

Y^{International}earbook



2023

Urban and Railway Transport Studies

**Mastère Spécialisé®
de l'École des Ponts ParisTech**

Systèmes de Transports
Ferroviaires et Urbains



URBAN AND RAILWAY TRANSPORT STUDIES'
INTERNATIONAL YEARBOOK
2023

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Écoles partenaires



Remerciements

Le MS® STFU remercie chaleureusement Alstom, Bombardier, SNCF, RATP, Siemens et Hitachi, les partenaires fondateurs de la formation.

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Urban and Railway Transport Studies' International Yearbook **2023**

Mastère Spécialisé® de l'École des Ponts ParisTech
Systèmes de transports ferroviaires et urbains



École des Ponts
ParisTech

DÉPUIS sa création en 1747, l'École des Ponts ParisTech 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 des Ponts ParisTech 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
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ParisTech's



**Federico
ANTONIAZZI**

Directeur du Mastère
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*Director of the Railway
and Urban Transport
System Engineering
Advanced Master®*

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

Cette étude porte sur un projet nouveau qui n'a pas été déjà étudié par le passé. Ainsi, les sujets sont choisis depuis 8 ans en collaboration avec l'Agence française de développement (AFD) et concernent des transports de masse dans les grandes mégapoles en voie de développement ou des pays que la Banque mondiale et les autres bailleurs de fonds accompagnent dans leur reconstruction. Mais les étudiants ne se rendent pas sur place. Ils sollicitent le vaste réseau des experts, des ambassades, des institutions financières, utilisent au maximum des ressources documentaires sur le web et... leur débrouillardise.

Pour la promotion 2023, l'AFD nous a proposé des projets situés en Asie, au Maghreb et dans les Caraïbes. Deux groupes ont travaillé sur des liaisons ferroviaires à l'échelle nationale : l'une à Cuba, l'autre entre Manille et San Fernando, aux Philippines. Les autres projets proposent des solutions de transport en milieux urbains : la création d'un métro à Khulna (Bangladesh) ; l'extension d'une ligne de métro (L2) existante à Tunis ; le prolongement de la ligne du métro du Sahel dans l'agglomération de Sousse (Tunisie). Du fait de leur qualité indéniable, certains de ces projets seront même présentés par Antoine Chèvre, expert transport auprès de l'AFD, aux agences des pays concernés.

Vous pourrez en parcourir les résumés dans ce *Urban and Railway Transport Studies' Yearbook*. Nous espérons que, tout comme les ambassades, les villes et les gouvernements qui nous demandent la diffusion de ces études, vous serez sensibles à la qualité de ces travaux. En vous souhaitant bonne lecture et bon voyage entre Cuba, Sousse, Tunis, Khulna et Manille...

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

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

For the 2023 class, together with the AFD, we have selected projects spanning three continents: Asia, North Africa and the Caribbean. Two groups worked on nationwide rail links: one in Cuba, the other between Manila and San Fernando in the Philippines. The other projects propose transport solutions in urban environments: the creation of a metro in Khulna (Bangladesh); the extension of an existing metro line (L2) in Tunis; the extension of the Sahel metro line in the Sousse conurbation (Tunisia). Due to their undeniable quality, some of these projects will even be presented to agencies from the relevant countries by Antoine Chèvre.

Their summaries are at your disposal in this Urban and Railway Transport Studies' Yearbook. We hope that, just like the embassies, cities and governments asking us to spread these studies, you will see just how interesting they are. We wish you a pleasant read and a good trip to Cuba, Sousse, Tunis, Khulna and Manila ...

Federico Antoniazzi
Françoise Manderscheid



**Françoise
MANDERSCHIED**
Responsable du
module C3
C3 module teacher

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

Le mastère a été créé en 2008 pour pallier la pénurie d'experts ferroviaires pour la RATP, la SNCF, Alstom, Siemens, etc. Cette formation propose une vision d'ensemble du système ferroviaire et urbain, selon une approche multidisciplinaire, intégrant les aspects techniques, économiques et réglementaires. 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.

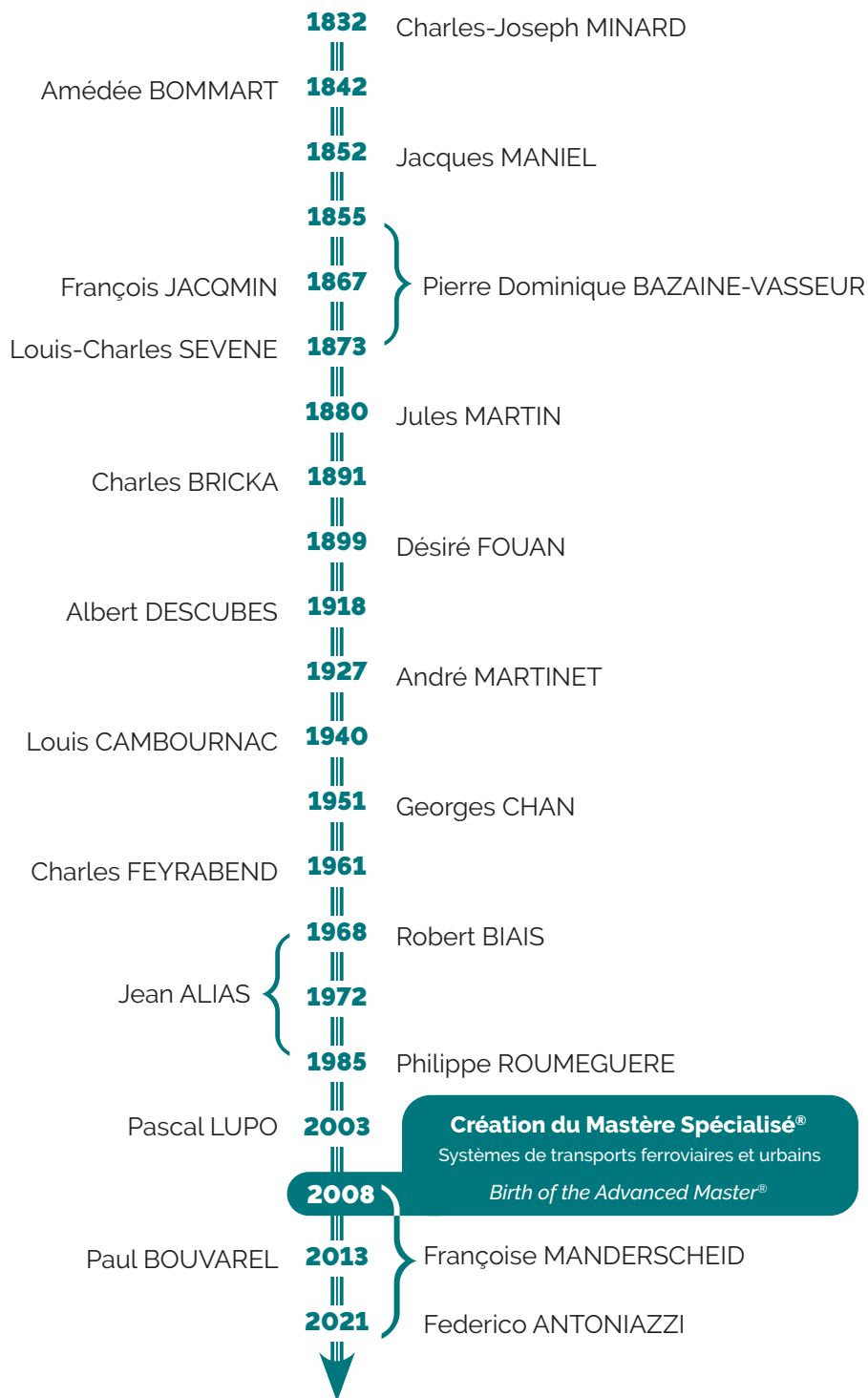
Nearly 160 professionals teach and supervise students on collective projects. The training course relies heavily on those: the design of an infrastructure, of a signalling plan or of rolling stock. Moreover, the students work along the year on a new transport system in a foreign country; the summary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

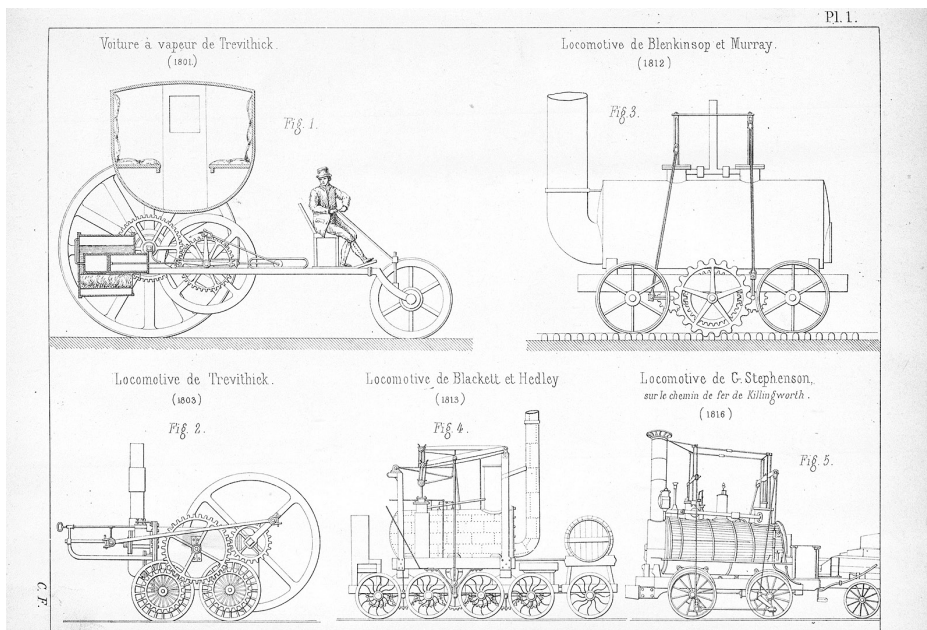
The Advanced Master® gives students the recognized title of "International Experts in Railway and Urban Transport Systems". In the same class, there are design or maintenance engineers, operating or signalling experts, system engineers, economists, project managers... Today, the alumni form a network 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.

Federico Antoniazzi

Enseigner le ferroviaire à l'École

Railway classes at the École





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.

La longueur exacte du tracé, en y comprenant les gares d'attache de Charlottenburg et de Nîmègue, est de 12,145 mètres.

Cette longueur au point de vue de l'infrastructure se subdivise en 7,964 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.

Station de Friedrichshagen.

Conditions du tracé.

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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La Source, diffuseur de savoirs
La Source, spreading knowledge

Rehabilitation of rail transport in Cuba



Clément BOLLENGIER
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École des Ponts
ParisTech

Cuba possède un héritage ferroviaire important : de nombreuses lignes couvrent la majorité du territoire. Néanmoins, le réseau – tout comme les trains – souffrent d'un manque important de maintenance. Les levées des sanctions américaines pouvant être espérées dans un futur proche, plusieurs pays s'intéressent aux opportunités de développement ferroviaire de l'île. La présente étude s'intéresse particulièrement au raccordement du port de Mariel, situé à 65 km de la capitale La Havane. Ce port, aujourd'hui exploité au tiers de sa capacité, pourrait devenir la porte d'entrée des flux de marchandises qui transitent dans la région une fois les sanctions levées. Cette étude présente succinctement les choix techniques que comportent le lancement d'un tel projet, au travers de la réhabilitation des sections du réseau existant, au travers de la création d'une nouvelle ligne ferroviaire ou encore de l'acquisition d'un nouveau matériel roulant. Enfin, une étude portant sur le montage de projet est proposée.

Mots-clés : fret, logistique, réhabilitation, pendulaire, Mariel

Cuba boasts a strong railway heritage, with numerous lines covering most of the country. Nevertheless, the network – like the trains – suffers from a serious lack of maintenance. With the lifting of US sanctions expected in the near future, a number of countries are paying increasing attention to the island's railway opportunities. This study focuses on the operation of the port of Mariel, located 65km from the capital, Havana. This port is currently operating at a third of its capacity, but could become the gateway for future goods flows in transit in the region once the sanctions are lifted. Technical solutions have been studied, including not only the rehabilitation of sections of the existing network and the creation of a new railway line, but also the acquisition of new rolling stock. Finally, this paper gives a quick overview of the project plan.

Keywords: freight, logistic, rehabilitation, commuter, Mariel

Introduction

The island of Cuba is located in the Caribbean and has the densest (7.6km/100km²) and most coherent rail network in Central America. However, this network is very old, due to a lack of investment following the collapse of the Soviet Union in 1990. Our study focused on the rehabilitation of this network in the light of the lifting of US sanctions.



Figure 1. Tren Francés (Cuba) route map, © D-øg, 5/10/2014, CC BY-SA 3.0 (source : Wikimedia Commons).

We started by a diagnosis of the country's railway situation and of the different modes of transport operated on the island. Then we identified several railway projects of interest for the country. Finally, we focused on a specific project, detailing the infrastructure, technical choices and project set-up required to complete it.

1. Overview of Cuba

This 1,200km-long island is mainly made up of plains, with a tropical savannah climate, forming a territory that is suitable for railway activity. The island's economic situation is highly complex: US sanctions prevent the island from doing business with companies buying properties previously owned by US citizens.

Only the island's neighbors, such as Venezuela or few communist countries such as Russia and China, trade with Cuba on a regular basis. Many of the country's youngest inhabitants are exiled, and the lack of activity and geopolitical climate with the United States are holding back the island's development.

2. Main goals of the project

2.1. Railways, a major asset for the development of the country

Cuba's railway system is in dire need of rehabilitation, given the lack of investment in recent decades. To remedy this situation, in 2015 the Cuban government launched a vast national plan for economic and social development through to 2030 (PNDES 2030). Among the objectives, the rehabilitation of rail transport was announced, including a major project supported by Russia to speed up renovation of Havana station and modernize the central line crossing the island from east to west.

This project alone cannot restore Cuba's railway system, however. The island's economic development would also benefit from the rehabilitation of the line between the port of Mariel and the rest of the island. In fact, Mariel is now seen as the Caribbean's leading "mega-port", due to its proximity to the Panama Canal and the significant flows of ships. The potential development of port activities – should US sanctions be lifted – would therefore be huge, given that the port is currently only operating at 30% of its maximum capacity.

This economic development would be followed by an explosion in the traffic of goods that would triple the number of containers transported by train from Mariel to the rest of the island.

In this context, rail freight, which currently accounts for 30% of the island's transport of goods, would have a major role to play.

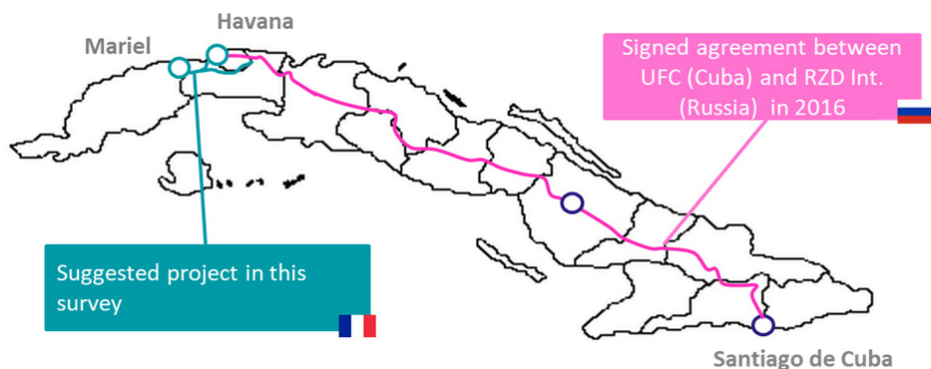


Figure 2. Railway projects in Cuba

© Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

While the perspectives for an explosion in rail freight traffic seem obvious, the development of the port of Mariel would also generate an increase in direct and indirect employment in the port area, and thus a need for more trains between Havana and the port.

2.2. Modernizing the line between the Port of Mariel and the rest of the island

After its creation in 2014, the line between the port of Mariel and the rest of the island is already in poor condition. Infrastructure maintenance is not done properly, and the network is deteriorating quickly. As a consequence, traffic speeds are quite low (limited to 30 km/h in urban areas due to the presence of numerous level crossings).

In addition, signaling requires the intervention of staff on the ground, which also drastically limits the traffic (around 20 trains per direction per day).

Finally, although the port of Mariel has a rail-connected terminal equipped with two container cranes, it does not seem to offer enough capacity to support the development of rail freight transport in the future.

Rehabilitation of the section between Mariel and the rest of the island is therefore critical to absorb the increase in maritime and passenger traffic, and contribute to the island's sustainable development objectives.

3. Increased traffic expected when sanctions are lifted

Considering the lifting of US sanctions, the quantities imported into the island and the modal share of rail transport, we estimated future transport needs. Firstly, for freight transport, where the total estimated need is 24 trains departing from Mariel and bound for the country's major logistics hubs. Some of these trains will go to Havana, but most of the traffic will have to bypass the country's capital.

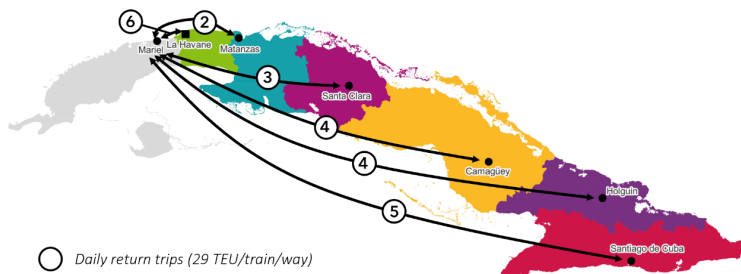


Figure 3. Projected freight traffic between the port and logistics zone © Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

The increase in the volume of imported goods arriving in Mariel from abroad will have a significant impact on the number of employees needed to operate the port and the business zone. We therefore estimate that the volume of passengers on the Havana – Mariel rail link should increase to reach a PPHPD of 4.444. The operating service range will then have to be extended and adapted to permit workers to commute at any time of day. The city center will then be linked to the port of Mariel in less than 45 minutes, with a peak hour departure frequency of 15 minutes. Finally, other services will continue to use the Havana – Mariel line network.

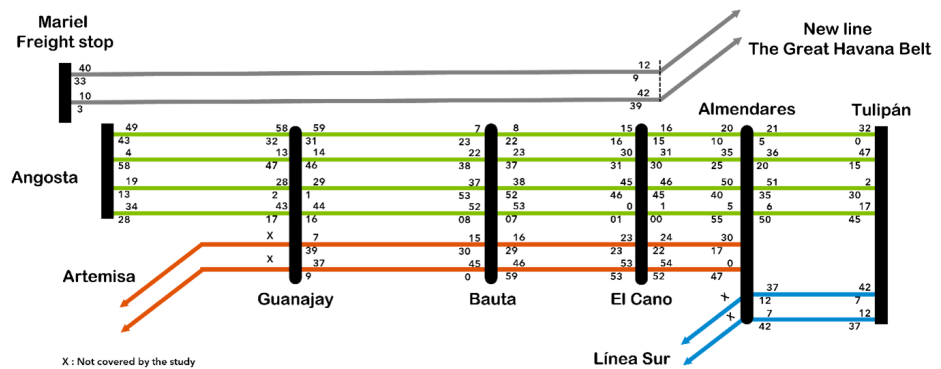


Figure 4. Suggested netgraph © Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

4. Project scenarios

Currently, the freight railway connection between the Port of Mariel and the eastern part of Cuba passes through the city center of Havana. This results in significant traffic congestion due to numerous level crossings and tight curves in the railway infrastructure. To address these issues, it is necessary to propose alternatives that would improve traffic flow in downtown Havana.

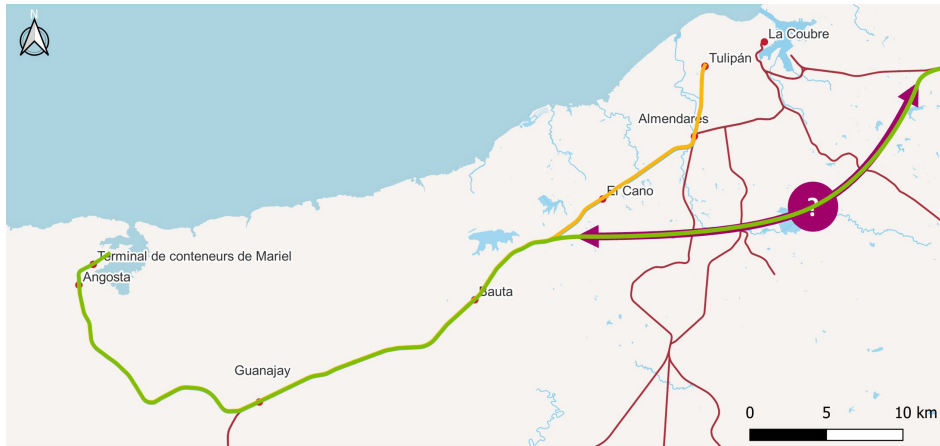


Figure 5. Mariel - Havana railway link and suggested bypass

© Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

Within the scope of this project, three alternatives have been put forward and compared thanks to a multicriteria analysis to determine their relevance.

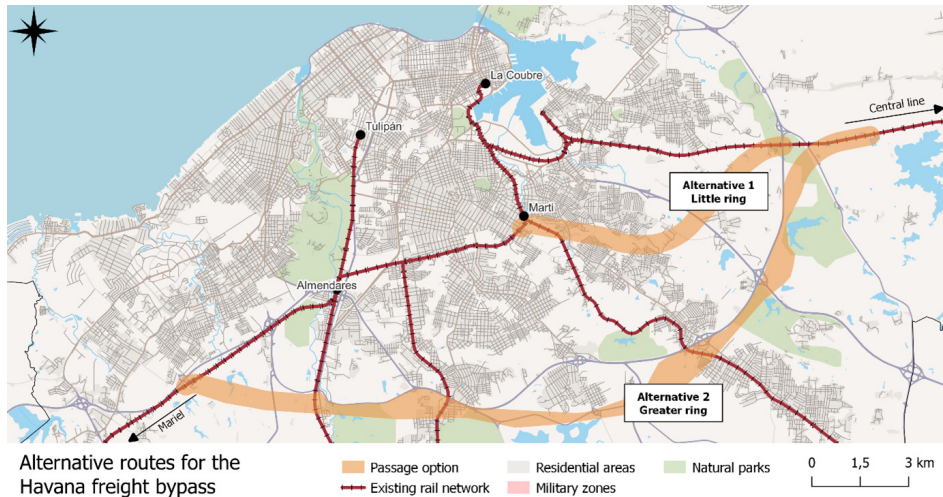


Figure 6. Alternative routes for the Havana freight bypass © Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023 (map data: OpenStreetMap contributors, CC BY-SA).

The first alternative, known as "Alternative 0", involves upgrading the existing infrastructure without any changes to the current alignment. This option has the same

operational constraints associated with the existing trainway. The second alternative, "Alternative 1", involves partial utilization of the existing infrastructure while creating a new connection to the central line through the urban areas of Havana. The third alternative, "Alternative 2", proposes the creation of a railway belt around Havana following the route of the current highway. In terms of operational efficiency, this last alternative appears to be the most suitable, although it would be more expensive.

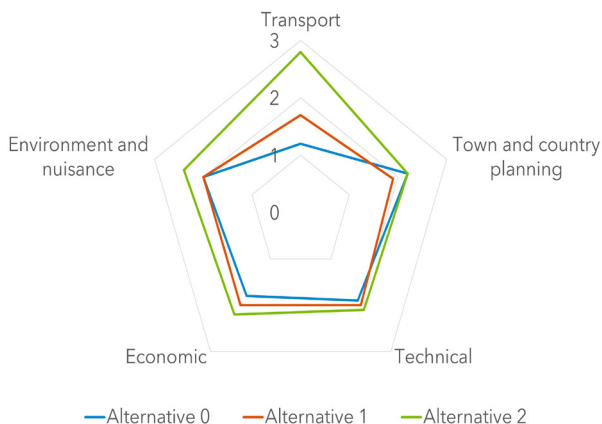


Figure 7. Multicriteria evaluation

© Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

The multicriteria evaluation has shown that the best choice in all aspects is Alternative 2, also called the "Greater ring" bypass. This option involves creating a railway belt around the city.

Another challenge addressed in the project scenarios to improve the railway connection between the Port of Mariel and the eastern part of Cuba is the lack of electrification on the railway line. Due to the island's inability to provide continuous power supply, electrification has never been considered. However, in the event of the lifting of the US sanctions, it is easy to imagine that the island will develop a stable electrical network offering electricity for train operations. This scenario is all the more desirable insofar as the Cuban government is committed to achieving greener and more sustainable economic growth.

After a comprehensive multicriteria analysis, we demonstrated that complete electrification of the railway network would contribute to the development of a more efficient and environmentally-friendly transportation system.

	NON ELECTRIFICATION	FULL ELECTRIFICATION
IMAGE & REPUTATION	Unchanged	 Modernity Nuisances
ENERGETIC EFFICIENCY	Unchanged	 Efficiency Power to mass
FEASIBILITY	Unchanged	 Few constraints
RELIABILITY	Unchanged	 Good reliability  Risk of cuts
DECARBONATION	Unchanged	 Energy mix
INVESTMENT COSTS	 Expansion of stations	 Massive Investments
OPERATING COSTS	 Unchanged rolling stock	 Energy mix
VANDALISM	Unchanged	 Vandalism risk

 Evolution if the embargo is lifted

Figure 8. Multi-parameter analysis

© Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

5. Technical choices

5.1. Infrastructure

We have seen that it is crucial to undertake a comprehensive renovation project that includes replacing the track ballast along the entire line and upgrading the sleepers, especially on the Almendares-Tulipan section, which is in the worst state.

To improve operational efficiency, it is essential to replace the current manual track switches with hydraulic ones. Ensuring safety on the railway system requires expanding the existing right-of-way and installing fences to secure the tracks.

In anticipation of future passenger demand, there are plans to expand both Tulipan and Almendares stations and equip all the stations along the train route.

Additionally, safety measures will be implemented to protect users, such as enhancing level crossings.

To accommodate the expected increase in traffic at the Port of Mariel, it will be necessary to expand the Angosta freight yard and construct a new container crane.

Furthermore, to facilitate the storage of goods traveling to and from foreign destinations, two storage centers will be established: one within the Port of Mariel area and another located along the new railway line, close to the central line. By implementing these upgrades and expansions, the railway system will be better equipped to meet the needs of passengers and support the anticipated growth in freight transportation, ensuring smoother operations and improved overall efficiency.

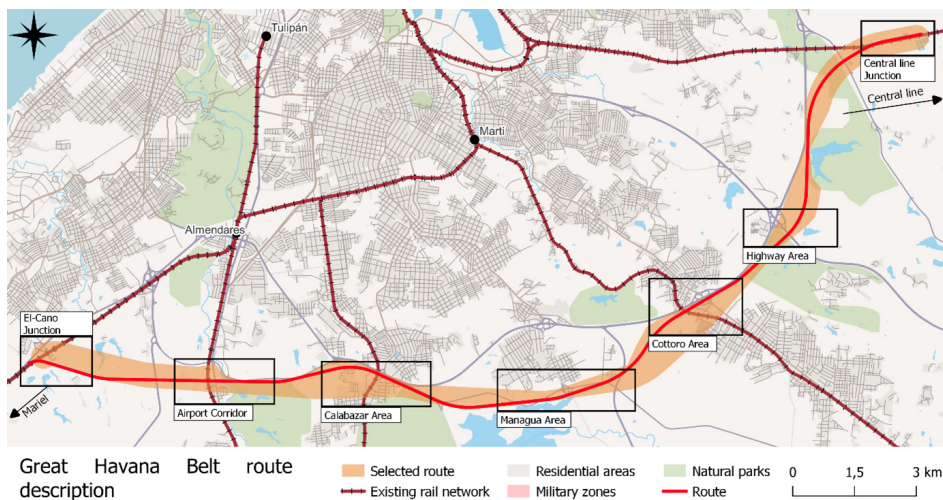


Figure 9. Great Havana belt route description © Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023 (map data: OpenStreetMap contributors, CC BY-SA).

For the new "Greater Ring" railway line, the alignment considers STI regulations, and it is planned to construct a double-track line with concrete sleepers and ballast to ensure continuity with existing railway lines. To prioritize safety and prevent accidents, level crossings are strictly prohibited along the trainway. The railway line is connected to the central line and the Almendares-Mariel line through flying junctions, a design choice made to maintain operational efficiency that would be difficult to achieve with intersecting tracks. The new line passes through five critical areas, including the Airport Corridor and the densely populated Cotorro Area. It is essential to make appropriate technical choices to minimize the impact on the existing environment. Careful consideration will be given to ensure that the construction and operation of the railway line

have the least possible negative effect on these sensitive areas. By adhering to these guidelines and incorporating environmentally conscious practices, the new "Greater Ring" railway line will provide a seamless connection with existing rail networks while prioritizing safety and minimizing disruption to the surrounding environment.

For both the rehabilitated line and the new railway line, the deployment of ETCS Level 2 is planned. This system will incorporate axle counter train localization. To effectively manage the traffic, a centralized control post will be established in Havana.

5.2. Rolling stock

The rolling stock currently used by the line's operator, Ferromar, is no longer consistent with the needs of the project. It is composed of locomotives operating at 80km/h and pulling freight wagons and vehicles dedicated to passengers. We recommend the introduction of a fleet of locomotives for freight services and the acquisition of a fleet of high-capacity EMUs for passenger services.

The locomotives will be dual mode, enabling the full potential of the electrified line to be exploited for freight transport. We believe it is necessary to use a second source of energy to provide a complete service to the island of Cuba, and we therefore recommend the use of a diesel engine. Regarding the EMU fleet concerned, we are suggesting the installation of a 100% electric double-decker train with a capacity of 1,300 passengers.

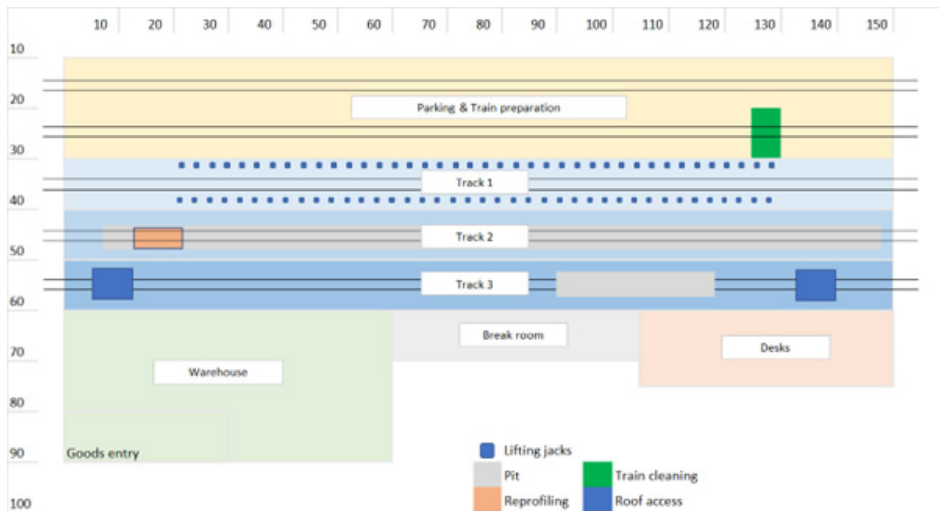


Figure 10. Mariel's depot © Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

The project plans to build a depot in Mariel and implement a series of measures to ensure 80% availability of the fleet. Equipped with 3 tracks hosting the infrastructure required for locomotive and multiple unit maintenance, this depot will ensure the autonomy of Cuban teams with a high level of industrialization.

The new rolling stock will have to be compatible with the new infrastructure, running at 120km/h and fitted with ETCS level 2 on-board signaling equipment.

6. Project management

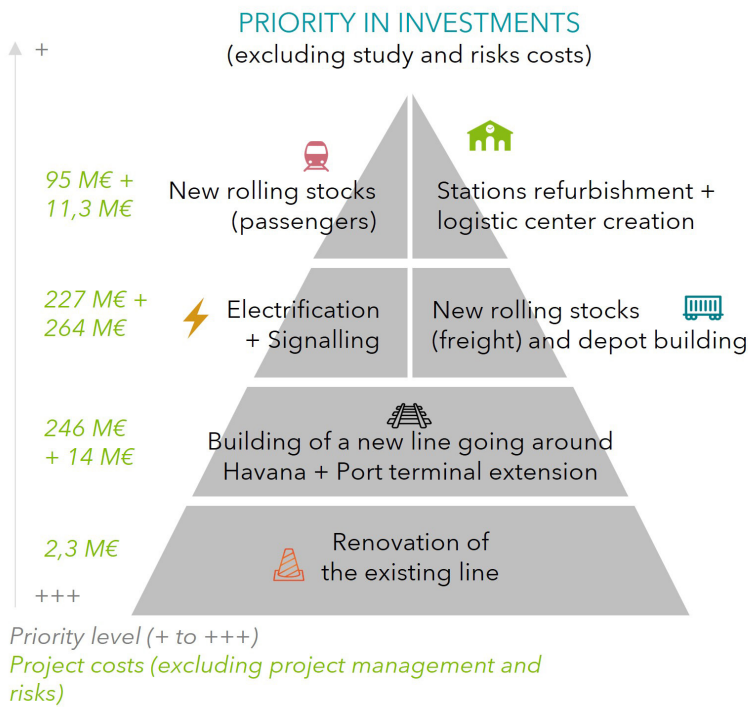


Figure 11. Priority in investments © Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

In total, the project is expected to last 12 years from the end of this study to commissioning of the line.

To ensure optimum operating conditions for the line, an estimated investment of €1 billion is required.

These costs include investment in infrastructure estimated at €736m, or €8.68m km (€7.82m/km excluding earthworks and buildings).

In addition, investments in rolling stock would be needed, including locomotives and freight container wagons, as well as passenger railcars. These costs are estimated at €329m.

Clearly, these investments will have to be examined in the light of the project's financing capacity. In case of a lack of funding, the project investments will have to be prioritized, as shown in the diagram opposite.

Financing such a project would require substantial public subsidies, as the revenues paid by passengers or shippers would not cover the fixed costs of the network.

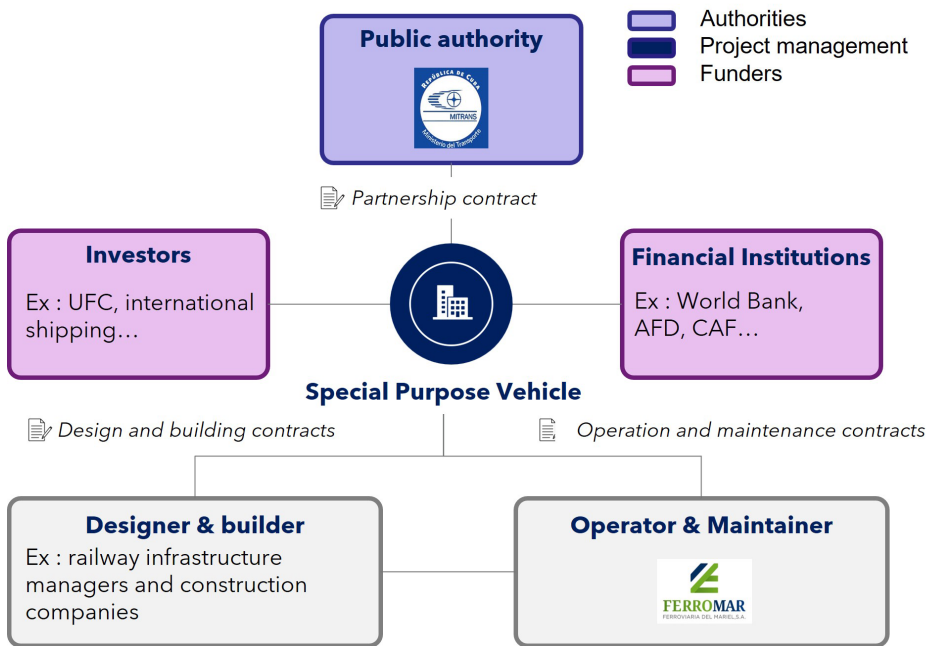


Figure 12. Suggested structure © Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

Given the public funds available, the signing of a public-private partnership will enable Cuban authorities to bypass this constraint. This is even more true given that, if US sanctions are lifted, the island will need to find foreign sources of funding quickly to improve rail transport on the island.

At this stage, several sources of funding are being considered. These sources are classified according to the type of financing for the project, without distinction

between those provided to the project company (financing of the works) and those provided to Ferromar (financing of the rolling stock).

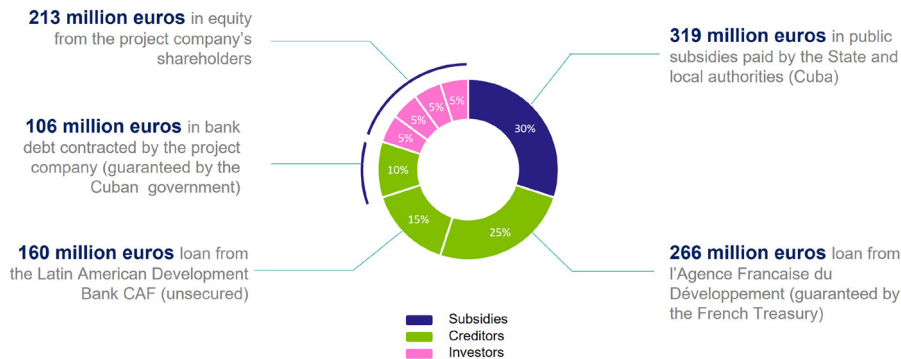


Figure 13. Funding allocation © Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

6.1. Financial considerations

Although initial estimates show that the traffic generated over a full year should enable the future operator Ferromar to generate an estimated net profit of €7.7 million each year, these results are largely due to the rail freight activity (91% of revenue), which indirectly covers the losses generated by passenger transport, i.e. workers wishing to travel from home to their workplace in Mariel.

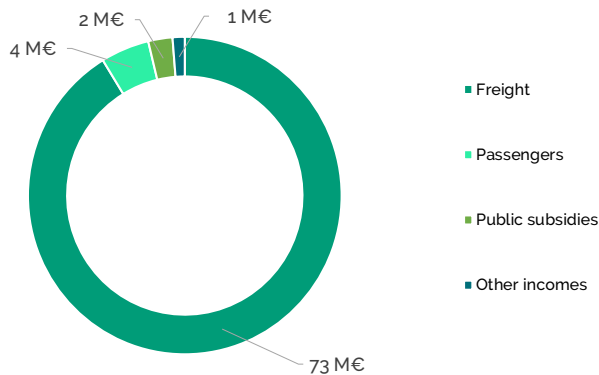


Figure 14. Revenue description © Manuel Herrera Tarrillo, Clément Bollengier, Maxime Clere, Ira Dobbelaere, 2023.

Conclusion

We have shown that the project to rehabilitate the railway line between the port of Mariel and the rest of the island is a major goal for the island's economic development if US sanctions are lifted.

However, there are a few hurdles that need to be mentioned before going ahead with this project, including the risk of Cuba defaulting on its debt repayments. In 2020, the Cuban government was struggling to repay its debt to creditors and foreign companies, despite debt restructuring negotiated in 2015 with the Paris Club.

In addition, the galloping inflation that the country is currently facing is likely to weigh heavily on the costs of the project, leading to an increase of the initial budget.

Finally, the economic spin-offs expected from the project will only be sustainable in the long term if they are accompanied by a strong infrastructure maintenance policy and good transport services offered to passengers.

Extension of the Sahel Metro in tram-train mode in the conurbation of Sousse (Tunisia)



Vincent BOURGEOIS
Hamza EL BEHJA
Jean-Jacques
KAKANOU KILI
Mariette LUSCAN

Ce projet analyse le territoire de l'agglomération de Sousse et ses enjeux de mobilité avant de proposer une solution de transport durable. Le scénario retenu propose une extension du métro du Sahel en mode tram-train sur 87 km. L'itinéraire suit les artères routières existantes et crée des pôles intermodaux. Le flux quotidien de passagers est estimé à 50 971, confirmant ainsi la pertinence du mode choisi. L'exploitation en mode tram-train présente des défis mais offre un service de qualité pour les usagers. Ce projet propose un dimensionnement et une spécification du matériel roulant et prévoit les travaux d'infrastructures. Le coût total du projet est estimé à 707 millions d'euros, des subventions publiques étant nécessaires pour atteindre l'équilibre financier. L'évaluation socio-économique démontre la rentabilité du projet pour la collectivité. Le projet impliquera l'État via la STTC, assurant la construction et l'exploitation, et un opérateur privé pour l'ensemble de la ligne.

Mots-clés : Tunisie, Sousse, transport périurbain de voyageurs, prolongement de ligne, tram-train

The project analyzes the Sousse transport system, identifies its limitations, and proposes a sustainable solution. Challenges include inadequate public transport and a heavy reliance on private cars. The chosen scenario extends the Sahel Metro with a tram-train system, covering 87km and improving accessibility. The route follows existing roads and creates intermodal hubs. The analysis estimates a daily flow of 50,971 passengers, confirming the project's viability. Tram-train operations present challenges but offer higher-quality service. The fleet size of 38 tram-trains is determined, and infrastructure enhancements are planned. The project's total cost is estimated at €707 million, with subsidies needed to balance the finances. The socio-economic assessment demonstrates positive impacts. The project will involve a balanced public-private structure, with the public-owned STTC managing construction and operation, and a private operator for the entire tram-train line.

Keywords: Tunisia, Sousse, suburban passenger transport, line extension, tram-train

Introduction

The transport system in Sousse, Tunisia has undergone significant changes, but is currently inadequate. This project analyzes the situation, proposes a sustainable and efficient public transport solution, and presents potential scenarios. We assess socio-demographic context, key stakeholders (SNCFT, ANME, AMMU, STS), and existing modes, such as private vehicles, STS services, irregular transport, and walking. Comparing scenarios, we consider environmental impact, integration, societal responsibility, accessibility, infrastructure, rolling stock, and service performance. Our proposed solution describes the tramway extension route, urban integration, technical aspects, and economic, social, and environmental benefits. Our goal is to improve transport, enhance quality of life, and promote sustainability in Sousse.

1. Diagnosis

The transportation dynamics of the Sousse conurbation indicate that movements within suburban centers predominantly occur on foot, while trips between suburban centers and between these centers and the city center rely heavily on private cars. For individuals without private vehicles, non-regular transportation serves as a relevant alternative.

Our project focuses on travel between the different centers, highlighting the following key flows:

- Northwest: Kalâa Kébira, Akouda, and Sousse.
- South/Southwest: Cité Ezzohour and Sousse, as well as Zawia Sousse and Sousse.
- West: Kalâa Sghira and Sousse.

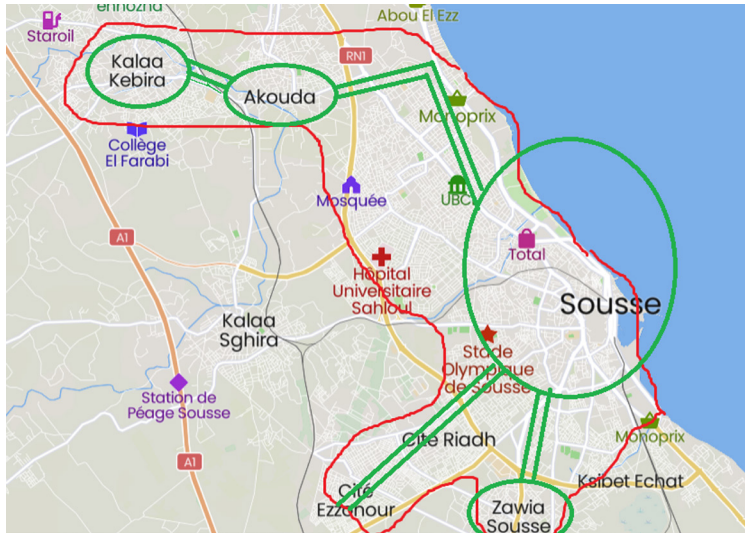


Figure 1. Main flows for current transport modes in the Sousse conurbation

© Hamza El Behja, 2023 (map data: GoogleMaps).

Sousse boasts a dynamic economy driving an anticipated rise in transportation demand. Trip-generating areas are located around the city center, providing a favorable environment for establishing an efficient public transportation system. However, challenges do remain. The convergence of commuting towards the historic center underscores the insufficient public transportation network across the conurbation. The struggling SNCFT faces limitations in executing large-scale projects.

Opportunities are arising with the recently-established mobility organizing authority, promising improved mobility policies. The presence of underutilized rail networks and stations presents possibilities for revitalization.

Nevertheless, potential threats include political instability affecting decision-making, and defining employment arrangements for the employees of the new operators.

To solve these issues, we must design a transportation system that caters directly to the major trip-generating centers, ensuring an attractive service that encourages a shift towards rail transportation. Establishing a structuring axis within the conurbation facilitates intermodal hubs and overcomes SNCFT limitations.

2. Scenario

This project proposes to extend the Sahel Metro with a new tram line from Sousse Bab Jedid to Sousse Ville, Akouda, and Kalâa Kébira. The tram-train system integrates the urban and railway segments, covering a total distance of 87km. By using electric

power, it reduces road pollution significantly. The route follows existing roads, optimizing space but requiring traffic flow reorganization during construction.

This scenario serves the growing Sousse conurbation, connecting the northern suburbs and key population centers. It enables the creation of multiple tramway stops, improving local accessibility. Intermodal hubs can be established in Sousse, Akouda, and Kalâa Kébira facilitating seamless transfers between modes.

Infrastructure-wise, it utilizes the existing Sahel Metro infrastructure for railways and constructs new tracks for the urban section. Tram signaling employs the STBS technology, while the railway section retains the automatic block system. The required tram-train rolling stock operates on 750V for urban areas and 25kV for railways, and is readily available.

Based on a multicriteria analysis, this project outperformed other scenarios. It extends the Sahel Metro as a tram-train system, fulfilling the project's objectives. Concerns about available rolling stock have been resolved. The scenario meets transportation needs, promoting sustainable modal shifts.



Figure 2. Map of the chosen scenario © Mariette Luscan, 2023 (map data: OpenStreetMap contributors, CC BY-SA).

3. Route and stations

The track runs for a total length of 84km, as follows:

- An urban zone: from Kalaa Kebira to Sousse Bab Jedid.
- A railway zone: from Sousse Bab Jedid to Mahdia.

The railway part of the route follows the current Sahel Metro route. The urban part of the route, the extension itself, needs to be determined.

The route of the urban part was designed to follow engineering rules, to limit the impact on land by using existing roads, to facilitate the urban integration of the new transport system, and to allow the creation of intermodal hubs.

The chosen route for the tram-train extension is composed of 5 different sections shown on the following diagram:

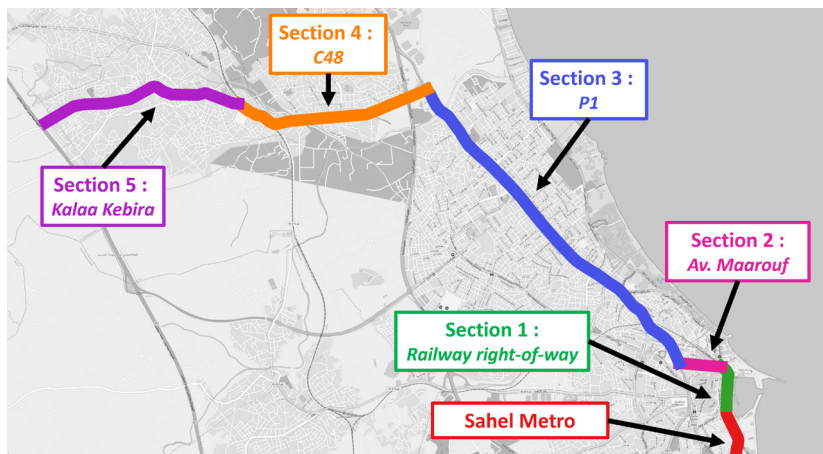


Figure 3. Chosen route © Mariette Luscan, 2023 (map data: OpenStreetMap contributors, CC BY-SA).

The new 14km of urban line enables the creation of 27 new stations (interstation of 500m on average). Their location allows connections with the existing transport network.

4. Traffic study

The traffic analysis includes both external and internal flows.

For the external flows, the Sahel Metro contributes 16,200 passengers per day to the urban section of the tram-train.

Regarding the internal flows, two calculation methods were employed. The first method was based on modal shift and mode choice, and the second method considers the tram-train's attraction area and modal share. After evaluating the results from both methods, the average internal flow was determined to be 34,771 passengers per day.

The total flow, combining the external and internal flows, amounts to 50,971 passengers per day. Based on this analysis, the calculated PPHPD for the Sahel Metro project is 4,720 passengers per hour per direction.

This finding confirms the relevance and viability of implementing the tram-train system in Sousse, as the PPHPD falls within the expected range for tramway projects.

5. Operation

Managing tram-train operations is challenging due to the mix of urban and interurban environments. The current Sahel Metro will be replaced by a tram-train service. Advantages include exclusive infrastructure for tram-trains and improved service quality. Disadvantages include complications for SNCFT and the loss of an important market. This option offers a higher-quality transport service and efficient operation.

High-frequency service will be provided during peak and off-peak hours. Frequencies on the railway section will improve the Sousse - Monastir - Mahdia corridor compared to the current Sahel Metro.

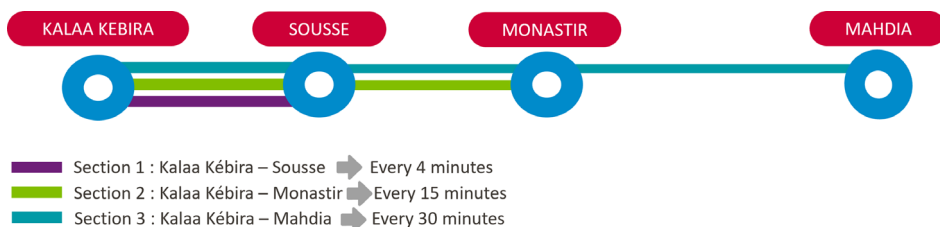


Figure 4. Frequency on each section at peak-hours © Vincent Bourgeois, 2023.

Rolling stock will be optimized and a single omnibus mission type will be offered.

Tram's commercial speed is 20km/h with 40-second station stops. The Sahel Metro train's commercial speed is 52km/h with 1-minute station stops.

6. Rolling Stock

Tram-train rolling stock will be meter-gauge and limited to a 65-meter platform length. A 160m² tram-train, 60 meters long, with 340 seats and foldable seats for a capacity of 385, is proposed due to project constraints and passenger demand.

To determine fleet size, peak-hour traffic and frequencies were considered:

- Sousse City segment requires 24 trains at a 4-minute frequency
- Sousse-Monastir segment needs 4 trains at a 15-minute frequency
- Monastir-Mahdia segment requires 4 trains at a 30-minute frequency

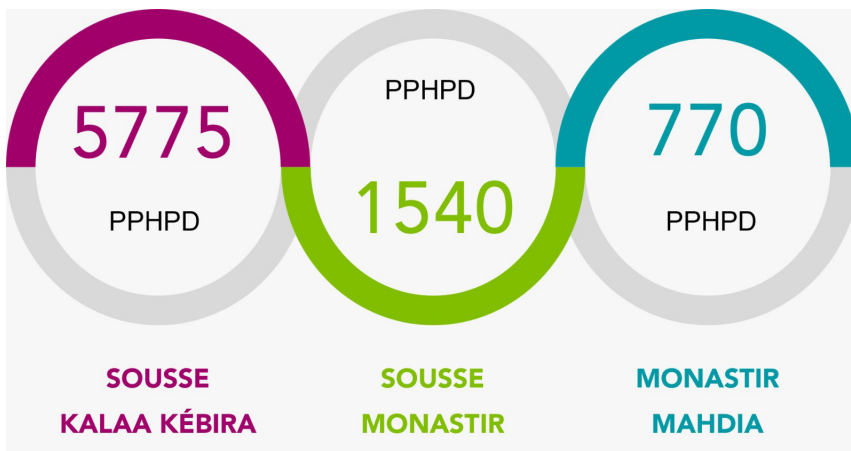


Figure 5. PPHPD for each section © Vincent Bourgeois, 2023.

Factoring in layover and turnaround times, an additional 4 trains are needed. In total, 32 tram-trains are necessary for nominal service. Adding 10% for maintenance and 10% as reserve, 38 trains are required. The fleet size and train storage align with the Space-Time Graph.

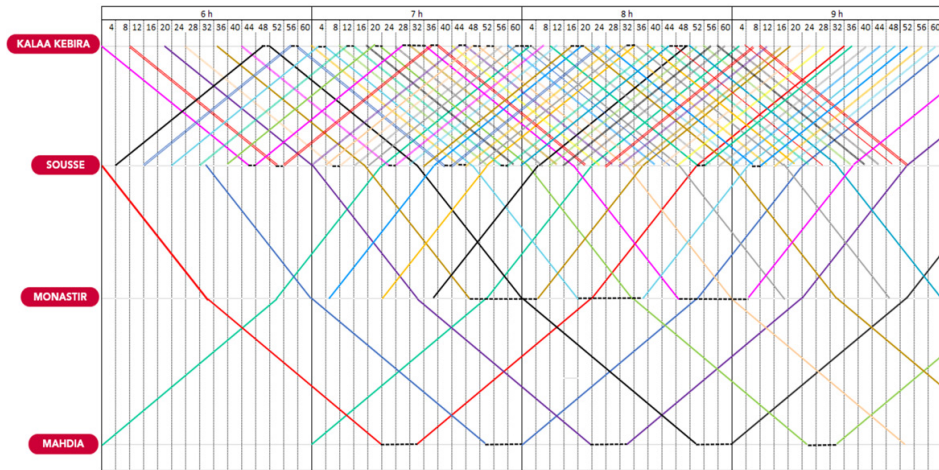


Figure 6. Space-Time Graph © Vincent Bourgeois, 2023.

7. Technical choices and infrastructure

As far as the train section is concerned, the project includes significant enhancements, such as removing 10 level crossings, renovating 20% of deteriorated sections, securing railway areas, and upgrading the Monastir signaling control system to computer-based interlocking. Tram infrastructure focuses on key intersections, using existing road bridges and constructing a new one at Kalâa Kébira station. The tramway platform utilizes continuous concrete track with embedded rails and steel fastenings. Drainage includes canals between and alongside the tracks.

The signaling system adopts France's STBS (Transmission System on Board and Ground). Tram signaling employs rectangular lights for stop (red bar) and proceed (white/green bar). Fixed signs display speed limits. Route control relies on the Interlocking system at Le Dépôt station. Road intersections have traffic lights that prioritize trams via preemption signals. A total of 162 signals and 198 beacons will be installed, approximately one every 172m along the tram route.

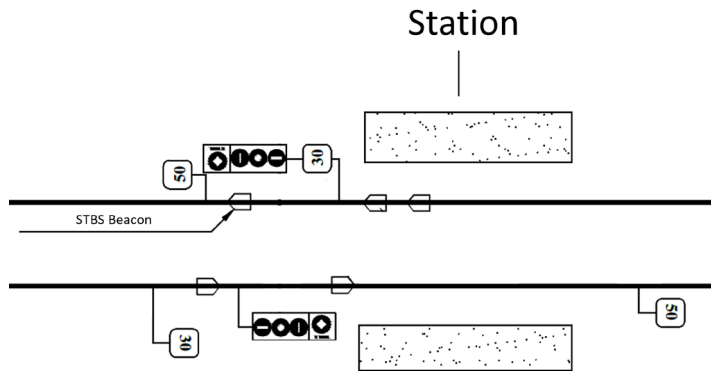


Figure 7: Representation of the in-station signaling © Vincent Bourgeois, 2023

Trams in Sousse operate with 750V DC power. Transformer-rectifier units convert the public network's 15kV AC to DC. Substations are spaced 7km apart, with two substations covering 7km each for the 14km tram line, and an additional substation in the middle for reliability purposes. Voltage drop at line ends is compensated by two parallel connection posts. Energy storage units facilitate regenerative braking and provide backup power. Required equipment includes three substations, two connection posts, and two energy storage units. Substations have a nominal power of 3MW, supporting 9MW for 1 minute. Peak hours provide an instantaneous power injection of 4.2MW.

The Sahel Metro project necessitates four maintenance and storage centers for tram-trains. Centers will be evenly distributed along the line in Sousse, with the main center in Kalâa Kébira featuring storage for 15 trains, a 7,000m² building for heavy maintenance, and a 4,000m² building for service and washing. The second center, between Sousse Sud and Sousse Zone Industrielle, offers storage for 18 trains and a 4,000m² maintenance building. Monastir and Mahdia will have storage depots for 3 and 2 tram-trains, respectively, without maintenance facilities.

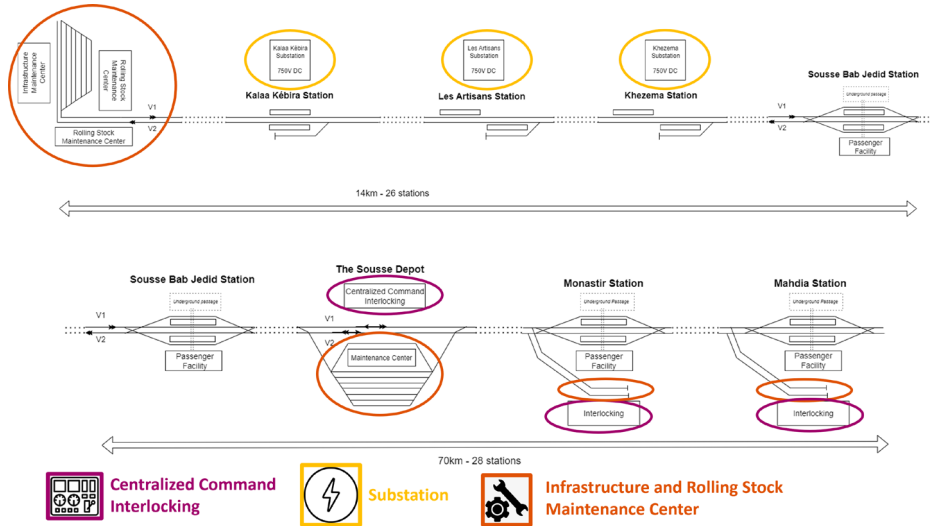


Figure 8. Line diagram with the main facilities © Vincent Bourgeois, Mariette Luscan, 2023.

8. Economic and financial feasibility

The project cost estimation reveals that civil engineering accounts for nearly 50% of the total cost, with a notable share allocated to the railway section for level crossing elimination and track renewal. Electrification represents over 25% of the cost, primarily focused on the urban area. Signaling, telecommunications, studies, rolling stock, and a risk provision contribute to the remaining expenses. The overall investment cost amounts to €707 million.

Regarding the operating and financial balance, operating revenues cover production costs, excluding rolling stock depreciation. However, only 19% of the total charges are covered by operating revenues, necessitating annual subsidies exceeding €35 million to balance the finances.

The socio-economic assessment considers factors such as time savings, cost savings compared to car travel, reductions in CO₂ emissions, noise mitigation, and safety improvements. The calculated net present value for the project stands at €77.2 million, indicating a positive socio-economic impact.

In conclusion, the Sahel tram-train project demonstrates economic and financial feasibility, accompanied by significant socio-economic benefits.

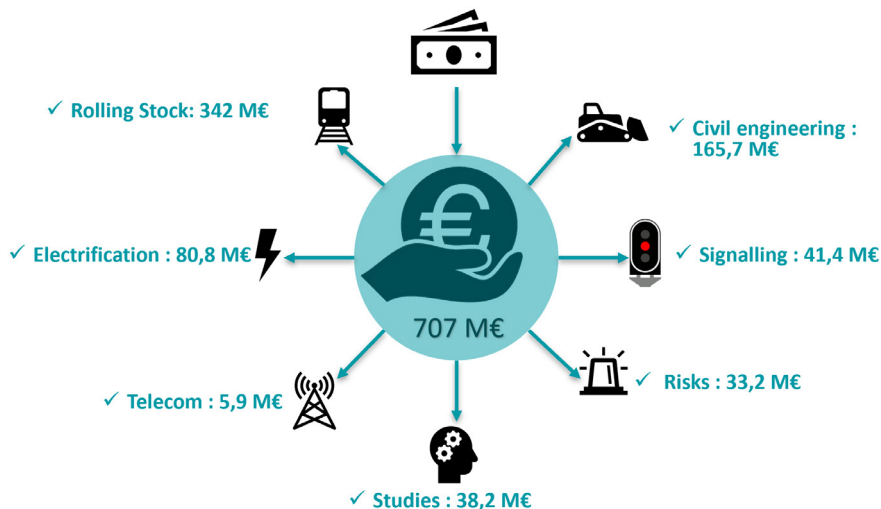


Figure 9. Breakdown of the total project cost © Jean-Jacques Kakanou Kili, 2023.

9. Project set-up

In Tunisia, strategic sectors like energy and transportation are managed by state-owned entities. When planning the Sousse tram-train project, the local context must be considered. Long-term private approaches may not suit institutional and social constraints.

The public sector faces structural issues that have an impact on service quality, and the expertise of experienced private actors is crucial for success. The project's structure will balance public-private interests. The core is the public-owned STTC (Sahel Tram-Train Company), managing construction and operation. The Tunisian government, Sahel municipalities, and AMMUS are key stakeholders. Technical expertise will be provided through project owner assistance. Construction will be under public project management. Financing relies on contributions and loans. Operation and maintenance will be contracted to a private organization for 10 years, with STTC remunerating the operator.

The project involves a private operator for the entire tram-train line, including Monastir-Mahdia. Legislative separation of infrastructure management and operations is a prerequisite. SNCFT will retain infrastructure management and delegate rolling stock operation to the new operator. Staff and maintenance personnel will be transferred under negotiated conditions.

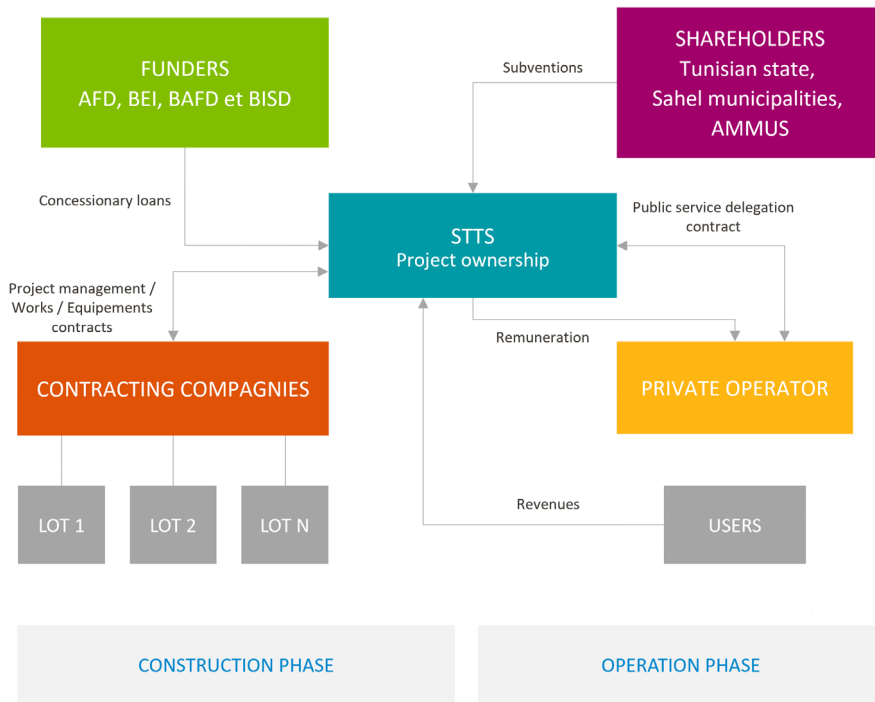


Figure 10. Project set-up diagram © Hamza El Behja, 2023.

Conclusion

To conclude, the proposed Sahel tram-train project offers a sustainable and efficient solution to the transport challenges of Sousse. It is economically viable, with significant socio-economic benefits. Collaboration between public and private stakeholders is essential for successful implementation and improved transport in Sousse.

Extension of light metro tram Line 2 line towards Ennasr (Tunisia)



Imen BEN HAMIDA SLIM
Adèle DARDE
Marine FERRERO
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François PHELIPPEAU



École des Ponts
ParisTech

Le Grand Tunis, région de la capitale de la Tunisie, voit sa population croître perpétuellement tout en ayant un potentiel de développement économique dans le futur. Cependant, son réseau de transport public est vétuste. En particulier, le réseau de Métro Léger, actuellement géré par la Transtu, souffre de négligence dans son exploitation et sa maintenance. En outre, le contexte politique en Tunisie est très complexe et favorise les projets routiers. Dans ce contexte, nous étudions le projet de l'extension de la Ligne 2 vers Ennasr, un quartier actuellement non desservi par le tramway mais par des bus uniquement. Le projet vise à apporter une solution aux problèmes de mobilités dans un centre urbain congestionné. Par ailleurs, par ce projet, nous voulons saisir l'opportunité d'apporter un souffle nouveau au système. En modernisant les infrastructures et les équipements, nous visons à accroître l'attractivité du système de transport urbain afin que les habitants du Grand Tunis adoptent leur Métro Léger.

Mos-clés : tramway, extension, renouvellement ligne, Tunis, renforcer offre de transport

The population of the Greater Tunis region of the capital of Tunisia is constantly increasing, bringing potential for future economic growth. However, it suffers from a dilapidated public transportation network. In particular, the light rail network, currently managed by Transtu, is poorly operated and maintained. In addition, the political framework in Tunisia is highly complex and continues to give priority to road projects. In this context, we study the project to extend Line 2 to Ennasr, an area not currently connected by light rail, but by bus only. The intention of the project is to provide a solution to the mobility problem in an urban center suffering from traffic congestion. Furthermore, we take the opportunity of this project to bring new life to the system. By modernizing the infrastructure and equipment, we aim to make the urban transport system more attractive so that the inhabitants of Greater Tunis embrace their light rail system.

Keywords: tramway, extension, line renovation, Tunis, strengthen transport system

1. Diagnostic and challenges of the project

The Ennasr district of the Greater Tunis region is a residential area connected to the region's economic activities. Ennasr I and II mainly comprise local shops and services, but with very few public green spaces and cultural activities.



Figure 1. Avenue Hédi Nouira, heart of Ennasr © Citizen59, 2010, CC BY-SA 3.0 (source: Wikimedia Commons).

Residents suffer from a shortage of public transport. The system in Tunisia is characterized by excessive centralization but a lack of coordination between actors. Transport policies often give priority to road projects over urban transport.

Collaboration between the Ministry of Transport and the Ministry of Equipment, Housing and Land Use Planning is unbalanced, resulting in a shortfall in urban transport investment.

Greater Tunis has various modes of transport, including a light rail system operated by public company Transtu. However, lack of maintenance reduces train availability and thus the capacity of the network. A major transport project is under construction in the region, the *Réseau Ferroviaire Rapide* (RFR, Rapid Rail Network), with the aim of connecting the suburbs to the center of Tunis.

The initiative to extend Line 2 of the Tunis light rail system aims to improve the situation, but faces internal and external challenges.

2. Route selection

4 scenarios have been developed:

- Extension of the existing line to connect the districts of Ennasr I and II to the center of Tunis
- Creation of a branch on Line 2, with La Jeunesse as a common station, to serve the districts of Ennasr
- Extension of Line 5 along the X20 expressway
- Creation of a BRT line linking Place de la République to the Ennasr districts.

A multicriteria analysis was conducted to evaluate the scenarios. Scenarios 3 and 4 were rejected due to their uncompetitive travel times and the additional investments required.

The analysis identified several arguments in favor of Scenario 2. It provides better service to residential and employment areas, has a sustainable business model with reduced operating costs, and allows for a concentration of traffic in the center of Tunis. Although it has a larger environmental footprint, it carries more passengers with fewer trains.

The final route involves the creation of a branch on light metro Line 2 along Avenue Hédi Nouria, with a terminus located in the first third of the avenue due to the steep slope.

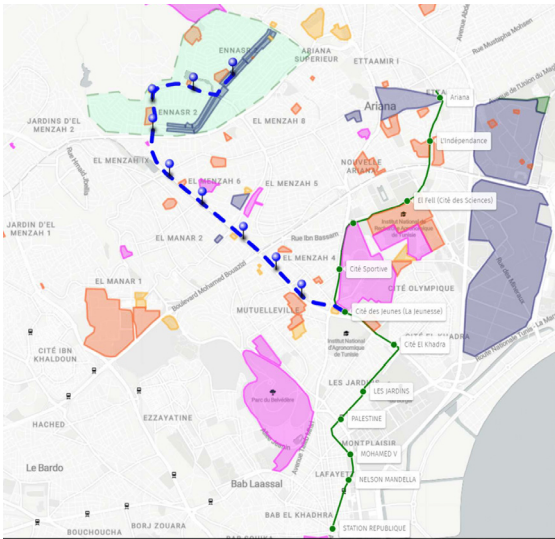


Figure 2. Route path selected to serve Ennasr

© Adèle Darde, 2023 (map data: OpenStreetMap contributors, CC BY-SA).

3. Passenger flow forecast

Once the final route has been selected, passenger flows can be estimated. The analysis consists in defining a catchment area of 500 meters around each station. The number of people inside each catchment area is then inferred from the demographic data, corrected by a forecast factor (target 2044). This yields a number of 84,000 persons. Under the assumption that only part of the active population takes public transportation, the predicted passenger flow is 25,600 passengers per day and per direction.

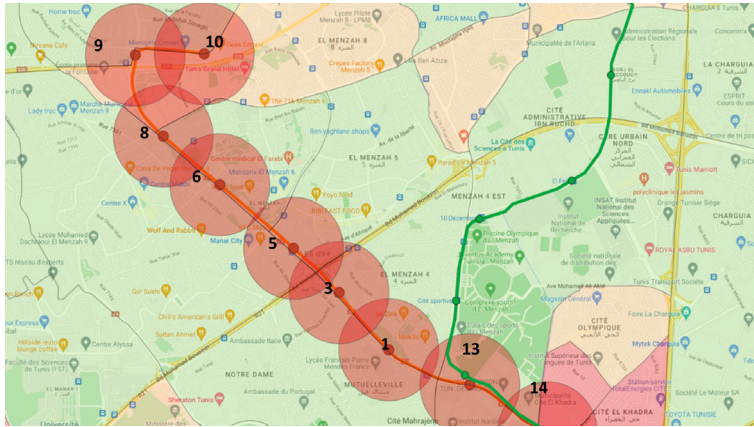


Figure 3. Catchment area around each station of the extension © Guillaume Morbin, 2023 (data: Institut National de la Statistique de Tunisie; map data: QGIS, CC BY-SA 3.0).

The breakdown of passengers over the day is projected based on a typical curve, with peak periods of 2 hours in the morning and 3 hours in the evening, and flatter traffic in between. This results in traffic of 5,300 PPHPD.

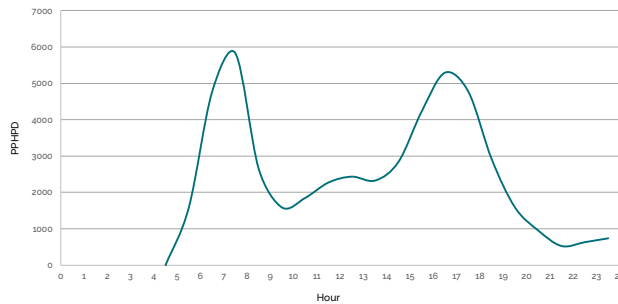


Figure 4. Breakdown of passenger flows over the day © Guillaume Morbin, 2023.

In addition, a major creek runs laterally along the corridor, necessitating the provi-

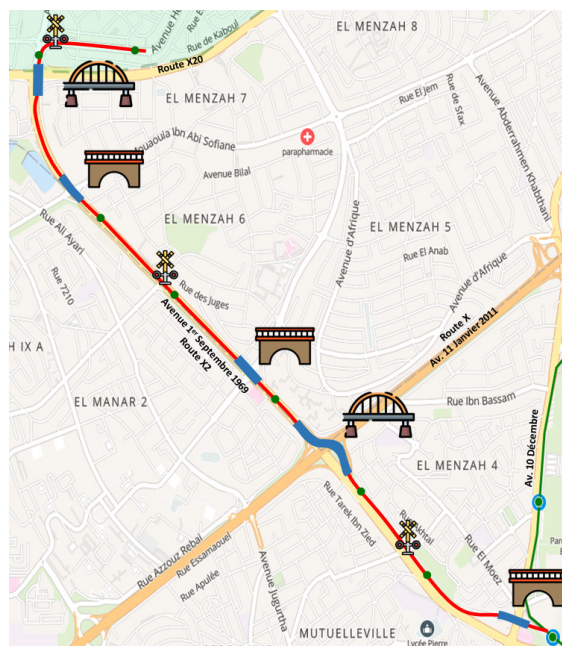


Figure 5. Route integration along Route X2 with crossing solutions © Imen Ben Hamida Slim, 2023 (map data: OpenStreetMap contributors, CC BY-SA).

The route presents three narrow radii at the junction with Route X. To reduce the

4.2. Route characteristics

The route is a 5.6km extension of light metro Line 2.

The fork is created after La Jeunesse station by inserting turnouts onto the existing tracks. The tracks then follow Route X2 along its east side as far as Menzah IV station. They then cross Route X (Avenue 14 Janvier 2011) and part of Route X2 (Avenue 1 Septembre 1969) over a viaduct leading to the central reservation of Route X2. The route then continues along the axis of Route X2 to Ennasr station. The overpass crosses Route X20, bends to run parallel to the Route X20 bypass on Avenue Hédi Nouira, and stops some 500m east of the X2-X20 intersection.

The planned terminus is located on the north side of Route X20, enabling the line to be extended towards the center of Ennasr along Avenue Hédi Nouira.

4.3. Bridges

5 concrete bridges are planned at the most important intersections with the highest traffic volumes, to maintain commercial speed and avoid generating road traffic congestion.

These include 2 major viaducts with respective lengths of 350m and 120m, and 3 slab bridges. There are also 3 level crossings. The type of structure for the viaducts is a U-shaped precast, prestressed concrete deck. This type of structure has many advantages, including its aesthetic appeal, speed of execution, possibility of cross-sections greater than 25m, low cost and safety features.

4.4. Stations

Station location choices are based on proximity to neighborhoods, location of intersections and bridges, normative recommendations, and existing characteristics. They are also designed to enhance intermodality for pedestrians and cyclists, and link the districts separated by Route X2.



Figure 6. Integration of stations and pedestrian pathways across Route X2
© Adèle Darde, François Phelippeau, 2023 (map data: Google Earth).

5. Infrastructure and trackside equipment

5.1. A track compatible with existing trams and with optimized costs

The extension will be connected to the existing Line 2. To ensure interoperability with the existing system, the tracks will have a standard gauge of 1,435. Track installation will be integrated into the roadway in road intersection areas. Elsewhere, track installation will involve laying ballast track to ensure lower project costs.

5.2. Modern systems to optimize availability and productivity

Modernization of the control-command and maintenance centers will contribute to the efficiency and productivity of Line 2. The trains and track will be equipped with locating equipment, communication devices and crossroad priority systems. Device communication will allow system monitoring to maintain increased overall availability. Train locations will be fed to the operation control center to manage train operations and passenger information systems. Crossroad priority systems will be studied in conjunction with road light signals with the aim of improving commercial speeds.

6. Attractive, efficient rolling stock

34 new trams will connect the Ennasr district to Tunis city center. Their final design will be chosen by the local population to involve them in the project. Capacity, comfort, and performance are expected to ensure the attractiveness, efficiency and productivity of the system. When operated in double units, the trains can accommodate 600 passengers. They will be interoperable with the existing light metro system and therefore contribute to its renovation.

7. A modernized customer relationship

The project relies on recent technologies to manage sales, passenger information and security through video surveillance. Several sales systems are planned to allow access for all to the transport system. There will be station sales terminals, rechargeable cards, or the Transtu app via mobile phones. The trainsets are equipped with validation terminals which are compatible with all the systems mentioned above. Equipment such as static line plans, screens and speakers, integrated in stations and in trains, will keep passengers informed throughout their journey. Information will also be available by digital means through the Transtu application or social networks. Finally, CCTV cameras fitted to the stations and trainsets will assist security teams in deterring anti-social behavior or responding faster to incidents.

8. Operation

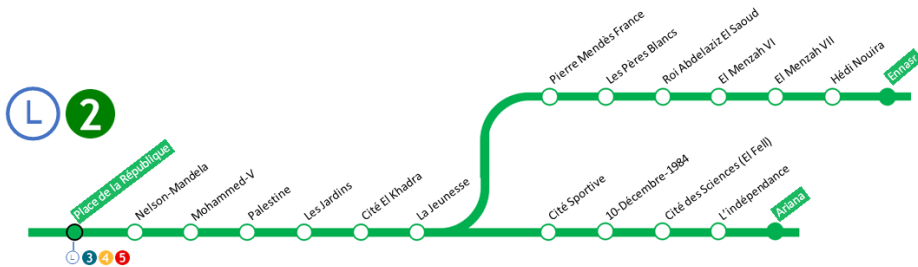


Figure 7. Schematic diagram of Line 2 with its extension © Adèle Darde, 2023.

Operational conditions are designed to match transport demand. Headway during peak hours is determined based on the capacity of a train of 606 passengers and the target PPHPD. That leads to a headway of 3 minutes on the central section and of 6

minutes on each branch. Journey times are simulated based on the characteristics of the rolling stock and the interstation distances; journey time from end to end is around 30 minutes, which is faster than by car (50 minutes).

The presence of a fork on the extended line induces operational complexities. To address them, a global analysis simulating peak-hour traffic was performed. The simulation identified the critical sections and bottleneck on the itinerary. In particular: the central section where the headway is minimal (3 minutes), the fork at La Jeunesse station where trains from Ennasr and Ariana converge, turnback management at the Place de la République terminus where the flow is the highest, and finally turnback management at the Ennasr terminus with limited siding positions. In conclusion, the timetable is robust and stable, and can be replicated during the day.

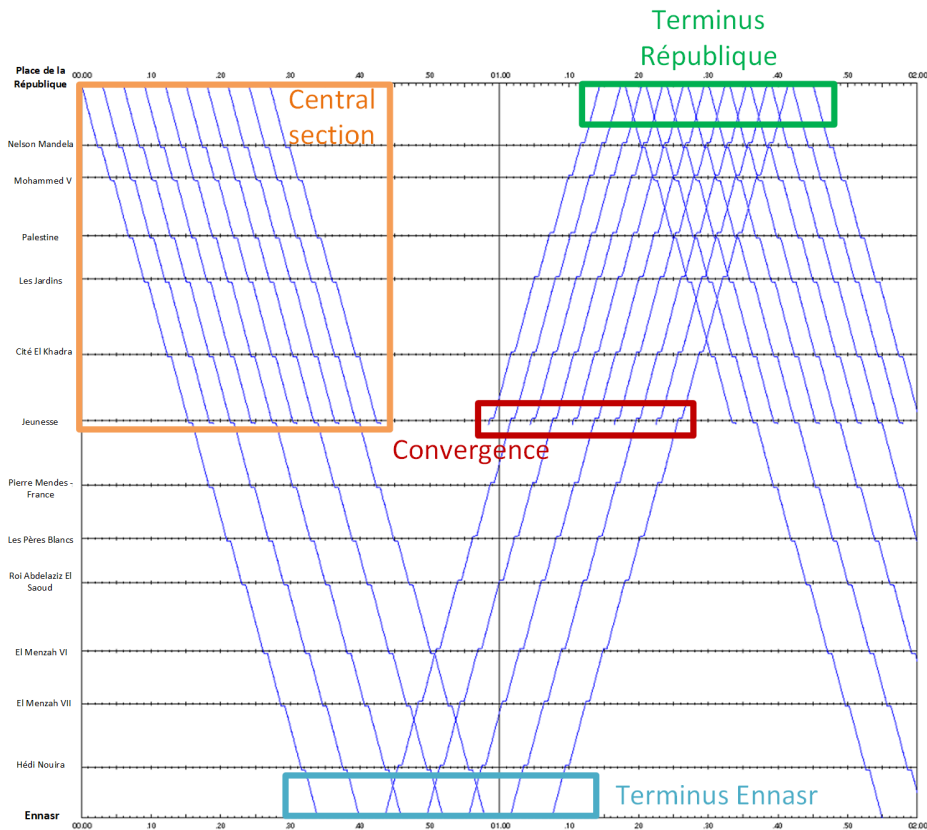


Figure 8. Critical sections on the train diagram during peak hour © Marine Ferrero, 2023 (source: OpenTrack).

9. Maintenance

Maintenance of rolling stock and infrastructures will be handled by the existing maintenance and storage facility in Ariana. As part of the extension project, this site must be upgraded and modernized to improve working conditions and enhance all maintenance activities. Ideally located with its connection to the current terminus of Line 2, the site also has empty land in the South, where a training center will be built.



Figure 9. Maintenance and storage facility in Ariana © Adèle Darde, François Phelippeau, 2023.

10. Conditions required to implement this project

To ensure the project's successful integration and functionality within the Greater Tunis light metro network, it requires the establishment of

- A single local transport authority: an RAOLT (Regional Authority Organizing Land Transport) would oversee and coordinate public transport services, including contributions from various local entities and private employers.
- Operations and maintenance skills.

Regarding the existing legal and institutional frameworks, we recommend the DBFM Design Build Finance and Maintenance model (PPP structure), leaving operations to the existing operator and including the financing, construction and maintenance of the system. This model requires a concession contract with the existing operator to guarantee service quality and regulation standards.

By implementing these recommendations, the project will improve the reliability of the light rail system, ultimately enhancing the overall public transportation network.

		PPP Models			Requirements from the local transport authority and the needs noticed
		DBF Design - Build - Finance	DBFM Design - Build - Finance - Maintenance	DBFOM Design - Build - Finance - Operation & Maintenance	
Design & Build	Civil engineering (structure work & infrastructure)	✓	✓	✓	
	Rolling Stock & Signalling	✓	✓	✓	Necessity to renew the trains of the line 2
Operation & Maintenance	Maintenance de l'Infrastructure		✓	✓	
	Rolling Stock & Signalling Maintenance		✓	✓	Renew the expertise of the staff
	Operation			✓	Preservation of the existing operator

Figure 10. Selection of the contractual model © Adèle Darde, 2023.

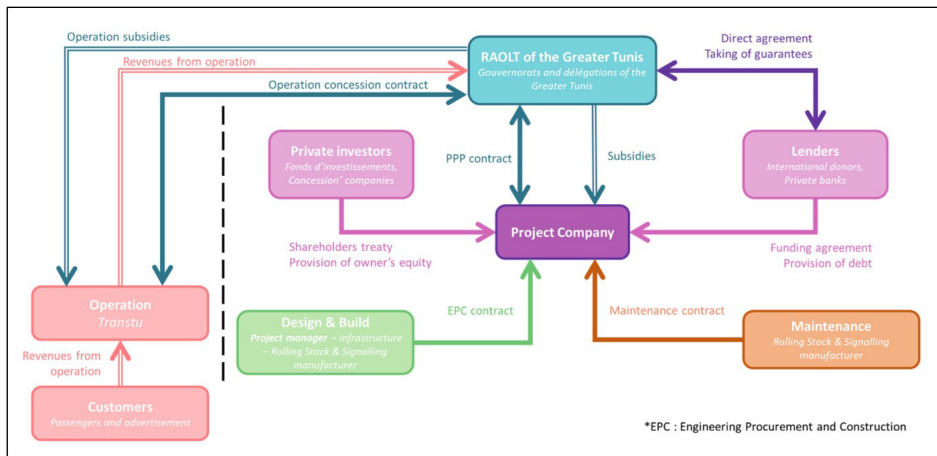


Figure 11 Contractual structure of the Ennasr project © Adèle Darde, 2023.

11. Economic and financial feasibility

During the 30-year contract with the Project Company, annual ridership will stabilize at 29.7M around year four. This project will require an initial investment of €176.95M.

Table 1 Estimated initial investment of the light metro L2 extension project © Adèle Darde, 2023.

Infrastructure work required	€64.83M	36.6%
Line infrastructure (tracks, signaling, overhead contact line)	€26.59M	15.0%
Rolling stock	€47.60M	26.9%
Workshop required for operations and maintenance	€6.10M	3.4%
Operating system	€2.17M	1.2%
Cost of studies and organisation	€11.98M	6.8%
Provisions for contingencies and unforeseen events	€17.67M	10.0%
TOTAL	€176.95M	100.0%

To incentivize use of this mode of transportation, three types of tickets are proposed (single ride, monthly, annual and school subscriptions) with a 50% reduction for school and social fares. Additionally, the stations offer opportunities for advertising revenue and commercial space utilization.

Total annual operating revenue amounts to €3.147M. The cost structure comprises personnel expenses, as well as costs associated with maintenance of the trains and infrastructure. Importantly, the evaluation incorporates the cost difference to reflect Tunisian conditions accurately. The annual costs are estimated at €10.1M for an annual distance travelled of 1,744,797km.

Considering depreciation of the initial investment (€9.03M), revenues cover 31% of the operating and maintenance costs. The balancing subsidy encompasses government compensations, financial charges, and taxes, amounting to €16.585M per year (based on the fourth year).

12. Planning and timeline

The creation of an institutional and regulatory coordination body for urban transport in Tunis is a crucial first step to ensure the smooth operation of the network. It will be responsible for coordinating transport intermodality in Greater Tunis and for steering the network's economic and financial performance.

Preliminary work and earthworks will be carried out to prepare the space required for the infrastructure, which may include archaeological excavations.

Construction of the engineering structures will follow, while taking care to maintain traffic on the main route of the X2. The drainage and roadway development operations will then be started, with the installation of footbridges to ensure the safety of passengers in relation to road traffic, particularly at the new stations.

The choice of rolling stock is crucial and must be made at the beginning of the project to anticipate possible delays. The necessary training for drivers and maintainers will start at the beginning of the project and will be carried out on the section already in operation between Barcelona and La Medina, allowing the equipment to be brought up to standard and the technicians to be trained in maintenance.

The recruitment and training of personnel, such as drivers, maintainers and operators, should begin 3 years before the new line is commissioned.

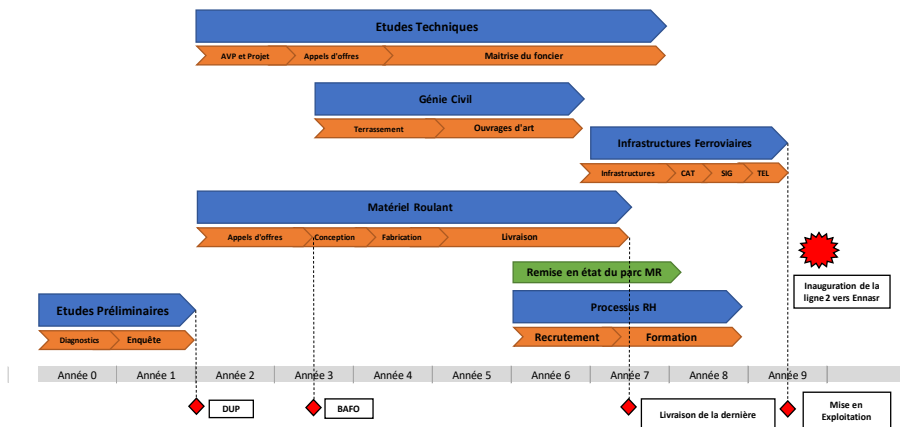


Figure 12: Project Schedule © Guillaume Morbin, 2023.

Conclusion

This project provides a response to the need for increased mobility between the suburbs and city center, with a public transport solution adapted to growing demand. Financed through a public-private partnership (PPP), this regional project will revitalize the Tunis public transport system. Together with the Réseau Ferroviaire Rapide (RFR), the extension will improve the capital's connectivity and enhance its transport network.

Development of Line 2 will contribute to upgrading neglected areas exposed to automobile pollution. The extension towards Ennasr will serve 50,000 additional inhabitants, considerably improving travel in the North and Northwest of Tunis, as well as in neighboring municipalities. It will facilitate the conversion and development of areas undergoing change, thereby boosting attractiveness and development.

However, the viability of the project is threatened by the current economic crisis in Tunisia, putting the country on the verge of default. Its high level of debt makes it difficult to obtain international financing unless there is positive political action in response to the IMF proposal. Political and economic measures will be needed to ensure the successful completion of the project and contribute to the country's economic recovery.

Creation of a metro line in Khulna, Bangladesh



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Le Bangladesh connaît une forte croissance démographique. L'exode rural engendre une urbanisation rapide et non maîtrisée. La mobilité est devenue un sujet de préoccupation des autorités locales pour répondre à un besoin croissant. Dans ce contexte, la création d'un transport en commun en site propre structurant à Khulna, 3^e ville du pays, a été étudiée. Une analyse multicritère et une analyse socio-économique désignent le métro aérien comme le mode le plus pertinent. Ce document présente l'étude préliminaire pour la réalisation de la ligne. Son lancement requiert une refonte de l'organisation de l'offre de transport incluant les transports informels actuels, une restructuration institutionnelle et une réorganisation des acteurs. Le montage de projet retenu est un contrat de partenariat public privé contracté entre l'autorité organisatrice de la mobilité, une maîtrise d'ouvrage privée, un exploitant et des promoteurs immobiliers dans le cadre d'un projet de renouvellement urbain.

Mots-clés : structuration de l'offre de transport, métro aérien, transports informels, Khulna, Bangladesh

The population in Bangladesh is growing significantly. A rural exodus is driving rapid, uncontrolled urbanization. In parallel, mobility has become a key topic for the local authorities who have identified an increasing transport need. This led us to explore the creation of exclusive-right-of-way public transport to bring more spatial structure to Khulna city, the third-largest city in Bangladesh. A multicriteria analysis followed by a socio-economic comparison showed that an elevated metro is the most adequate transport solution. Our paper shows the preliminary study for creating such a line. This also comes with a rearrangement of the current range of transport (since a major part of it is informal transport), an institutional reorganization, and a reshuffle of the stakeholders. The proposed set-up for this project is a public-private partnership between the local authority in charge of mobility, a private project owner, an operator and a real estate developer to support urban renewal.

Keywords: Rearrangement of the transport offer, elevated metro line, informal transport, Khulna, Bangladesh

Introduction

The population in Bangladeshi cities is growing significantly. The consequence of massive urban migration is that urbanization is quick and therefore uncontrolled. In the meantime, the local authorities have identified the increasing population's need for, and interest in mobility. In this context, the opportunity to implement an exclusive-right-of-way public transport system in Khulna, the third-largest city in the country, will be explored. Our work is based on documentary research and exchanges with members of the "Urban and Rural Planning" Department at Khulna University.

1. Context of the study

Khulna city is in south Bangladesh along the Bhairab and Rupsa rivers. The local geographic constraints have shaped urban development in a city that is 17km long and around 4km wide.

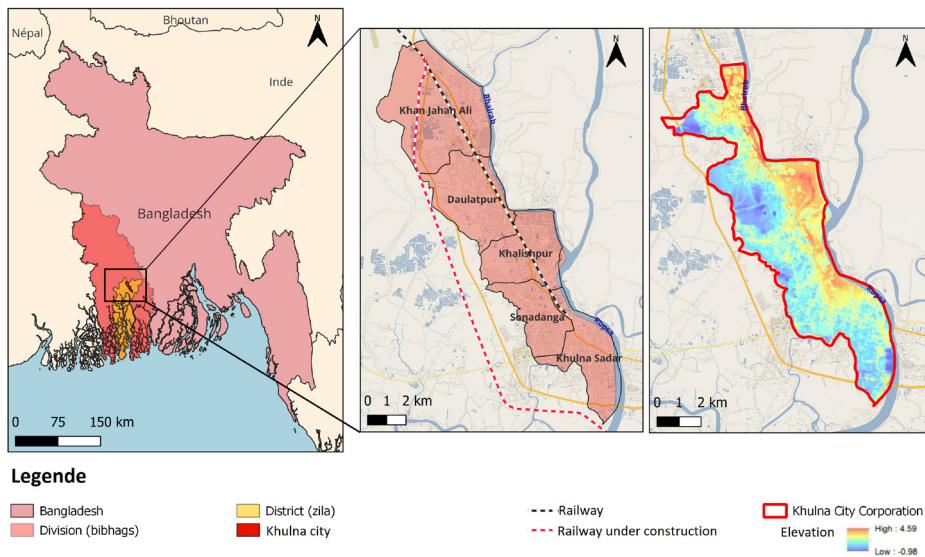


Figure 1. Map of the location of Khulna City © Clémentine Fasquel, 2022 (map data: QDIS, CC BY-SA 3.0).

The transport offer in Khulna city is very large. Public transport is essentially provided by licensed rickshaws and some rare bus lines. Informal transport is also by rickshaw, but with no license delivered by the local transport authorities. Because it

is cheap for short distances, can circulate easily in the narrow streets and offers up to 6 seats, the rickshaw is by far the most popular mean of transport in Khulna city.

The major challenge for the road network is congestion. Walking and cycling represent respectively 21% and 5% of the modal shares, but the local population is critical of the transport authority for not investing in the infrastructure to secure and further develop these means of transport. Khulna has intercity train services with up to 6 trains per day departing from the main railway station. These connect Khulna to other cities via non-electrified railway tracks. It is important to note that there are currently no railway transport options within Khulna city, and no such projects have been announced.

The following picture shows the challenges identified with diagnostic of the territory.

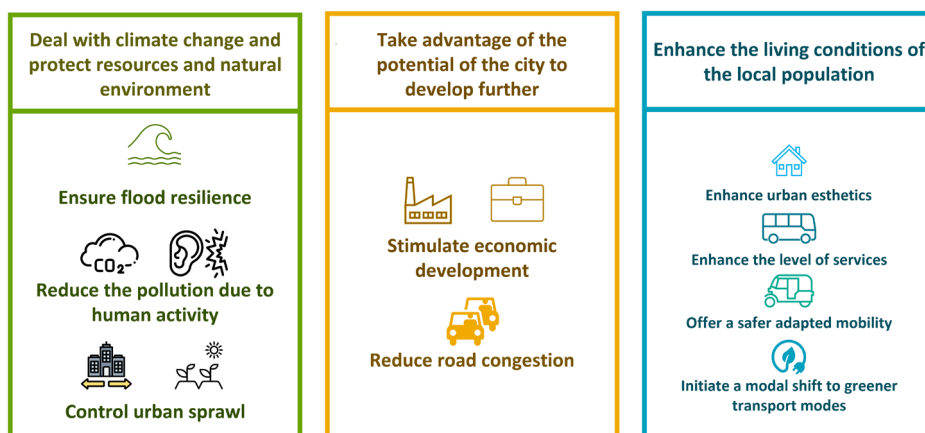


Figure 2. Identified challenges © Lorenn Boumah Ngwenkele, Clémentine Fasquel, Alexandra Halchin, Céline d'Halluin, Olivier Parlavecchio, 2023.

2. Transportation mode selection

From the diagnosis, key criteria were identified for the choice of the proposed mode. In a practical sense, the need that has been identified is for a transportation mode that can operate safely during floods, has a minimal impact on road traffic thanks to a small footprint, and improves the current issues (pollution, noise, congestion).

The Person Per Hour Per Direction (PPHPD) assessment was conducted by three distinct methods. It was calculated based on total population, travel rate, and modal share taken by the new mode. The second evaluation was by comparative analysis with a similar city. The last method involved a detailed examination of the displaced

population within a radius of the stations. All three assessments led to a PPHPD value of 13,000.

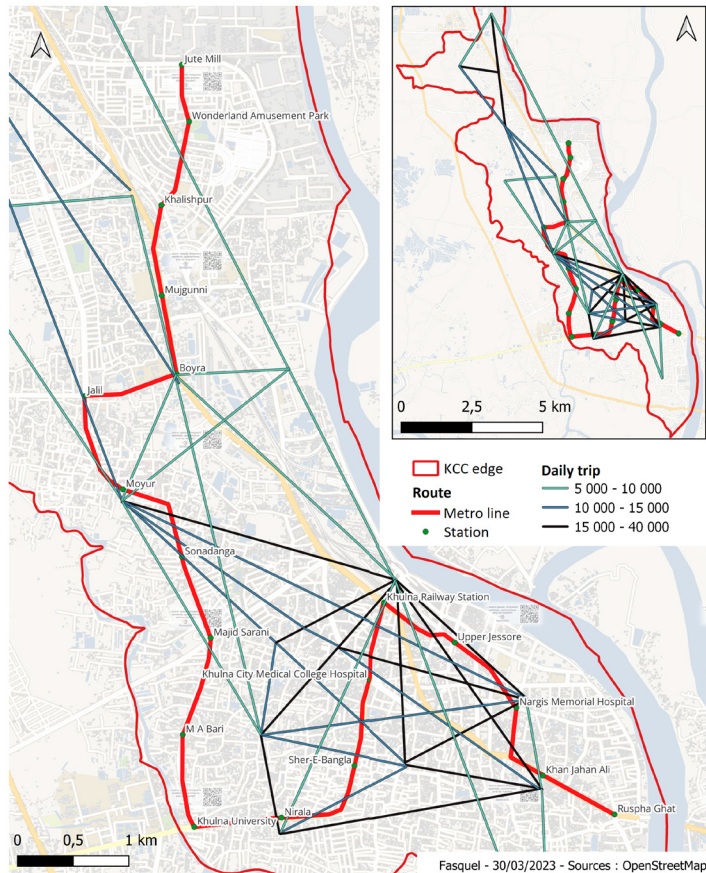


Figure 3. Number of daily trip in Khulna city
© Clémentine Fasquel, 2023 (map data: OpenStreetMap contributors, CC BY-SA).

Via a multicriteria analysis, the urban modes capable of achieving such a PPHPD were compared. The analysis focused on 4 aspects: service quality, environmental impact, technical feasibility and economic viability. The detailed quotations are given in the table below. As a result, the tram option was eliminated and for the remaining modes, a socio-economic evaluation was carried out.

Category	Quality of service						Environment				Technical feasibility							Economics				Total
	20%						20%				20%							40%				
Criteria and weighting	Confort	Safety	Commercial speed		Route	Attractivy	Total	Energy	Carbon footprint	Nuisance	Total	Floor area	Resilience to floods	Maintenance	Standardisation	Road traffic impact	Work duration	Total	Costs Rolling Stock	Costs Operation	Costs infrastructure	Total
	1	4	3	1	1	10	3	4	3	10	3	2	2	1	1	1	10	3	4	3	10	
	BRT	1	4	9	3	1	18	9	4	9	22	3	2	6	3	1	2	17	9	12	9	30
Tramway	2	4	6	2	3	17	9	12	6	27	6	2	2	1	1	2	14	6	8	6	20	19,6
Metro	3	12	9	3	3	30	9	12	6	24	9	6	4	2	3	1	20	6	8	3	17	22,6
Train	3	8	3	1	1	16	6	4	3	13	9	2	6	2	2	3	24	3	4	9	16	17
Gondola	1	12	9	3	3	28	9	8	6	23	6	6	4	1	3	2	22	9	12	6	27	25,4
Tram-Train	3	12	9	2	3	29	9	8	6	23	6	2	4	1	2	2	17	6	8	9	23	23

Figure 4. Multicriteria analysis to compare urban modes © Lorenn Boumah Ngwenkele, Clémentine Fasquel, Alexandra Halchin, Céline d'Halluin, Olivier Parlavecchio, 2023.

The socio-economic analysis provided decisive insight into the comparison of possible modes. Despite its high infrastructure costs, the metro emerged as the mode with a highly favorable socio-economic balance, due to its ability to provide fast journeys for passengers without a negative impact on road traffic. The BRT would significantly impact road space. Although the tram-train initially seemed advantageous by utilizing existing infrastructure, a complete redesign would be required to accommodate acceptable traffic within the framework of an urban mode.

	 BRT	 Tram-train	 Elevated metro
Rolling stock	€48.4M	€41.3M	€60.3M
Infrastructure	€44.4M	€63.6M	€493.7M
Operation	€-61.8M	€-28.1M	€23.6M
Economic total	€-147M	€-133M	€-530M
Socio-economic total	€-557M	€163M	€619M
Net Present Value after 10 years	€-704M	€-351M	€89M

Figure 5. Socio-economic analysis to compare urban modes © Olivier Parlavecchio, 2023.

The proposed elevated metro system is a 14.4km-long line connecting attractive areas of the city, starting from the industrial sector in the northeast and extending to the southeast. With 19 stations at an average distance of 800m, it will serve as a central backbone, around which a finer network will be organized. Being a completely new and elevated line, it effectively addresses space constraints and flood-prone areas. Further analysis is needed to assess its viability, including evaluating PPHPD and estimating costs.

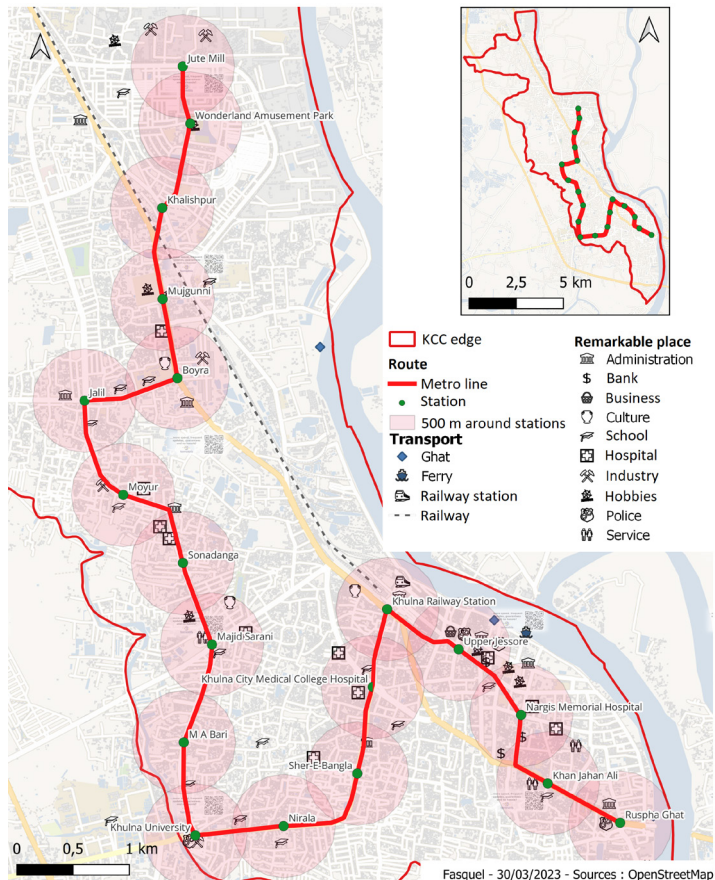


Figure 6. Map of the metro line route

© Clémentine Fasquel, 2023 (map data: OpenStreetMap contributors, CC BY-SA).

3. Our proposition

3.1. Technical feasibility study

The rolling stock will be designed for a maximum speed of 85km/h. It has dynamic braking with regenerative and pneumatic braking to minimize mechanical braking and optimize energy expenditure.

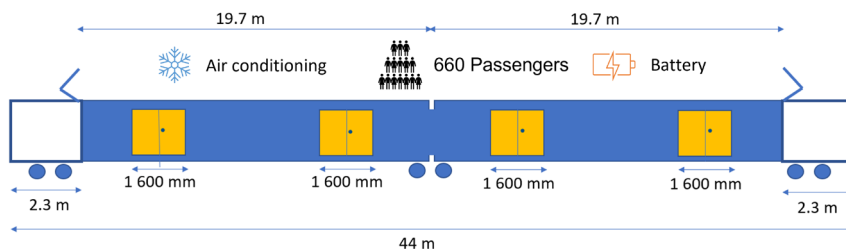


Figure 7. Rolling stock diagram © Céline d'Halluin, 2023.

Trains will be equipped with a Communication Based Train Control system to enable short time intervals and cover the current and future PPHPD. The target level of automation is GoA2 with key automated functions including speed control, acceleration, braking and parking time management.

The route includes curves with a minimum curvature radius of 80m. The stations are located near these curves to ensure safe traffic speeds. The main track will be a slab track with a standard gauge of 1.435m. It is more uniform, rigid and lightweight compared to a ballasted track. It experiences less degradation and requires less maintenance, resulting in improved availability. To reduce noise pollution, sound panels will be installed along the tracks. Environmental assessment and measures to avoid, reduce and compensate for environmental impact will be conducted for the construction and operation phases.

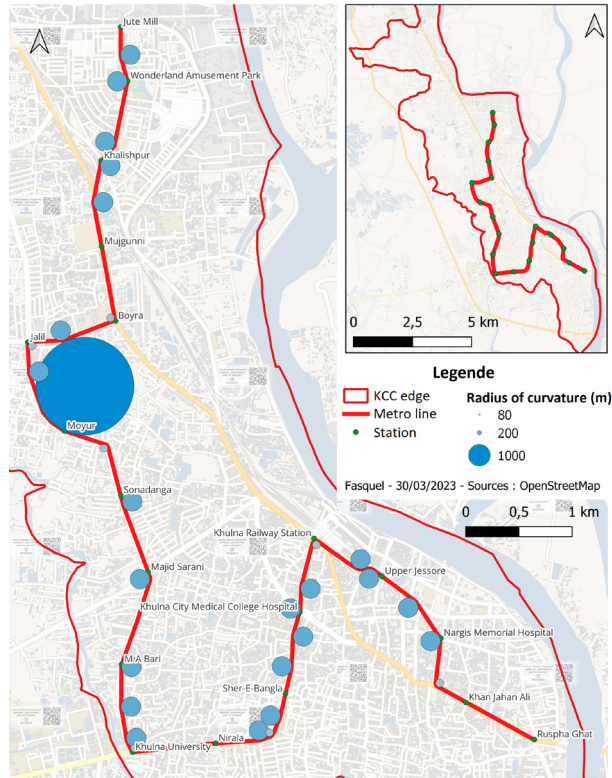


Figure 8. Station location and curvature radius of the metro line
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The solution chosen for the construction of the metro line will be a boom. The piers will be positioned in the center of the traffic lanes to separate the flows and to avoid taking up space on the pedestrian paths. The quality of the soil is poor, deep foundations will be provided to ensure the stability of the structure.

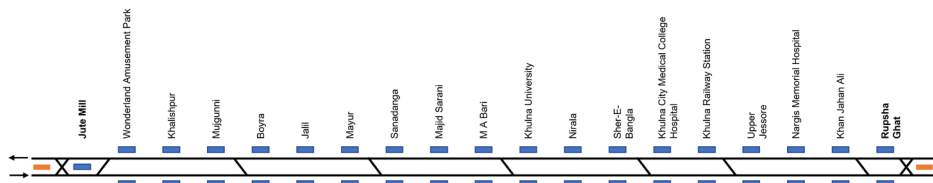


Figure 9. Infrastructure Diagram © Clémentine Fasquel, 2023.

The stations will be designed to straddle road traffic and provide multiple access points for passengers, including stairs and elevators. They will accommodate up to 560 passengers and feature amenities such as street furniture, passenger information, and camera surveillance systems.

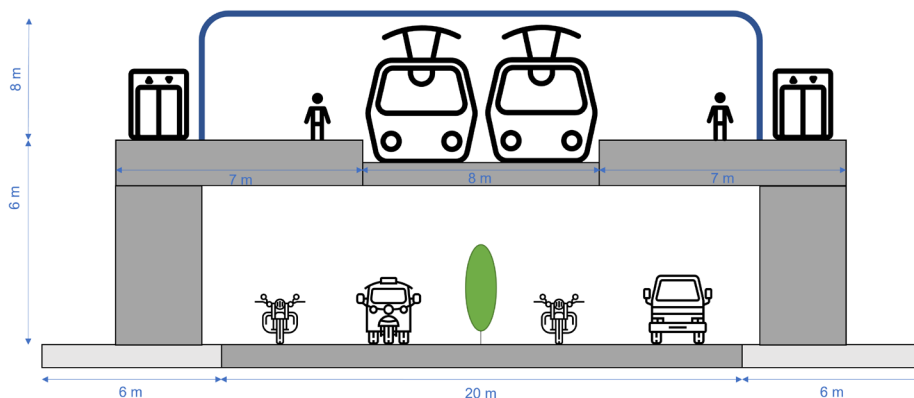


Figure 10. Station schematic diagram © Clémentine Fasquel, 2023.

We have chosen to supply our trains via a 1500V catenary. It offers higher electrical performance in speed and power, and a high-voltage power supply. One substation is necessary for our 14km line.

The maintenance and storage site will ensure night and off-peak storage functions for 36 trains in multiple units to clean trains using a washing machine, and to maintain and repair rolling stock thanks to the maintenance workshop equipped with 4 tower-in-pit tracks and 3 tracks equipped with footbridges.

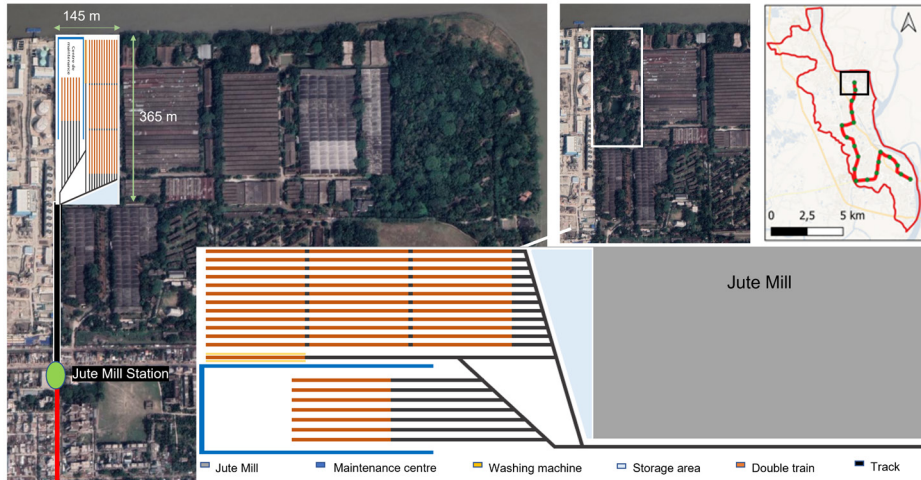


Figure 11. Warehouse schematic © Clémentine Fasquel, 2023 (map data: QDIS, CC BY-SA 3.0; Google Earth).

3.2. Operation and Maintenance Scheme

Our offer includes a comprehensive service that covers all 19 stations on the line. The frequency and operating hours are adjusted according to day type (regular or off-peak) and specific time (peak hours, intermediate periods, or off-peak hours). The service runs continuously all year round.

Normal operations correspond to weekdays, totaling 49 weeks per year. We estimate 3 weeks per year with reduced activity, resulting in a total of 245 operation days. To ensure a high-quality service, the line will operate within a broad timeframe starting from 5:30 AM and ending at 11:30 PM. The frequency of service varies throughout the day, with intervals of 3min during peak hours and 7min during off-peak hours. The off-peak day corresponds to weekends (Friday and Saturday) and 3 weeks totaling 120 operational days. The line operates on a reduced time range from 7:00 AM to 10:00 PM.

Analysis of traffic flows reveals that station times vary depending on the level of activity: 60s for the busiest stations, 40s for moderately busy stations, and 25s for terminal stations. Track speed of 80km/h is chosen for techno-economic balance. Round-trip time is 64min, resulting in a commercial speed of 26.8km/h for the line. Technical time of 3min 30s is added at each terminus, making round trip time 72min. During peak hours, 24 trains operate with a layover of 1min and 30s at each end. Each train operates in average 12.75 hours and covers 312km. The total fleet size is 28 trains (including spare trains and maintenance fleet).

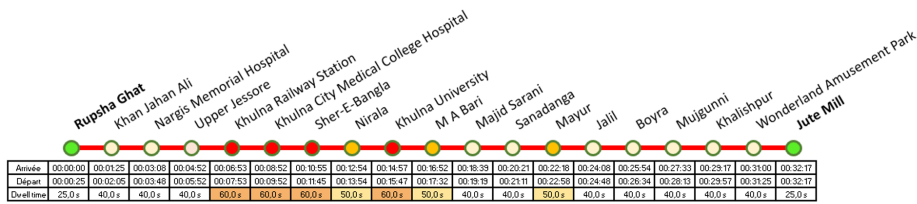


Figure 12. Operational Timetable © Céline d'Halluin, Alexandra Halchin, 2023.

To ensure continuous service and efficient response to incidents, various measures have been implemented, such as temporary services for busy stations and track normalization. Service tracks strategically located along the line enable train parking at intermediate stations and serve as a temporary terminus. In case of evacuations, passengers will use platforms between tracks.

Maintenance is carefully planned year-round to achieve a cost-effective balance, with dedicated trains for ongoing maintenance. Infrastructure maintenance is prioritized, with regular surveillance and measurement systems in place. A comprehensive approach to preventive and corrective maintenance, supported by a Computer-Aided Maintenance Management System, enhances equipment performance monitoring and intervention effectiveness.

3.3. Restructuring of the transport network

To enhance transportation services and complement the metro offer, the public transport authority (PTA) will implement regulations for rickshaws. While some rickshaws operate without licenses and outside PTA supervision, they fulfil travel needs and provide social inclusion for low-income individuals. Rickshaws offer flexibility and operate during non-peak hours, weekends and floods. They can adjust their services quickly without contractual obligations to the PTA.

Rickshaws will be organized by geographical area to meet local trip needs. The PTA will control how many rickshaws will operate in each zone thank to licenses. They will be identifiable by the color associated with the area. The division is designed to avoid competing trips with metros because rickshaws will not be allowed to change zones. Knowing the travel flows, key routes not served by the metro are identified. They connect the 47 garages located in trip attractor or emitter areas.

The drivers will be grouped into Economic Interest Groups. A manager in each establishment will ensure the vehicles are loaded according to their arrival order and the users' destinations. They will handle the validation of transport tickets and collection of revenue.

The PTA will define the pricing of tickets and receive a portion of the revenue. Preferential fares will be granted to people travelling on the metro and using rickshaws as a feeder mode. A ticket can be used for a rickshaw trip to reach the metro or their destination from a station, but also to travel by rickshaw in the same area. A rickshaw trip between two zones will be more expensive proportionally to the distance traveled. When the metro is closed, licensed rickshaws will be organized in on-demand transport with booking.

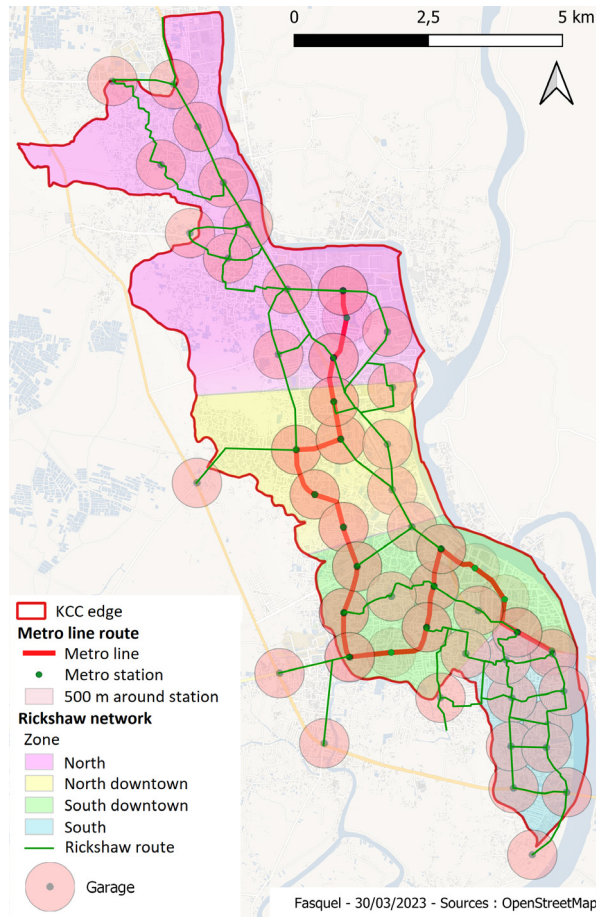


Figure 13. Organization of the rickshaw network
© Clémentine Fasquel, 2023 (map data: OpenStreetMap contributors, CC BY-SA).

3.4. Urban planning around metro stations

Metro stations will be built on the principle of Transit Oriented Development. This urban planning project aims to promote the modal shift towards the metro by improving its accessibility, and to facilitate intermodality. As an illustration, the railway station area is a central point of the metro line and the city, encompassing a mix of activities and two slums. A real estate program will offer decent housing in these spaces, with 17 five-level buildings to respect the current urban landscape, comprising 1,360 housing units to anticipate future population growth.

To respond to the increase in jobs in the tertiary sector, offices will be provided with 14 buildings to offer 7ha of office space. Shops will be on the ground floors and a shopping center will be constructed in Khulna Station.



Figure 14: Map of the TOD layout around Khulna Railway Station
© Clémentine Fasquel, 2023 (map data: QDIS, CC BY-SA 3.0).

4. Implementation

Our focus is on addressing the governance and financing aspects of this project, during both the construction phase and the operation-maintenance phase.

This project aims to establish close international collaboration between France and Bangladesh. Its objective is to engage international private actors who combine expertise in the realization of such projects with financing capacity. It is important to generate and sustain local economic and industrial activity. In addition, since international donors are expected to provide financial support, the project must provide governance guarantees and effectively manage the risk of corruption.

We propose to create a Mobility Organizing Authority to ensure the match of transport supply with demand and coordinate all mobility in the territory. The overall project management (construction + operation-maintenance) will be assigned to a dedicated entity responsible for coordinating stakeholders and building the contractual framework. Following a concession model, the operator will be remunerated by ticket sales and passenger traffic-based compensation mechanism. Penalties will also be provided for the non-attainment of quality objectives. The operator will acquire the rolling stock through a finance lease and assume responsibility for its maintenance. The governance structure is described in the diagram below.

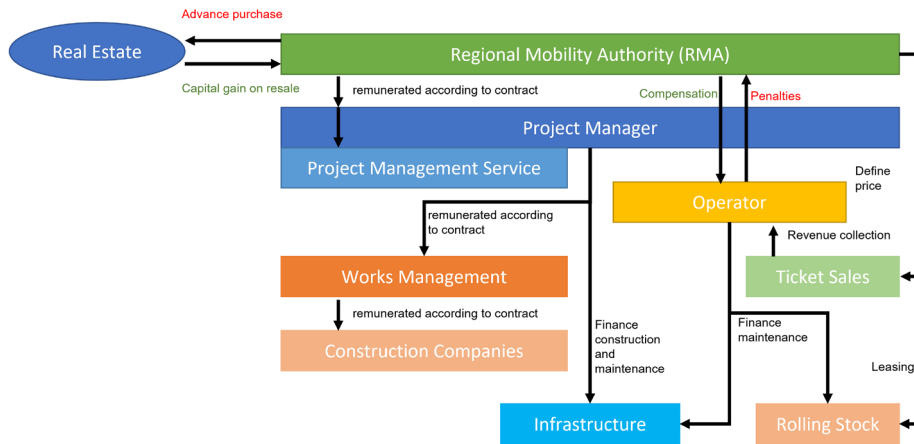


Figure 15. Operational and financial organization © Olivier Parlavecchio, Lorenn Boumah, 2023.

Our economic balance sheet reveals a very slight operating margin linked to the metro activity. This is due to the high capacity of each trainset, which generates substantial revenue, while the high speed limits the size of the rolling stock fleet.

Moreover, the restructuring and regulation of the rickshaw supply aim to create complementary services and yield a significantly positive operating profit.

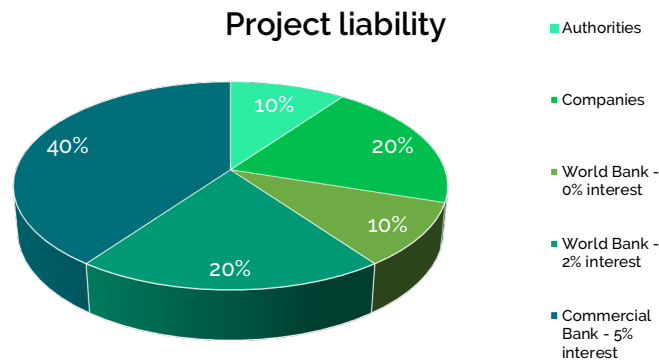


Figure 16. Shares repartition © Olivier Parlavecchio, 2023.

The project requires strong investment and it is crucial to secure public resources. One potential approach is to introduce a transport payment tax linked to the wage bill of the employment area.

We are exploring a mixed financing approach with partner companies, private banks, and international donors such as the World Bank. The latter would provide loans at 0% and 2% rates. The overall funding mix is shown in the diagram below.

This set-up generates an overall internal rate of return of 6.3% demonstrating its profitability and significant economic potential.

Conclusion

Revitalizing the public transportation system in Khulna city is a challenging endeavor that is crucial for its development and attractiveness. Following a multicriteria analysis and a socio-economic assessment, the elevated metro has emerged as the optimal transportation mode. It not only provides opportunities for future line expansion across the Rupsa River, but also incorporates infrastructure features designed specifically to accommodate increased capacity.

The restructuring plan for the informal transport sector is instrumental in gaining public acceptance, ensuring economic viability, and integrating the new mode of transportation into the daily routines of the population.

With a favorable operational balance, the project enables the proposal of a concession agreement. Despite significant investments, particularly in infrastructure, the financial structure is designed to achieve satisfactory profitability. This is achieved notably through the implementation of a tax model like the French "Versement Transport".

High-speed railway connection between Legazpi and San Fernando in the Philippines



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

Mots-clés : grande vitesse, interurbain, ferroviaire, report modal, Philippines

The French development agency requested a study of the creation of an interurban railway link on the main island of the Philippines. Key challenges relate to the performance of the existing network. Weak points of the country are a significant lack of railway culture and vulnerability to global warming. The proposal is to construct a new, higher-speed infrastructure that is well connected to the existing network. It aims to be competitive with air and road transportation for long distances, while offering freight and regional traffic. The operation is structured around an integrated enterprise working under a concession contract comprising infrastructure management and operation, with construction staggered over five consecutive phases. In addition, the project contributes to sustainable development by opting for renewable energy self-production. The surplus energy produced will be sold to boost income. Finally, this network can serve communication purposes targeting the whole population, with a high-speed railway service, power supply and future services contributing to the Philippines' green mobility.

Keywords: high-speed, interurban, railway, modal shift, Philippines

Introduction: context of the study

Since 2012, many projects have focused on partial rehabilitation of the existing Filipino railway network. This study aims to analyze the interest of connecting San Fernando in the North of Luzon to Legazpi in the South.

The Philippines is a developing country with the world's 32nd economy, but still faces severe inequalities. There is a clear distinction between the upper and lower classes, and this is reflected in transport habits. Filipinos mainly use cars in their daily transportation and that causes major congestion issues in the Manilla suburban area. As for interurban trips, the lower classes travel by bus, which is cheaper but takes considerably longer, whereas tourists and rich inhabitants mostly fly between major cities, even for trips within Luzon Island. These are currently the two alternatives for long-distance travel in the country, as the railway network has been abandoned over the years due to lack of infrastructure maintenance and climate events damaging the rails.

The Philippines is very vulnerable to typhoons, storms and heavy rains due to the humid tropical climate. The archipelago is also located in a seismic area, so there are many mountains and volcanoes. This geography is therefore a significant factor for railway projects in terms of maintenance and route choice.

The Philippines is therefore in need of sustainable projects to continue its growth, while addressing climate change. The government in place has launched the "Build Better More" program to favor sustainable investments from 2022 to 2028, including 13 projects in public transportation.

1. Challenges

1.1. Existing railway network performance

Although Luzon's railway network consisted of more than 1,000km of track from the North to the South of the island back in the 60s, it is now estimated at less than 150km. The whole network is Cape gauge and is not electrified. It is now decrepit and offers only 3 services with limited frequencies: a suburban commuter service in the Metro-Manila urban area, a regional commuter service in the Bicol area (limited to Sipocot-Naga since the destruction of the southern stretch to Legazpi), and an inter-provincial service between the southern part of Metro Manila and Lucena, which re-opened last year. A project exists in the North between Angeles and Clark Airport in the form of a commuter service from Tutuban central station, under construction with a Japanese lead. Another initiative to re-create the Bicol link from Metro Manilla was considered with a Chinese lead, but suffered from a lack of commitment from the Chinese institutions and was cancelled.

1.2. Estimation of mobility needs

Analysis of Luzon shows an imbalance in population distribution: 33% of the population (~13 million inhabitants) live in the Manila area. The gravity model shows strong interactions between provinces around the capital. The population density in other regions is lower but remains noteworthy, so it makes sense to offer express and regional railway services.

The main modes of intercity mobility in the Philippines are buses and planes. Depending on their financial means, Filipinos choose the transport that suits their needs, but there is no rail culture in the country. The current offer is very unbalanced, both in terms of duration and price per passenger.

Buses are the cheapest form of long-distance transport (€0.07/pax/km) but also the longest (2h30 per 100km). Airplanes cover long distances (> 300 km) and are the preferred mode of transportation for the wealthier classes (€0.26/pax/km).

A table below summarizes the pros and cons of different modes of transportation.

Mode	Cost	Comfort	Avg Speed	Frequency
Bus	€0.07/pax/km	Low	40 km/h	~120 bus/day
Plane	€0.26/pax/km	Business Class, Standard Class	300 km/h	~4-6 flights/day

Analysis of air and bus traffic shows that a significant number of passengers take the bus to travel long distances. Fewer people can afford air travel. Daily passenger flows are estimated to be up to 6,500 pax/day between Manila and Naga, 4,000 pax/day between Manila and Legazpi, and 600 pax/day between Manila and San Fernando.

The regions studied in Luzon have considerable tourism activities. In 2019, some 22 million tourists visited Luzon.

The Philippines is the worldwide leader in rice, coconut and pineapple production. These products are intended for domestic markets, but also for export. Analysis of agricultural production shows potential for using freight to connect ports and airports to make freight transportation more robust.

It is therefore important to provide more frequent services between the provinces of Manila, Pampanga (Angeles), Laguna and Quezon (Lucena). Reduced-frequency flows would also be relevant to railway service coverage for other regions.

1.3. Stops and Types of Service

Diagnostic and demographic studies have identified areas that should be served by a long-distance railway link. Taking into account size, spacing between stations, provincial population, tourism and economic activities, 9 major areas have been identified:

- North Luzon with San Fernando (La Union), San Carlos, Tarlac then Clark airport (rather than Angeles city)
- Central Luzon with Quezon City (Metro-Manila area) then San Pablo and Lucena
- Bicol with Naga then Legazpi

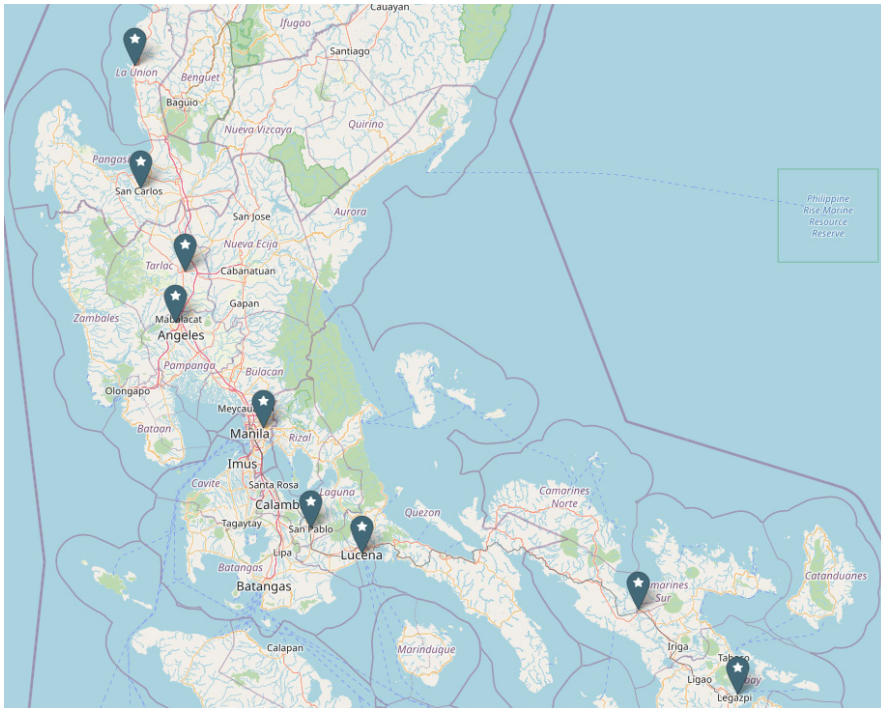


Figure 1. Commercial stop identification © Rustem Abdrakhmanov, Rémi Berthuit, Chloé Develiolglu, 2023
(map data: OpenStreetMap contributors, CC BY-SA).

Tutuban Central Station in Metro Manila is isolated from existing public transportation, such as the LRT and MRT networks. Construction of a new station in Quezon City would therefore be relevant, located at the crossing point of the LRT2 and MRT3 lines. The route would then connect with the existing PNR commuter service at San Pablo reached by the East.

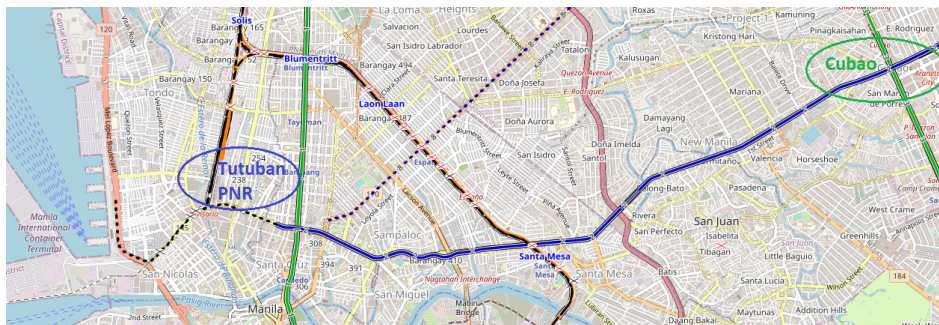


Figure 2. Station focus © Rustem Abdrakhmanov, Rémi Berthuit, Chloé Develioglou, 2023
(map data: OpenStreetMap contributors, CC BY-SA)

It is important for railway services to be consistent with local transportation needs. Hence the idea is to offer a high-speed interregional train with few stops and compressed journey times, like the TGV in France, to compete with road and planes. For this purpose, new infrastructure is required on all or part of the rail route.

Traffic is then split into several categories. High-speed train with first and second classes, like the airline model, to target businessmen, tourists and also Filipinos in need of a fast transit solution. Regional traffic is projected to use adapted lines on the Quezon-Lucena and Naga-Legazpi sections. Finally, most of the route is adapted to freight traffic.

2. New Infrastructure

2.1. Route

Once the stops and service have been defined, a route connecting the identified areas can be drawn. In this study, the 700km-long route is divided into 5 phases, according to the characteristics of each portion and also the relevance of the associated service.

To ensure that the infrastructure is suitable for the expected high-speed performance, a detailed analysis is then required. Many constraints along the route have been identified and require the design of engineering structures, such as bridges, tunnels and earthworks, to overcome obstacles such as gradients, mountains, flood zones or protected areas. The five phases are summarized below according to the different high-speed criteria to be met:

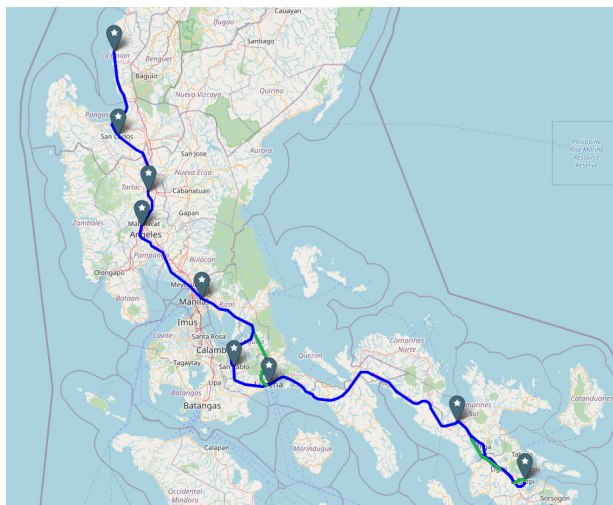


Figure 3. Proposed and alternative routes © Rustem Abdrakhmanov, Rémi Berthuit, Chloé Develioglou, 2023
(map data: OpenStreetMap contributors, CC BY-SA).

Phase	Length [km]	Incl. Bridges [km]	Incl. Tunnels [km]	Maximum slope [‰]	Minimum curve [m]	Maximum cant [mm]	Maximum speed [km/h]
Clark – Quezon	98.9	0	14	26	8 700	93	260
Quezon – San Pablo	99.8	15	32.3	18	5 000	160	260
San Pablo – Lucena	44.6	11	0	7.2	2 150	160 300 with tilting	230 with tilting
Lucena – Naga	214	21	12	10	3 850	160	260
Clark – San Fernando	181	127	0	21	5 100	160	260
Naga – Legazpi	88.4	4.7	0	6.2	1 800	160 300 with tilting	200 – 250

On one section, it was decided to rehabilitate the existing railway to enable regional traffic and reuse existing and historical stations.

2.2. Electrification

Total installed power capacity in the Philippines is 20GW, of which 14GW is on the Luzon grid. The main energy sources are coal (47%), gas (11%), and hydro (10%). About 12% of Filipinos do not have access to electricity and the Philippine grid is already pushed to the limits of its capacity.

To ensure the operability of the new long-distance line, an additional source of energy must be provided. The costs of the project include a hydroelectric power plant, designed to produce the energy required for operating the line.

The capacity of the power plant is sized on peak-hour railway service with the maximum number of trains on the line. As the powerplant continues to produce energy during off-peak hours, overproduction is sold at market price.

2.3. Technical facilities

The route includes 18 stations: 9 for the high-speed service and 9 for regional traffic. Half of them are entirely new, mainly on the northern part of the route, whereas the other half are existing, renovated PNR stations, especially for regional traffic between Naga and Legazpi.



Figure 4. Passenger Services Stop

Stations are completed by 12 track change facilities near major bridges and tunnels, reducing the impact of maintenance operations.

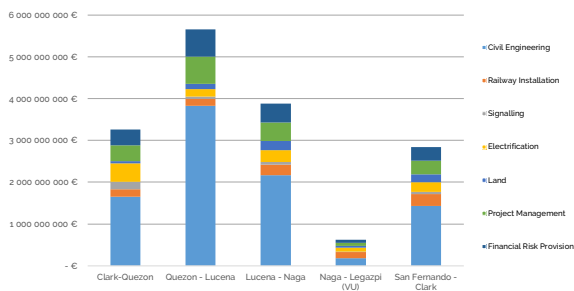
Line maintenance is organized in 3 sections (Clark Airport, Metro Manila, Naga) with dedicated maintenance workshops grouped with rolling stock maintenance facilities and multimodal freight terminals.

The line is equipped with ETCS Level 2 Baseline 3 release 2 and entire GSM-R coverage. RBC are limited and traffic is managed from a central command room located in Manila.

2.4. Capital Expenditure

This new line represents more than 700km in length, including 50km of tunnels for a total cost of €16.3 billion, *i. e.* €22M/km, similar to the French "Rhône-Alpes" High Speed line.

This cost includes civil engineering (60%), railway installation, signaling, electrification (including self-production), land, risk provision and project management (15% each). Rolling stock acquisition is excluded.



Figures 5. Cost per Phase

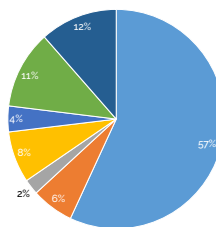


Figure 6. Cost per Category

Although the first phase includes initial cost and power plant construction, the second phase turns out to be the most expensive due to the tunnel sections (> 30km).

3. Operation

3.1. High Speed Service

Two long haul services (San-Fernando – Lucena and Clark – Legazpi) are offered every hour, overlapping each other to have the best frequency on the central section, along with reinforcement of the airport service and alignment on frequencies proposed by air for Clark – Naga.

The fleet of high-speed rolling stock necessary to provide this service with frequencies of up to 5 trains per hour on the central section is estimated at 25 trains, including maintenance requirements and operating reserves.

The Alstom Pendolino is chosen to operate this line, since its tilting capacity allows operation at highest speed (260km/h). These trains are leased under an Operation & Maintenance contract with provision of a dedicated depot located near Quezon City.

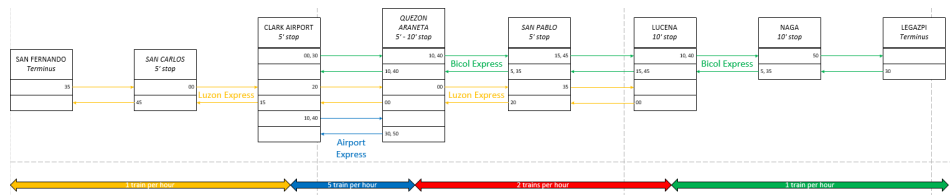


Figure 7. Line schematic diagram © Rustem Abdrakhmanov, Rémi Berthuit, Chloé Develiolgu, 2023.

Track maintenance and rescue operation are performed with a Stadler Eurodual Coco bimodal locomotive.

3.2. Regional and Freight Opportunity

The extension from south of Naga to Legazpi, along with modernization of the existing conventional line, revives the “Bicol Regional” connection serving all the stations maintained on the route.

During the identification of stops and choice of the route, a dedicated profile is planned for regional commercial stops on the Quezon - Lucena section. A "Laguna Regional" connection of the regional type could then be considered, similar to that planned on the Naga - Legazpi section.

	---Quezón --	-- Santa-Cruz --	-- San Pablo --	-- Candelaria --	----- Lucena
Regional Service					
	Luzon Express				
	Bicol Express				
	Laguna Regional				

Thanks to agricultural and industrial activities, there is huge potential for freight train services during off-peak hours. Port facilities and terminals will be installed to ensure the multi-modality.

3.3. Operational Expenditure

The annual operational expenditure is estimated for all 5 phases, with the cost of the acquisition and maintenance of the rolling stock spread over 30 years. Therefore, the

expenses are divided into 4 main cost items: infrastructure maintenance, rolling stock acquisition and maintenance, human operating resources and hydroelectric plant operation. This represents a total annual cost of €365.5M.

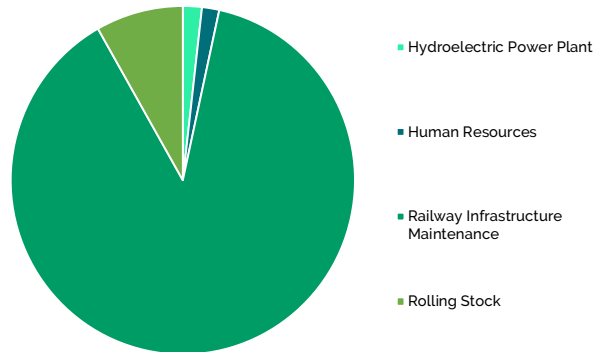


Figure 8. Operational Cost Breakdown ©

On the other hand, total income generated both by hydroelectric plant and train operations is estimated to be as much as €388.5M per year, broken down as follows:

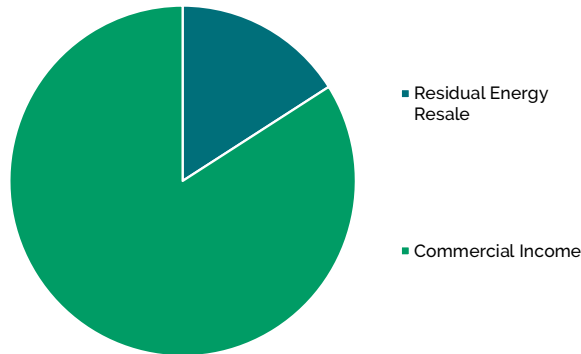


Figure 9. Operational Revenue Breakdown ©

It is important to note the imbalance between plant operating costs and revenues. As a matter of fact, hydroelectric costs represent only around 2% of the total expense, whereas the revenues generated account for up to 16% of the total income. This significant difference is what makes the whole system sustainable.

4. Project Implementation

4.1. Structure and funding

As on the Sud Europe Atlantique High Speed Line in France, construction and operation are integrated within the same structure, with experts as stakeholders. The choice has also been made to integrate the operation infrastructure manager, high speed operator and power supplier, as with the SNCF and SDEM (Société Hydro-Électrique du Midi). This allows a railway culture to be established that does not exist today. The national airline can also be included among the stakeholders as the proposed service comes into head-on competition with existing domestic air links.

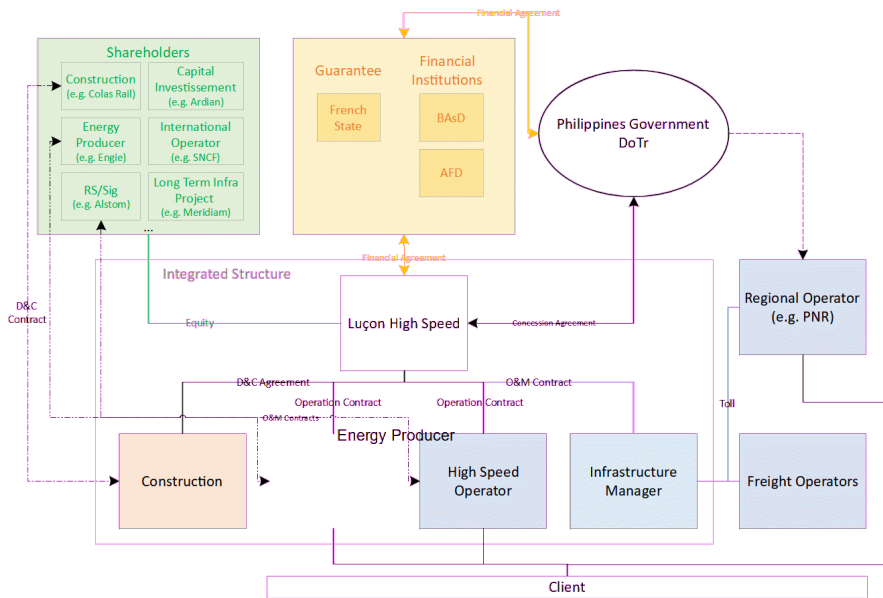


Figure 10: Project and financial structure

For construction, public funding was considered due to the public service provided by some sections, but a Public Private Partnership with the Philippines government on a "Build Operate and Transfer" model was preferred. A 50-year concession agreement will be designed to have access to rail franchises to operate services, with the obligation to hand over the infrastructure at the end. This infrastructure is financed by a loan granted by actors such as ADB and AFD with a French state guarantee.

Interfaces with the client are multiple – direct with the high-speed train and power distribution, but also indirect through future regional traffic operated by separate operators (e. g. PNR) and freight traffic paying tolls for access to the infrastructure.

5. Planning

As mentioned before, the construction work is split into 5 phases. The strategy is based on the most core services first, then extending the network over the course of the project to attract even more passengers. Therefore, the first phase connects Clark airport to Quezon City, then a link is created between Quezon City and Lucena. In the third phase, the network is extended down to Naga and finally, the fourth and fifth phases are constructed simultaneously at both ends, reaching San Fernando in the North and Legazpi in the South, respectively.

A typical schedule of activities is depicted for phases 1 and 2 and can be adapted for subsequent phases. Each phase is divided into at least four stages: land acquisition, civil works, railway equipment and tests. Stages and even phases overlap to optimize delivery times. Both phases 1 and 3 include construction of maintenance centers, and acquisition and tests of rolling stock.

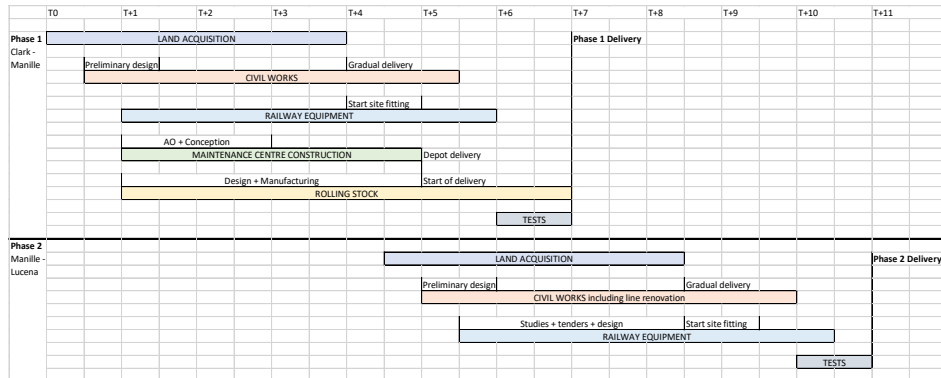


Figure 11. Schedule

6. Attractiveness of the transport offer

To analyze the attractiveness and relevance of a transport offer, the combination of a price-time model and gravity model is used. The price-time model estimates the modal shares of rail and air transport as a function of prices and travel times. A gravity

model completes this price-time model and allows to estimate traffic gains due to a reduction in travel times in areas served only by rail and the traffic induced by the new connection.

For all the routes studied, rail beats the other modes of transportation.

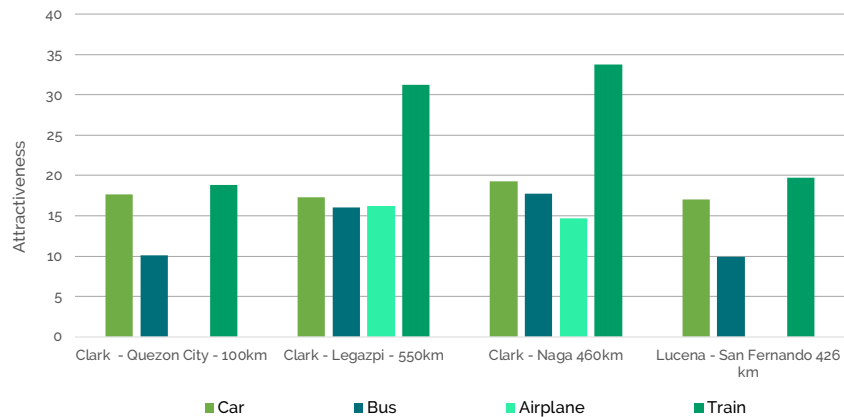


Figure 12. Attractiveness Analysis

La promotion 2022-2023

The students



ABDRAKHMANOV Rustem
Ingénieur Systèmes hybrides
ALSTOM



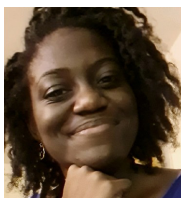
BEN HAMIDA SLIM Imen
Systra



BERTHUIT Rémi
Ingénieur Test & Commissioning
Hitachi



BOLLENGIER Clément
Chef de projet
ALSTOM



BOUMAH NGWENKELE Lorenn
Ing. Sécurité de fctm¹ logiciel
Ortec Group



BOURGEOIS Vincent
Adjoint au responsable de section
SNCF



CLERE Maxime
Adjoint au directeur Transformation
SNCF Voyageurs



DARDE Adèle
Analyste Projet et business développement
RATP Dev



DEVELIOGLU Chloé
Ingénieure Signalisation
ALSTOM



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Superviseur d'essai RER
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SNCF Réseau



FASQUEL Clémentine
Kéolis



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LUSCAN Mariette
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MORBIN Guillaume
Responsable Pôle gestion de
crise
SNCF Réseau



PARLAVECCHIO Olivier
Chef de projet Réorganisation
SNCF Réseau



PHELIPPEAU François
Ingénieur Système tramway
ALSTOM

Le voyage d'études aux Pays-Bas

The study trip in Netherlands

Du 10 au 12 mai 2023, 21 élèves de la promotion STFU 2022 – 2023 se sont rendus aux Pays-Bas dans le cadre de leur voyage d'étude ferroviaire. L'objectif du voyage était de découvrir le système ferroviaire et urbain hollandais, sous l'encadrement de Willem-Jan Zwanenburg (directeur de REBEL), Yann Piriou (responsable opérationnel chez RATP) et Federico Antoniazzi (directeur du Mastère Spécialisé®).

Après un trajet à grande vitesse dans une rame Thalys fraîchement renouvelée, la promotion a débuté son voyage avec la visite d'un centre de triage à gravité. Situé à proximité de Rotterdam et de son port, le triage de Kijfhoek est le plus grand triage des Pays-Bas. Il permet notamment de gérer le trafic à destination de la Belgique et de l'Allemagne. Des sujets techniques ont été présentés par ProRail, notamment sur l'exploitation de locomotives automatiques contrôlées à distance et sur le système de tri automatique des wagons. Un focus spécifique a également été réalisé sur la coactivité et la présence d'acteurs ferroviaires multiples sur le site. Enfin, les perspectives d'avenir et la stratégie de continuité d'exploitation du trafic fret ont été présentés et questionnés par la promotion.

La journée s'est poursuivie par la découverte du plus grand port européen, celui de Rotterdam. Cette visite terrain a permis aux étudiant.e.s de découvrir les installations, notamment ferroviaires, présentes sur le site et de réaliser le gigantisme des volumes de conteneurs transportés.

Le lendemain matin, après un trajet régional réalisé en train, le gestionnaire d'infrastructure ProRail nous a accueilli dans son siège social à Utrecht. Après une présentation de la topologie du réseau ferroviaire hollandais, la stratégie d'amélioration de la ponctualité a été discutée, notamment en abordant :

- la simplification de nœuds ferroviaires comme celui d'Utrecht, avec la suppression de nombreux appareils de voies et des travaux réalisés tout en continuant l'exploitation ;
- la mise en place de la signalisation européenne ETCS ;
- l'utilisation de nouvelles technologies au service des métiers sur le terrain.

L'excursion dans le centre-ville d'Utrecht a ensuite été ponctuée par la présentation du plus grand parking à vélo du monde (12 500



places), situé à proximité immédiate de la gare et favorisant fortement l'intermodalité vélo – train.

La seconde journée du voyage s'est terminée par la visite du musée national des chemins de fer néerlandais accessible... en train ! En effet, une station terminus raccordée au réseau est intégrée au sein même de l'enceinte du musée. De nombreux trains d'époque étaient exposés et visitables : les étudiants ont pu se mettre dans la peau des voyageurs de l'époque et mieux comprendre les évolutions techniques.

La dernière journée de voyage a été consacrée à un échange axé sur la tarification des transports urbains au Pays-Bas, et notamment sur l'Openbaarvervoerchipkaart : cette carte permet de se déplacer sur l'ensemble des réseaux de transport dans le pays, notamment sur le réseau ferroviaire opéré majoritairement par Nederlandse Spoorwegen (NS).

Le voyage terminé, les élèves ont souligné la qualité des interventions de tous les conférenciers et guides. Les retours sont unanimes : ce voyage d'étude permettant de développer l'intérêt et la curiosité pour d'autres systèmes de transports ferroviaires et urbains dans le monde renforce assurément le caractère international de la formation.

FROM the 10th to 12th of May 2023, 21 students from the Railway and Urban Transport System Engineering Advanced Master® traveled to the Netherlands as part of their railway study trip. The goal of the trip was to discover the Dutch rail and urban system, under the supervision of Willem-Jan Zwanenburg (director of REBEL), Yann Piriou (operational manager at RATP) and Federico Antoniazzi (director of the Advanced Master®).

After a high-speed journey on a newly-refurbished Thalys train, the class began the trip by a visit to a shunting yard. Located near Rotterdam and its port, the Kijfhoek hump yard is the largest in the Netherlands and handles traffic bound for both Belgium and Germany. Technical topics were presented by ProRail, hinging on the operation of remote-controlled automatic locomotives and the automatic wagon sorting system. A specific focus was made on co-activity and the presence of multiple rail stakeholders on the site. Finally, the outlook for the future and business continuity strategy for freight traffic were presented, followed by questions from the audience.

The day went on with a visit to Europe's largest port, Rotterdam. This field trip enabled the students to discover the facilities on site, particularly the rail facilities, as well as considering the huge volume of containers transported.

The following morning, after travelling via a regional train, the infrastructure manager of ProRail welcomed us to its head office in Utrecht. Following the introduction of the topology of the Dutch rail network, the strategy for improving punctuality was discussed, with particular emphasis on :



The simplification of rail hubs such as Utrecht, with the removal of numerous switches carried out while continuing operations

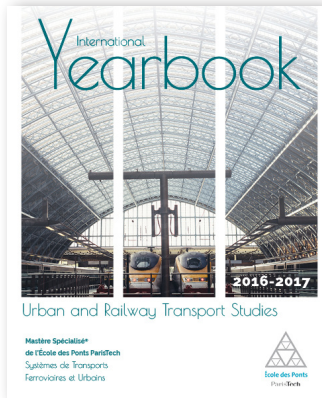
- *The introduction of the new European signaling system ETCS*
- *The use of new technologies*
- *The excursion to Utrecht city center then included a presentation of the world's largest bicycle parking facility (12,500 spaces), located right next to the station, demonstrating the strong emphasis on bike-train intermodality.*

The second day of the trip ended with a visit to the Dutch National Railway Museum, which is accessible... by train! In fact, a station connected to the railway network is built into the museum itself. A large number of vintage trains were on display and could be visited, giving the students a chance to put themselves in the shoes of travelers decades ago and gain a better understanding of technical developments.

The last day of the trip was devoted to a discussion on urban transport fares in the Netherlands, and in particular the Openbaarvervoerchipkaart: this card allows travel on all the country's transport networks, including the rail network operated mainly by Nederlandse Spoorwegen (NS).

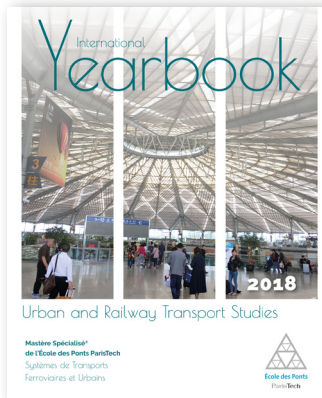
At the end of the trip, the students praised the quality of all the speakers and guides. The feedback was unanimous: this study trip helped to develop interest and curiosity about other rail and urban transport systems around the world, and certainly reinforces the international nature of the course.





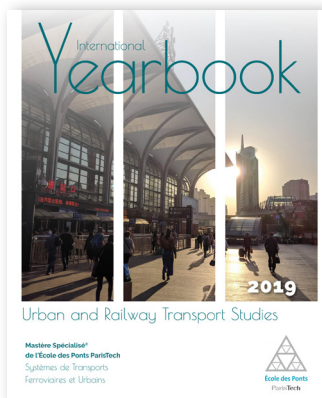
Yearbook 2016-2017

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



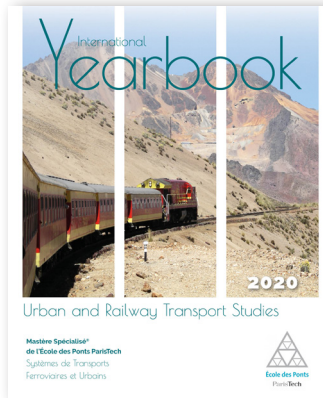
Yearbook 2018

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



Yearbook 2019

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



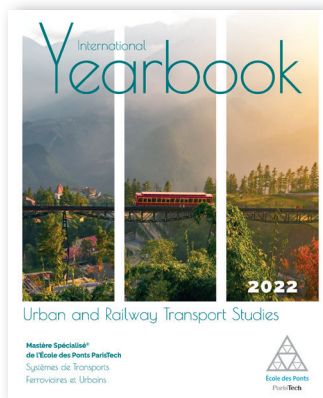
Yearbook 2020

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



Yearbook 2021

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



Yearbook 2022

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



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Ce *Yearbook* a été réalisé par la Direction de la Documentation, des Archives et du Patrimoine de l'École des Ponts ParisTech, 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.

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This Yearbook was made by the Department of Documentation, Archives and Heritage of the École des Ponts ParisTech, 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 2023 ont été regroupés dans cet ouvrage afin de donner un aperçu de leur qualité et de leur technicité. Cette année, deux groupes se penchent sur les problématiques d'une liaison ferroviaire à l'échelle nationale, l'une à Cuba, l'autre aux Philippines. Trois autres groupes proposent une solution de transport innovante et adaptée à l'échelle d'une ville (Sousse, Tunis et Khulna, au Bangladesh). À travers la multiplicité de ces contextes et de ces lieux, s'esquissent ainsi dans ce *Yearbook* les contours des mobilités futures : 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 2023 studies have been gathered in this book to give an overview of their quality and technicality. This year, two groups are looking at the problems of a nationwide rail link, one in Cuba, the other in the Philippines. Three other groups are proposing an innovative transport solution adapted to the scale of a city (Sousse, Tunis and Khulna, Bangladesh). 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.