International Yearbook

2019

Urban and Railway Transport Studies

Mastère Spécialisé®
de l'École des Ponts ParisTech

Systèmes de Transports
Ferroviaires et Urbains

École des Ponts
ParisTech

URBAN AND RAILWAY TRANSPORT STUDIES
INTERNATIONAL YEARBOOK
2019

Encadrants à l'École des Ponts ParisTech

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Avertissement

Warning

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

École des Ponts
ParisTech

Édito

Editorial

DEPUIS 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 dément pas année après année, nous a conduit à les réunir dans un *Yearbook* pour vous les faire partager.

SINCE its creation in 1747, École des Ponts ParisTech has always put infrastructure in the spotlight, 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 metro in Paris; François Lacôte, one of the pioneers of TGV within SNCF and Alstom; as well as Jean-Marie Duthilleul, architect of numerous train stations. This tradition is still very much alive today, since the school hosts several training courses dedicated to transport and mobility, such as the "Railway and Urban Transport System Egineering" 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 *to share them with you.*

Sophie Mougard

Sophie MOUGARD

Directrice de l'École des Ponts ParisTech

École des Ponts ParisTech's Headmaster

L'édito de la directrice du Mastère Spécialisé®

C'EST dans le cadre du Mastère Spécialisé® « Systèmes de transports ferroviaires et urbains » que les étudiants réalisent 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 comme Systra ou Parsons. Ce travail collaboratif, faisant jouer les complémentarités des savoir-faire, prend la forme d'un mini-mémoire.

Cette étude porte sur un projet qui n'existe pas encore et qui n'a pas été étudié. Ainsi, les sujets sont choisis depuis 3 ans avec l'Agence française de développement et concernent des transports de masse dans les grandes mégapoles en voie de développement ou des pays que la Banque mondiale accompagne 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 net et… leur débrouillardise.

Pour la promotion 2019, l'Agence française de développement nous a proposé des projets situés sur trois continents : l'Asie, l'Afrique et l'Amérique du Sud. Un groupe a travaillé sur une liaison ferroviaire dans le golfe de Guinée entre Abidjan et Lagos, un autre sur une ligne péri-urbaine à Dhaka au Bangladesh. Les autres projets concernaient deux projets de TCSP (Transports Collectifs en Site Propre) : l'un pour Cúcuta, ville-frontière entre le Venezuela et la Colombie, l'autre pour la ville de Djibouti.

Vous pourrez en parcourir les résumés dans ce *Railway and Urban 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 sensible à la qualité de ces travaux. En vous souhaitant bonne lecture et bon voyage entre Lagos, Cúcuta, Dhaka et Djibouti…

Françoise Manderscheid

Françoise MANDERSCHEID

Directrice du Mastère Spécialisé® « Systèmes de transports ferroviaires et urbains »

Advanced Master's Headmaster

A word from the Advanced Master's headmaster

IT is for the "Urban and Railway Transport System Engineering" Advanced Master® that students have to design a transport project in a foreign city. 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, allowing students to complement one another with their different savoir-faire, is carried out in the form of a short thesis.

This study has to develop a project that has never been made or studied before. That's why, for the past 3 years, topics have been chosen together with the Agence française de développement 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 towns they study. They make use of a large network of experts, embassies and financial institutions, online resources and... their own resourcefulness.

For the 2019 promotion, we have selected together with the Agence française de développement projects concerning three continents: Asia, Africa and South America. Two groups of students worked on railway subjects: one along the Gulf of Guinea, between Abidjan and Lagos, from Ivory Coast to Nigeria; the other on the reopening of an old railway in Great Dhaka area, in Bangladesh. The third group worked on a BRT project in Cúcuta, a town located on the border between Colombia and Venezuela. The last one worked on a tramway project in Djibouti City.

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

Françoise Manderscheid

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, Bombardier, Siemens, etc. Cette formation propose une vision d'ensemble du système ferroviaire et urbain, selon une approche multidisciplinaire, intégrant les aspects techniques, économiques et règlementaires. Elle s'adresse à des professionnels ayant déjà plusieurs années d'expérience en transport. 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), ainsi que leurs infrastructures. On insiste particulièrement sur 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 grands projets, notamment le tracé d'une infrastructure, la conception d'un plan de signalisation et la conception d'un matériel roulant. Ce dernier se trouve être le 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 ». Se côtoient dans une même promotion ingénieurs de conception ou de maintenance, experts en exploitation ou en signalisation, ingénieurs systèmes, économistes, chefs de projet. Aujourd'hui les anciens élèves du Mastère constituent un réseau de 350 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.

Françoise Manderscheid

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 RATP, SNCF Alstom, Bombardier, 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 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. Indeed, the training course relies heavily on them: the design of an infrastructure, the design of a signalling plan and the design of rolling stock. Specifically, the latter happens to be the design project for 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 title of "International Experts in Railway and Urban Transport Systems". In the same class, there are design or maintenance engineers, operating or signalling experts, systems engineers, economists, project managers… Today, the alumni form a network of 350 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.

Françoise Manderscheid

Enseigner le ferroviaire à l'École

Railway classes at the École

1832 — Charles-Joseph MINARD

Amédée BOMMART — 1842

1852 — Jacques MANIEL

1855 — Pierre Dominique BAZAINE-VASSEUR (1855–1873)

François JACQMIN — 1867

Louis-Charles SÉVÈNE — 1873

1880 — Jules MARTIN

Charles BRICKA — 1891

1899 — Désiré FOUAN

Albert DESCUBES — 1918

1927 — André MARTINET

Louis CAMBOURNAC — 1940

1951 — Georges CHAN

Charles FEYRABEND — 1961

1968 — Robert BIAIS

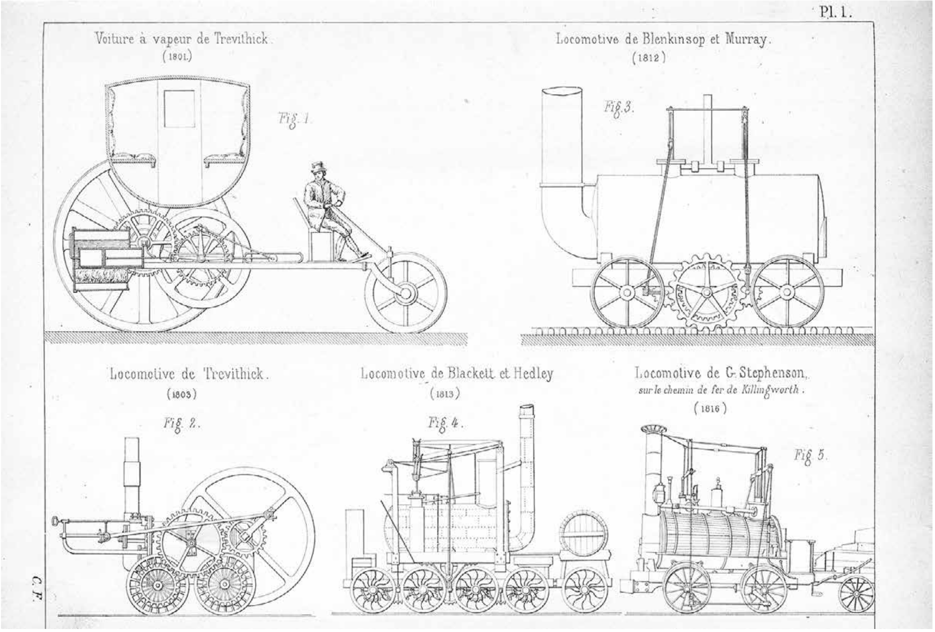
Jean ALIAS (1968–1985) — 1972

1985 — Philippe ROUMEGUÈRE

Pascal LUPO — 2003

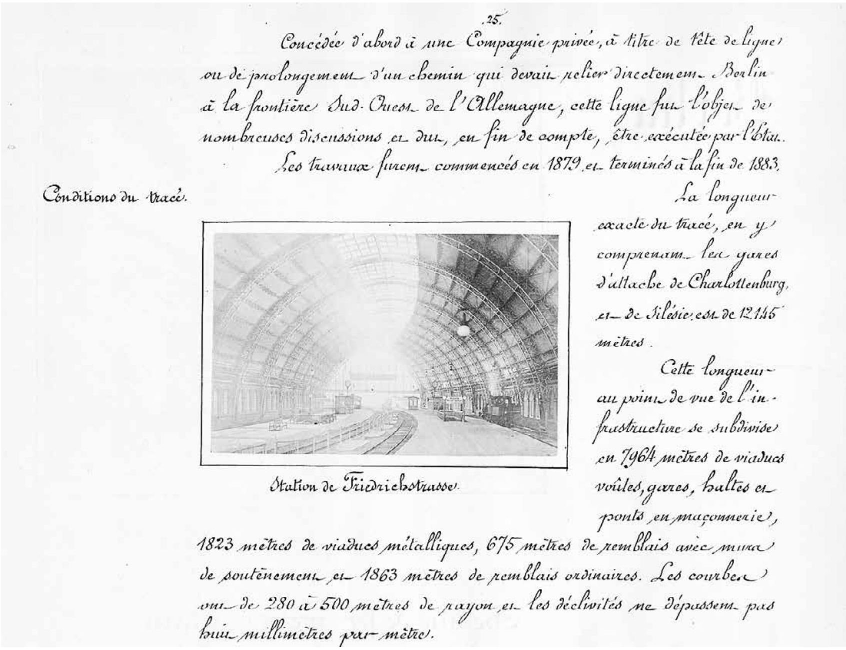
2008 — **Création du Mastère spécialisé®**
« Systèmes de transports ferroviaires et urbains »
Birth of the Advanced Master®

Paul BOUVAREL — 2013 — Françoise MANDERSCHEID (2013–)



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

Page from Pierre Dominique Bazaine-Vasseur from 1873.



.25.

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

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

Conditions du tracé.

La longueur exacte du tracé, en y comprenant les gares d'attache de Charlottenburg et de Silésie est de 12145 mètres.

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

Station de Friedrichstrasse

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

Page from a 19th century students' project journal

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Creation of an Abidjan-Lagos Railway Line

Thibaut HANNART
Éléonore LABAUDINIÈRE
Yann LE NOC
Jérôme TORQUATO
Anna TSYGANOVA

École des Ponts
ParisTech

Le chemin de fer en Afrique est aujourd'hui un vecteur majeur de développement humain et économique. Voilà pourquoi le développement du transport ferroviaire de masse, en particulier entre mégalopoles à croissance démographique forte, est crucial. L'axe Abidjan/Lagos est l'une des principales régions métropolitaines africaines, un corridor très peuplé et une zone stratégique (grâce à ses ports et ses points d'entrée) pour l'hinterland du golfe de Guinée. C'est l'espace idéal pour développer un projet ferroviaire de 1 000 km de liaison inter-pays en Afrique de l'Ouest. C'est le projet que nous avons élaboré en suivant cinq grands axes :

- comprendre le contexte, pour percevoir l'intérêt de cette liaison ;
- définir avec précision le besoin de mobilité ;
- proposer un projet de mobilité ferroviaire cohérent, pertinent et réaliste au travers d'une étude de faisabilité ;
- évaluer le coût global de l'offre proposée ;
- établir un montage de réalisation complet : financement, organisation et phasage de réalisation.

Mots-clés : Afrique de l'Ouest, corridor Abidjan/Lagos, mobilité, liaison ferroviaire mixte, faisabilité, projet d'émergence

Today, railway transportation in Africa is a major asset for human and economic development. It is therefore of great importance to develop it, especially between fast-growing megalopolises. The Abidjan/Lagos axis is one of the main African metropolitan regions, a heavily populated corridor and a strategic area (ports and entry points) for the Gulf of Guinea's hinterland: all arguments in favor of railway development. This West African, transcontinental thousand-kilometer railway project is based on five main points:

- *to understand the West African context so as to better appreciate the interest of connecting five countries;*
- *to define precisely the need for mobility;*
- *to propose a coherent, relevant and realistic railway mobility project through a feasibility study;*
- *to evaluate the global cost of this proposition;*
- *to establish a comprehensive plan regarding funding, organization and realization phasing.*

Keywords: West Africa, Abidjan/Lagos corridor, mobility, mixed railway link, feasibility, emergence project

Introduction

This study examines the feasibility of the creation of an Abidjan/Lagos railway line. Railway transportation in Africa is a major asset for human and economic development. Developing it is therefore of great importance, especially between metropolises with strong demographic growth.

In fact, the Abidjan/Lagos axis is one of the main African metropolitan regions, a heavily populated corridor and a strategic area (ports and entry points) for the domestic market of the Gulf of Guinea countries, all arguments in favor of railway infrastructure.

This presentation of our project begins with a general overview of the corridor, followed by a short diagnosis based on socio-economic and flow analysis. Secondly, we present a system design and solutions for route, tracks, signalling and rolling stock. Thirdly, we ponder operations and maintenance for such a large project. Lastly, we do a quick overview of costs estimations, planning, project organization and funding. To carry out this study, we have excluded the geopolitical aspects and assumed that all governments involved would support the project.

1. General overview and diagnosis

The project connects five countries with different pasts but a common future, if only because of their simultaneous developing in the same area. Côte d'Ivoire, Togo and Benin have a history of French colonization, with language and currency as their main inheritance. Ghana and Nigeria are English-speaking countries with their own currency. The two cities chosen for the project are both of importance in their respective countries, both located on the Gulf of Guinea and both in the middle of an extensive demographic and economic expansion. Major trading is already occurring between the two; to be linked by railway could only benefit them.

1.1. Socio-economic analysis

The first step before laying down the route between Abidjan and Lagos is to study this geographic area in order to evaluate the most relevant places this new line shall connect. Population, economy and distance were our main criteria in this analysis.

Indeed, the first aspect to consider when studying traveler transportation is population. This project will only be meaningful if it connects all main urban areas in the corridor with one another. Along the corridor between Abidjan and Lagos, each country has at least one city with more than a million inhabitants; and fewer than 1,000 km separate all these cities from one another. Moreover, the population growth in this area is around 2.6% per year, meaning the travel needs will rapidly increase.

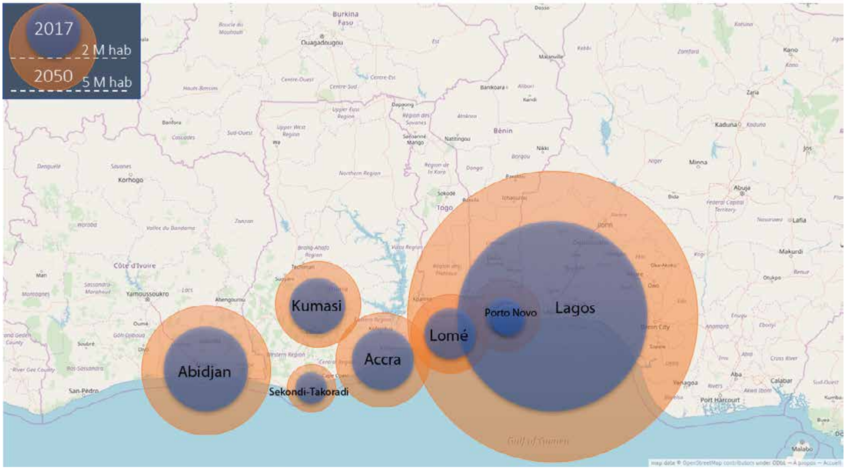

Figure 1: Estimated population in 2017 and forecast in 2050. Map: © OpenStreetMap Contributors, CC-BY-SA. Modified by Thibaut Hannart, Éléonore Labaudinière, Yann Le Noc, Jérôme Torquato, Anna Tsyganova, 2019.

From an economic perspective, Nigeria looms over West Africa, mostly because of oil export. Ghana and the Côte d'Ivoire come in second place with an identical GDP: around $ 45 billion. Benin and Togo are last, with a GDP of $ 9.3 billion and $ 4.8 billion respectively in 2017. All five countries have a buoyant economy with an annual GDP growth situated between 5.9% and 7.4%.

To refine our choice, we compared the road distances between eligible cities. Two areas of importance emerged:

- between Accra and Lomé;
- between Lomé and Lagos are five important cities fewer than 150 km apart from each other (Lomé, Abomey-Calavi, Cotonou, Porto Novo and Lagos).

It must otherwise be noted that two important cities are relatively isolated:

- more than 500 km separate Abidjan from Accra;
- Kumasi (2+ million inhabitants) is farther than 200 km away from all others important cities.

Based on this analysis, we identified six main cities in need of a railway connection. Going from West to East: Abidjan, Accra, Lomé, Cotonou, Abomey-Calavi, and finally Lagos. Let us also note that Tema, with its port serving Accra, is an important connection for freight service. Sekondi-Takoradi and Cape Coast, in Ghana, are smaller but very active cities, which makes them points of interest in our project.

Our study will focus on the Abidjan/Lagos axis via Accra, and will not study the service to Kumasi, which might however represent an interesting complementary project, with a dedicated Kumasi/Accra line.

1.2. Flow analysis

Many people are traveling between Abidjan and Lagos, not only to neighboring countries but also all along the corridor. However, the main journey routes are Abidjan/Accra, with 18 million travelers per year, and Lomé/Cotonou, with over 26 million travelers per year (2030 forecast, based on a 2014 Japan International Cooperation Agency study). Going by the modal report for rail transportation depending on distance, we made a traveling numbers estimation for the projected railway line.

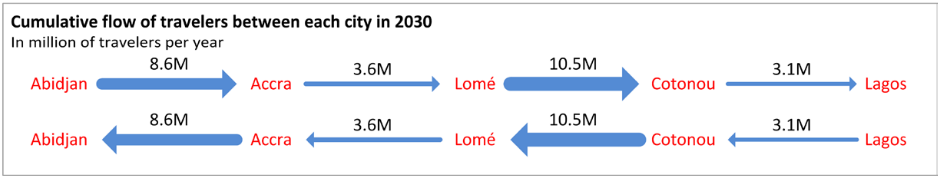

Figure 2: Railway travel numbers estimation in 2030 © Thibaut Hannart, Éléonore Labaudinière, Yann Le Noc, Jérôme Torquato, Anna Tsyganova, 2019, based on JICA study Collection of Relative Data to International Ports Traffic and Transboundary Corridors in West Africa.

The current state of mobility supply, put side-by-side with travel demand, clearly opens up a significant opportunity for the railway system. The inaccessibility of private transport (private car) as well as the important demographic and economic growth in the corridor seem to call for a modern, fast and safe means of mass transportation.

Regarding freight, exports are low between neighboring countries. We noticed that cement is one of the weightiest commodities subject to trade in the area. Nigeria and the Côte d'Ivoire also exchange important volumes of oil. These products are easy to carry in mass transport, which makes them good candidates for freight services.

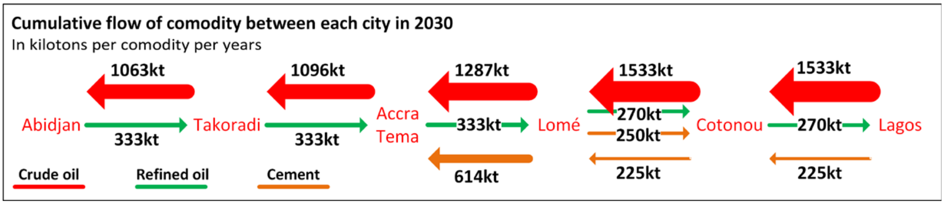

Figure 3: Cumulative flow of commodities in 2030 © Thibaut Hannart, Éléonore Labaudinière, Yann Le Noc, Jérôme Torquato, Anna Tsyganova, 2019.

It must be noted that railway networks already exist in the countries in question. But these networks are historical—either Cape or meter gauge—and mainly run along a north-south axis for freight. However, we shall include them in our project in order to allow interoperability, especially in terms of track gauge.

2. Overall analysis approach

To perform an objective study, we adopted a process based on step-by-step and iterative cycles, as described in the following figure.

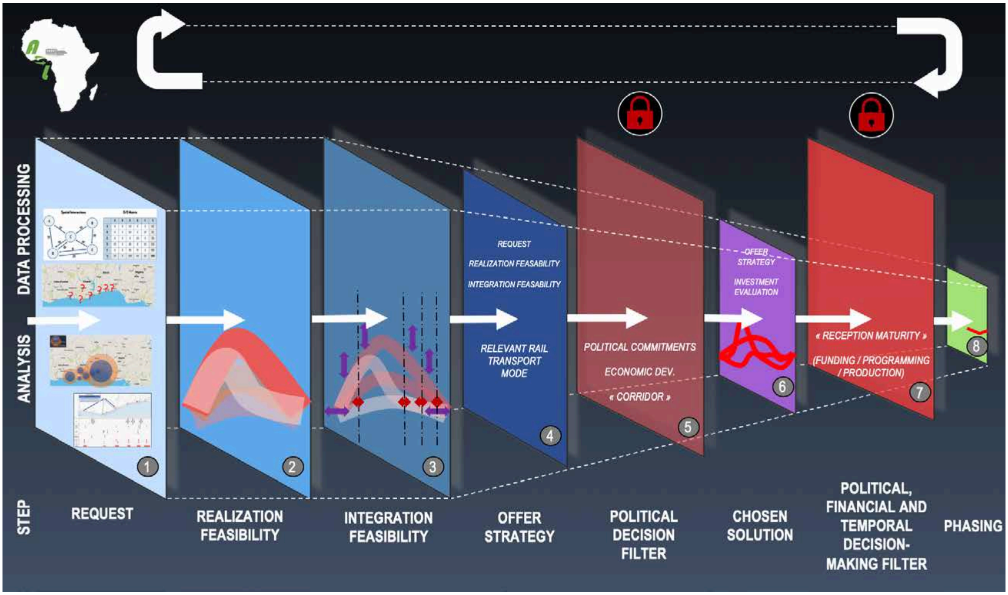

Figure 4: Overall analysis approach © Thibaut Hannart, Éléonore Labaudinière, Yann Le Noc, Jérôme Torquato, Anna Tsyganova, 2019.

3. Route and tracks

A multi-criteria analysis will allow us to design our system in the most objective way possible, specifically when it comes to our route proposal. The main aspects we took into consideration were: presence of important cities, points of interest, factories, population and passengers/goods flow.

The route we picked has the following characteristics:

- a "Côte d'Ivoire/Ghana" sector characterized by a coastal route, with the presence of several structures across numerous rivers and extant communication axes;
- a "Togo" sector characterized by a coastal route, with the presence of several structures across numerous rivers and extant communication axes, but also an unfavorable context of hydrographic constraints and urbanization;
- a "Benin/Nigeria" sector characterized by an unfavorable route due to the need for earthworks (geology/hydrography, and marshy areas/urbanization), meaning the aforementioned works shall be bridges and viaducts for the most part;

- the offshoots (lines connecting extant stations in the city center to the new station in the north of the city) represent a constraint regarding land acquisitions. This subject is critical, especially because of the high urban density of the areas to cross, and shall be given due consideration.

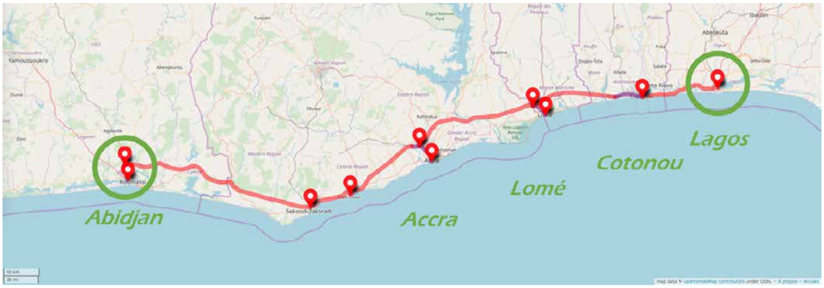

Figure 5: Forecast route © Thibaut Hannart, Éléonore Labaudinière, Yann Le Noc, Jérôme Torquato, Anna Tsyganova, 2019.

Regarding construction, our choice was set on a ballasted double track railway, in order to cope with the population growth predictions. To reduce the investment cost, the line shall not be electrified in the short run. On the whole, the line is presenting a coastal profile.

In cross section, the project is composed of a platform with two tracks on an overall breadth of 13.90 m. The main track occupation is around 100 m on average—from 25 m to 150 m for the most important embankments. The total length of the line is 919 km on the main route, plus 81 km of offshoots.

Our study takes into account environmental aspects on a macroscopic scale. The route shall have a minimal impact on the environment. We devised it according to the following principles:

- protected environment zones: no impact, or very limited impact with compensation;
- hydrographic network: preservation and recovery of natural flows. This point is very important due to the route being perpendicular to numerous rivers;
- high-density urban zones: preservation and minor impact, by bypassing them on the north side.

Tracks shall be made up of 1,500-meter-long blocks with automated color-light signals; and on the reverse track, there will be automated permissive signals for longer sections, to allow for continued operation even in case of degradation. In terms of on-board signalling and radio communication, KVB (French ATP) shall be our preferred train equipment, as it is a simple and robust system. Three signalling centers shall cover the entire line. They shall be located at both ends and in the middle of the line. Moreover, shunting boxes shall equip technical stops to allow on-site maneuvers.

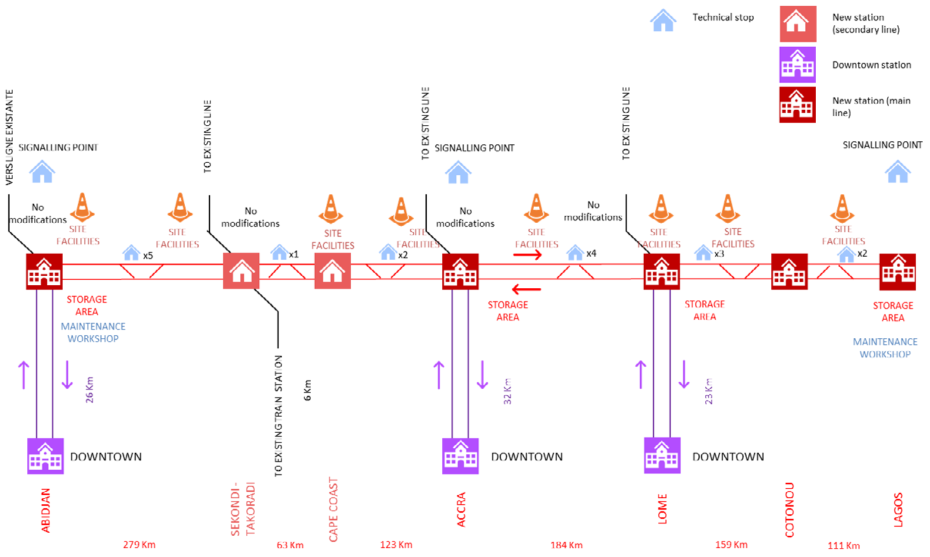

Figure 6: Diagram of railway amenities © Thibaut Hannart, Éléonore Labaudinière, Yann Le Noc, Jérôme Torquato, Anna Tsyganova, 2019.

4. Operation

4.1. Missions

In order to answer travelers' needs in 2030, four distinct missions will be running all day long:

- Abidjan/Lagos via new stations;
- Lomé/Cotonou;
- Abidjan/Accra from city center to city center (omnibus with stops at Sekondi-Takoradi, Cape Coast and Accra New Station);
- Accra central station to Lagos via new stations in Accra and Lomé.

Our fixed goal is to offer a travel time at least equal to highway travel (e.g. for a Cotonou/Lomé trip) or inferior (45 minutes less between Abidjan and Lagos). Traveling from Abidjan to Lagos will only take 7h35.

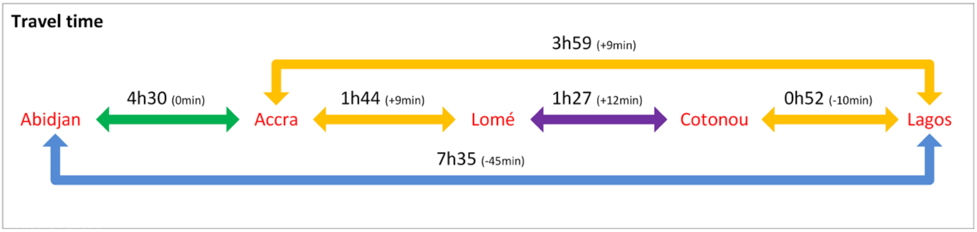

Figure 7: Theoretical travel time © Thibaut Hannart, Éléonore Labaudinière, Yann Le Noc, Jérôme Torquato, Anna Tsyganova, 2019.

For this passenger service, 134 Diesel Multiple Units (DMU) trains are needed. During the service day, trains composition shall vary from a single unit to a three-unit train, in accordance with demand fluctuation.

Concerning freight in 2030, the following missions shall be run:

- two missions between Abidjan and Lagos for oil transportation, crude oil from Lagos to Abidjan and refined oil from Abidjan to Lagos;
- three missions for cement transportation:
  - two from Lomé to Cotonou and Tema;
  - one between Lagos and Tema.
- four shuttle missions between ports and stations in Takoradi, Lomé, Accra and Cotonou.

Freight operation will run at night on a weekly basis. Due to a slow speed, freight missions between Abidjan and Lagos will be done over two nights with a stop at Accra (close to the new station). Empty returns shall be done in only one night. For this freight service, 31 locomotives are needed as well as 280 tank wagons (for oil) and 51 silo-powder wagons (for cement).

4.2. Rolling stock

On this non-electrified railway line, the traction mode shall be electrical-diesel technology. Motors are designed to be able to run on the entire line, depending on the route characteristics.

DMU trains shall perform passenger service; their technical characteristics allow them to run at a maximal speed of 160 km/h. The diesel traction based on power packs could evolve in the future into hydrogen technology. These trains can be set into a three-unit configuration if needed and can include passenger services.

For freight service, we need locomotives with characteristics allowing them to run at a maximal speed of 160 km/h. Towing a 1,200 tons convoy, speed will be down to 105 km/h on flat tracks and 35 km/h on 25‰ slopes (maximum). As mentioned above, tank wagons will carry crude and refined oil, and silo-powder wagons, cement.

5. Costs estimation and profitability

High investments are needed for such a line, especially on its eastern section which will necessitate bridges and viaducts due to terrain issues. To answer the passenger demand, an important DMU fleet is necessary. Finally, the CAPEX rises up to € 19 billion.

CAPEX	
Total	€ 19,299,000,000
Maintenance costs per year	
Total	€ 47,782,272
Operations per year	
Total	€ 218,589,558

Table 1: Project costs summary.

These high costs, mostly due to numerous civil works, would sink the project if an important modal report (up to 75%) didn't let us forecast major revenue. The ticket price has been set to 0.08 €/km: below international coaches and above informal transports, but with a higher quality of service. This estimation leads us to an annual income of € 1.2 billion. The operating balance ends up positive, reaching € 574 million.

Taking into consideration the time gain and the time value, the reduction of greenhouse gas emissions, the CO_2 ton price and finally the road safety improvement and the value of statistical life, the socio-economic balance of the project reaches € 2.6 billion euros, demonstrating that this railway line would have a strong positive influence on the area.

6. Planning

We estimate the overall duration of this project to last between 15 and 20 years, from emergence to operation.

Steps	Global term	A-1	A+0	A+1	A+2	A+3	A+4	A+5	A+6	A+7	A+8	A+9	A+10	A+11	A+12	A+13	A14	A+15	A+16
Prospective	Variable																		
Emergence	From 2 years to 4 years																		
Definition	From 4 years to 5 years																		
Design-Realization	From 6 years to 8 years																		
Ending	From 1 year to 2 years																		
Operation	after commissioning																		

Table 2: Project schedule.

We propose a geographic phasing, based on a multi-criteria analysis of the readiness of all involved countries. Taking into account projections of economic and population growth, assessments of state solvency, and passenger per distance ratios, the following axes shall be realized in priority:

- priority 1: Lomé – Cotonou;
- priority 2: Abidjan – Accra;
- priority 3: Cotonou – Lagos.

7. Project organization and funding

A vertically separated setup seems to best fit this project, where the infrastructure is managed by a public company, while a private company oversees operations. The Contracting Authority as well as the Regional Company of Abigos Railways (SRCF Abigos) shall be created with all five countries as equal shareholders. The SRCF shall remain in charge of maintenance through a dedicated entity with its own staff. The railway concessionaire shall deal with the management of the rolling stock purchased by the SRCF and ticketing, as well as train operation.

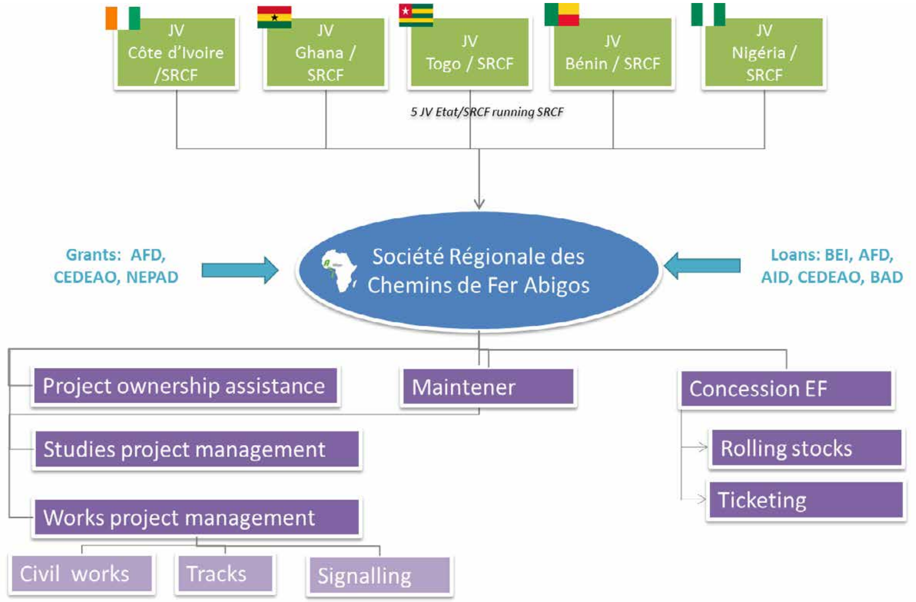

Figure 8: Project organizational setup © Thibaut Hannart, Éléonore Labaudinière, Yann Le Noc, Jérôme Torquato, Anna Tsyganova, 2019.

The funding shall be distributed proportionally to construction costs, and shall supply the SRCF following this repartition:

- countries' own investments: 40%, each country paying 8% of the total project cost;
- grant funds: 30%;
- low interest rate loans from international financing institutions: 30%.

Conclusion

Given the state of the existing road network on the Abidjan/Lagos axis, the mobility demands, the population density along the coastal zone as well as the galloping growth of both economy and demography in this area, the need for proper infrastructure is paramount.

On the one hand, this railway project between the different cities is, as this study demonstrates, a significant investment for all five countries. Nevertheless, the socio-economic analysis clearly shows that the long-term benefits of such a line far outweigh the costs.

On the other hand, this project is, as we have seen, clearly desired by current actors. Today, we are witnessing a real comeback of rail transport in Africa, which constitutes an indisputable vector of development. This movement can only be beneficial to the emergence of an interregional link project.

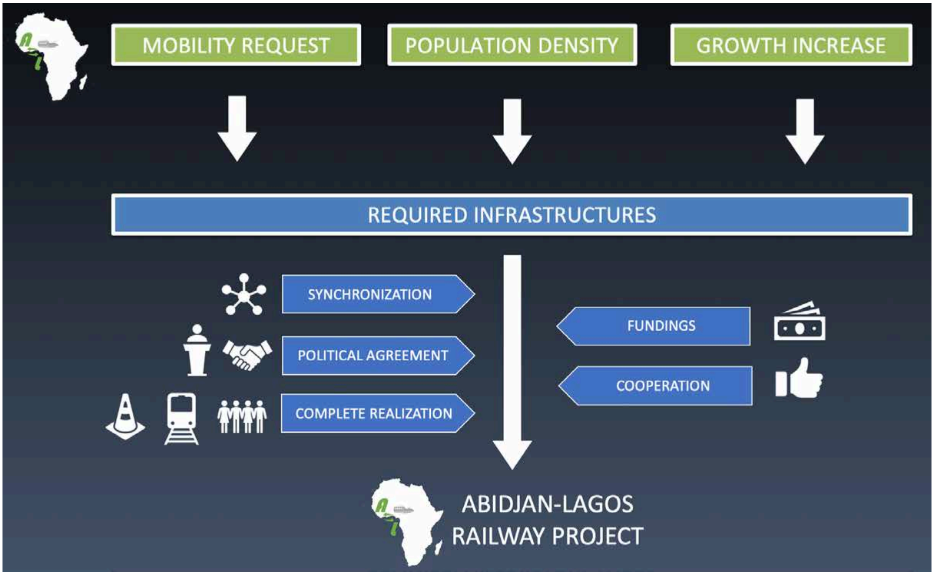

Figure 9: Abidjan-Lagos railway project summary © Thibaut Hannart, Éléonore Labaudinière, Yann Le Noc, Jérôme Torquato, Anna Tsyganova, 2019.

Dhaka Suburban Railway Line, Bangladesh

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Avec plus de 160 millions d'habitants en 2018, le Bangladesh est le huitième pays le plus peuplé du monde. Sa population continue de croître, en particulier dans les villes, générant une urbanisation désorganisée, des embouteillages et de la pollution. Dans ce contexte, la mobilité est devenue une priorité, en particulier pour la capitale, Dhaka. Ce projet étudie l'opportunité et la préfaisabilité de créer une offre de transport en commun en modernisant une ligne de chemin de fer de banlieue qui traverserait Dhaka du nord au sud sur une voie de 50 km, avec 18 nouvelles gares. La solution choisie est la combinaison de plusieurs scénarios : la première partie au sol avec l'élargissement de la voie et le remplacement des passages à niveau par des ponts ferroviaires ; la seconde partie sur un viaduc suspendu. Avec 815 000 voyages quotidiens, nous avons estimé qu'il était nécessaire d'installer 33 trains sur deux niveaux, ayant une capacité de 3 260 passagers et un intervalle de 4 ou 8 minutes. Ce nouveau projet améliorera sans aucun doute l'économie de la ville ainsi que la qualité de vie des habitants et des passagers.

Mots-clés : étude de choix du système de transport, modélisation de la demande, train deux niveaux, périurbain, Dhaka (Bangladesh)

With over 160 million inhabitants in 2018, Bangladesh is the eighth most populated country in the world. Its population continues to grow, especially in urban areas, resulting in disorganized urbanization, congestion and pollution. Mobility has thus become a priority, especially in Dhaka, the capital. This project studies the opportunity and pre-feasibility of improving mass transit through the modernization of a suburban railway line crossing Dhaka from north to south, with a new 50 km track and the creation of 18 stations. The chosen solution is the combination of several possibilities: first, the ground option, with the widening of the track and the replacement of level crossings with rail bridges; second, the elevated option, with an overhead viaduct. With 815,000 daily trips, we evaluated the need for rolling stock to number up to 33 double-decker trains. They will each carry a maximum of 3,260 passengers, with a headway of 4 or 8 minutes. This new project will improve the overall city's economy, and the life quality of the residents and passengers.

Keywords: transport system analysis, demand modelling, double deck train, suburban, Dhaka (Bangladesh)

Introduction

With over 160 million inhabitants in 2018, Bangladesh is the eighth most populated country in the world. Its population continues to grow, especially in urban areas, resulting in disorganized urbanization, congestion and pollution.

Figure 1: Dhaka street market © Kroisenbrunner, 2015, CC-BY-SA (source: Wikimedia Commons).

Mobility has become a priority, especially in Dhaka, the capital. This project studies the opportunity and pre-feasibility of improving mass transit through the modernization of a suburban railway line crossing Dhaka from north to south.

1. Socio-demographic analysis

Dhaka is the centre of the political, cultural and economic life of Bangladesh. With over 24 million inhabitants today in the Greater Dhaka, it is expected to become the third largest metropolis in the world by 2030 with about 35 million inhabitants.

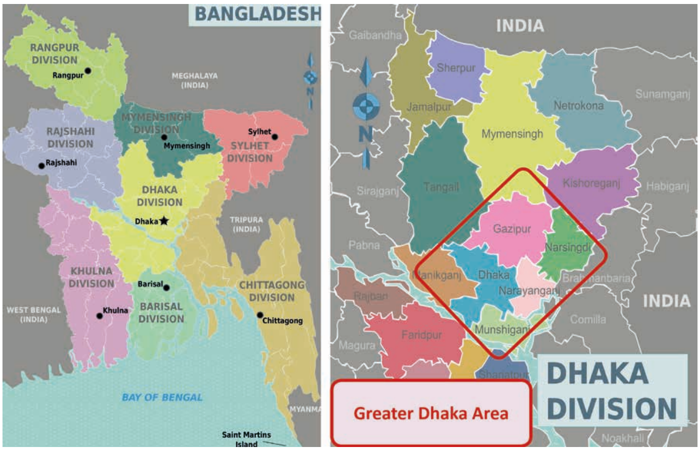

Figure 2: Map of Dhaka. Left: © Armanaziz, Peter Fitzgerald, Cacahuate, JamesA, 2008, CC-BY-SA (source: Wikimedia Commons). Right: © James Adams, Cacahuate, 2012, CC-BY-SA (source: Wikimedia Commons). Modified by Maxime Allegre, Cyril Dugimont, François Joly, Fanida Mezzane, Jean-Baptiste Rousseau, 2019.

Regarding the natural context, many areas in Dhaka are highly vulnerable to flooding, which usually occurs during the monsoon season from June to September. The highest temperatures usually occur in April, often going over 45°C. Most of the Dhaka area stands on sand and sediment, a type of soil which offers no resistance to earthquakes. Furthermore, the increasing pollution of air and water, resulting from traffic congestion and industrial waste, is a public health issue.

1.1. Sociodemographic and economic context

Dhaka is the commercial heart of Bangladesh. With an annual growth rate up to 6.1%, its projected Gross Domestic Product (GDP) for the year 2020 is about € 111 billion. The monthly median income in Dhaka is estimated at € 142, although a large part of the population lives below the poverty rate, many surviving with less than € 2.5 a day.

There is a continuous population growth in Dhaka with an average annual growth rate up to 4.2%. This is the result of an ongoing migration from rural areas all over Bangladesh to Dhaka's urban areas. Many reasons motivate this exodus, job search being the main one.

Therefore, the population density is very high in Dhaka city: over twice higher than in Paris! Due to low income, though, nearly one third of its inhabitants are actually living in slums.

Area	Population	Density
Greater Dhaka Area	24 million	3,300 per km^2
RAJUK	18 million	7,940 per km^2
Dhaka City	8.5 million	47,000 per km^2
Paris	2.2 million	21,000 per km^2

Table 1: Population density of Greater Dhaka Area.

1.2. Urban trend

	2020	2025	2030	2035
RAJUK area (million people)	20.2	23.2	25.1	26.3
Outsiders Area (million people)	10.6	10.7	12.0	12.2
Total (GDA) (million people)	30.8	33.9	37.1	38.5

Table 2: Demography expectation.

Rajdhani Unnayan Kartripakkha (RAJUK), the Capital Development Authority, has introduced a development plan called the "Regional Development Plan". It promotes a polycentric urban structure within the Greater Dhaka Area (GDA). The main objective is to redistribute authority and responsibility from the Dhaka city center to the urban centers located within the regional boundaries of RAJUK and GDA, in order to alleviate the pressure on the city center in terms of densification.

The regional axis from north to south passing through Gazipur and Narayanganj is one of the priority lines. However, its potential development rests on an improvement of transport systems to meet with the growing demand.

2. Transport in Dhaka: supply & demand analysis

2.1. Networks and transport analysis

At this moment in time, the main transportation modes in the GDA are motorcycles, private cars, buses, rickshaws and taxis. Motorized transport is most in use and the city is suffering from serious congestion problems: the average speed has lowered down to 7 km/h! This generates enormous socioeconomic losses estimated to up to 3.2 million working hours per day.

Figure 3: The current situation in Dhaka © joiseyshowaa, 2008, CC-BY (source: Flickr).

Buses are the most commonly used transportation mode in both urban and intercity. Intercity buses connect the center of Dhaka to the different districts of the GDA and the mainland.

Although the bus is the least expensive transportation mode (0.016 €/km), it often offers an irregular and overcrowded service.

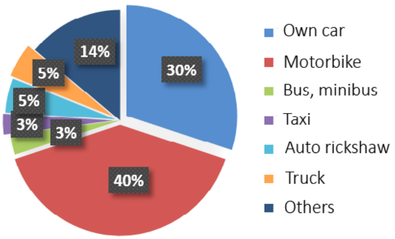

Figure 4: Part of motorized vehicles in the GDA in 2013 © Maxime Allegre, Cyril Dugimont, François Joly, Fanida Mezzane, Jean-Baptiste Rousseau, 2019.

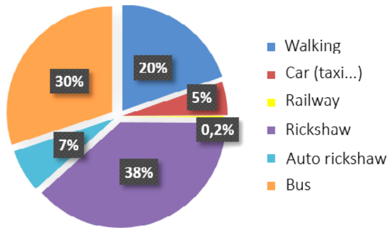

Figure 5: Modal share distribution © Maxime Allegre, Cyril Dugimont, François Joly, Fanida Mezzane, Jean-Baptiste Rousseau, 2019.

Plus, over short distances (1-3 km) GDA residents are mainly using rickshaws. In 2010, the average fare for the rickshaws was about € 0.21 per trip (the average trip being about 1.5 km) and the average journey time was about 20 minutes.

As for taxi services, they have started in Dhaka almost 18 years ago with a very limited number of cars and poor quality of service. A new private taxi/car service with modern features was launched in 2014; however, it is the most expensive of all options, taking itself out of the affordable price range of the residents.

Besides, most people in Dhaka prefer walking. Almost 20% of journeys are made on foot, but the dedicated infrastructure such as sidewalks are insufficient: pedestrians are forced to walk along the roadway, to the detriment of traffic and safety.

Dhaka is also surrounded by rivers, meaning that there is a shipping transport service available. It connects Sadarghat to Ashulia (29 km) over 6 stations. The fare is low (about € 0.10 per ticket) yet it remains mostly underused. Shipping is also used for material transportation.

2.2. Rail transportation network: the current suburban line

Train service in Bangladesh is basically divided in two categories: intercity and commuter trains. Currently, Dhaka is connected to the different districts of Bangladesh by a total of 44 rail links. Nearly 15,000 passengers from Narayanganj and 10,000 from Gandaria, Fatullah and Cahra commute to Dhaka every day. Kamalapur, located in the center of Dhaka, is known to be Bangladesh's largest railway station.

Even though trains are cheaper than buses and considered safer because of the lower number of accidents and victims, their success is impeded by the issues listed below:

- the average speed of trains is very low, and they are often late;
- the network design is very old (double gauge, not electrified);
- rolling stock and signalling facilities are obsolete;
- people often wander onto the tracks;
- many manual level crossings intersect with busy roads;
- station facilities are in very bad condition;
- the parking spaces for road vehicles at train stations are insufficient (occupied by temporary retailers);
- the stations are non-multimodal;
- there is a shortage of intercity train tickets.

Freight rail represents only 4% of market shares in the whole of Bangladesh. The line we will consider in this study is currently used for freight transport between the port of Chittagong (entry area for all goods imported into Bangladesh) and Dhaka Cantonment Station. It is vital to the import/export balance to and from Dhaka, and we must therefore endeavour to keep it.

2.3. Transportation project under study & development

The Dhaka Transport Coordination Authority (DTCA) launched in 2015 a 20-year transport plan that provides for the creation of strategic road links, the implementation of water transport around Dhaka and the construction of five MRT and two BRT lines. Civil work has begun on MRT 6 and BRT 3. The metro lines MRT 1 and 4, not financed yet, will align on the current railway line.

2.4. Passengers demand analysis

Trips occur mostly from home to workplaces, schools & universities, mosques, shopping centers, markets and hospitals. Most workplaces are located in the center of Dhaka, Narayanganj and Gazipur, renowned as the most important industrial poles of GDA. Clearly, the most densely populated residential areas of Dhaka are around the railway line.

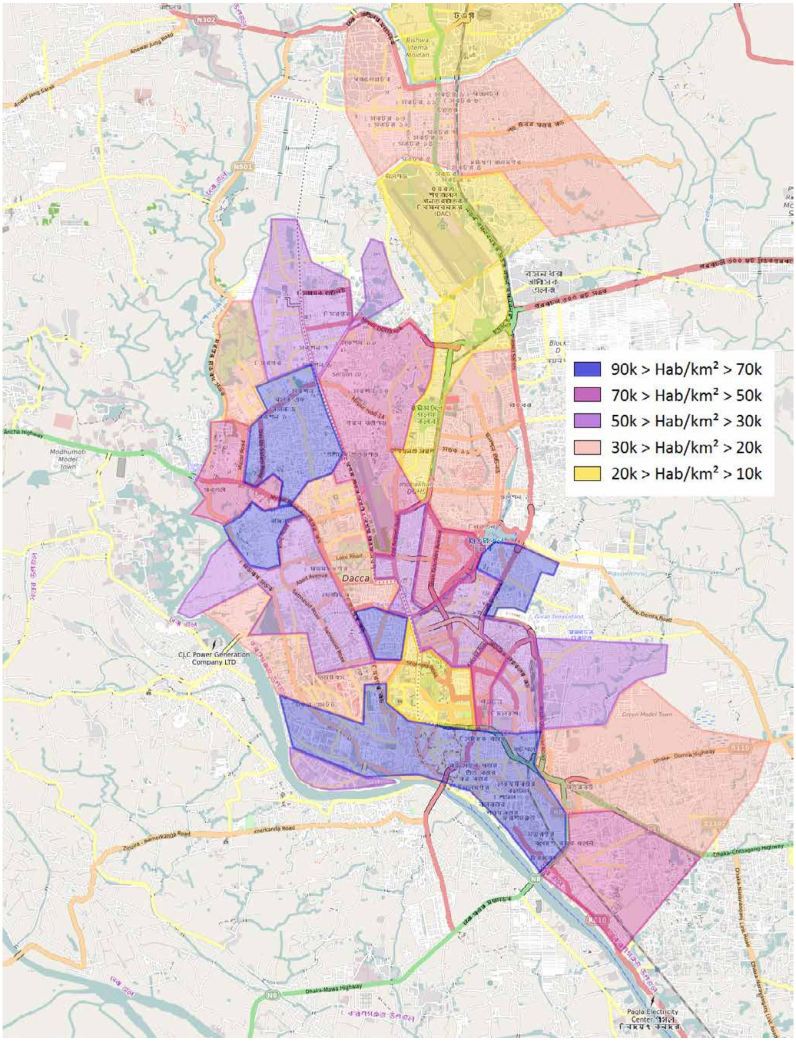

Figure 6: Heavy residential areas. Map: © OpenStreetMap Contributors, CC-BY-SA. Modified by Maxime Allegre, Cyril Dugimont, François Joly, Fanida Mezzane, Jean-Baptiste Rousseau, 2019.

All these findings confirm the hypothesis of the high demand for transport in Dhaka and especially around the axis of the existing railway line. To confirm this, we evaluated the aforementioned demand using a gravity model. The estimated number of potential daily trips is 814,876.

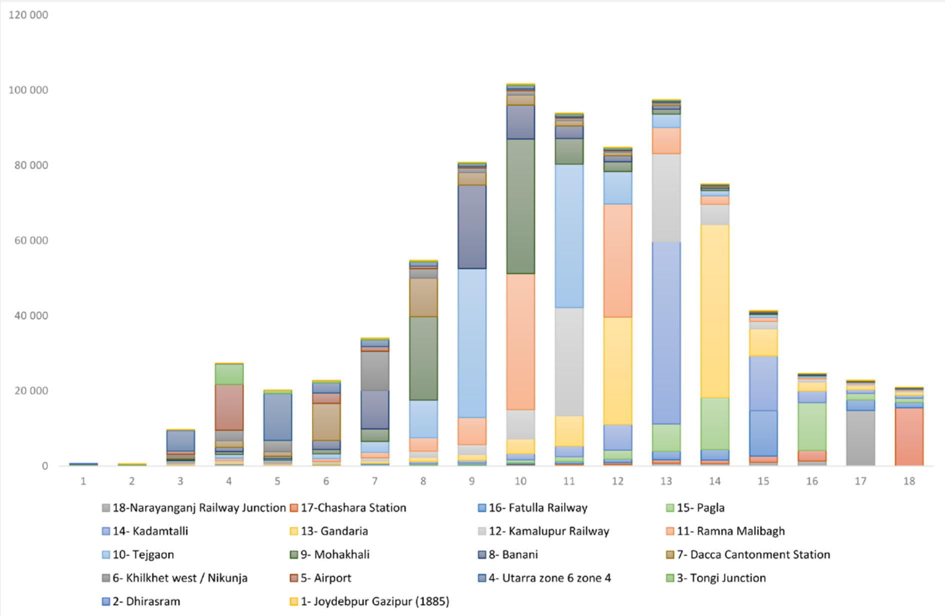

Figure 7: Stations flow graph © Maxime Allegre, Cyril Dugimont, François Joly, Fanida Mezzane, Jean-Baptiste Rousseau, 2019.

3. Issues & scenarios

Following the diagnostic elements detailed above, we propose a mass transit solution ("RER" regional train) which will connect the two largest industrial centers of the GDA (Gazipur and Narayanganj) with a 50 km track following the same route as the existing line. Two new electrified tracks will be installed.

Regarding civil work, the following four scenarios were discussed:

- scenario 1: two ground lines side by side with the two lines maintained for freight and intercity trains;
- scenario 2: construction of elevated tracks, keeping intercity and freight tracks on the ground;
- scenario 3: underground infrastructure, keeping intercity and freight tracks on the ground;
- scenario 4: combination of scenarios 1 and 2.

Even accounting for the lower cost of the first scenario, the multi-criteria analysis led us to choose the fourth scenario, which just fits better within the city, especially regarding its constraints (crossing level, flood zone). Here are the main features of the project summarized in the following SWOT matrix.

Figure 8: SWOT analysis © Maxime Allegre, Cyril Dugimont, François Joly, Fanida Mezzane, Jean-Baptiste Rousseau, 2019.

4. Technical solution choice

4.1. Infrastructure

The chosen solution is a combination of the two scenarios previously described: a northern part on the ground with the widening of the track and the addition of two new tracks (four in some large stations), plus level crossings being replaced with rail bridges; and a southern part on overhead viaduct. The technical characteristics are as described below.

North zone:

- 7 stations (+3 with the north option);
- 4 lines on the ground;
- tracks on slabs;
- 2 bowstrings bridges (+2 Bi Beam with north option);
- 20 level crossings replaced by rail bridges;

Viaduct-ground transition zone:

- ground transition station: Dhaka Cantonment;
- elevated transition at 21,900 pk.

South zone:

- 11 stations;
- prestressed concrete viaduct tracks with segments of constant height;
- 9 super flyovers (flyover already existing or under construction).

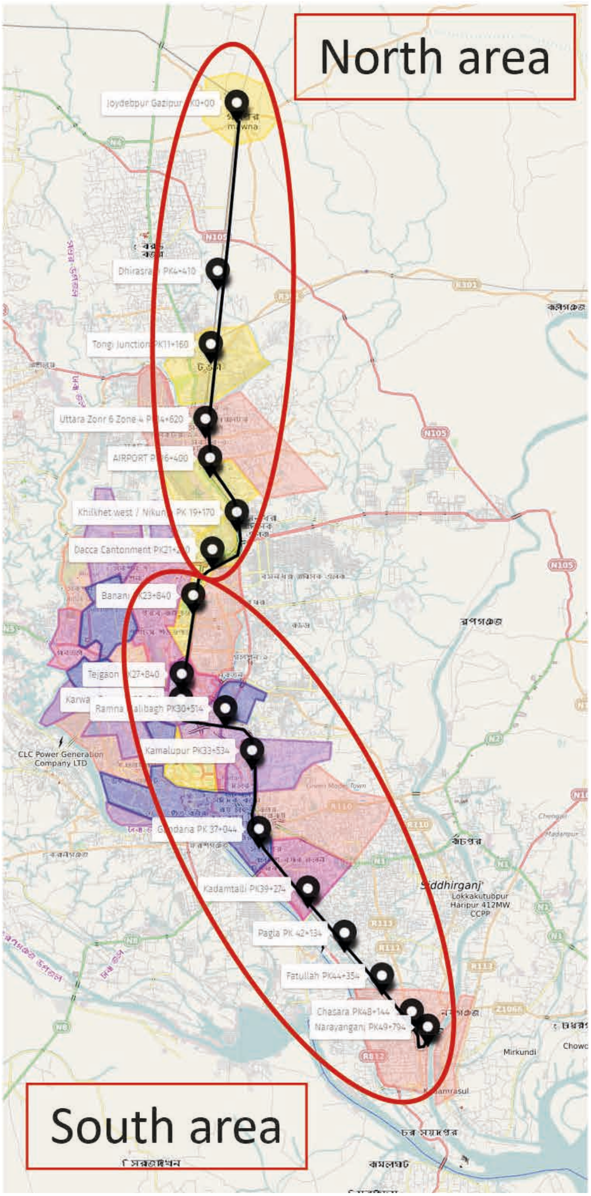

Figure 9: North and south areas of the line. Map: © OpenStreetMap Contributors, CC-BY-SA. Modified by Maxime Allegre, Cyril Dugimont, François Joly, Fanida Mezzane, Jean-Baptiste Rousseau, 2019.

4.2. Operation

We have defined the following operating assumptions.

Number of daily trips	815,000 trips
Operating hours	From 5 a.m. to midnight
Number of days of annual operation	302 days (no service on Fridays, plus 11 national days off)
Headway in peak hour	4 minutes
Headway in off-peak	8 minutes
Average density of passengers	6 p/m²
Commercial speed	50 km/h
Service trip	10%

Table 3: Operating hypothesis.

To meet the high demand of transport in Dhaka, we chose the system to achieve an operation within an hourly amplitude of 19 hours (from 5 a.m. to midnight) at a commercial speed of 50 km/h. The travel time is reduced to one hour and six minutes in one direction, compared to the current situation. We assume that the context of Bangladesh—meaning users are not used to this type of transport—will impact commercial speed in the first years of operation. It can be improved over time by deploying communication efforts about good practices to follow, and the accompaniment of users during their travels.

4.3. Equipment and maintenance

Based on the operating assumptions and the estimated 50,000 PPHPD, we were able to estimate the necessary rolling stock numbers to up to 33 trains to be operated at rush hour, and 7 in security reserve, by choosing to increase the reserve by 20%. Those trains will have a capacity of 3,260 passengers (with a density of 6 people/m²) and will be composed of 6 double-decker cars with 3 doors on each side.

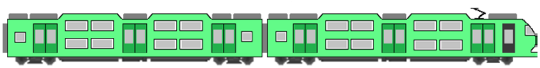

Figure 10: Proposed trainset © Maxime Allegre, Cyril Dugimont, François Joly, Fanida Mezzane, Jean-Baptiste Rousseau, 2019.

The signalling system to be implemented is a Communication Based Train Control (CBTC). This operation mode is realized on the basis of mobile cantons associated with on-board localization and ground-edge transmission. This system allows a safe management of train movements and train driving, as well as it ensures a good supervision and management of traffic.

The proposed electrification system is 25 kV/50 Hz (alternative single-phase). Its advantages are numerous: lowered initial costs, simplified maintenance, high braking energy recovery capacity (30%), lower line losses, lower currents, and almost non-existent parasitic currents. The power requirements were determined with peak hour requirements: 66 MVA on the basis of 33 trains per hour, with a maximum power of 5,100 kW. The annual energy consumption is estimated at about 111 million kWh, costing € 6.3 million.

Two maintenance workshops should be built: one in the north zone of Gazipur, equipped with a tower in pit, an axle tower, a wheel boring machine, a press for stalling and shifting the wheels, a lifting bench and a washing machine. The second workshop will be in Kamalapur for fast interventions between two operating services. We estimate staffing needs at 742 jobs, including 140 drivers, 34 supervisors, 112 people in charge of rolling stock maintenance, 100 people in charge of infrastructure maintenance, and 356 people in commercial and administrative service (including stations).

5. Economic and financial analysis

We estimated the investment and realization costs of our project at € 1.51 billion. Our estimation comprises a part proportional to the length of line construction, and a fixed part taking into account the maintenance centers, the costs of the particular bridges, the rolling stocks, the stations and platforms, and the ticketing, as well as the centralized control station.

Our proportional costs take into account the acquisition of land, civil works and earthworks, tracks, catenary electrification and associated substations, signalling and various accesses, as well as ancillary works (protection, environmental).

With expenses of € 27.07 million (including energy consumption, external purchases and staff costs) as well as revenues of € 74.24 million (including tickets and subscriptions sales), we obtain an operating balance sheet EBITA (Earnings Before Interest, Taxes and Amortization) of € 47.17 million, including income minus expenses. Including the worker profit participation fund and the financial write-downs, we get an operating profit of € -1.03 million.

Taking into account the time saved compared to the time it takes today to make the same trip by car or by train, plus the time saved at crossings, plus decongestion and environmental gains, we get from a 30-year study a socio-economic Net Present Value (NPV) of up to € 1,499.43 million. This project is therefore of genuine interest despite the investment cost and the required balancing subsidies.

6. Requirements

6.1. Project management

For the organizational set-up, we propose the Dhaka Transport Coordination Authority (DTCA) as the mobility authority, a joint venture (DTCA and Bangladesh Railway) as contracting owner, and a project management to be determined by an international tender.

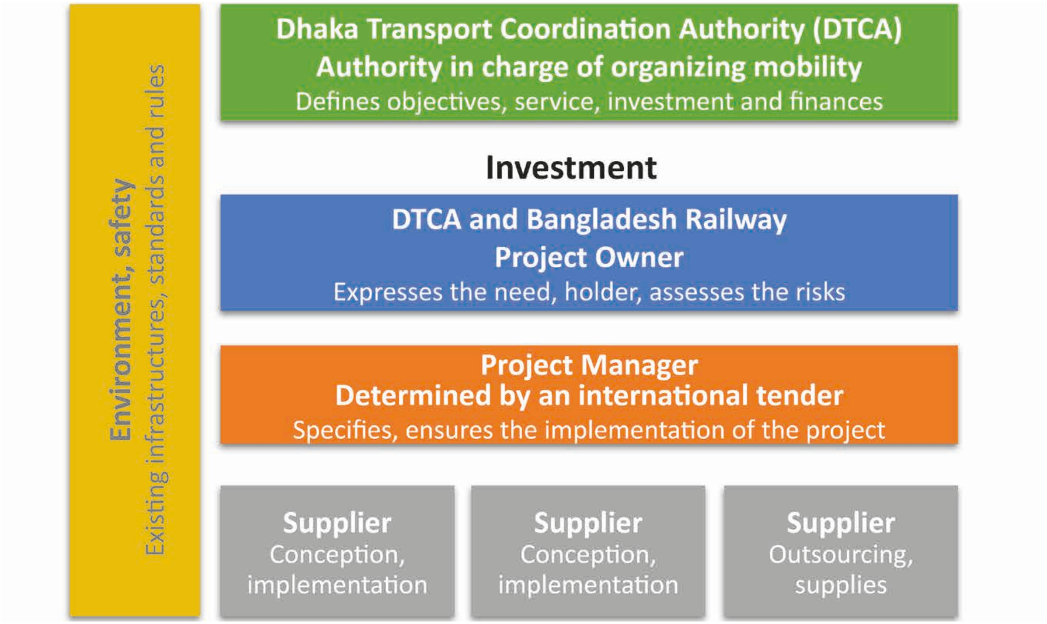

Figure 11: Organizational actors in the project © Maxime Allegre, Cyril Dugimont, François Joly, Fanida Mezzane, Jean-Baptiste Rousseau, 2019.

6.2. Funding

The amount to be invested, accounting for risk and additional studies, is € 1,903.77 million. It can be financed by 35% of donations and grants as well as 65% of loans from various local and international actors, with an interest rate up to 2%.

6.3. Project schedule

The project schedule can be detailed in three phases:

- emergence validation–with stakeholder validation, feasibility diagnoses and funding validation. Duration: 1 year;
- study, release of rights of way, and main tenders (civil engineering and rolling stock). Duration: 2.5 years;
- construction and training of staff. Duration: respectively 5 years and 2 years.

Conclusion

Our study clearly shows that Dhaka urgently needs a well-functioning public transport system. In order to respond to this challenge, our project focuses on the modernization of a suburban railway line crossing the city of Dhaka from north to south.

This mass transit project, with double-decker trains, latest-generation signalling and renewed infrastructures, will efficiently connect the new residential neighbourhoods and regional centers of the north and south to the city center and the employment centers. It will contribute to improve passenger flow and reduce congestion and pollution in the city. Consequently, this will improve the overall economy of the city, and thus contribute to improve the life quality of the residents.

Bus Rapid Transit (BRT) in Cúcuta, Colombia

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La présente étude vise à déterminer puis dimensionner le système de transport le plus adapté aux besoins de mobilité des habitants de l'aire métropolitaine de Cúcuta (CMA). À partir d'un premier diagnostic de la situation, qui expose les caractéristiques socio-économiques et démographiques, ainsi que les pratiques de mobilité, nous proposons une solution de transport de type BHNS (Bus à Haut Niveau de Service). Nous en décrivons les hypothèses d'exploitation, qui conditionnent le dimensionnement de l'infrastructure. C'est à Bogotá que le premier BHNS, un moyen de transport de masse, a été inauguré en 2000. Suite au succès du *TransMilenio,* les principales agglomérations du pays ont développé des systèmes de transport analogues avec moins de succès, notamment du point de vue économique. Nous avons pris en compte cet élément pour proposer un BHNS économique et un phasage réaliste : ainsi, deux lignes de 15 km desservent chacune un point frontalier, le centre-ville et une agglomération périphérique dynamique. Un planning organisationnel et une analyse financière complètent cette présentation de projet.

Mots-clés : étude de choix du système de transport, Bus à Haut Niveau de Service (BHNS), exploitation, optimisation économique, Cúcuta (Colombie)

The purpose of the present study is to design a transport system compatible with the mobility habits of the residents of Cúcuta metropolitan area's (CMA). First, we will analyze the current mobility practices in the area, taking into account socioeconomic and population data, as well as existing transport networks. To fit with demand forecast and existing infrastructure constraints, we will suggest implementing a new BRT. We will detail operating services and infrastructure design, and provide a cost-benefit analysis. First introduced in Bogotá (2000), the BRT has already been implemented in many Colombian municipalities. Each of these implementations was a mixed success, especially regarding economic results. Based on this feedback, our proposition is to launch the BRT in Cúcuta in two stages. Our transport map comprises two main lines (15 km each) meeting in the Cúcuta metropolitan area core, also reaching all the way to a dynamic outlying center and a border point. We will conclude our study with some implementation details regarding a prospective planning and risk analysis.

Keywords: alternative systems review, Bus Rapid Transit (BRT), operation, economical optimization, Cúcuta (Colombia)

Introduction

The Republic of Colombia is located in the north of the South American sub-continent, stretching from the Pacific Ocean to the Caribbean Sea on a southwest-northeast axis. Its neighboring countries are Panama to the west, Venezuela and Brazil to the east and Ecuador and Peru to the south. With a population of almost 50 million, this developing country represents the fourth largest South American economy after Brazil, Argentina and Venezuela.

The Cúcuta metropolitan area (CMA) is situated in the northeast of Colombia and is the sixth largest urban hub of the country, after (in decreasing order) Bogotá, Cali, Medellín, Barranquilla and Cartagena. Cúcuta currently stands in the international spotlight as the biggest Colombo-Venezuelan border city. The CMA is the main crossing point for economic and political Venezuelan refugees. This border could be either a major asset or a severe handicap in terms of economy, sociology and security.

The urban transport area includes the cities of Cúcuta itself, Los Patios and Villa del Rosario (all part of the CMA) as well as Urena and San Antonio de Táchira, both located in Venezuela. These five cities form the Cúcuta Binational metropolitan area (BMA) with a population of almost one million. The BMA is currently spreading at an important rate, particularly in Villa del Rosario and Los Patios, both located in the south of the area.

As in most emergent country cities, being motorized is synonym of individual achievement. The current public transportation system is provided by the informal sector and presents a significant lack of coherence and efficiency, which is responsible for a lot of congestion and pollution. The CMA wants to reconsider this system and develop a mass transit public transportation system instead.

We shall now endeavor to map out the best transportation system for the CMA according to its geographic, economic and social specificities. We will first propose a CMA multi-criteria diagnosis before studying the transportation demand to provide a detailed technical solution. Finally, we will specify how the implementation of such a solution could be done.

1. Diagnosis

1.1. Cúcuta, a border city

Cúcuta is geographically isolated. The nearest Colombian city is Bucaramanga, a five-hour drive away. The international airport Camilo Daza allows one to reach Bogotá in one hour and ten minutes. Its only foreign destination is Panama. There is no railway network in this region. The city has grown on a north-south axis along the border, stuck between mountains to the west and the Venezuelan border to the east.

Two international bridges located in the CMA are connecting Colombia and Venezuela. The Simón Bolívar international bridge links Villa del Rosario (Colombia, part of the CMA) to San Antonio del Táchira (Venezuela). Las Tienditas International Bridge connects Cúcuta to Urena. The bridge was never inaugurated as the end of its construction coincided with the border's closure in August 2016.

From a sociodemographic standpoint, a large part of the population is disadvantaged. The flow of Venezuelan refugees has exacerbated this situation. The CMA population was slowly growing until the arrival of over 150,000 Venezuelan refugees, making CMA the first destination of Colombia. The unemployment rate in the area reaches almost 16%, which is 6% more than the average national rate.

The economy is mainly based on coal exportations and some manufactured products. Thanks to the proximity of mountains and natural parks, the tourism sector is growing fast. The CMA, sitting on an international border and between two capitals (Bogotá and Caracas) is a strategic transit point for goods and illegal activities. The informal sector covers 70% of the local economy, against 50% for the national economy. It is important to note that both Venezuelan and Colombian currencies are used by CMA inhabitants.

1.2. Governance

Colombia is a decentralized country, which is quite rare in South America. There are four main administrative levels: national, departmental, metropolitan and municipal. Concerning public transportation projects, the national and the metropolitan levels are the most relevant.

As decision maker and main funder of such projects, the Transportation Ministry is the most important actor. The ministry requires candidate metropolitan areas to carry out project studies and to establish transport authorities. In accordance with the fulfillment of these criteria, the ministry then defines the scheduling and the funding of different projects in the country. These points are summarized in a public document from the Transportation ministry called economic and social policy national council.

The metropolitan area of Cúcuta is the co-founder of this project and responsible for its governance. CMA is the most important local actor to define the transportation solution most fitting for the local needs. Each municipality is represented in the CMA: while Cúcuta is the most populated and powerful city, Los Patios and Villa del Rosario municipalities are two growing residential cities.

1.3. Existing travel demand and public transport networks

The Cúcuta metropolitan area is divided into several connected municipalities: Cúcuta, Los Patios and Villa del Rosario. Massive roads connect these urban centers to each other. The river crossing through the area also embodies the west Venezuelan border. The CMA has been built with Cúcuta as its focal point, around which revolve most economic activities and housing areas. Due to population growth, Cúcuta is the object of an urban sprawl, specifically in the southwest. The distribution of activities in the CMA is represented on the following map.

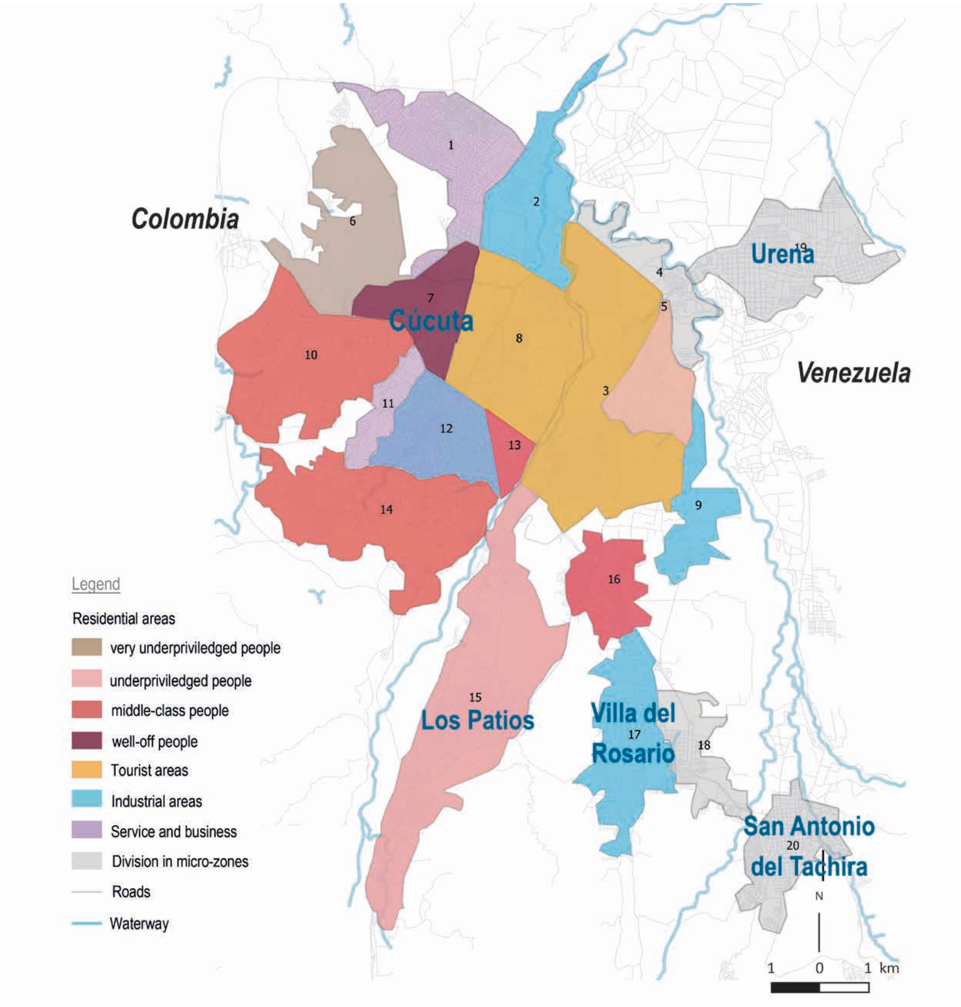

Figure 1: Activities distribution in the Cúcuta metropolitan area. Map: © OpenStreetMap Contributors, 2016, CC-BY-SA (D.S.C.C. - L.H.D. Gomez, « Celula Polifuncional modelo de expansion urbana en Cucuta » Pontificia universitad javierana falucltad de arquitectura y diseno carrera de arquitectura, Bogota D.C). Modified by Léa Cherki.

We can observe that activities (housing, business and tourism) are split in the CMA. Residents with different social backgrounds do not mix with each other, and tourism concerns a large surface area in the historical center. Therefore, there is an important need to commute daily. Due to the distribution of housing and business areas, travel demand has a star structure centered on Cúcuta.

The map in figure 2 illustrates the important link between Colombia and Venezuela. However, because of the existing political context in Venezuela, we did not include Urena and San Antonio del Táchira in our transport design.

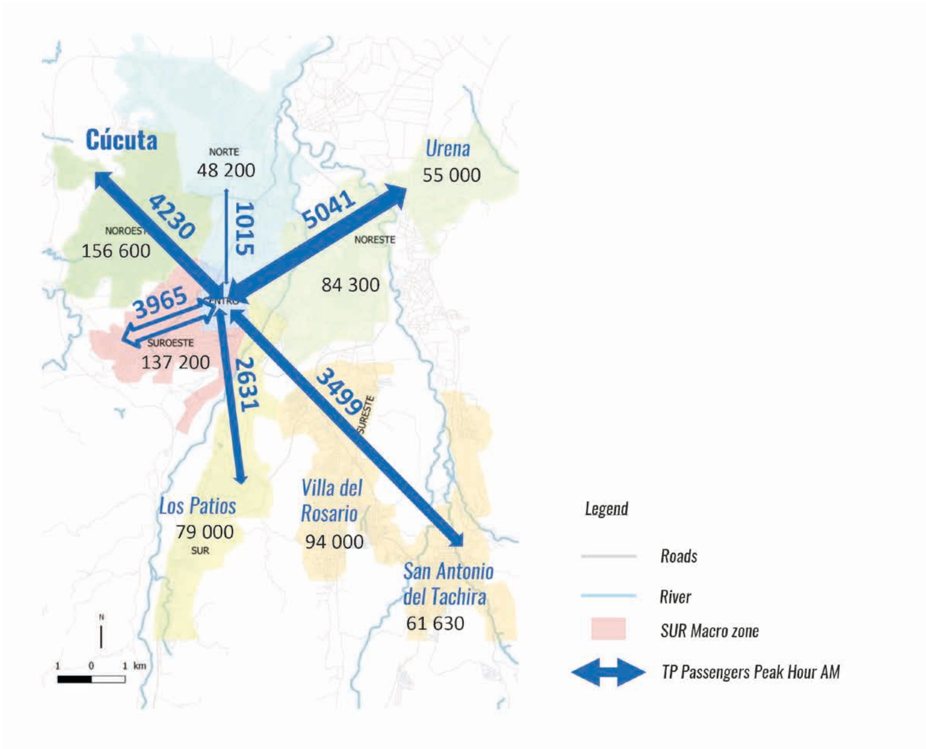

Figure 2: Passenger flow in Cúcuta metropolitan area. Map: © OpenStreetMap Contributors (UNDP, DNP), CC-BY-SA. Modified by Léa Cherki.

The CMA, as a local stakeholder, regulates public transport for the metropolitan area. 90% of trips are motorized. According to the following graph, buses are most used.

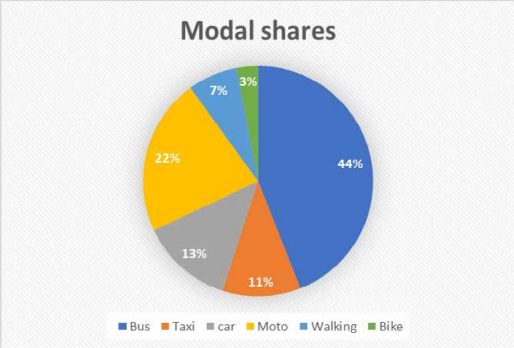

Figure 3: Transport modal distribution in the Cúcuta metropolitan area © Léa Cherki, Henri Jacquier, Boubekeur Merabet, Adela Purcell Soriano, 2019, based on CMA data.

Although buses are useful for large commutes, they are competing with mopeds, which are a symbol of ownership. Bus services today are provided by ten operator groups that gather several small businesses. The size of those groups, and the fact that they have representatives, can facilitate discussions and agreements on future network changes.

The rolling stock (851 vehicles and 17,110 seats) is owned by these operator groups. They have five types of vehicles (*automóvil, microbús, campero, busetas*) with low capacity that explains the huge bus congestion in CMA. Furthermore, buses do not have proper stops, meaning passengers have to ask the bus driver to get on and off the bus. The existing bus lines run almost everywhere in Cúcuta, but they do not have a structured organization. Existing bus network characteristics are merged in the following table.

Average travel distance	37 km
Average travel time	99 minutes
Commercial speed	16.8 km/h
Bus rate	4-16 minutes
Fares	16,000 pesos (€ 0.45) per travel

Table 1: Summary of the existing bus network.

2. The future transport network

We chose the BRT solution for three main reasons: because of the high passenger capacity, because it appeared to be the most economical solution, and finally because it is the most common mass transit solution in the country, which means that the public authorities have a large feedback on such a system.

BOGOTA	10 985 285	Transmilenio	X	Metrocable (2018)	en projet
CALI	4 022 967	Masivo Integrado	X	X	X
MEDELLIN	3 909 729	Metroplus	Tramvia de Ayacucho (2016)	Metrocable (2004)	Metro (1995)
BARRANQUILLA	2 450 127	Transmetro	X	X	X
CARTAGENA	1 576 312	Transcaribe	X	X	X
BUCARAMANGA	1 150 993	Metrolinea	X	X	X
PEREIRA	920 784	Megabus	X	X	X
CUCUTA	**824 551**	design stage	X	X	X
NEIVA	488 927	in progress	X	X	X

Figure 4: Benchmark of the Colombian urban transportation system © Léa Cherki, Henri Jacquier, Boubekeur Merabet, Adela Purcell Soriano, 2019.

2.1. Forecast demand

Forecast demand was estimated using an adapted four-stage model. We established 20 zones and their centroids. Distribution of public transport trips was obtained from existing 2011 data. For each zone, a basic gravity model helped to work out the exchange transport flow from one zone to another. Due to our reference data, we assumed that all trips were made using public transport (modal split) without any mode change from private vehicle to public vehicle. We considered that passengers would rather use the BRT because of the time gain, than take the pre-existing buses. We forecast long-term demand using population growth rate as a reference for demand increase. We obtained 3,586 PPHPD in 2035 for the busiest section. Travel demand is mainly oriented towards the center of the metropolitan area.

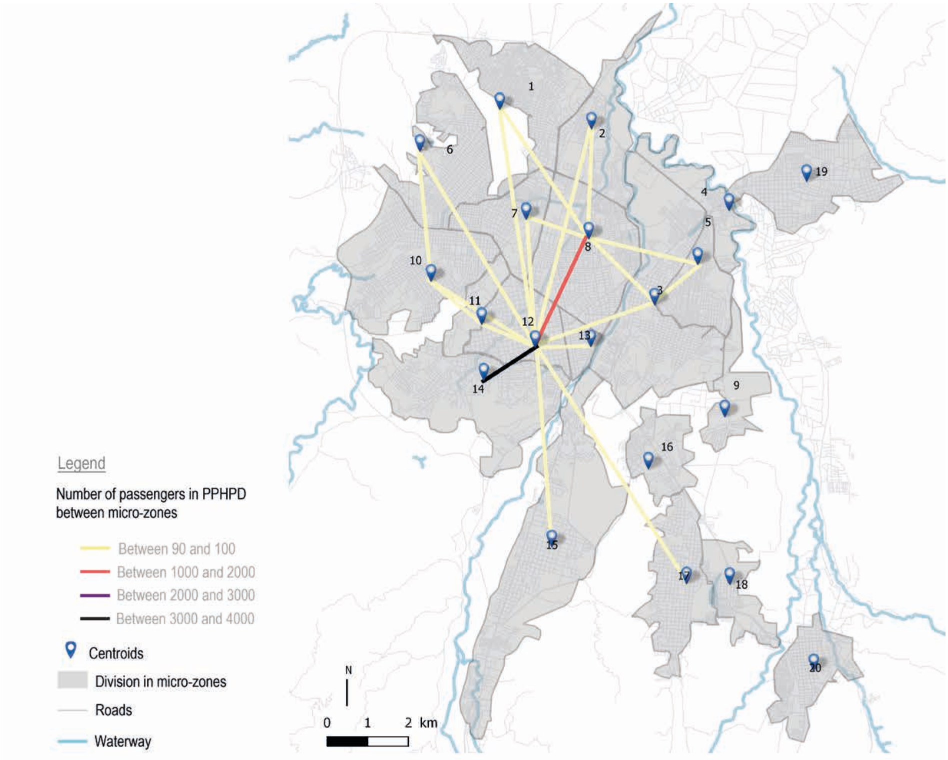

Figure 5: Demand forecast (2035). Map of main public transport trips between microzones (PPHPD) © OpenStreet-Map Contributors, 2016, CC-BY-SA (D.S.C.C. - L.H.D. Gomez, « Celula Polifuncional modelo de expansion urbana en Cucuta » Pontificia universitad javierana falucltad de arquitectura y diseno carrera de arquitectura, Bogota D.C). Modified by Léa Cherki.

2.2. Route choice

According to the diagnosis, the route must consider the following points:

- attract current passengers to the new transport system;
- supply to the current and future demand;
- serve the main points of interest;
- connect different cities of the CMA and the two border points with Venezuela;
- remove congestion, namely in the Cúcuta city center;
- reduce journey times within the CMA;
- enable an urban restructuring.

To reach these goals, we have decided to create two Bus Rapid Transit (BRT) lines. Both of them will meet each other in the city center and form a X. Each one will serve a border point, the city center and one growing residential city. The existing road infrastructure in the southwest part of the city doesn't make it easy to implement BRT lines. Each line would be about 15 km long: line A would include 22 stations, and line B, 26 stations. The average distance between two stations would be about 650 m, which would allow all buses to reach a high-performance commercial speed.

To match the forecast demand completely, we recommend increasing bus services between the southwest and the CMA center and removing current bus services on sections circulated by the BRT.

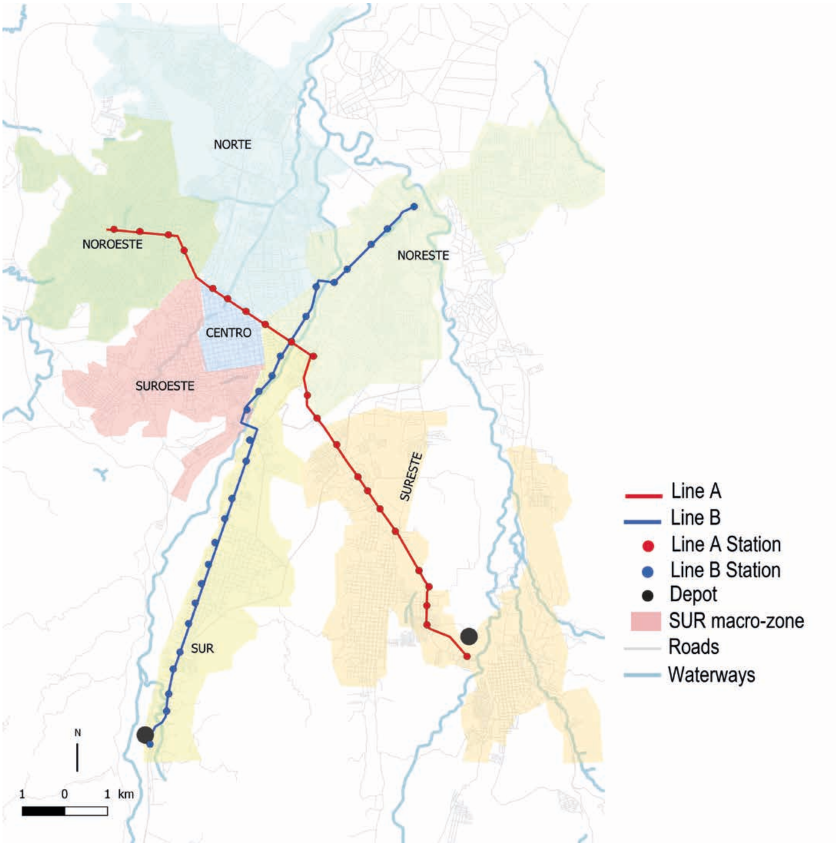

Figure 6: Future BRT network map. Map: © OpenStreetMap Contributors, 2016, CC-BY-SA (D.S.C.C. - L.H.D. Gomez, « Celula Polifuncional modelo de expansion urbana en Cucuta » Pontificia universitad javierana falucltad de arquitectura y diseno carrera de arquitectura, Bogota D.C). Modified by Léa Cherki.

2.3. Infrastructure description

We chose a seven-meter-wide dedicated busway single lane, physically separated from the other lanes. We designed two different kinds of stations, both with a central platform and an 11-meter-wide lane.

The urban stations will be located in high-density population areas, reachable by pedestrian crossings. The fast lane stations will be constructed in areas where the BRT runs in expressway, which implies the construction of passengers' bridges. Platforms will be 5 m wide and 27 m long, enabling the operation of bi-articulated buses. Platforms will be 32 cm high, designed for low-floor modern buses to facilitate passengers accessibility.

All stations will be sheltered and closed, as well as equipped with display panels for passengers information and advertising. Stations will be accessed through revolving doors which will include tickets validation.

2.4. Operating

For operating purposes, hypotheses have been made according to the BRT route specifications. Our aim was to reduce travel time and increase commercial speed. We decided to maintain bus priority at crossroad junctions, and to stop other vehicles with a red light. Based on these assumptions and considering the PPHPD, we decided to implement articulated buses with 415 seats. A summary of these hypotheses and related results is presented in the following grid.

	Line A	Line B
Inter station distance	679 m	608 m
Peak time interval	5 minutes (first 15 years) and then 4 minutes	5 minutes (first 15 years) and then 3 minutes 30
Off-peak time	10 minutes	
Dwell time	40 sec (and then 30 sec)	
Commercial speed	26 km/h	24 km/h
Travel time	34 minutes	38 minutes
Passenger density	7 passengers/m^2	
Number of buses	17	19 (then 22 for a 3 minutes 30 interval at peak times)
Opening hours	5 a.m. – 11 p.m.	

Table 2: Main BRT assumptions and specifications.

Taking into account demand forecast and opening hours for 244 days a year, we determined the daily traffic for each line. Furthermore, we calculated travelled distance for one year, including distances to depots (close to terminus).

	Opening date (OD)	OD + 15 years	OD + 30 years
Line A – daily passengers	49,000	61,300	82,200
Line B – daily passengers	49,000	61,300	93,909
Line A – distance travelled in one year (km)	565,348	628,544	628,544
Line B – distance travelled in one year (km)	688,568	755,912	860,832

Table 3: PPHPD per line.

As a conclusion of this section, we propose a SWOT analysis.

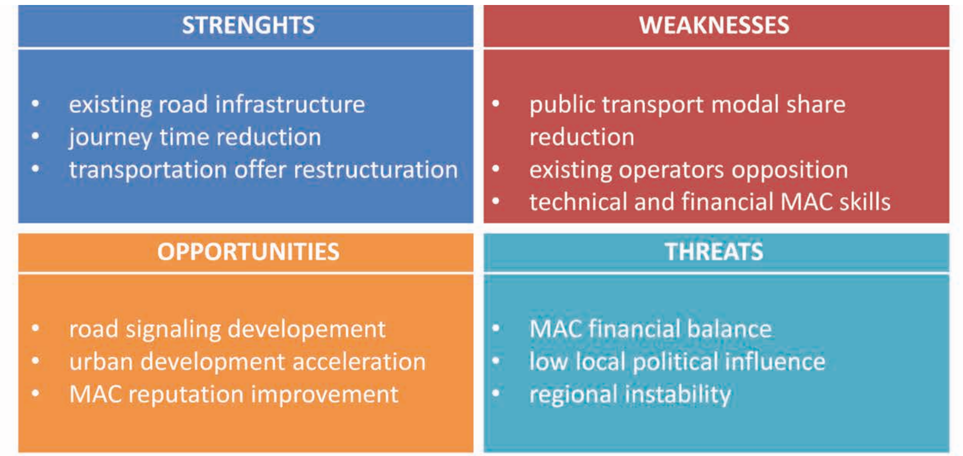

Figure 7: SWOT analysis © Léa Cherki, Henri Jacquier, Boubekeur Merabet, Adela Purcell Soriano, 2019.

3. Implementation

3.1. Planning

We chose to launch the BRT in two steps: first line A, then, 15 years later, line B. That choice has been made to avoid simultaneous road work on the two main CMA roads.

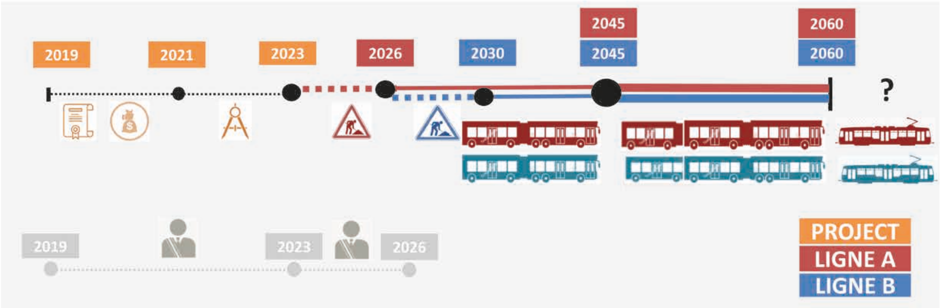

Figure 8: Project implementation © Léa Cherki, Henri Jacquier, Boubekeur Merabet, Adela Purcell Soriano, 2019.

3.2. Project governance

The governance of the project is based on the Cartagena BRT. There is a need to create a transport authority within the CMA entity in charge of the BRT management both for project design and at operating stage. The next figure showcases relationships between stakeholders during project design and operating stage. Cash flow between CMA as transport authority and operator companies is also represented.

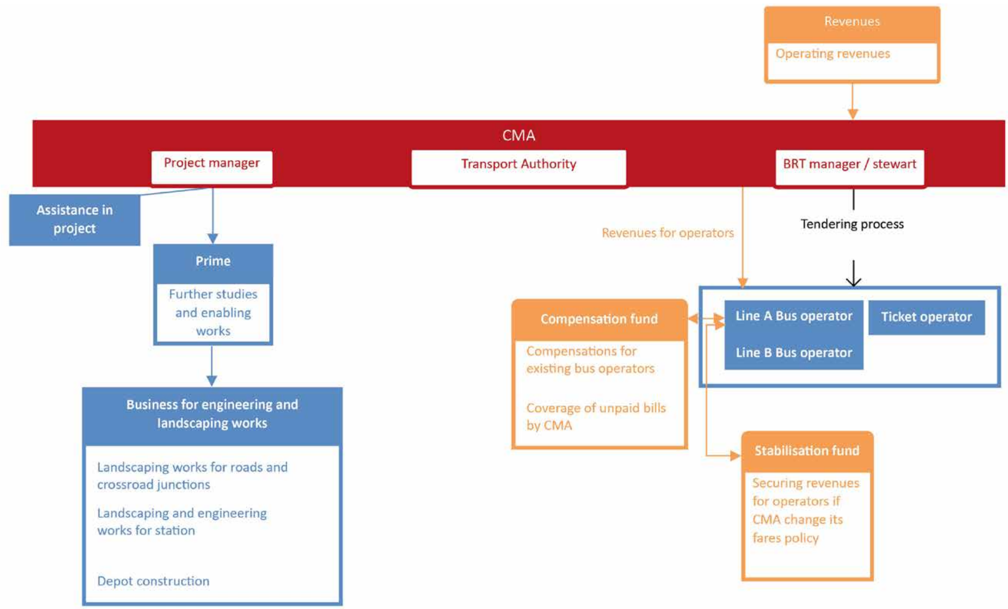

Figure 9: Project governance organization chart © Léa Cherki, Henri Jacquier, Boubekeur Merabet, Adela Purcell Soriano, 2019.

Due to bus network changes, we recommend to consult existing bus operators before any proposals. Many bus drivers could have their services removed. We suggest that CMA's bus operator terms of reference should include a commitment to hire those drivers.

3.3. Investment budget

The next diagram describes the investment budget requested to implement the technical solution as described above. It represents € 5 million per kilometer based on 2019 economic conditions, which is an economical enough solution for a BRT mass transport system.

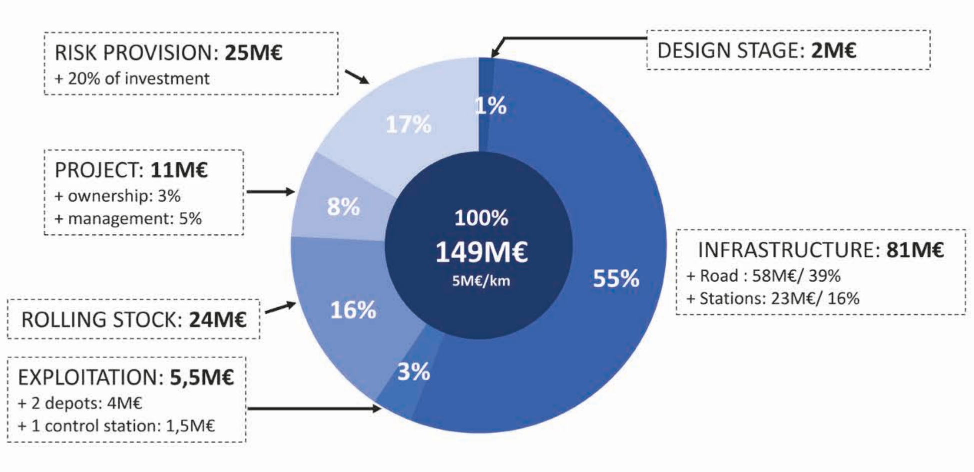

Figure 10: Investment budget 2019 economic conditions © Léa Cherki, Henri Jacquier, Boubekeur Merabet, Adela Purcell Soriano, 2019.

3.4. Operating assessment

The following diagram is an operating result projection which aims to determine whether the designed BRT operation needs subsidies, is self-balanced, or will allow infrastructure costs to be reimbursed. The ticket price is € 0.60 compared to the current € 0.45.

For our purpose, the operating result, which comprises both rolling stock depreciation and reimbursement, is positive to the height of € 3.5 million per year. Meaning, the projected BRT operation is generously self-financed but does not cover the infrastructure costs.

OPERATING RESULT	+ 3 591 860 €

OPERATING COSTS	€	11 934 691
kilometric cost	€	6,69
Personnel expenses	€	3 383 473
Rolling stock maintenance	€	1 645 324
Existing operators fund collection	€	1 500 000
Taxes	€	1 106 400
Rolling stock reimbursement	€	1 062 409
Rolling stock depreciation	€	940 185
Energy	€	784 810
Fleet insurance	€	658 130
Other administrative expenses	€	621 062
Concessionnaire ticketing	€	232 898

OPERATING INCOME	€	15 526 551
Kilometric benefit	€	8,70
Commercial income	€	11 167 589
Reduced tariff subsidies	€	3 242 203
Advertising income	€	1 116 759

Figure 11: Operating result projection © Léa Cherki, Henri Jacquier, Boubekeur Merabet, Adela Purcell Soriano, 2019.

3.5. Cost-benefit analysis

The Net Present Value (NPV) has been calculated over 35 years from 2025 to 2060. 2025 was chosen for reference because it corresponds to the year right before the implementation of the first line, which will be the line A in 2026. The NPV allows us to compare the existing scenario and the BRT scenario. Colombia, as a confirmed emerging country, benefits from a 7% discount rate. We chose a 2% inflation rate, half as much as the previous two decades.

As a result, we obtain a positive NPV of almost € 2.2 million, which suggests the project might attract international investors.

3.6. Funding

The benchmark from other BRT Colombian projects teach us that the central state provides 70% of the investment, while local administrations give the remaining 30%. The central state financing is necessary to cover the exchange rate risk and traceability of the payments when a project benefits from foreign investors, which is almost systematic for such infrastructure projects.

The project presents a lot of risks, mainly due to the local political instability and the low technical and financial skills of the local authorities. Private investors are therefore not likely to take part in this project. The private sector would ask too much guarantees, damaging the global project business plan. That's why we excluded a Public-Private Partnership (PPP).

However, Cúcuta is the most important border point between Colombia and Venezuela, which could attract institutional investors, such as international or local development banks, and could prompt them to invest in a symbol city of the current political Venezuelan crisis.

Conclusion

The feasibility study proposes a mass transit transportation system solution for the CMA, including the binational transport demand. Even if no route crosses the border, each line has a terminus upon it, Urena in the north and San Antonio del Táchira in the south. We detailed only the BRT project but it is important to have in mind that the regular bus services must be restructured, namely to supply the BRT corridors.

The operation strategy is scalable in order to satisfy the transport demand until 2060. Afterwards, in case of congestion, the infrastructure could be transformed from a BRT system into a tramway system, with a much greater passengers capacity. Moreover, the border situation could generate a demographic and economic boom. The proposed network will probably be extended, namely on the other side of the border, and become a cross-border transport system, which would have a great symbolic value beyond the sheer practical applications.

Creation of a tramway line in Djibouti City, Djibouti.

Adel CHOUKRI
Redouane HEBBAL
Morgane PÉRÈS
Blandine VERNIER

École des Ponts ParisTech

Avec une population de près de 600 000 habitants, Djibouti, capitale du pays du même nom, dispose actuellement d'une offre de transport en commun assez limitée et le taux de motorisation des habitants très faible ne facilite pas les déplacements quotidiens. La congestion routière reste malgré tout importante dans la capitale. C'est dans ce contexte que s'inscrit ce projet de réalisation d'un transport en commun en site propre, permettant de répondre à la demande en transport et de décongestionner la voirie en basculant une grande partie de la mobilité du bus vers le TCSP. Un système de tramway est envisagé pour faire face à la demande. Le projet d'un linéaire de 16 km et 24 stations relie le cœur historique de la ville au quartier de Balbala, secteur actuellement le plus peuplé : on envisage un trafic de 16 millions de voyageurs annuels à moyen terme. Des études de faisabilité technique ainsi qu'une analyse financière et socio-économique complètent cette étude afin de valider la pertinence du projet.

Mots clés : Djibouti, tramway, étude transport, faisabilité technique, étude financière

With a population of nearly 600,000, Djibouti City, the capital of the country of Djibouti, is currently facing a real transport problem because of a limited public transport offer combined with a small number of car owners. Congestion is still omnipresent because of ill-maintained roads in a limited number. In this context, we propose the implementation of a transport system with a private infrastructure to cope with the growing demand and to decongest the city. After an urban analysis considering population movement, main attractive spots and the evolution of transportation demand, a system of tramway is suggested. The tramway line will extend over a length of 16 km with 24 stations connecting the center of the city to the suburb of Balbala, the most populated area. 16 million annual passengers are expected in the medium term. We will propose technical feasibility studies as well as a financial and socio-economic analysis to fully validate this project.

Keywords: Djibouti, tramway, transport study, technical feasibility, financial study

Introduction

The following report is an exploratory study of a new urban passenger transport system design for Djibouti City, capital city of the country of the same name. The country's urban demographic and economic growth entails a growing demand for transportation. Currently, it is mainly provided by a partly informal and generally unstructured public transport system. The main issue is therefore to answer this increasing need for mobility while limiting the congestion of the city.

1. Generalities about Djibouti

With almost 1 billion inhabitants, Djibouti is one of the smallest countries in Africa (23 000 km^2), and one of the poorest. But thanks to its strategic location in the Horn of Africa, its economy has been growing since 2001: great world powers such as China are using it more and more as an economic and military platform. Most investors are interested in the freight transport sector: three merchant ports were inaugurated last year.

The population of Djibouti City is estimated today at about 600,000 citizens, and 21,000 more per year are expected between 2015 and 2030.

The city is divided into two large urban sub-groups, the border between them being materialized by the river Ambouli, also known as "Oued Ambouli". This delimitation is geographical, economic and social all at once. The first three districts, at the northeast of Oued Ambouli, constitute the oldest part of the city—a heritage of the late nineteenth century French colonization. The center of the city centralizes administration services and tertiary activities.

West of Oued Ambouli is the suburb of Balbala, a more recent urbanized formation from the 1960s. It is characterized by spontaneous and/or informal urbanization. Those are the most disadvantaged neighborhoods with limited access to various services and urban networks. Balbala represents 60% of the population of Djibouti, and 64% of its unemployed people.

The anticipation of population growth entails the need to organize and prepare for future issues, including mobility. The current public transportation network clearly does not meet the demand.

2. Mobility in Djibouti City

2.1. Demand

Although there is no statistical data about mobility and bus passenger, we conducted some socio-demographic analyses to determine the potential demand for urban transport. These are mainly based on age and occupation (students, unemployed people, workers, etc). For each category, we defined need assumptions for trips, which allowed us to construct an origin-destination matrix. This matrix was also developed to estimate the demand forecast by 2029 and 2039, taking into account the urban, population and economic development in upcoming years.

The second point highlighted by our studies regards the travel flow between Balbala and the city center, which is the predominant long origin-destination. We estimate 34,400 daily trips on this axis today, 63,600 in 2029 and 85,000 in 2039.

2.2. Actual offer

The daily mobility in Djibouti City is mainly done through public transport (buses, minibuses and taxis). Personal transport is very scarce (only 3.6% of citizens have a car). In 2002, a reform reorganized the sector of public transport, implementing a regular service. This was a definite improvement, but we can observe a mismatch between the supply and demand. Congestion in the city is part of one's daily routine, above all in the city center. The poor quality of infrastructures is also a contributing factor to the daily difficulties Djiboutians must face.

With the increased development of Djibouti City in recent years, the urban transport crisis has reached a worrying level: in the absence of a structured system, and considering the rapid urban and demographic sprawl, the informal private sector remains the only way to answer the growing demand.

2.3. Transport project

This diagnostic conducts us to propose a mass transit system to connect Balbala with the city center through an on-site system. Indeed, the implementation of public transport in private areas solves both mobility and congestion problems, not to mention the issues to come as the city keeps growing. This project can also have an indirect positive impact, like mitigating the gap between both areas.

The chosen transport solution is the tramway, which is more advantageous than a Bus Rapid Transit system for the following reasons:

- greater passenger capacity, making it better suited to meet the demand;
- optimized costs thanks to longer equipment life and a reduced number of drivers;
- better flexibility with the demographic and urban evolution of the city;
- more comfort for travelers.

2.4. The demand on the layout

The following table summarizes the estimation of the daily attendance, thanks to our origin-destination matrix. Those numbers will allow us to size up the transport system needs (rolling stock, infrastructure).

	2029	2039
Balbala-city center movement's demand	63,600	85,000
Estimated TCSP modal share	85%	85%
Frequency deducted	54,000	75,300
Person Per Hour per Direction (PPHPD)	5,400	7,530

3. Rolling Stock

We consider the demand until 2029, in order to guarantee proper service at least until then. With a PPHPD of 5,400, we estimate the rolling stock capacity to 450 passengers.

With 24 stations and a hypothesis of a 30 second stop for each, the tramway commercial speed is calculated at 23,5 km/h. The number of rolling stock is estimated at 20; that is 17 of them in service at peak hours, and 3 for the reserve.

The CITADIS 402 (Alstom) is a rolling device that fits the technical needs defined in our project, above all regarding its passenger capacity. It presents several additional advantages: it is a well-tried technology, which reduces acquisition risks, and it is also a modular tramway which can be specifically adapted for Djibouti (interior and exterior design, car structure, travel information, embedded options, etc.). Our study is based on the characteristics of the CITADIS 402.

4. Infrastructure

4.1. Civil engineering

The construction of tramway lines is scheduled in three steps (see the layout in figure 1 on the next page).

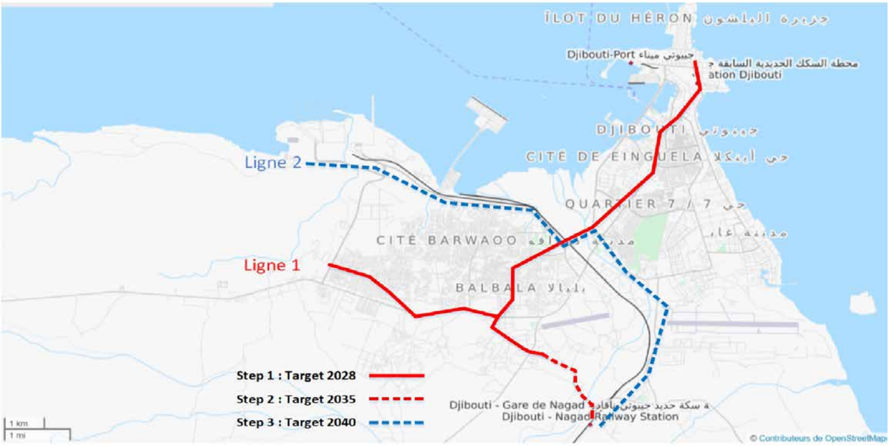

Figure 1: Map © OpenStreetMap Contributors, CC-BY-SA. Modified by Adel Choukri, Redouane Hebbal, Morgane Pérès, Blandine Vernier, 2019.

According to our studies, the building of Line 1 is considered a priority in order for the project to meet the mobility demand, especially our first step, which comprises a 18,2 km section of Line 1, plus depot and technical areas; it will connect Marabout to the new neighborhood of PK12. Our layout will integrate an embranchment in the middle of the line in order to serve the new university in the south of the city.

Our second step will be to extend Line 1 from the university to the Nagad train station. Our third and last step will complete the project thanks to a west-east axis starting in the Nagad train station and connecting important infrastructures, such as the port, the airport and the Djibouti railway station. The complete configuration of Line 1 is illustrated in the figure 2 below.

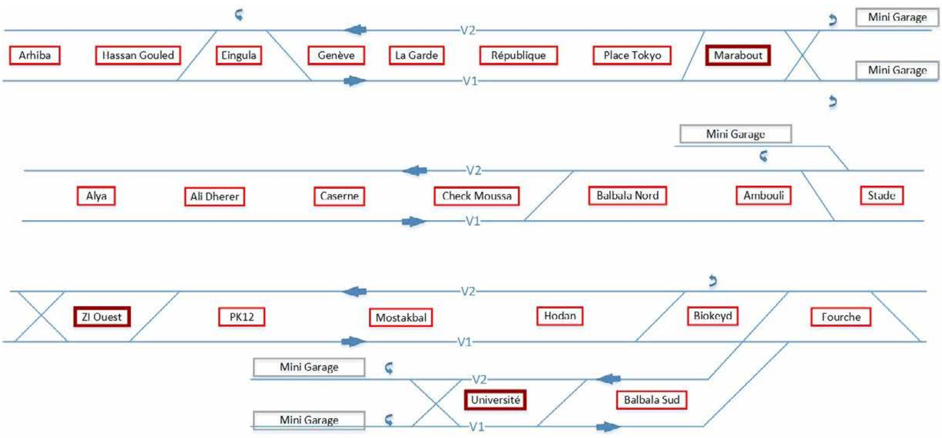

Figure 2: © Adel Choukri, Redouane Hebbal, Morgane Pérès, Blandine Vernier, 2019.

Each track comprises crossovers or switches to enable operation in degraded mode with partial loops. The number of switches is optimized to favor a high commercial speed and satisfy operation constraints. The maintenance workshop and the main depot are located past the ZI West terminus.

These preliminary studies' other crucial point is the location and the number of stations. Indeed, the 24 stations have been selected and placed according to two main criteria: available space and attractiveness to passengers. We also chose to place them close to road intersections whenever possible, in order to reduce the distance to pedestrian paths.

The layout is optimized to minimize the civil works cost; only one bridge is required where Line 1 crosses the Ambouli river. After an examination of Ambouli area topology, we chose a 130-meter concrete bridge, with five 6-meter-high spans. The width of the bridge deck is estimated to 10 m. The figure 3 recaps the configuration of the bridge.

Figure 3: The bridge © Adel Choukri, Redouane Hebbal, Morgane Pérès, Blandine Vernier, 2019.

4.2. Signalling, energy and maintenance

The signalling of tramway systems is based on an on-sight train operation so the collision risks can be fully controlled by the driver. To ensure efficient operation, priority will be given to tramways—for example through traffic lights synchronization.

We will privilege an overhead power line because of its easy, low-cost implementation. Six sub-stations will be installed every 3 km to transform the electricity distributed by "Électricité de Djibouti" into 20 kV, and thus meet our need for energy supply.

To ensure better service, this project includes the implementation of four stabling areas, one at each terminus, one in the city center, and one close to the stadium. The depot at "ZI West" comprises a workshop, a washing machine, and 4 tracks to park up to 16 tramway cars.

5. Operation

5.1. Transport plan

The transport plan is developed according to the following elements: travel time by section, passenger exchange time at each station, and terminus time. In all stations, the dwell time is 30 seconds. The travel time by sections is described in the table below.

Marabout – ZI section	37 minutes
Marabout – University section	29 minutes

The terminus time is described in the table below.

Terminus	Interval at 5 minutes on the central section
Marabout	5 minutes
ZI West	10 minutes
University	10 minutes

These elements allow us to evaluate the performance of the line. Overall, this performance is homogeneous over the entire course: double track, homogeneous fleet of vehicles (identical speed limit) and a single type of mission for tramways. The most significant point of the line is the level crossing at the fork, with two incompatible convergent/divergent routes.

The configuration of the fork suggests that track circuits will be occupied by trams at a stop. This feature does not affect the incompatible route time as seen in the configuration in figure 4.

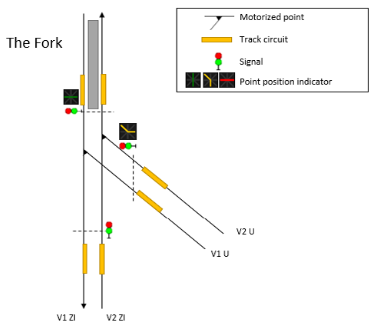

Figure 4: © Adel Choukri, Redouane Hebbal, Morgane Pérès, Blandine Vernier, 2019.

Considering our theoretical time grid, we might revise our crossing time at 3 minutes for two main reasons:

- to guarantee a robustness margin between two trams, so as to avoid trapping trams in the border stations;
- to let cars through for a longer time, so as to decongest the crossroads.

These elements allow us to develop a theoretical time table (see the chart below—a time table from a 5 a.m. to 7:35 a.m. timeframe).

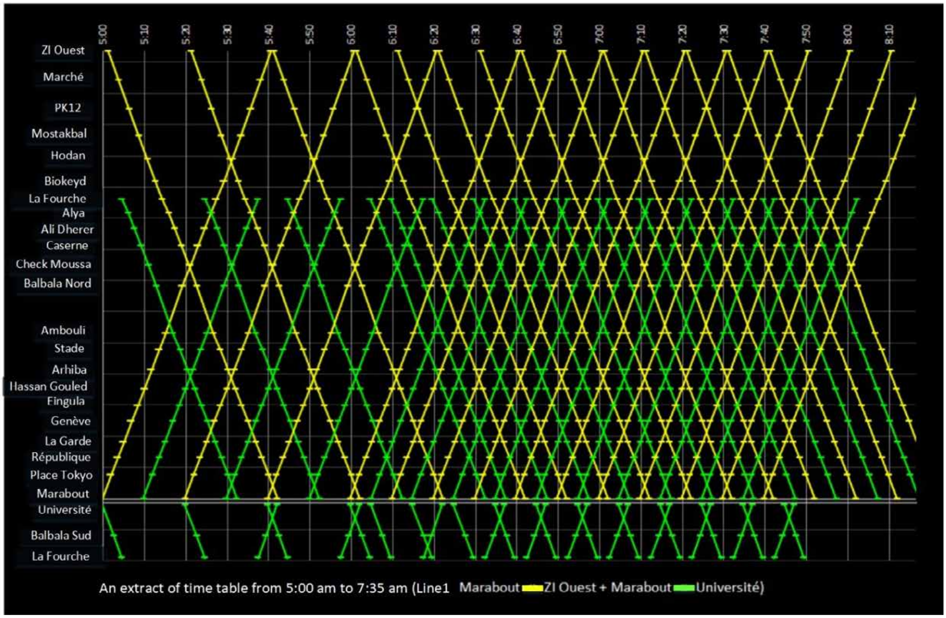

Figure 5: © Adel Choukri, Redouane Hebbal, Morgane Pérès, Blandine Vernier, 2019.

Frequent traffic records will have to be made to refine the schedules according to the actual traffic. In fact, the transport plan must not be frozen, even in the short term, in order to optimize the running time.

5.2. Regulation and traveling experience

We have chosen a regulation by intervals rather than a planned schedule: trams will be either accelerated or stopped to ensure the expected interval. In degraded situations, some missions can be deleted or reorganized to guarantee smooth traffic on the line.

The operation of the Djibouti tramway should also consider local specificities and context to ensure a better integration. Staff will be present in every station to inform travelers and sell tickets; furthermore, all stations will be equipped with automatons to ensure tickets sales anywhere in the network. We also want to facilitate passenger access to the tramway by promoting multimodality—that is to say connecting city bus stations to tramway stations.

6. Project implementation

6.1. Project actors

This infrastructure project requires the definition of the involved actors (see the figure 6) in the upstream phase of commercial commissioning:

- project owner (Djibouti City Hall): the entity that expresses its needs and finances the project;
- project management (after calling for tender): shall technically supervise the project and ensure the concordance between the needs expressed by the project owner, the tramway design and the tramway construction.

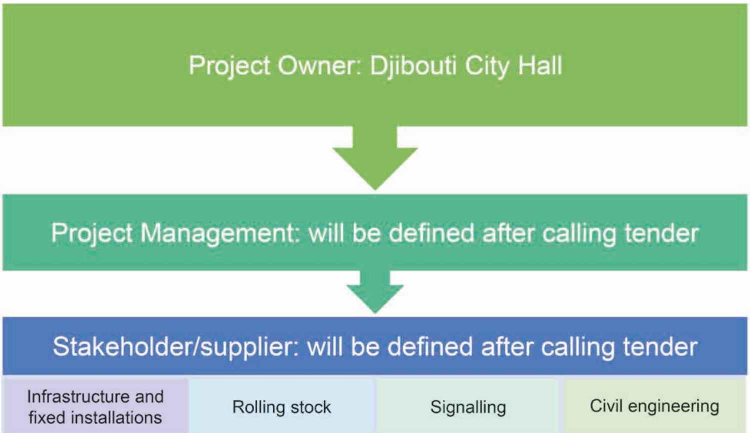

Figure 6: © Adel Choukri, Redouane Hebbal, Morgane Pérès, Blandine Vernier, 2019.

The design and implementation phases of the project will involve different suppliers and stakeholders. These will be selected by tender based on four parts of the project (railway infrastructure and fixed installations, rolling stock, signalling and operating system and construction). This divide aims to simplify the management of the collaboration between all companies.

6.2. Planning

The first phase of the Line 1 tramway project in Djibouti City is planned over 7 years, starting from the beginning of the feasibility studies.

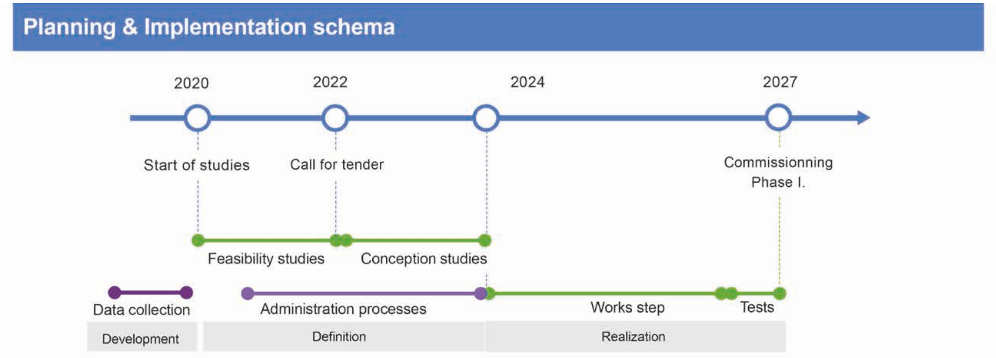

Figure 7: © Adel Choukri, Redouane Hebbal, Morgane Pérès, Blandine Vernier, 2019.

7. Profitability of the project

The total cost of the project corresponding to the first phase is estimated to € 304 million: over € 17 million per km.

The estimated operation cost is € 3 million a year, the most important expenses being wages and energy consumption. The first expenditure item was calculated according to the average income in Djibouti and to an estimate of the staff numbers needed to ensure proper service.

The revenue is mainly connected to the sale of single tickets and subscriptions. The number of tickets sold was estimated according to the demand hypothesis, and the fee was based on the current bus fare. We estimate the sale of transport tickets to bring in € 3.3 million a year.

The financial profitability of the project is calculated from the Net Present Value. The calculated NPV is positive, taking into account the environmental consequences and excess passengers. This project is therefore well-suited to the community in question, notably thanks to its time-saving quality.

Conclusion

This project is an implementation study of a transport system aiming to solve traffic congestion and meet travel demands in Djibouti City.

The study is based on a socio-economic analysis of the city, allowing us to estimate transport needs in Djibouti City. However, the lack of data leads to a potential inaccuracy in traffic forecast.

It should also be remembered that the creation of the tramway line is only the first step towards structuring urban transportation in Djibouti City. Many actions are also important in terms of multimodality, such as a better organization of the bus and minibus network and of the highways. Strong political support is therefore needed to accompany these changes.

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Après presque une décennie de voyages en Angleterre, les étudiants de la onzième promotion du Mastère Spécialisé® STFU se sont envolés pour Shanghaï pour une semaine de découverte des transports ferroviaires et urbains chinois. Le programme a alterné séquences de rencontres avec les universitaires et visites accompagnées par des professionnels des transports publics et des chemins de fer chinois, en anglais ou en français.

L'université de Tongji qui nous accueillait est mondialement reconnue dans le domaine ferroviaire : l'École des Ponts ParisTech a signé avec elle un accord de double-diplôme pour le transport en 2008. Nous y avons écouté plusieurs conférences portant sur le développement du chemin de fer en Chine (le premier mondial avec 22 000 km de lignes à grande vitesse), son modèle économique et ses choix technologiques, en particulier pour la grande vitesse.

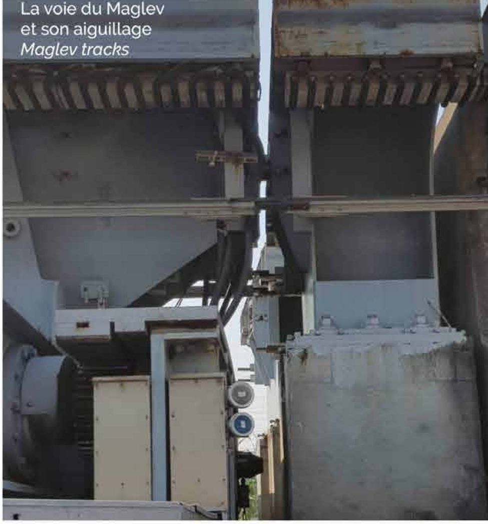
Lors d'une journée sur le campus de Jiading (qui dépend de Tongji), nous avons visité plusieurs laboratoires de recherche spécialisés en transport et ainsi observé plusieurs installations de test : soufflerie, sustentation magnétique avec la maquette grandeur nature du Maglev mis en service en 2004, simulateur de conduite, etc. En Chine, la recherche ferroviaire bénéficie d'un budget considérable, signe de l'importance stratégique des transports aux yeux des pouvoirs publics chinois.

After almost a decade visiting England, this promotion of students of the Advanced Master® flew to Shanghai for a week, in order to discover Chinese urban and railway transportations. The schedule included both meetings with academics and guided tours by public transports professionals and Chinese experts, speaking English or French.

The university of Tongjj that welcomed us is well-known all over the world in the railway field : the École des Ponts ParisTech has set up with them a double-degree agreement in transport in 2008. We attended there several conferences dealing with the evolution of railway and urban transit in China (the Chinese network being the longest in the world with 22 000 km of railway), its economic strategy and its technological choices, such as their preference for high-speed train.

We spent a day on the Jiading campus to visit the research laboratories: we saw the test track site, the wind tunnel, the life-sized Maglev model, and so on. In China, research in the railway field benefits from an important budget, which shows how much transport is strategic for Chinese public authorities.


Pudong la nuit
Pudong by night


La voie du Maglev
et son aiguillage
Maglev tracks


Les étudiants devant la statue de Mao Zedong à Tongji
The students in front of Mao Zedong statue in Tongji


Les étudiants du MS® avec le vice-président de l'IFCIM
The MS® students with the IFCIM vice-president

L'IFCIM à Tongji
The IFCIM in Tongji


Un *teamleader* du groupe : Cyril Dugimont

Coté visites, le programme concocté grâce au réseau d'entreprises partenaires du MS® a été d'une très grande variété.

Une grande partie d'entre elles était orientée vers le transport urbain (métro et tramway). Nous avons ainsi constaté le dynamisme et la rapidité avec lesquels le métro de Shanghai s'était développé en 10 ans, de même que les fortes exigences de l'opérateur Shantong. Grâce à Alstom Chine (CASCO), nous avons même pu entrer dans le PCC de la ligne 10, en charge de la régulation de cette ligne automatique. Le tour de piste n'aurait pas été complet sans un projet de tramway construit par Kéolis, où nous avons réalisé que l'insertion urbaine n'était pas une priorité en matière d'urbanisme.

Pendant quelques instants, nous avons atteint 431 km/h dans le Maglev entre l'aéroport de Pudong et le terminus de la ligne 2, avant de sillonner la ville en tous sens en transports en commun.

Côté équipements ferroviaires, nous avons visité l'usine Alstom de construction de climatiseurs et l'atelier d'entretien de la ligne 8 édifié et exploité par Bombardier aux dimensions gigantesques. Mais nous sommes restés abasourdis devant la gare de Shanghai-Sud, cette magnifique cathédrale ferroviaire d'une taille considérable, construite en partenariat avec l'agence d'architecture d'AREP et celle de Hongqiao.

Un court voyage en TGV vers la cité-jardin de Suzhou a conclu cette semaine ferroviaire qu'une partie des étudiants a choisi de prolonger, soit vers Pékin, soit vers Lhassa… en train bien sûr.

The other tours were quite diverse, thanks to the Advanced Master® professional network.

The majority of visits focused on urban transport (metro and tramway). We saw at once how strongly and quickly the subway of Shanghai had developed in ten years and how so had the requirements of the operator Shantong in terms of exploitation on a daily basis. We were even able to see the PCC of line 10 thanks to Alstom China, who was in charge of the regulation of this automatic line.

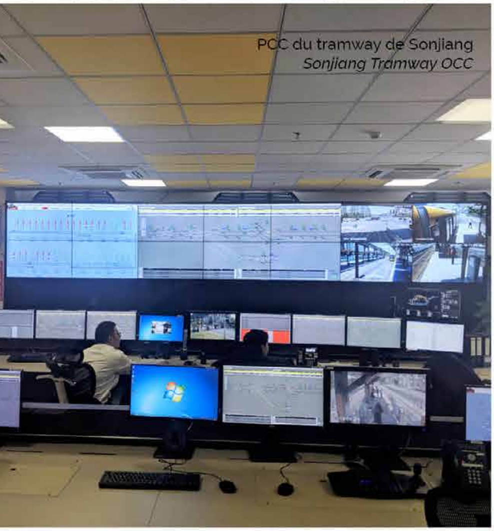
We reached in a few minutes the 431 km per hour in Maglev between the airport of Pudong and the end of line 2, before travelling in public transportation throughout the city. But we couldn't have left without observing a LRT project made by Kéolis Chine, adorning a different design from the urban insertion than the one we see in France or in Europe.

About railway equipment, we saw the Alstom construction factory of air conditioners and the line 8 gigantic maintenance workshop, built and operated by Bombardier. But we were in awe in front of the Shanghai South railway station: a sort of huge railway cathedral, built in partnership with AREP's architecture office and of course with that of Hongqiao.

A short travel in HST towards the garden city of Suzhou ended this railroad week, that some students chose to extend, either towards Beijing or Lhasa… by train, of course.


Gare de Shanghai-Hongqiao
Shanghai-Hongqiao station

Université de Tongji : centre de recherche ferroviaire
Tongji University: Rail Transit Laboratory


PCC du tramway de Sonjiang
Sonjiang Tramway OCC


Le dépôt de KEOLIS
KEOLIS warehouse


Le Maglev à Shanghaï
The Maglev in Shanghai

Vitesse du Maglev à Shanghai
Maglev speed in Shanghai

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La Source, spreading knowledge

Ce *Yearbook* a été réalisé par la Direction de la documentation de l'École des Ponts ParisTech en collaboration avec Françoise Manderscheid, responsable du MS® « Systèmes de Transports Ferroviaires et Urbains ». Ce travail d'édition s'inscrit dans la continuité des missions de conservation et de diffusion des savoirs de l'École.

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

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

This Yearbook *was made by the Documentation Department of the École des Ponts ParisTech, in close collaboration with Françoise Manderscheid, headmaster of the "Railway and Urban Transport System Engineering" Advanced Master®. This editorial work is a way of fulfilling the school's mission to conserve and disseminate knowledge.*

The Documentation Department provides students with an 800 m² space, called 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 les éléments concrets de la mise en œuvre : maintenance, mais aussi financement et planification.

Les résumés des travaux de la promotion 2019 ont été regroupés dans cet ouvrage afin de donner un aperçu de leur qualité et de leur technicité. Cette année, si deux projets s'occupent de décongestionner deux villes en pleine croissance, Dhaka (au Bangladesh) et Djibouti, les deux autres doivent intégrer les problématiques transfrontalières à leur solution de transport pour Cúcuta en Colombie et pour le golfe de Guinée, d'Abidjan à Lagos. À travers la multiplicité de ces contextes et de ces lieux, s'esquisse 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 "Urban and Railway Transport System Engineering" Advanced Master® have to take on a challenge: invent a transport line for a city or a place from another continent. In small groups, they study the economic, geographical and even social contexts, to find the most suitable traffic solution. They finish their study with the more practical aspects of implementation: maintenance, but also funding and planning.

Summaries of the 2019 studies have been gathered in this book to give an overview of their quality and technicality. This year, if two projects are busy decongesting two growing cities like Dhaka (in Bangladesh) and Djibouti City, the two other ones have to take the cross-border context into account to propose a suitable transport solution in Cúcuta (Colombia) and in the Gulf of Guinea, from Abidjan to Lagos. Beyond the diversity of these contexts and places, it is thus the future of our own mobility we can discern in this Yearbook*: embark on a journey to the heart of thinking and innovation in the world of tomorrow.*

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