry up to 230 passengers, operate 3–5 km without overhead lines, reach speeds of 70 km/h, and recharge quickly using ground-based systems. This ensures accessibility, energy efficiency, and operational resilience.

3- Socioeconomic Analysis

The modernization of Lviv's tram system has significant socioeconomic implications, affecting transportation habits, cost efficiency for users, and broader urban attractiveness. This transformation is crucial not only for sustainable urban mobility but also for long-term regional development.

Modal Shift and Public Transport Usage

Modern, more comfortable and higher-capacity rolling stock encourages a modal shift from private combustion engine vehicles to public transport—particularly the tram. Increased service frequency, improved ride quality, and better accessibility (e.g. more seating, shorter waiting times) make tram travel more appealing. For instance, a tram arriving every 5 minutes during peak hours offers a clear advantage over personal car use, especially in congested urban areas.

Economic Gains for Users

From a financial perspective, the tram offers significant cost savings. A yearly public transport pass at €300 is vastly more affordable than the €3,000 average annual cost of maintaining a private car. For families, the collective savings are even higher—€1,200 per year for four transport passes compared to the fixed and variable costs of car ownership (fuel, insurance, maintenance, parking, etc.).

Comparative Socioeconomic Indicators

Category	Time (per year)	Cost (per year)	CO_2 Emissions (per year)
User – Without change	208 hours	€3,000	544 kg CO_2
User – With tram	230 hours	€300	7 kg CO_2
City – Without change	—	€200M	187,500 tons CO_2
City – With tram	—	€400M (rev.)	93,750 tons CO_2

Although public transport travel may increase daily commute times slightly, the environmental and financial benefits are considerable. These gains extend to urban planning, with trams using 10x less space per passenger than cars, making them more efficient during rush hours.

Wider Benefits: Infrastructure and Environment

Tramway modernization reduces infrastructure wear due to road traffic, minimizing maintenance costs and lowering fine-particle pollution. It also alleviates traffic congestion, which improves public health and urban livability.

Social Acceptance and Stakeholder Engagement

Public consultation and stakeholder involvement are essential. The city of Lviv must engage citizens, businesses, elected officials, and institutions through forums, referendums, or public votes to ensure the project's legitimacy and broad-based support. This participatory approach reflects the values of democratic urban development.

Impact on Local Economy and Tourism

The tramway's revitalization also stimulates local commerce and tourism. Better transport access increases footfall to local shops, leisure venues, and tourist sites. Citizens gain purchasing power through transport savings, and the city benefits from increased tax revenue and local economic growth. This model mirrors successful strategies in other European countries, particularly France, where public transport investments are closely tied to economic development policies.

4- Risk Analysis

The implementation of a project inevitably involves certain risks. It is therefore essential to identify these risks, classify them, assess their criticality, and plan preventive and control actions - both before and during the project. It is important to note that this project will begin after the end of the current war in Ukraine; therefore, risks related to the ongoing conflict are not included in the risk analysis.

At this stage of the project, 13 risks have been identified across six categories: technical, financial, political, social, planning, and legal.

Evaluation of Risk

After identifying the project risks, they are evaluated and classified into four levels of criticality (C): Critical, High, Moderate, and Low, based on their frequency and their impact on project completion.

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

Risk	C	Planned Action
The infrastructure is in worse condition than expected	Critical	Detailed inspection before the start of the project
Delay or cancelation of funding	Critical	Diversification of financial funds
Political fragility	High	Monitor political risks regularly and prepare adaptation scenarios

Conclusion

To conclude, we consider this proposal an ambitious project for the city of Lviv and the surrounding urban area, in particular with regard to the mobility of populations. This project radically changes the way transport in Lviv is organised, a city previously over-reliant on cars and underserved by alternative transport options such as the tram. This projects paves the way for the reinvention of the city's transport system, combining multiple modes of transport and soft mobility options, including bicycles, trams and buses.

The "French-style" component of this plan is to be implemented via the development of streets around the tram network in the historic center. This also has positive socioeconomic repercussions as well as a beneficial impact in terms of energy transition and efforts to address the city's carbon footprint .

The creation of a mass transit system in Harare

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ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES
IP PARIS

Le projet de transport ferroviaire urbain de Harare propose la revitalisation et l'électrification du corridor ferroviaire existant dans la capitale du Zimbabwe afin de créer un service ferroviaire de banlieue structuré (Réseau Express Régional – RER). Ce RER est envisagé comme une initiative transformatrice visant à alléger la pression sur la mobilité urbaine, à réduire la dépendance au transport informel et à soutenir une croissance urbaine inclusive. Le projet comprend un corridor est-ouest de 44,5 km entre Ruwa et Mashonaland, avec une branche nord vers Tynwald. La population de Harare a dépassé les 2,4 millions d'habitants en 2022 et devrait dépasser les 3,2 millions d'ici 2040. Cette urbanisation rapide, conjuguée à un investissement insuffisant dans les transports publics formels, a exacerbé la congestion, la pollution et les inégalités. Plus de 70 % des déplacements se font à pied ou en transports informels (kombis), tandis que seulement 0,5 % utilisent le train. Ce projet exploite l'infrastructure sous-utilisée du NRZ (National Railways of Zimbabwe) pour créer un réseau ferroviaire à grande capacité et à faibles émissions afin de remodeler la mobilité urbaine.

Mots-clés : étude de faisabilité, mobilité, Harare, Zimbabwe, exploitation, *mass transit*, RER, transports, système de transport

The Harare Urban Rail Mass Transit Project aims to revitalize and electrify the existing railway corridor in Zimbabwe's capital, establishing a structured suburban rail service (Suburban Express Train – SET). Conceived as a transformative initiative, the SET is designed to relieve pressure on urban mobility, reduce reliance on informal transport, and foster inclusive urban growth. The proposed network features a 44.5 km east–west corridor between Ruwa and Mashonaland, with a northern branch to Tynwald. Harare's population surpassed 2.4 million in 2022 and is projected to exceed 3.2 million by 2040. Rapid urbanization, combined with insufficient investment in formal public transport, has intensified congestion, pollution, and inequality. Over 70% of trips are made on foot or via informal transport (kombis), while only 0.5% use the train. This project leverages underutilized National Railways of Zimbabwe (NRZ) infrastructure to deliver a high-capacity, low-emission rail network, reshaping urban mobility in Harare.

Keywords: feasibility study, mobility, Harare, Zimbabwe, operations, mass transit, SET, transport, transport system

1 Context and needs assessment

1.1 Urban mobility diagnosis

A project of this magnitude begins with a rigorous feasibility study of Harare Province, home to 2.4 million residents. The key challenge is to determine the most appropriate solution within the constraints of a developing country, emphasizing simplicity, efficiency, cost-effectiveness, and rapid implementation to maximize positive impact.

Harare Province represents approximately 16% of Zimbabwe's population and is experiencing accelerated urban expansion, especially on its periphery. Persistent economic instability, hyperinflation, shortages, and periods of weak governance have shaped the province's spatial development, driving dependence on non-motorized and informal transport modes.

Figure 1. Distribution of trips by mode of transport. © Authors.

Transport governance in Harare is fragmented among several stakeholders: the Ministry of Transport, Zimbabwe United Passenger Company (ZUPCO), National Railways of Zimbabwe (NRZ), and the City of Harare. Our analysis highlighted limited institutional coordination, driven by unclear mandates and insufficient human and financial resources.

We propose targeted support to these institutions, aiming to establish a robust, integrated governance model suited to the project's ambitions.

Figure 2. Institutional governance of Zimbabwe's railway sector. Source: Zimbabwe Infrastructure Report 2019

As the economic and administrative heart of Zimbabwe, the province has a high concentration of employment in tourism, services, and industry, creating significant daily commuting flows and placing the already fragile urban transport network under further strain.

Given the population's reliance on informal transport, the project's objective is to provide a reliable, rapid, and accessible alternative, with frequent service, integrated connections, and affordable fares to ensure both appeal and inclusivity.

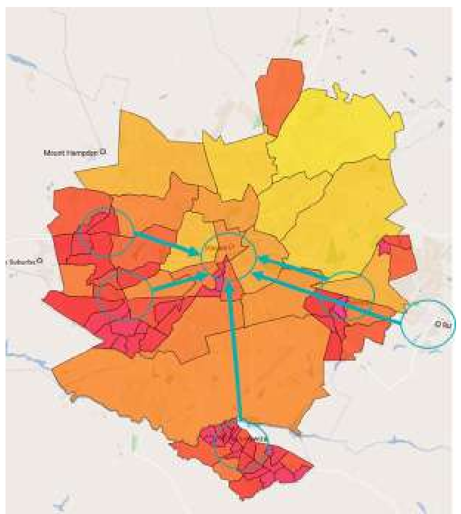

Figure 3. Main urban mobility corridors and population density in Harare Province. © Authors.

1.2 SWOT analysis

To inform system design, we conducted the following SWOT analysis:

Table 1. SWOT Analysis

Strenghts	Weaknesses
+ Steady demographic growth (1.5%/year) creating strong demand for mobility.	– Low economic resilience: monetary crisis, poverty, indebtedness of operators.
+ Existence of an historic, city-spanning rail network (NRZ).	– Outdated, underutilized, and partially abandoned rail network (approx. USD 400 million required for rehabilitation).
+ Proof of concept: Ruwa–CBD commuter train success in 2021.	– Institutional fragmentation with overlapping roles.
+ Harare's central economic and administrative role.	– Insufficient and unclear ZUPCO network, low frequency, no metropolitan transport authority.
+ Extensive informal transport (kombis, mushika-shika) serving peripheral areas.	- Unregulated informal transport with safety and organizational challenges.
Opportunities	**Threats**
+ Existing railway rights-of-way, minimizing expropriations.	– Political instability hindering reforms or competition.
+ National reform project restructuring the NEZ (RICA, ZRSC, NRZ regulator).	– Risks of insufficient sustainable financing (need for major private investment).
+ Urban transport prioritized in Harare's Master Plan (focus on integration and sustainability).	– Unregulated informal competition possibly undermining rail usage.
+ Major passenger flows aligned along east–west and south axes.	– Ongoing financial and operational crisis in ZUPCO and NRZ.
+ Support from international donors for urban rail pilots (e.g. Ruwa–CBD).	– Fragmented projects and lack of metropolitan coordination.

2 System design and network planning

2.1 Corridor selection

The diagnostic presented in the previous chapter has helped identify the key mobility challenges in Harare: population pressure on the outskirts, road congestion, the weakness of the structured transport network, and a heavy reliance on the informal sector. These findings highlight the urgent need to develop a rail-based alternative adapted to the metropolitan context.

In this regard, we have examined the potential for a metropolitan rail system, leveraging the existing railway corridors between Ruwa, downtown Harare, and Mashonaland, while assessing various possible extensions to the south and west instead.

Several scenarios were studied, we opted for the East-West RER line scenario with a northern branch to Tynwald.

This scenario was chosen as the basis for the feasibility study. It envisages the renovation of a railway line between Ruwa, Harare CBD, and Mashonaland, with a branch to Tynwald, using existing railway infrastructure.

This choice optimizes costs and limits urban impact, while guaranteeing a robust, rapidly deployable, and environmentally friendly solution. The East-West corridor, although degraded, offers strong potential: sufficient width, proximity to key facilities, absence of major natural obstacles, existing engineering structures, and bridges already in place, facilitating its rehabilitation.

Figure 4. Metropolitan Rail Project Corridor. Source: Google Earth

The creation of a mass transit system in Harare

2.2 Infrastructure and track upgrades

To reduce project costs, it was decided to use the existing right-of-way of the Mashonaland–Harare–Ruwa section. To improve performance along this segment (currently limited to 90 km/h), a target speed of 120 km/h was set. A geometric analysis of the existing alignment identified a critical curve radius of 600 meters. With a proposed cant of 190 mm/m and a cant deficiency of 70 mm/m, lateral acceleration reaches 0.7 m/s² — a value consistent with passenger comfort standards.

Speed increases on the line are feasible outside densely urbanized areas, provided that track and signaling upgrades are undertaken. To enhance safety and traffic flow, key level crossings will be replaced with grade-separated overpasses and underpasses.

Sections with geotechnical instability will undergo excavation work, platform leveling, and improved lateral and transverse drainage. The track will be fully renewed using long welded UIC 60 rails mounted on monoblock concrete sleepers, enhancing stability and reducing maintenance needs. Most components will be supplied by South African manufacturers. Cant corrections in curves will support the target speed of 120 km/h.

Regarding the northern branch, the existing right-of-way from the former system allows for single-track operation, helping to avoid major infrastructure costs.

As part of the project, it was decided to electrify the line using 3,000 V DC, to ensure consistency with regional standards and provide reliable traction performance. Electrification will be carried out using a CSRR catenary system, known for its robustness, stability, and ease of maintenance—particularly suited to high-traffic lines and the planned operating speeds.

Power supply will be ensured by a network of rectifier substations spaced approximately 30 km apart, guaranteeing reliability and service continuity. Their placement will take into account the needs of the line, topography, and possibilities for connection to the national grid, with additional studies planned to optimize their location and sizing.

2.3 Choice of stations

The 50-kilometer network will include 24 stations distributed along three main corridors: North, East, and West. With an average spacing of 1.5 to 2 kilometers, the design aims to strike the right balance between travel speed and accessibility.

Stations will be located in high-demand areas, such as Epworth and downtown Harare, with a strong focus on intermodality including integration with ZUPCO buses, kombis, and park-and-ride facilities as well as digital ticketing systems.

Existing stations, such as Harare Central, will undergo complete modernization, while new stations will be built using modular, functional, and streamlined designs.

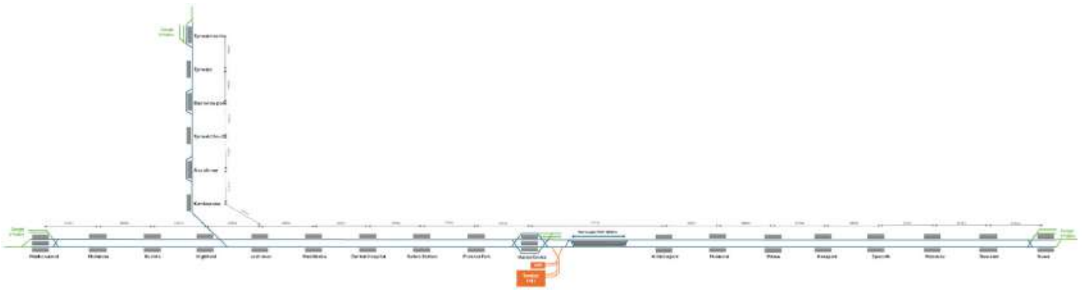

Figure 5. Network station distribution. © Authors.

3 Operations and rolling stock

3.1 Rolling stock

For our project, we have chosen to operate the X'Trapolis Mega, an electric multiple unit train developed by Alstom, specifically designed to meet the needs of suburban and regional transport in Africa. Built for a 1,067 mm (Cape gauge) track, it is currently being deployed by the Passenger Rail Agency of South Africa (PRASA) as part of a large-scale modernization program of the South African rail fleet. It is, therefore, a train specifically engineered to suit operating conditions in Africa.

Figure 6. Train X'Trapolis Mega. Source: Alstom

The selection of Alstom's X'Trapolis Mega is part of a strategic approach to equip Zimbabwe with modern, reliable rolling stock tailored to its specific needs. This train is a proven solution, offering significant technical and economic advantages while supporting regional development and skills transfer. Moreover, the manufacturer is French, which aligns perfectly with our partnership strategy involving the French Development Agency (AFD).

To ensure proper maintenance and storage of the rolling stock, we have decided to expand and modernize the existing maintenance and depot facility in Tynwald.

3.2 Operating plan

The operation of the RER system forms the foundation of this study, as the assumptions made at this stage have directly informed subsequent needs for rolling stock, signaling, and capacity. The baseline modeling was derived from a maximum speed of 120 km/h, with an acceleration of 1 m/s² and a deceleration of 0.8 m/s².

An estimated daily ridership of approximately 300,000 passengers, along with strong projected population growth in the coming years, has informed the operational choices.

Travel times have been calculated using realistic commercial speeds: 44 minutes between Harare North and Tynwald North at an average of 46 km/h, and 26 minutes between Ruwa and Mashonaland at 51 km/h.

In this context, a 10-minute headway between single-unit trains has been adopted for each line, with extended operating hours from 5 a.m. to midnight, similar to the Dakar TER. On the central segment, which is more densely populated, this frequency is doubled, with one train every five minutes.

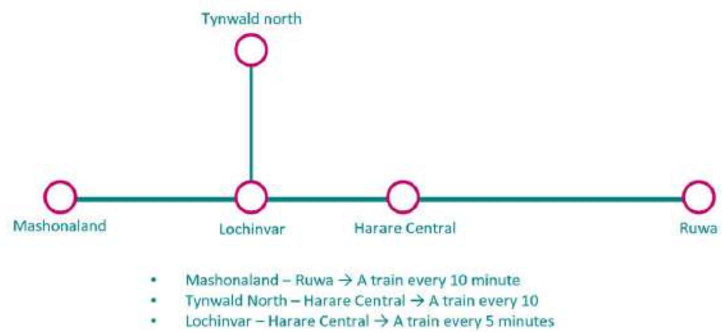

Figure 7. Service pattern and stop diagram © Authors.

The designed system offers a high degree of flexibility to adapt to the needs of the transport authority. Capacity can be adjusted by modifying train configurations from single units to double or even triple formations or by reducing headways between services, within the limits allowed by the signaling system. However, transitioning to triple-unit (UM3) operations would require prior platform lengthening.

Finally, to ensure reliable operations and accommodate daily contingencies, the fleet has been sized at seventeen trainsets, including a 15% reserve margin for maintenance and unforeseen events. This sizing guarantees both the robustness and scalability of the system in response to future challenges.

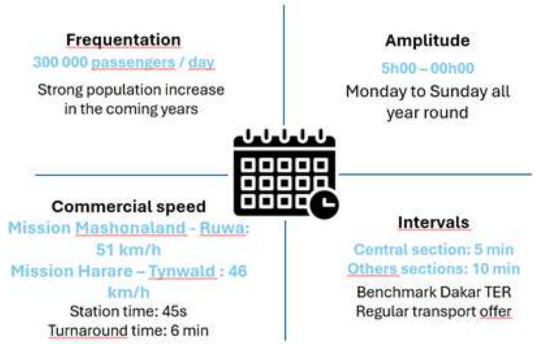

Figure 8: Operations summary. © Authors.

4 Socioeconomic and financial analysis

4.1 Financial structure

Following a detailed analysis of all associated costs, the total project budget from preliminary studies to commercial launch is estimated at €636.65 million.

To maintain operational services, an annual operating budget of €20 million is required. The overall budget is allocated as follows across the main cost categories:

In terms of project financing, the provisional financial structure is as follows:

- French Development Agency (AFD): €200 million
- Partner banks: €300 million
- Government of Zimbabwe: €136.65 million

The creation of a mass transit system in Harare

The Harare metropolitan authority will also contribute by providing an operating subsidy to ensure the financial sustainability of the RER line.

Civil engineering	**P.U (€)**	**Nombre estimé**	**Total (€)**
Single track regenaration	1 470 000 / km	50 km	73 500 000,00 €
Creation of a ballasted track	1 500 000 / km	40 km	75 000 000,00 €
Stations	2 000 000 / station	24	48 000 000,00 €
Track switches	150 000 / unit	21	3 150 000,00 €
Maintenance site	25 000 000,00 €	1	25 000 000,00 €
Command control station	5 000 000,00 €	1	5 000 000,00 €
Bridge	2 000 000 / unit	2	4 000 000,00 €
Small bridge	500 000 / unit	4	2 000 000,00 €
Secondary maintenance base	2 000 000,00 €	2	4 000 000,00 €
Automatic Half-Barrier Crossing (AHBC)	350 000 / unit	6	2 100 000,00 €
LX removal	1 200 000 / unit	3	3 600 000,00 €
			245 350 000,00 €
3000 V Electrification	**P.U (€)**	**Estimated number**	**Total (€)**
Double-track catenary installation	3 000 000 / km	40 km	120 000 000,00 €
Single track catenary installation	1 500 000 / km	10 km	15 000 000,00 €
Power substation	3 500 000 / unit	3	10 500 000,00 €
			145 500 000,00 €
Signaling and telecoms	**P.U (€)**	**Estimated number**	**Total (€)**
ERTMS (ETCS + GSM-R)	350 000 / km	100 km	35 000 000,00 €
Axle counter (new generation)	150 000 / km	100 km	15 000 000,00 €
ARGOS	6 000 000 / unit	1 center	6 000 000,00 €
Intermediate dispatch center	1 500 000 / unit	4 centers	6 000 000,00 €
Passenger information system	50 000 / station	24 stations	1 200 000,00 €
			63 200 000,00 €
Rolling stock	**P.U (€)**	**Nombre estimé**	**Total (€)**
Rolling stock	4 500 000 / unit	17 units	**76 500 000,00 €**
Other costs	**P.U (€)**	**Nombre estimé**	**Total (€)**
Study	530 550 000,00 €	10 % of total cost	53 055 000,00 €
Provision for risks	530 550 000,00 €	10 % of total cost	53 055 000,00 €
Total CAPEX			**636 660 000,00 €**

Figure 9. CAPEX cost allocation. © Authors.

4.2 Socioeconomic impact

The socioeconomic evaluation of the project is critical, as it considers both quantitative and qualitative impacts on society and the environment. The analysis aims to quantify and monetize the project's social benefits over a 40-year period, comparing them to the associated costs. From a socioeconomic perspective, the project is considered beneficial if total benefits exceed total costs over the study period. Non-monetized benefits include improved social cohesion, enhanced quality of life, greater accessibility, tourism development, and positive environmental impacts.

Our assessment first focused on travel time savings compared to private car use and current public transport options. This was based on an estimated modal shift to the new SET system. The resulting annual time-saving benefit is estimated at €238 million.

We then considered gains from positive externalities, including reduced air pollution and CO_2 emissions due to modal shift, improved road safety from fewer accidents, and lower noise pollution as a result of reduced urban congestion. The total monetized value of these externalities is estimated at €1,600,922.97 per year.

Lastly, we calculated the project's Net Present Value (NPV) over a 40-year horizon using the following methodology:

$$\text{VAN} = -636{,}660{,}000 + \sum_{t=1}^{40} \left(\frac{219{,}807{,}807}{(1+0.12)t}\right) + \frac{2{,}362{,}230.14}{(1.12)\text{^}40} = \textbf{€1,175,386,476.55}$$

Our project therefore benefits from €1,175,386,476.55 over a period of 40 years, which corresponds to the lifespan of our system.

Années			Total	Année 1	Année 2	Année 3	...	Année 38	Année 39	Année 40
Investissement initial	Coût étude						...			
	Coût Infra		-560 160 000,00 €	-14 004 000,00 €	-14 004 000,00 €	-14 004 000,00 €	...	-14 004 000,00 €	-14 004 000,00 €	-14 004 000,00 €
	Coût MR		76 500 000,00 €	1 012 500,00 €	1 012 500,00 €	1 012 500,00 €	...	1 012 500,00 €	1 012 500,00 €	1 012 500,00 €
	Valeur résiduelle		2 362 230,14 €				...			2 362 230,14 €
Flux de trésorerie	Recette prévues	Ventes de billets	63 000 863,63 €	213 069,28 €	231 180,16 €	250 830,48 €	...	4 359 344,00 €	4 729 888,24 €	5 131 928,74 €
		Ventes marchandises					...			
		Subvention AFD	200 000 000,00 €	5 000 000,00 €	5 000 000,00 €	5 000 000,00 €	...	5 000 000,00 €	5 000 000,00 €	5 000 000,00 €
		Subventions					...			
	Coût d'exploitation	Salaires	-800 000 000,00 €	-7 500 000,00 €	-7 500 000,00 €	-7 500 000,00 €	...	-7 500 000,00 €	-7 500 000,00 €	-7 500 000,00 €
		Energies		-5 000 000,00 €	-5 000 000,00 €	-5 000 000,00 €	...	-5 000 000,00 €	-5 000 000,00 €	-5 000 000,00 €
		Maintenance		-7 500 000,00 €	-7 500 000,00 €	-7 500 000,00 €	...	-7 500 000,00 €	-7 500 000,00 €	-7 500 000,00 €
	Bénéfices annuels (surplus + externalités)			239 807 807,33 €	214 114 113,69 €	191 173 315,79 €	...	3 620 732,83 €	3 232 797,17 €	2 886 426,04 €
	VAN financière		1 175 386 476,55 €	209 104 376,01 €	183 428 793,85 €	160 507 646,27 €	...	-22 936 423,17 €	-22 953 814,39 €	-20 335 915,08 €
Taux d'actualisation				1,00	1,12	1,12	...	1,12	1,12	1,12

Figure 10. Financial summary. © Authors.

5 Project management and governance

5.1 Project planning

The project planning is constructed in a traditional manner, which depending on the choices of the project owner, will enable certain durations to be shortened.

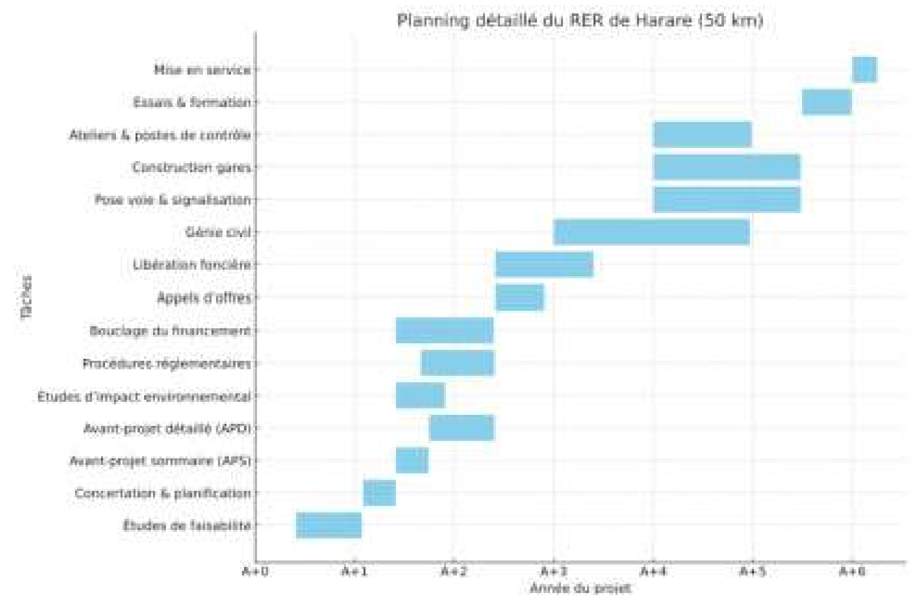

Figure 11. Implementation timeline. © Authors.

5.2 Institutional organization

The Harare Metropolitan RER project represents a major leap forward in terms of technology, capacity, and operational complexity compared to the current bus-based system. Given the scale of this transformation, we believe it would be beneficial for the existing transport governance structures and agencies to seek guidance from a knowledgeable consultancy or expert organization in the field to support a smooth transition.

We therefore propose the creation of a new institutional framework based on three key entities:

- A Transport Authority (AOT), overseen by local government;
- An Infrastructure Manager (GI);
- A Rail Operator (EF).

These entities should align with the European model of competitive tendering to promote fairness and performance. In practice, this means the Transport Authority would regularly tender out the operations (EF) and infrastructure management

(GI) functions. The AOT would also have the option to retain or outsource project ownership and delivery responsibilities (MOA).

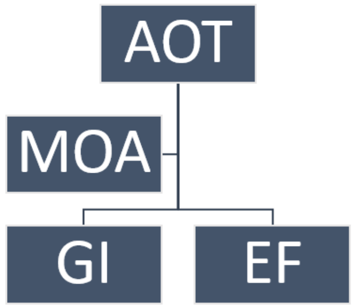

Figure 12. Proposed institutional organization for Harare Province. © Authors.

Conclusion

In the upbeat environment of a growing city, where crowds ebb and flow each morning in an often chaotic dance, a new surge of energy is pulsing along Harare's long-neglected railways. This project, rooted in the careful reuse of existing railway corridors, is more than simply a line of steel and electricity: it is a promise of equity, a shared artery for a metropolis at a crossroads.

Behind the figures and the kilometers of track, there are individuals such as the early-morning commuter, the student with their ambitions for a better future, a working mother, or a young person without the means to afford a private vehicle who come into view. The train here becomes more than a means of transport: it becomes a bridge between the outskirts and the city's heart, between environmental emergency and the ambition for measured development, and between endured informality and a chosen collective path.

As modern trains prepare to breathe life into the tracks of the past, Harare is designing a new kind of mobility: smoother, fairer, and more sustainable. An engineering project, certainly, but above all, a societal project, where infrastructure becomes a vehicle for dignity, inclusion, and urban renewal.

Denpasar Tram - Bus Network Upgrade

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ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES
IP PARIS

Bali et sa capitale Denpasar se caractérisent depuis de nombreuses années par une croissance démographique et économique importante. La ville fait aujourd'hui face à d'importants problèmes de congestion de ses axes routiers. L'usage des 2 roues motorisées y est la norme pour les déplacements, garantissant des temps de parcours limités comparé à la voiture individuelle. L'offre de transports publics, limitée à un faible réseau de bus très peu fréquenté, est anecdotique. Une réflexion à l'échelle métropolitaine pour mettre en place un véritable réseau de transports en commun s'avère aujourd'hui nécessaire. La mise en place d'un réseau de tramway, sujet de la présente étude, doit offrir à la ville un système de transport qui permettra de révolutionner la qualité de vie à Denpasar. Ce projet de tramway est non seulement une manière de rendre les déplacements plus rapides et plus sûrs, mais il permettra également d'envisager une politique urbaine dans son ensemble, avec des interconnexions entre modes de transports, la création d'un réseau cyclable, ou encore un réaménagement urbain des zones traversées par ces lignes. Cette solution garantira à Denpasar un développement soutenable pour les prochaines décennies. La ville sera alors un modèle pour les localités du reste du pays, qui cherchent également à se doter d'infrastructures de qualité pour faire face à leurs défis.

Mots-clés : Denpasar, tramway, transport public, mobilité durable, développement urbain, Indonésie

Bali and its capital, Denpasar, have experienced significant demographic and economic growth over a prolonged period in the 21st century. Today, the city is facing major congestion problems on its roadways. The use of motorized two-wheeled vehicles is the norm for getting around, ensuring shorter travel times compared to private cars. On the other hand, the public transport offer is minimal, limited to a scarcely-used bus network. A metropolitan-scale approach to establishing a proper public transportation network is now necessary. The implementation of a tram network, which is the subject of this study, aims to provide the city with a transportation system that will revolutionize the quality of life in Denpasar. This tramway project is not only a way to make travel faster and safer, but will also enable a broader urban policy, including intermodal connections, the creation of cycling lines, and the urban redevelopment of areas crossed by the tram lines.This solution will ensure sustainable development for Denpasar in the coming decades. The city will then serve as a model for other localities across the country that are also seeking to develop quality infrastructure to meet their own challenges.

Keywords: Denpasar, tram network, public transport, sustainable mobility, urban development, Indonesia

Denpasar Tram - Bus Network Upgrade

1. Territorial Diagnosis of the Denpasar Metropolitan Area

The Denpasar Metropolitan Area encompasses the cities of Denpasar, Badung, Gianyar, and Tabanan. It is undergoing a period of intense transformation driven by rapid demographic, spatial, and economic dynamics. Between 2000 and 2024, the region witnessed a 40% increase in population, and this upward trend is expected to continue with an additional 30% growth projected by 2040.

The demographic structure of the Denpasar Metropolitan Area is relatively young, with 48% of the population under the age of 29 and 93% under the age of 65. This creates huge potential for public transport usage, particularly among students and workers. However, this same demographic dynamic also increases the overall demand for mobility and puts pressure on the transportation network, especially during peak hours.

Nonetheless, public transportation remains underdeveloped. The two main bus services—Trans Metro Dewata (launched in 2020) and Trans Sarbagita (operational since 2011)—suffer from low ridership, with a modal share of less than 1% of all trips. This is due to various factors, such as insufficient service frequency, lack of suitable infrastructure, uncomfortable stops, and a lack of dedicated lanes. As a result, users largely favor individual transport, which is considered faster and more practical.

As a result, private motorized two-wheelers have become the dominant mode of transport. Motorcycles account for over 82% of Bali's vehicle fleet, a trend that continues to grow. This contributes to major issues of congestion, air and noise pollution, and traffic fatalities. Most of the existing road network measures less than 10 meters in width, providing little room for dedicated public transport lanes or safe pedestrian footways.

Institutionally, transport governance in Bali is fragmented. Different levels of administration — such as BAPPEDA (regional planning), the City of Denpasar, Dinas Perhubungan (transport agency), and other decentralized services — are involved in planning and operations. This multi-layered form of organization complicates the coordination and implementation of structuring projects to address long-term planning challenges related to urban mobility.

2. Proposal for a Public Transport Network in Denpasar

In response to the pressing need for improved urban mobility in Denpasar, Bali's rapidly growing capital, we have developed a proposal for a modern public transport network. It is structured around three tram lines and one Bus Rapid Transit (BRT) line, each designed to address the city's mobility challenges while respecting geographical constraints and integrating urban dynamics.

Figure 1. Proposed tram network in Denpasar. Blue Line = T1; Red Line = T2; Green Line = T3; Orange Line = BS1 © Authors. Source: Tool used for the tram line routes: Google My Maps.

Line T1, identified as the primary axis of the network, connects the northern suburb of Ubung to the airport in the south, spanning 18 km and including 30 stations. This line serves densely populated neighborhoods and crosses major commercial areas, making it highly strategic.

South of the airport, however, the terrain becomes significantly steeper, especially around the peninsula zone university campus. To address this, a BRT line is proposed to ensure accessibility to the southernmost areas. The BS1 route covers 7 km with 7 stations and is specifically designed to handle steep gradients which exceed the limits of standard tram vehicles.

Line T2 runs along a west–east axis, connecting residential neighborhoods in the west to business and administrative areas in the center and commercial areas in the southeast. With 31 stations distributed over 19 km. The terrain along the T2 corridor has a moderate relief, which simplifies implementation.

The third tramway line, T3, forms an arc connecting the western, northern, and eastern suburbs of Denpasar. At 23 km long with 36 stations, this peripheral route was designed to enhance east–west and inter-suburban travel without requiring transit through the city center. T3 serves newly developing residential and economic activities in coastal zones, offering a more direct link for inter-district travel. It also provides transfer opportunities to the other lines, supporting an integrated and flexible network. The topography along T3 is varied but still within acceptable limits for tram operation.

Prioritization of lines – multi-criteria analysis

In order to prioritize the implementation phases, a multi-criteria analysis was conducted, taking into account factors such as population served, multimodal connectivity, road width availability, access to key activity hubs, and estimated construction effort.

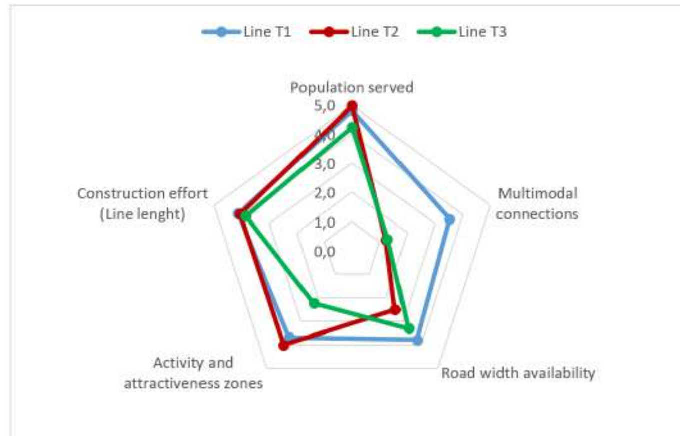

Figure 2. Multi criteria evaluation (Rating: 1 = Worst → 5 = Best). © Authors.

This analysis favored Line T1 as the optimal starting point. Its corridor combines high ridership potential, manageable terrain, and strategic significance, including direct access to the airport and integration with the BRT system. The alignment of T1 also runs through relatively straight and wide streets, simplifying construction logistics and minimizing land acquisition challenges.

Lines T2 and T3, while equally important for long-term network viability, were ranked lower for initial implementation due to lower transport connectivity and more complex urban settings, among other factors. Nevertheless, both are important to the overall vision and for the long-term viability of the network. As the urban population continues to grow and traffic volumes increase, the implementation of these additional lines will become increasingly urgent.

3. Project Line 1 (North-South Axis)

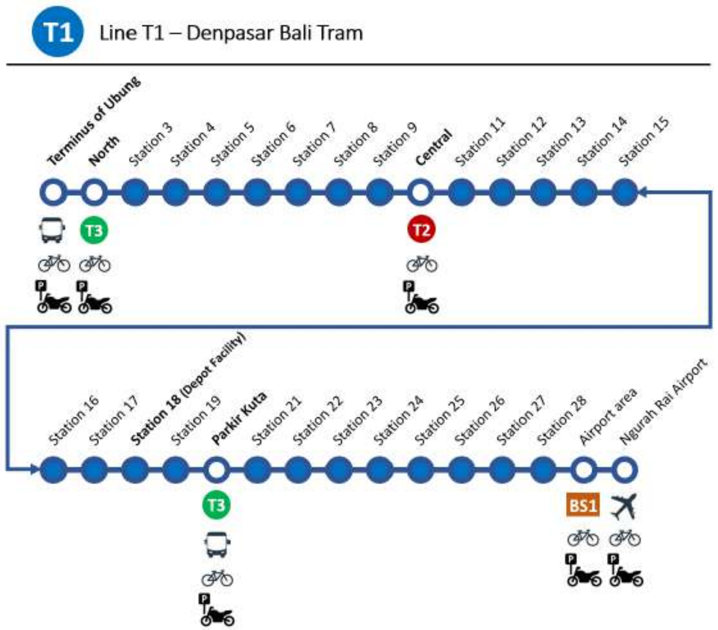

Figure 3. Proposal for the T1 line plan. © Authors.

Demand, Operation & Rolling Stock

An estimation of transport demand was calculated by means of an isochrone map with a setting of 10 minutes' walking distance around the future Line T1 stations. The method used estimates a figure of 10,000 PPHPD (people per hour per direction) during rush hours.

Considering an interval of 4 minutes, the line's capacity reaches the required PPHPD using Alstom Citadis 305 trams operating in double unit (with 321 passengers per single unit, based on the conventional 6 passengers per square meter). Considering a commercial speed of 19 km/h, a turnaround time of 6 minutes, one reserve vehicle and 10% of the fleet in maintenance, the round-trip duration totals 126 minutes, and the minimum required fleet size is 72 vehicles (single units).

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There is an opportunity for increasing the capacity to 12,000 PPHPD in the future by reducing the interval to 3 minutes. In this case, the minimum required fleet size is 94 vehicles, i.e. 22 additional vehicles.

The static dimension of the double unit is 2.65 meters wide and 68 meters long and the dynamic gauge limit in tight curves (25 meters) is 3.3 meters.

Figure 4. Rolling stock Citadis 305; Source: Alstom.

Integration in Urban Environment

The tramway project in Denpasar is designed with a strong focus on urban integration, as it will significantly reshape the city's surface-level infrastructure. The main principles guiding its implementation include:
Reducing space for motorized traffic to encourage more sustainable modes of transport.

- Developing protected bike lanes, potentially shared with electric scooters, depending on local policy decisions.
- Minimizing expropriations by using existing road widths to reduce costs and improve public acceptance.
- Greening the streetscape to enhance environmental benefits.

The tramway route is divided into three sections based on available road width:

Northern Section (14 m wide, 5 km)

- Characterized by dense residential and commercial areas with narrow streets.
- Proposal: Remove motor vehicle lanes, install two-way tram tracks, and add protected bike lanes.

Central Section (18 m wide, 4 km)

- Characterized by wider streets with medium-sized businesses and activity zones.
- Proposal: Convert to one-way traffic, install two-way tram tracks, and protected bike lanes.

Southern Section (25+ m wide, 9 km)

- Characterized by large commercial zones and proximity to the airport.
- Proposal: Maintain two-way traffic with reduced lanes, install tram tracks in the center, and add bike lanes on both sides.

Below is the representation of the tramway integration into the roadway:

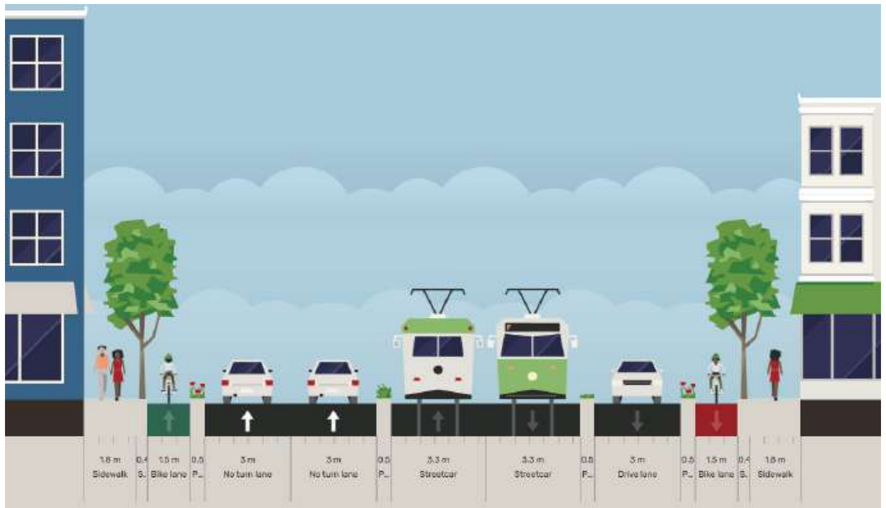

Figure 5. Example of a section 25+ m wide. Source: Tool used for the insertion proposal: Streetmix.

Tram Stops and Infrastructure

Tram stops will be adapted to the space available along the route. A platform with features such as ticket machines, validators, shelters, passenger information systems, technical cabinets, CCTV, and electrical substations where required will be installed.

Depending on the available space, different configurations will be taken into consideration. Stations located in a wide area (especially in the southern part), will have two side platforms, while stations located in the narrow section, will use a central platform to reduce land use. However, in the narrowest areas, a degree of expropriation may still be necessary to accommodate the stops.

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Examples of station integration in their environment, for two side platforms and central platform types:

Figure 6. Example for two side platforms. © Authors. Source: Tools used: Google My Maps for Geographic positioning ; SketchUp for 3D layout of stations and platforms.

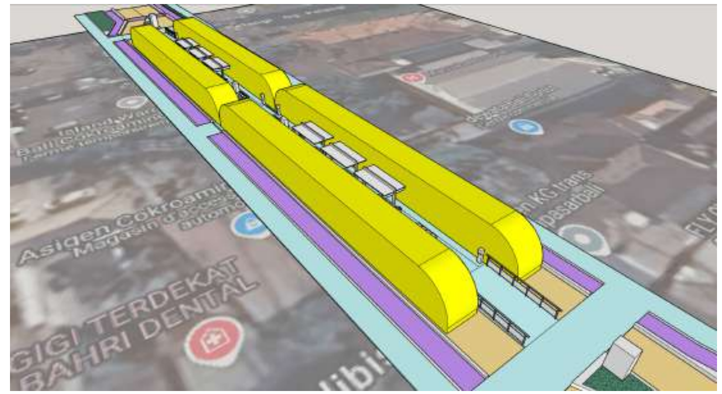

Figure 7. Example for central platform. © Authors.

Track Surface Materials

Three surface types were considered:

- Grass: Aesthetically pleasing and eco-friendly but costly to maintain in Bali's rainy climate.
- Concrete: low maintenance and cleaning, suitable for the southern section.
- Paving stones: Locally produced, visually appealing, and culturally integrated – recommended for the city center.

Civil Engineering

The area through which the tramway passes is characterized by soft, unstable soils predominantly composed of sandy silts and alluvial deposits. These soils, while fertile, present challenges in terms of load-bearing capacity and susceptibility to settlement, especially as a result of seismic activity. Consequently, the project requires specialized foundation techniques and careful geotechnical treatment to ensure long-term track stability and passenger safety. Furthermore, Bali's tropical climate – with its high levels of humidity and significant seasonal rainfall – necessitates robust drainage systems and waterproofing measures to protect both the track infrastructure and electrical equipment.

Main engineering works also include the refurbishment of three river-crossing bridges, two redesigned roundabouts, and a frame bridge over a major road to support the additional tramway infrastructure.

Infrastructure, Power Supply & Signaling

The tramway track employs grooved rails within street-running sections to enable safe coexistence with vehicular and pedestrian traffic, despite the higher installation costs associated with this technology, estimated at 2 to 3 million euros per kilometer. In contrast, dedicated depot areas utilize conventional Vignoles rails to optimize cost-efficiency while maintaining operational standards.

Electrical power supply for the tramway primarily relies on an overhead catenary system. In sensitive urban areas, particularly near heritage sites where overhead lines could compromise aesthetic values, the choice of a battery-powered segment is preferred over a ground-level power supply system (APS) for a 500 meter-long section.

To ensure consistent power delivery and system stability, the project includes between 10 and 12 electrical substations spaced roughly every 1.5 to 3 kilometers. These substations convert high-voltage power to the tramway's operating voltage and provide control and safety functions critical for uninterrupted tram operation.

The signaling system integrates both rail and road traffic control elements, essential for safe tram operations in an urban environment. Railway signaling utilizes axle counters instead of track circuits, given their superior reliability in humid tropical conditions. Roadway intersections are managed by means of Tram Driver Assistance Signals and traffic lights designed to prioritize tram movements over cars while ensuring pedestrian and vehicle safety.

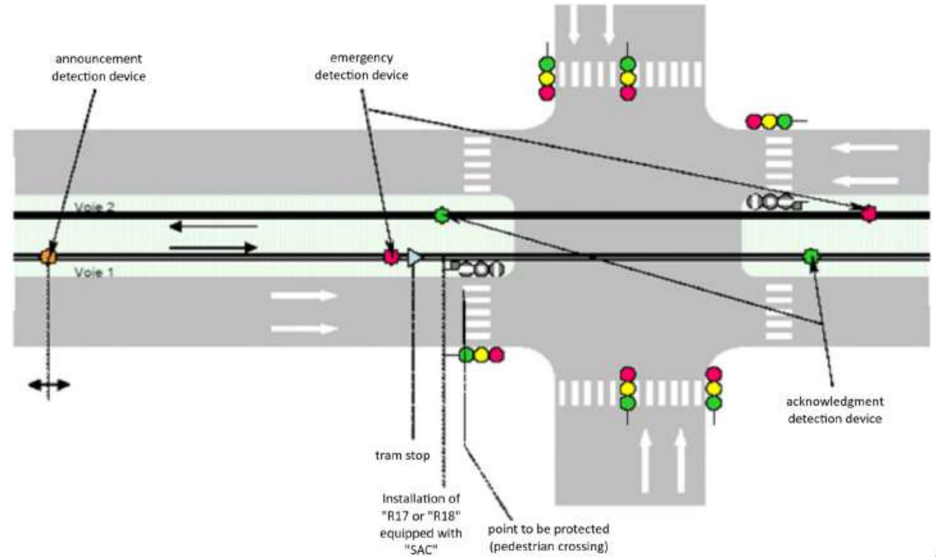

Figure 8. Example of a road and tram signaling system.
Source: Stéphane Giraud, Urban transport signaling from MS STFU module.

The project includes a large depot facility covering approximately 8 hectares, sited primarily on agricultural land to reduce expropriation needs. The depot is designed for an initial capacity of 72 trams, with provisions for a potential expansion to 94 units. It incorporates maintenance workshops, washing and parking lanes, administrative offices, and a centralized control room that oversees the operational management of the tramway fleet.

4. Economic Evaluation, Planning, Risks and Governance

CAPEX

The total capital expenditure (CAPEX) for the T1 tram line is estimated at €386 million. This includes all major construction and system installation costs, starting with civil engineering works such as land acquisition, earthworks, track laying, construction of small structures and a depot, station infrastructure, and the urban integration of the line into

Denpasar's streetscape. Electrification of the 17-kilometer line, including the installation of overhead contact lines and substations, represents a substantial portion of the cost. The signaling and centralized control systems, along with passenger information infrastructure, are also key investments to ensure safety and operational efficiency. The most significant single expense is the rolling stock, consisting of 72 trams acquired at an average price of €2 million each. The remaining capital investment covers project management, technical engineering support, and a contingency reserve equivalent to 10% of the total investment, to account for unforeseen risks or changes in scope.

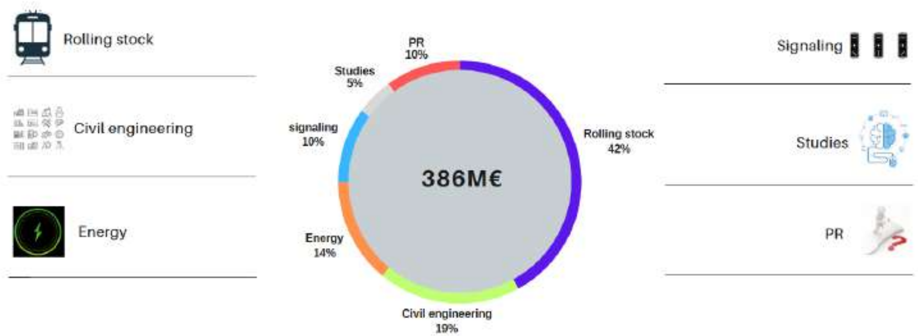

Figure 9. Project Cost. © Authors

OPEX

The annual operational expenditure (OPEX) for the line is estimated at approximately €7 million. This covers 4 main cost centers: workforce salaries, maintenance supplies of infrastructure and vehicles, energy consumption, and technical assistance for system operation.
The OPEX are resumed in the following table, considering a 20% increase for long term inflation:

Cost center	Value	Value +20%
Workforce salaries	€1.65M	**€2M**
Energy consumption	€0.85M	**€1M**
Maintenance supplies	€2.88M	**€3.45M**
Technical assistance contract	**€0.5M**	
TOTAL	**€5.38M**	**€7M**

5. Conclusion

This study enables the determination of the most suitable public transportation system for creating a major tram network in the heart of Denpasar Metropolitan Area, to be developed in the coming decades. This project will facilitate a modal shift toward public transport, enhance efficiency, and address climate-related challenges. Line 1 running North-South was selected as the priority line to be implemented. Subsystems related to rolling stock, infrastructure and operations, were taken into consideration and addressed in order to offer the right sizing. Underpinned by a rigorous analysis dedicated to the integration of the tramway in its urban environment, this project responds directly to public needs which will facilitate its acceptance by the city's population.
The creation of the tram network in Denpasar represents a flagship project for French companies, which have developed extensive expertise in the provision of systems associated with such operations.

Rehabilitation of the railway corridor between the cities of Bizerte, Tunis, Sousse, and Sfax

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Ce projet porte sur la réhabilitation d'un corridor ferroviaire historique reliant les principales villes côtières de Tunisie — Bizerte, Tunis, Sousse et Sfax — qui a été progressivement délaissé au profit du transport routier. S'étendant sur plus de 370 km, la ligne présente d'importantes disparités en matière d'infrastructures, notamment des écartements de voie différents : standard (1 435 mm) entre Bizerte et Tunis, et métrique (1 000 mm) entre Tunis et Sfax. Cela a conduit à diviser l'analyse en deux sections : nord et sud. Les propositions à court terme comprennent le renouvellement partiel du matériel roulant, la suppression des passages à niveau à haut risque et la création de voies d'évitement. À plus long terme, l'électrification progressive et la modernisation du système de signalisation visent à garantir la durabilité. Une extension vers Gabès est également envisagée afin de permettre une future connexion avec le réseau ferroviaire libyen.

Mots-clés : réhabilitation ferroviaire, Tunisie, infrastructure, écartement des voies, électrification, connectivité régionale

This project focuses on the rehabilitation of a historic railway corridor linking Tunisia's main coastal cities —Bizerte, Tunis, Sousse, and Sfax — which has been gradually sidelined in favor of road transport. Spanning over 370 km, the line shows major infrastructure disparities, including different track gauges: standard (1,435 mm) between Bizerte and Tunis, and metric (1,000 mm) between Tunis and Sfax. This led to a division of the analysis into two sections: North and South.Short-term proposals include partial renewal of rolling stock, removal of high-risk level crossings, and the creation of passing loops. In the longer term, progressive electrification and signal system upgrades aim to ensure sustainability. An extension to Gabès is also considered to enable future connection with the Libyan railway network.

Keywords: railway rehabilitation, Tunisia, infrastructure, track gauge, electrification, regional connectivity

Rehabilitation of the railway corridor

Introduction

Since the 2011 Jasmine Revolution, Tunisia has embarked upon a hopeful yet turbulent democratic transition, marked by persistent political and economic instability. As a consequence, these upheavals have weakened several strategic sectors, including rail transport. Once a vital part of passenger and freight mobility, the Tunisian railway network now suffers from a lack of modernization and no longer meets the country's evolving needs. As a result, users increasingly turn to alternative transport modes such as private cars or collective buses—often less safe and more polluting. Against this backdrop, the French Development Agency (AFD) has initiated a strategic review of the Bizerte–Tunis–Sousse–Sfax rail corridor. The aim is to promote sustainable mobility, boost the railway's reliability, and strengthen the overall competitiveness of Tunisia's rail system.

Diagnosis

The Bizerte–Tunis–Sousse–Sfax rail corridor connects Tunisia's four main cities, where 70% of the population lives. However, the railway remains outdated and underused. The national operator is caught in a spiral of decline: fewer passengers mean less revenue, leading to poor maintenance and degraded service.

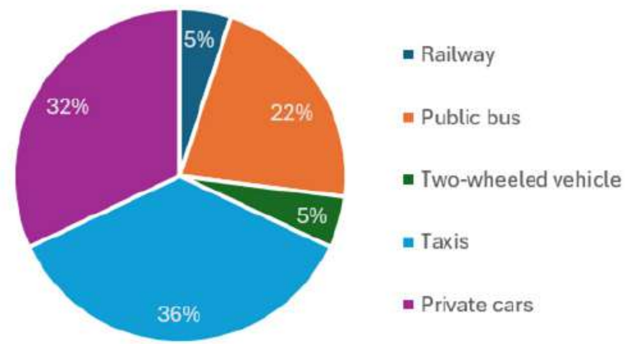
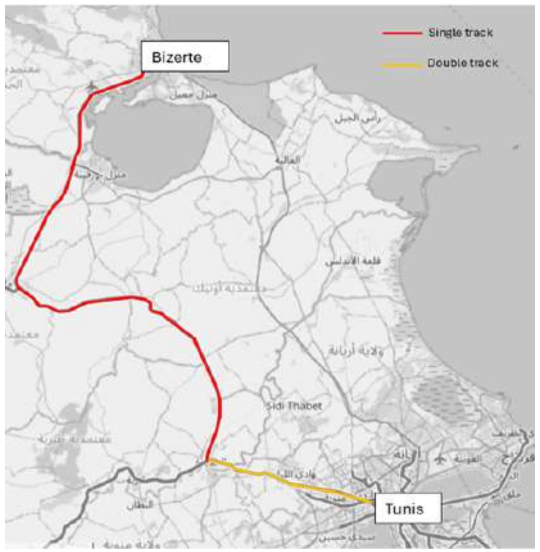


Figure 1. Modal Split in Tunisia. © Authors.

As rail use has dropped, road traffic has increased—bringing serious consequences: worsening air pollution, especially in Tunis and Sfax; high rates of road accidents on some of the world's most dangerous roads; and growing economic stagnation that fuels emigration.

In this context, rehabilitating the corridor is a key response to Tunisia's challenges. It would make rail transport more reliable, reduce road risks, and help boost economic activity in the regions it serves.

The railway corridor is divided into two distinct sections. The northern section, between Bizerte and Tunis, is standard gauge. Its infrastructure is aging, with track components nearing the end of their service life. However, the rolling stock in this section is relatively modern and still has many years of service ahead. The southern section, connecting Tunis to Sousse and Sfax, is meter gauge. While much of the track has been renewed over the past decade, the trains are old, unreliable, and frequently out of service.



(Left) *Figure 2. Northern section between Bizerte and Tunis. .© Authors.*

(Right) *Figure 3. Southern section between Tunis, Sousse and Sfax.. © Authors.*

What both sections have in common is a lack of service offer, which prevents road users from considering rail as a viable alternative. To address this, we proposed tailored solutions for each section, with one common goal: expanding rail services to provide a sustainable transport option. A traffic study was conducted to estimate the potential ridership, allowing us to define a coherent service plan adapted to the specific needs of each part of the corridor.

Table 1. Potential train ridership estimation.

Section	Type of vehicule	Total people transported by road	% modal shift to train depending on initial transport mode	Number of potential new train users	Total per section
Bizerte - Tunis	Private vehicle	25011	5%	1250,55	13187
	Van	7365	5%	368,25	
	Taxis and Shared Taxis	21761	45%	9792,45	
	Bus	8880	20%	1776	
Tunis - Sousse	Private vehicle	119621	5%	5981,05	63072
	Van	35224	5%	1761,2	
	Taxis and Shared Taxis	104078	45%	46835,1	
	Bus	42472	20%	8494,4	
Sousse - Sfax	Private vehicle	19260	5%	963	10155
	Van	5671	5%	283,55	
	Taxis and Shared Taxis	16758	45%	7541,1	
	Bus	6838	20%	1367,6	

Following the diagnostic phase, we identified areas for improvement for each section, with a focus on implementing solutions that can be deployed quickly to efficiently revive the railway corridor.

Table 2. Recap of improvement measures identified after the diagnostic phase

Sections / Current and Proposed Service		Track Gauge / Operating Regime / Electrification	Infrastructure Condition	Rolling Stock	Common and Specific Areas for Improvement
Northern Section	**Section n°1** Bizerte – Tunis 96 km 2 round trips/day	Standard (1435 mm) Single track on 95% of the section Electrification on 15% of the section	Deteriorated	Relatively good condition	- Increase transport service - Strengthen rolling stock maintenance (modernize the Tunis workshop, train staff...) - Infrastructure maintenance work (track renewal, ballast, upgrade to standard gauge with long welded rails...) - Removal of certain level crossings - Securing some level crossings with automatic light signals
Southern Section	**Section n°2** Tunis – Sousse 149 km 4 round trips/day	Meter gauge (1000 mm) Double track on 95% of the section Electrification on 7% of the section	Good condition	Obsolete and deteriorated	- Increase transport service - Electrification of certain areas in view of rolling stock renewal - Rolling stock renewal - Removal of certain level crossings - Securing some level crossings with automatic light signals
	Section n°3 Sousse – Sfax 132 km 4 round trips/day	Meter gauge (1000 mm) Single track on 95% of the section No electrification	Very good condition	Obsolete and deteriorated	

Short term solutions

As highlighted in the diagnostic section, the current SNCFT railway network across the three studied corridors is significantly underutilized. Rather than opting for a complete reconstruction using a "greenfield" approach, we have favored a strategy of upgrading and optimizing the existing infrastructure, following a "brownfield" logic. Additionally, we collected data on traffic levels along Tunisian roads and highways in order to gain a clear picture of current road mobility, and thus better assess the potential modal shift gains for rail transport

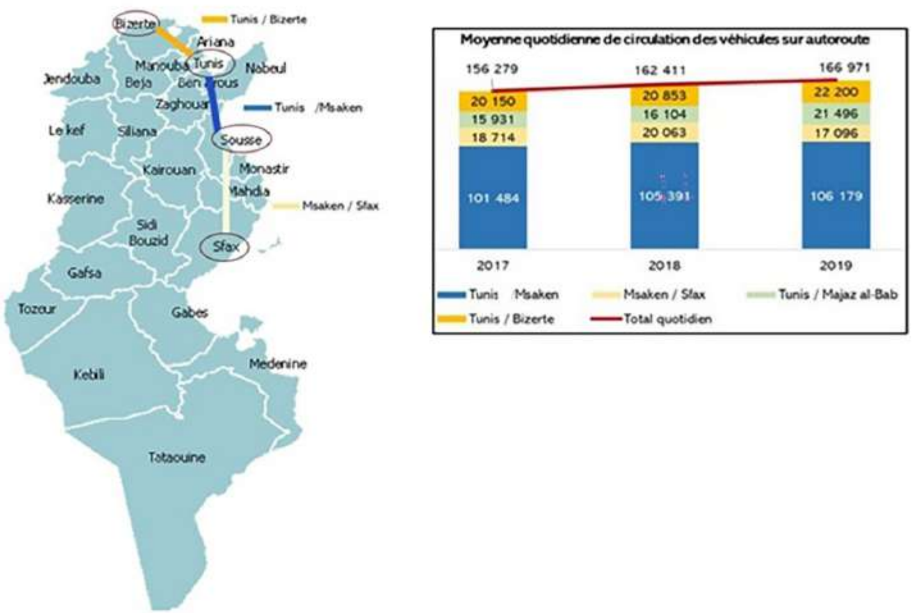


Figure 4. Main highways use and frequency per day in Tunisia. © Authors.

The study provides valuable insights into modal shift intentions, indicating the proportion of people willing to switch to train travel depending on their original mode of transport (private car, bus, shared taxi, etc.). This enabled us to project the potential number of short-term rail users. These results are a key element in sizing the future service offering, both in terms of capacity and frequency.

Bizerte – Tunis Section (Northern Segment)

1. Establishment of the new Service Plan

After evaluating the potential for modal shift from road to rail, we estimated that approximately 13,200 people per day could potentially take the train between Bizerte and Tunis if the rail service were improved. Upon reviewing the current service (only 2 trains per day operate from Bizerte to Tunis), travel times, and the stations served, we observed that the commercial speed is inconsistent and generally low along the northern section. The travel time by car is 1 hour compared to 2.5 hours by train.

We decided to offer a 19-hour operational window, with one train per hour during peak times and one train every two hours during off-peak hours. The first departure is at 5:00 am and the last at 9:00 pm, with the final arrival at 11:59 pm. Both direct and semi-direct trains (serving every other station) are proposed to reduce travel time.

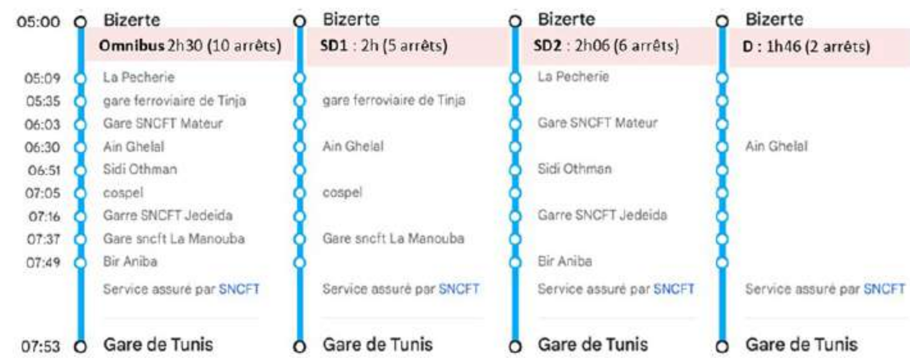


Figure 5. Different railway services proposed for Bizerte – Tunis. © Authors.

The challenge posed by the predominantly single-track layout on this northern section requires special attention to train crossings. Taking into account the infrastructure configuration on the northern section (double track from Tunis to Djedeida and passing loops at the stations in Tunis, Mateur, Tinja, and Bizerte), we were able to adjust the service plan to concentrate crossings at strategic locations, as shown in the space-time diagram in Figure 8. Nevertheless, conflict for trains crossings were identified and marked using colored areas and the numbers 1 to 4, with several modifications to the existing infrastructure being required as a consequence, such as the modernization of the passing loops at Tinja and Mateur stations and the doubling of the single track at the Cospel and Ain Ghelal stations.

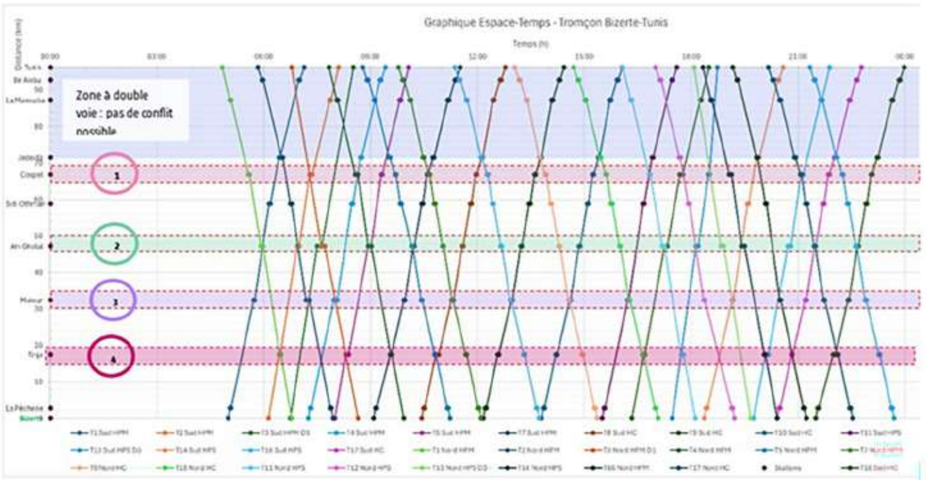


Figure 6. Space-time diagram for Bizerte – Tunis. © Authors.

To implement the proposed service offering, the 12 CSR-brand DMU railcars assigned to the Bizerte–Tunis section, which were put into service in 2012, will be used. Their relative modernity means they retain good operational potential in the short and medium term.

2. Necessary Works for the Elimination and Improvement of Level Crossings

As part of efforts to improve the commercial speed between Bizerte and Tunis, we found it relevant to study the density of level crossings along this section. The objective was to determine whether there is a correlation between their concentration and the commercial speed of trains. An excessive number of level crossings forces the train drivers to reduce speed when approaching these sensitive points.

The construction of a rail bridge between Bizerte and La Pêcherie is planned. A rail bridge is a railway structure that allows a railway line to pass over an obstacle such as a road, river, or another traffic route. This type of structure is commonly implemented as part of level crossing elimination projects, in order to secure intersections between road and rail traffic.

Furthermore, near Tunis—specifically between Djedeida and La Manouba—two level crossings serving residential areas have been identified. Given their usage and the associated risk, securing them requires the installation of SAL 4-type automatic light signaling systems.

Figure 7. Rail bridge creation between Biezerte and La Pêcherie © Authors

Figure 8 Level crossings to be updated to SAL4. © Authors.

Tunis – Sousse and Sousse – Sfax Sections (Southern Segments)

Following the same methodology used for the northern section, we developed a new service plan for the southern section connecting the stations of Tunis, Sousse, and Sfax. Unlike the northern section, the rolling stock currently in service on the southern section presents significant deficiencies and must be progressively replaced in order to meet the requirements of the new services planned as part of the enhanced transport offering.

After several studies and discussions with experts involved in the Master's program, our attention turned to the Continental BEMU rolling stock developed by Alstom, currently in operation in Germany for regional transport services.

Caractéristiques	Information
Model chosen	Alstom Coradia Continental BEMU
Type de propulsion	Train électrique à batteries (Battery Electric Multiple Unit – BEMU)
Autonomie maximale	120 km en mode batterie
Recharge	- En ligne sous caténaire (recharge dynamique à 100 %) - En station de recharge statique
Temps de recharge	Environ 30 minutes (statique ou dynamique, selon les hypothèses actuelles)
Niveau optimal d'usage des batteries	Entre 40 % et 80 % pour prolonger la durée de vie
Avantage principal	Ne nécessite pas d'électrification continue ; peut circuler sur lignes partiellement électrifiées
Coût estimé d'une rame	15 Millions d'euros

The new trains will allow SNCFT to fulfill the proposed service solution, passing from 5 to 16 round trips per day and reducing travel time by 45 minutes between Tunis and Sousse and by 23 minutes between Sousse and Sfax. This times reduction makes using rail services a faster solution than journeys by road. In addition to consistency and reliability, new trains will offer comfort and improved passenger experience for train users in the southern segments. It is also worth remarking that the southern sections are the ones with the highest potential passenger gain as per modeled transport modal shifts (especially the Tunis Sousse section with 63,000 passengers per day).

Figure 9. Alstom Coradia Continental BEMU. © Authors.

The replacement of the rolling stock fleet, currently powered by thermal engines, will require the development of electrical infrastructure to supply energy to the new trains. Partial electrification (to be used with bimodal electric-battery trains) is the chosen solution due to the reduced impact of the electrification project (in terms of CAPEX, environmental footprint, and deployment speed.

With a range of 120 km in electric traction mode thanks to its batteries, the chosen rolling stock appears to be the most suitable for the characteristics of our section, given the distance to be covered without electrification. It requires approximately 30 minutes under catenary to achieve a full recharge, either running or stationary. This charging time, combined with the commercial speed (approximately 73 km/h) on the line, enabled us to estimate the length of track that would be relevant to electrify.

Below is the conceptual electrification diagram we developed, taking the previously mentioned considerations into account:

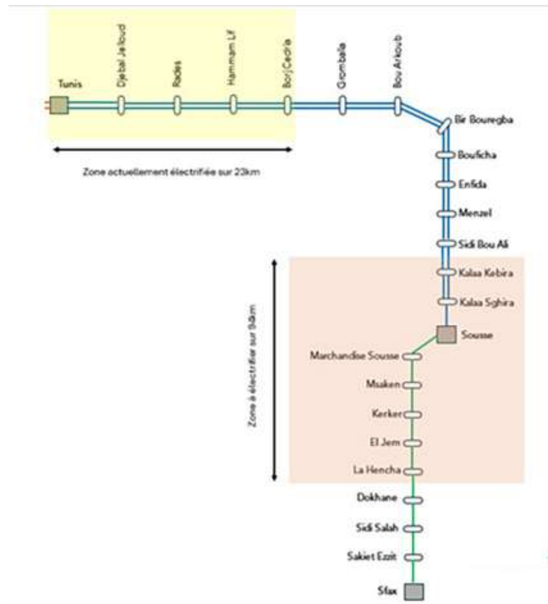
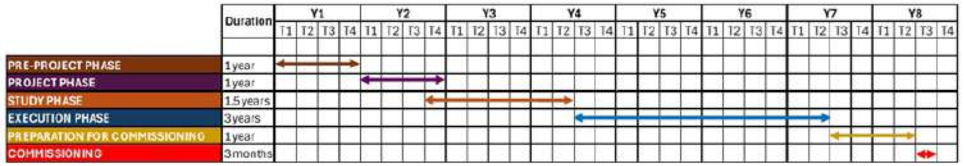


Figure 10. Track electrification diagram. © Authors.

Project Schedule

The implementation of the project is planned over a total duration of 7 years, including 3.5 years for studies, 3 years for construction, and 1 year for testing and commissioning of the new facilities.

Table 3. Project Schedule. © Authors.



Overall project cost

Works on the northern section are estimated at €100.8 million, covering level crossing removal (via SAL 2 and 4 solutions), construction of two engineering structures, track upgrades, and rental of a high-output renewal train. Labor represents around 30% of the base cost. The southern section is estimated at €396.1 million, including level crossing upgrades, engineering works for two passing loops, partial electrification, labor, and the purchase of BEMU trains from Alstom. A 10% contingency has been added to account for risks. The total estimated cost of the project is €546.5 million. It will be partially financed through a Public-Private Partnership (PPP) arrangement covering design, construction, maintenance, and potential operations. Alternatively, funding may be provided by institutions such as AFD, EBRD, or other donors. SNCFT is the contracting authority (MOA) for the project.

Table 4. Overall project cost. © Authors..

Nature of works	Total Price (€)
Total North Section	**100 764 250 €**
Level Crossing Works	5 860 000 €
Track Works	70 275 000 €
Labor (30% of crossing, structure, and track work)	22 840 500 €
High-output Train Rental	1 788 750 €
Total South Section	**396 069 333 €**
Level Crossing Works	1 520 000 €
Structure Works	3 000 000 €
Track Works	9 000 000 €
Partial Electrification (35%)	106 533 333 €
Labor (30% of crossings, structures, tracks, electrification)	34 656 000 €
Acquisition of BEMU Trains	240 000 000 €
Provisions for risks (10%)	**49 683 358 €**
Total Project	**546 516 942 €**

Socioeconomic study

To evaluate the project's economic viability, factors such as passenger forecasts, revised fare structures, SNCFT revenues, projected operations, new operating costs, and infrastructure maintenance were taken into consideration.

At a 4.5% discount rate, the Net Present Value (NPV) is -€221 million, reflecting a lack of direct financial profitability. However, when accounting for social benefits (e.g. consumer surplus, CO_2 emission reductions, noise mitigation, and decreased accidents and mortality) over a 40-year horizon, the NPV turns positive, reaching €38.97 million. This supports the project's justification from a socioeconomic perspective.

Long term solutions

The aim of the previous chapter was to explore short-term solutions to quickly restore rail traffic and passenger interest in using rail services. The following suggestions are to be considered within the next 10 to 15 years to ensure the success of the Tunisian national railway. However, sustainable execution and consolidation of the short-term solutions - explained in the following chapter - are necessary to permit long-term solutions efficiency.

Global railway electrification

The full electrification of the main railway line from Bizerte to Tunis is a key requirement to ensure high performance on this strategic corridor. Investing in catenary electrification is both necessary and strategic for the success of the project. Electricity demand will significantly increase with the operation of the line. For example, SNCF has improved its energy autonomy by installing photovoltaic panels on its buildings. Tunisia benefits from high and consistent solar exposure throughout the year, which presents an opportunity to reduce dependence on energy imports and promote renewable energy sources. Moreover, four solar energy production areas are currently under development in Tunisia.

Electrification should first be prioritized on the southern section of the line, due to its higher passenger density. This would reinforce the limited electrification already implemented in the area as part of the short-term solution. If the new transport service proves successful in the short term, the northern section of the line will also be electrified. Electrifying the line will enable optimization of the rolling stock and support its technological evolution. Hybrid Continental BEMU trains currently operating on the southern section could be converted from battery-powered to catenary electric traction during mid-life maintenance. The space freed up by removing the batteries could be repurposed to improve passenger comfort and increase train capacity.

Replacement of trackside signaling

The Bizerte–Sfax corridor is currently underutilized due to the presence of various types of signaling systems that limit the line's operational capacity. Sections still operating with manual block signaling (shown in red in Figure 7) will be upgraded to Automatic Block Signaling (BAL) to increase train frequency by 60% through shorter block sections. This modernization of the signaling system could be carried out in parallel with the track doubling works.

The double-track sections currently equipped with Automatic Block Signaling (shown in orange in Figure 7) will be modernized through the installation of the European Rail Traffic Management System (ERTMS). This system transmits signaling information directly to the driver's cab using trackside balises and radio communication. According to the French Railway Safety Authority (EPSF), this upgrade can increase line capacity by 30 to 40% by reducing the interval between trains.

The combination of these two signaling upgrades will make it possible to offer an alternative to private car use.

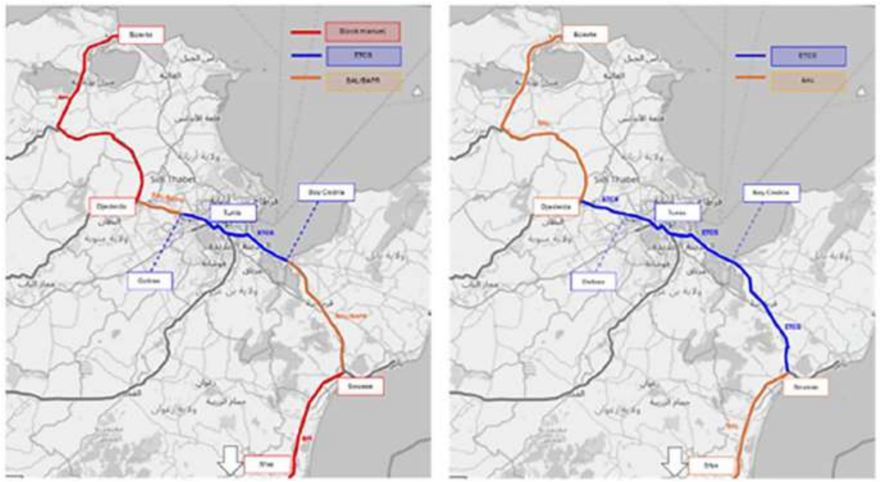


Figure 11. Different types of signaling blocks between Bizerte and Tunis (current version on the left, after modernization on the right). © Authors.

Opening up the extension to Gabès

With the aim of further developing the project to rehabilitate the railway line between Bizerte and Sfax, it seemed relevant to us to propose the extension of this modernization program to the city of Gabès. The fifth largest urban area in the country by population and experiencing substantial demographic growth, Gabès asserts itself as a major urban center on the Tunisian coast, similar to Tunis, Sfax and Sousse.

It is also a leading industrial hub, largely thanks to its port, which occupies a strategic position in the export of phosphates to southern Europe. The modernization of the rail service to this city would offer a real opportunity to boost trade, while improving the competitiveness of the railway facing the highway linking Gabès to Sfax, currently much faster (1h 50 min by road compared to 2h 45 min by train).

The modernization of this railway axis would also facilitate the relaunch of freight transport, in particular the transport of phosphate extracted in the Gafsa region, currently transported for the most part by road. This modal shift towards rail would meet several challenges identified in our diagnosis, particularly the reduction of road accidents, a priority objective in view of national data.

Statistics show that most road accidents in Tunisia involve heavy vehicles, whose consequences are often particularly serious. The development of rail freight would thus contribute to securing road infrastructure by desaturating the road network.

Finally, the proximity of Gabès to the Libyan border makes it a strategic crossing point for future exchanges between Tunisia and Libya. In a context where a railway line project towards the Libyan border is being planned, the extension to Gabès would be part of a long-term vision of regional rail connectivity, serving the revitalization of the Maghrebian economy.

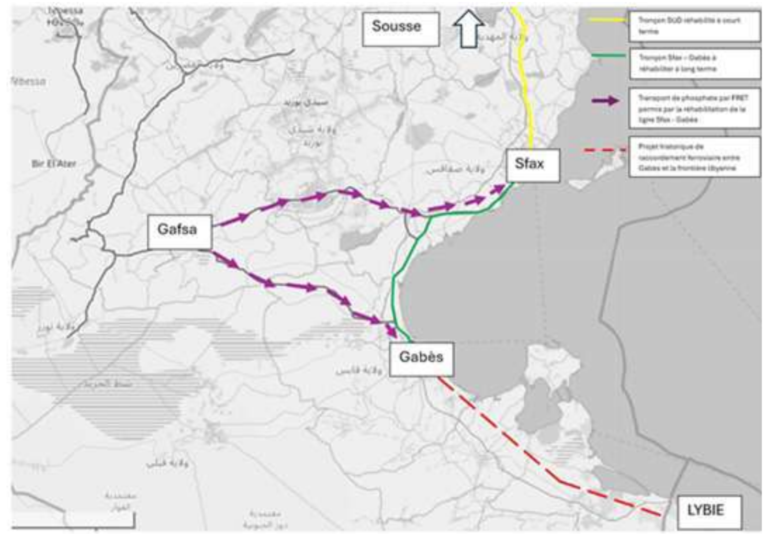


Figure 12. Diagram representing the resumption of phosphate transport by FRET from Gafsa resulting from the rehabilitation of the line to Gabès. © Authors.

Rehabilitation of the railway corridor

Conclusion

By implementing our project to rehabilitate the railway line linking Bizerte to Sfax, and with a view to its extension to Gabès, we affirm our ambition to provide Tunisia with a railway infrastructure capable of meeting its economic, social and environmental challenges.

This project is fully in line with the logic of network modernization, by focusing on the electrification of the line, the renewal of rolling stock, as well as a revised fare offer to meet user expectations. All these measures are aimed at enhancing the reliability and attractiveness of rail transport, while encouraging a modal shift of freight and passengers towards a safer and more environmentally friendly mode of transport.

By significantly improving the competitiveness of rail compared to road transport, this project contributes to a desaturation of the road network, reducing accidents and supporting a sustainable economic dynamic for the territories served.

Finally, through opening up the network to serve Gabès and the prospect of a future connection to the Libyan border, this modernization program is part of a long-term vision of improved regional rail connectivity, facilitating the integration and development of the entire Maghreb region.

La promotion 2024-2025

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SNCF

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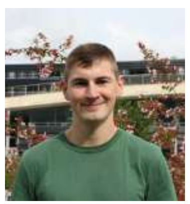

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STRMTG (KEOLIS)

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RATP

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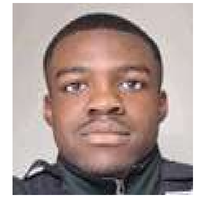
KEOLIS

NOTIO TAFOMPA Fritz Donald
MASTERIS



POATY Ohmcel
SNCF Voyageur

POULET Freddy
ALSTOM

ROCHE Thibaut
Transdev

RODRIGUEZ Lucia
SNCF

SACKO BA Fatoumata
SNCF

TAING Leang
RATP

TAUPENAS Vincent
SNCF

Le voyage d'études en Autriche et Allemagne
The study trip in Austria and Germany

Du 12 au 16 mai 2025, les étudiants de la 17e promotion du Mastère spécialisé des Systèmes de Transports Ferroviaires et Urbain (2024–2025) ont effectué un voyage d'étude en Autriche et en Allemagne. L'objectif de ce voyage était de découvrir les briques du système ferroviaire et de transport urbain des deux pays. Le groupe était accompagné de M. Federico Antoniazzi, Directeur du Mastère Spécialisé, et de M. Didier Derks, Responsable de Mastère pour l'INSA des Hauts-de-France. Après un long mais agréable voyage en train de nuit de Paris à Vienne, le groupe a débuté son expédition par une visite du siège et des installations de production de Plasser & Theurer, un fabricant autrichien de machines d'entretien et de pose de voies ferrées. Le rendez-vous comprenait une présentation de l'entreprise, mettant en avant sa vision et ses innovations, suivie d'une visite guidée de l'atelier de construction. Les étudiants ont ainsi pu découvrir les technologies d'avenir en matière de construction et d'entretien de l'infrastructure.

Le lendemain, en empruntant le réseau de transport public viennois, le groupe s'est rendu à Rail Tec Arsenal (RTA). Cet institut de recherche et d'essais indépendant, reconnu à l'international, est spécialisé dans les tests des véhicules ferroviaires, routiers, aériens ainsi que tout équipement technique qui pourrait être soumis à des conditions climatiques extrêmes. À leur arrivée, les étudiants ont été chaleureusement accueillis par les représentants de l'entreprise, qui leur ont présenté la mission, les activités et les installations de RTA. L'un des moments forts de la visite fut la découverte d'une soufflerie impressionnante, préparée pour un test à -20°C, permettant aux étudiants de comprendre comment RTA peut garantir la fiabilité et la sécurité des systèmes de transport en simulant des conditions climatiques pouvant varier de -45°C à +60°C et avec un vent pouvant aller à 300 km/h.

La visite s'est poursuivie au dépôt de tramways de Favoriten. Après une présentation générale sur la capacité, l'infrastructure et l'organisation du dépôt, les étudiants ont eu l'opportunité unique d'expérimenter une manœuvre de marche arrière d'un tramway et d'observer de près le processus de lavage des rames. Cette expérience pratique leur a permis de mieux comprendre comment le fonctionnement fluide du système peut permettre d'assurer la qua-


Sonderzug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lité du service offert aux usagers. La journée s'est conclue par une visite au siège de Wiener Linien, l'entreprise qui gère la majorité du réseau de transport public de Vienne. Une présentation complète de l'entreprise et des caractéristiques clés du système de transport viennois a été suivie d'un échange enrichissant entre les étudiants et le représentant de Wiener Linien, afin de comparer les pratiques et les valeurs opérationnelles avec celles de leurs propres pays. Ensuite, l'attention s'est portée sur le projet de construction des nouvelles lignes de métro U2 et U5.

Les étudiants ont pu en apprendre davantage sur le budget, les défis majeurs et les bonnes pratiques liées à ce projet ambitieux.

Le troisième jour, le groupe a pris le train en direction de Munich, profitant de paysages magnifiques tout au long du trajet. La destination était le site de l'exploitant Transdev, un opérateur ferroviaire majeur dans la région de Bavière. Lors de cette visite, les étudiants ont découvert le réseau exploité par l'entreprise en Bavière, sa capacité opérationnelle actuelle, les difficultés du réseau allemand ainsi que des cas concrets de son infrastructure. Une présentation a également été consacrée à l'engagement de Transdev en faveur de la mobilité verte en Allemagne, mettant en lumière leur vision d'un avenir plus durable avec le transport ferroviaire. Cette visite enrichissante a marqué la dernière étape du voyage d'étude. Le groupe est rentré à Paris avec de nouveaux savoirs, une perspective internationale élargie et des souvenirs inoubliables de cette expérience collective et éducative unique.

F**ROM** *May 12th to 16th, 2025, the students of the 17th promotion (2024–2025) of the Executive Master in Railway and Urban Transport System Engineering embarked on a rail study trip to Austria and Germany. The goal of this trip was to explore the key components of the railway and urban transport systems in both countries. The group was accompanied by Mr. Federico Antoniazzi, Director of the Specialized Master's program, and Mr. Didier Derks, Program Manager at INSA Hauts-de-France.*

After a long but joyful overnight train journey from Paris to Vienna, the group began their expedition with a visit to the headquarters and production facilities of Plasser & Theurer, an Austrian manufacturer of railway track construction and maintenance machines. The visit included a company presentation highlighting its vision and innovations, followed by a guided tour of the construction workshop. The students were introduced to cutting-edge technologies in infrastructure construction and maintenance.

The following day, using Vienna's public transport network, the group visited Rail Tec Arsenal (RTA). This internationally recognized, independent research and testing institute specializes in testing railway, road, and air vehicles, as well as technical equipment under extreme climatic conditions. Upon arrival, the students were warmly welcomed by company representatives who presented RTA's mission, activities, and facilities. A highlight of the visit was the impressive wind tunnel, prepared for a -20°C test, demonstrating how RTA

ensures the reliability and safety of transport systems by simulating conditions ranging from -45°C to +60°C with wind speeds up to 300 km/h.

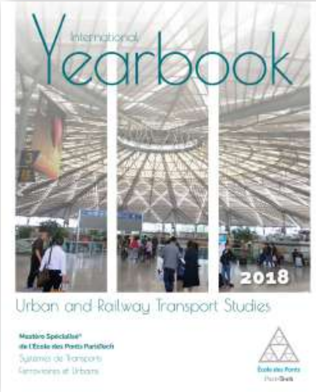
The visit continued at the Favoriten tram depot. After a general presentation on the depot's capacity, infrastructure, and organization, the students had the unique opportunity to experience a tram reversing maneuver and observe the train washing process up close. This hands-on experience helped them better understand how smooth operations contribute to high-quality service for passengers. The day concluded with a visit to the headquarters of Wiener Linien, the company managing most of Vienna's public transport network. A comprehensive presentation of the company and the key features of Vienna's transport system was followed by a rich exchange between the students and a Wiener Linien representative, comparing operational practices and values with those in their home countries. The focus then shifted to the construction project of the new U2 and U5 metro lines. The students learned more about the budget, major challenges, and best practices related to this ambitious project.

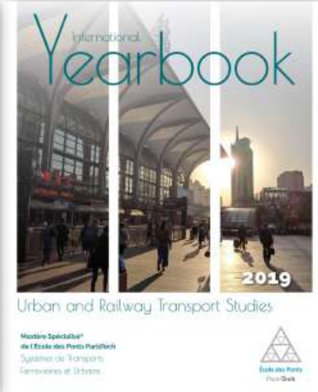
On the third day, the group took a train to Munich, enjoying beautiful landscapes along the way. The destination was the site of TRANSDEV, a major railway operator in the Bavaria region. During this visit, the students explored the network operated by the company, its current operational capacity, the challenges of the German network, and real-life examples of its infrastructure. A presentation also highlighted Transdev's commitment to green mobility in Germany, showcasing their vision for a more sustainable future through rail transport.

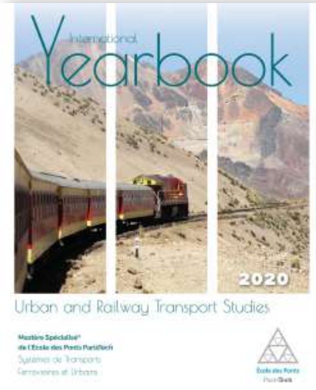
This enriching visit marked the final stage of the study trip. The group returned to Paris with new knowledge, a broadened international perspective, and unforgettable memories from this unique collective and educational experience.

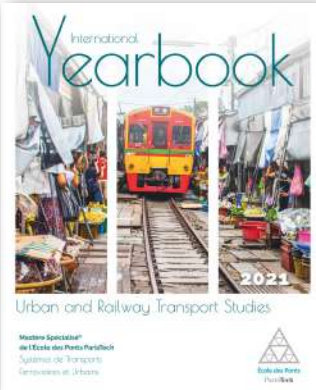
Sujets des précédents Yearbooks

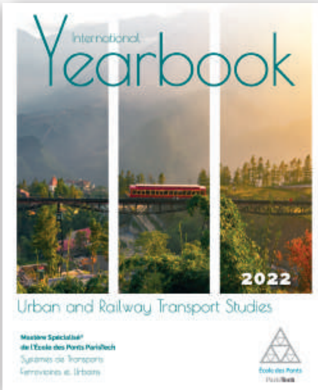
Previous Yearbooks contents

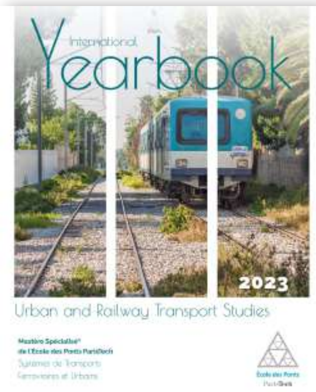


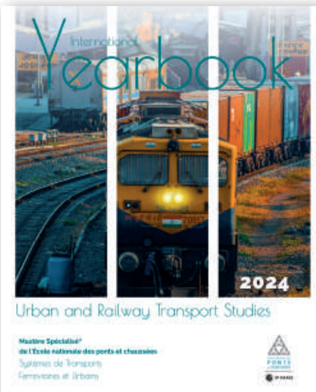












Yearbook 2016-2017

- 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

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- Implementing a Bus Rapid Transit system in Lusaka, Zambia
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Yearbook 2021

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- New Railway line in Indochina
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- Railway Connection between Java and Sumatra (Indonesia)
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- Designing one or more tramway lines for the city of Vadodara (India)

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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.*).

170 000 ouvrages et revues de référence, dont des ressources en ligne — ebooks, revues scientifiques et bases de données spécialisées, sont disponibles et complétés par un riche patrimoine de 80 000 documents accessibles sur demande. Les étudiants bénéficient de sessions de formation aux ressources et aux outils documentaires intégrés aux cursus.

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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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 2025 ont été regroupés dans cet ouvrage afin de donner un aperçu de leur qualité et de leur technicité. Cette année, trois groupes d'élèves se sont penchés sur le développement de liaisons ferroviaires intra-urbaines, à travers l'étude d'un service de type RER dans la capitale du Zimbabwe (Harare) ; la modernisation du tramway de Lviv en Ukraine ; et le développement d'un tramway à Denpasar (Bali, Indonésie). Deux autres groupes se sont intéressés à de nouveaux services ferroviaires de voyageurs (Trans-Tunisie), ou combiné avec du transport de fret minier (Namibie), en appréhendant les besoins en infrastructures et matériels roulants. 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 2025 studies have been gathered in this book to give an overview of their quality and technicality. This year, three groups of students focused on the development of intra-urban rail links, through the study of an RER-type service in the capital of Zimbabwe (Harare); the modernization of the tramway in Lviv, Ukraine; and the development of a tramway in Denpasar (Bali, Indonesia). Two other groups focused on new passenger rail services (Trans-Tunisia) or combined passenger and mining freight transport (Namibia), assessing infrastructure and rolling stock requirements. 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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