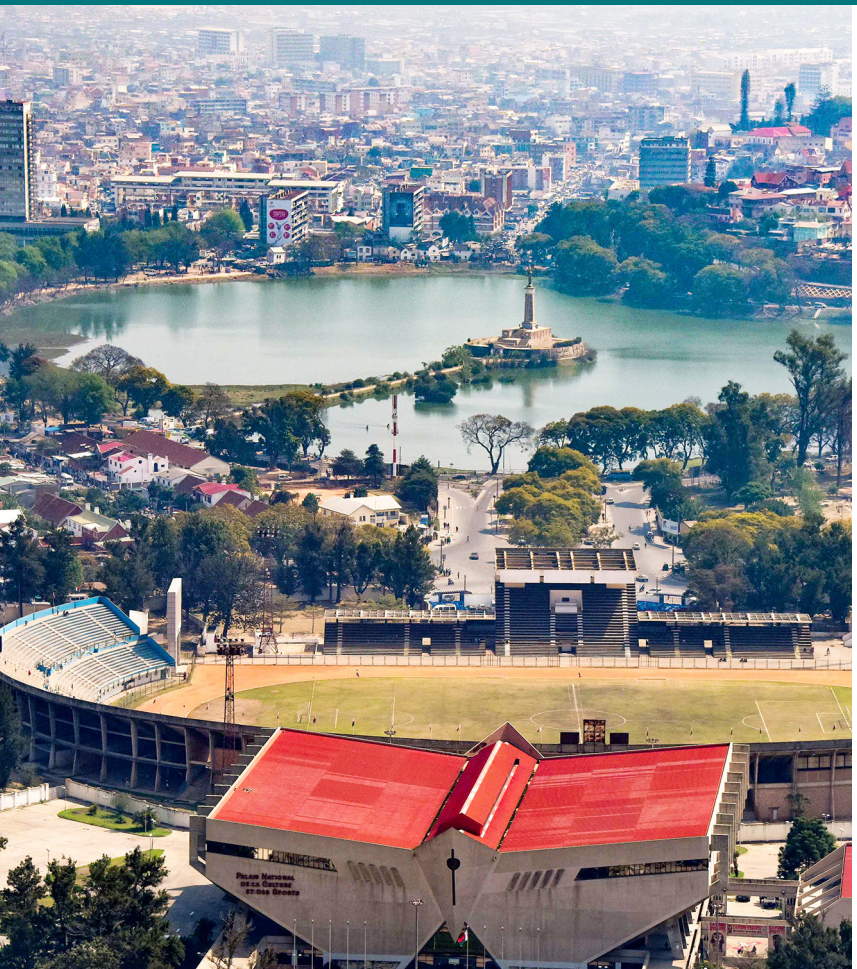
A metrocable system in Antananarivo, Madagascar



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Mots-clés

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Introduction

This study wishes to analyze the situation of Antananarivo in terms of transportation needs and to submit a proposal for a new means of transport for the population of the city.

It will assess the situation of Madagascar thanks to a socio-economic analysis and highlight the needs of the local people that justify a transportation project.

We will then describe the final choice for the route and the selected system. The last part of the analysis will go through the lifecycle cost for this type of project.

1. Madagascar in a nutshell

Antananarivo, the capital city of Madagascar, has a population estimated at 1.2 million inhabitants in 2014 distributed among 6 districts. The country ranks among the poorest ones in the world with a GDP of $392 per inhabitant, mainly because of the constant political instability since 1991.

Half of the population in Antananarivo is less than 15 years old. Moreover, the high level of rural exodus to the capital has been poorly controlled, leading to a chaotic occupation of the territory. Throughout decades, urban development has become uneven and uncontrolled. As a consequence, it has now an overcrowded territory and people live on unconstructible areas in slums around the city.

A few years ago, Madagascar was considered a country with a high economic development potential. Indeed, before one of the many political crises in 2009, economic growth was reaching 5% annually, but since then, it hasn't yet got back on its feet. Apart from the slow economic growth, it must be noted that Antananarivo is the center of most of the country's economic activities, especially in trade and the tertiary sector. The city is also a place where most companies establish themselves.

The World Bank, which has given its support to the country since 1963, has granted in 2016 an access to the turnaround facility loan of the international Development Association (IDA). It wishes to give the country a strong support for its economic growth through investments in some key sectors such as transport, infrastructures, education and development of the rural regions. The last diagnosis performed by

the World Bank showed that extreme poverty was related to the lack of investment combined with a slow economic growth and a lack of political management.

Indeed, the political instability did not give much opportunity for the country to invest in order to boost the economy or to highlight the country's natural resources. This lack of involvement did not give the population any means to contribute in any way through labor and by paying taxes. So public service cannot be developed and economic development cannot be achieved properly due to the rapid demographic growth. The World Bank wishes to help Madagascar come out of this vicious circle.

To conclude these few words on Madagascar's situation, from an environmental perspective, the soil is made of earth crust, indicating a steady and solid ground. The relief is composed of rolling hills with an altitude range between 1200m and 1400m. Although there has been a magnitude 5.9 earthquake on Richter scale in January 2017, the majority of it was barely felt and was close to a magnitude 2 or 4 on the Richter scale.

Even though the island located in the Indian Ocean is on the path of cyclones, Antananarivo suffers less damage than coastal towns, thanks to its geographical location in the center of the country.

2. Existing transportation network and its management

The analysis of the administrative entities in relation with the public transportation shows the existence of many not quite official agencies.

At the top, the state department of transport gives managing and regulation authority to the "Agence des Transports Terrestres" (ATT). Meanwhile, the city of Antananarivo and its greater area has its own managing and regulation authority which leads its own development strategy. This entity is known as "la direction des transports de la commune d'Antananarivo" (CUA).

On the other side, two cooperatives control urban transportation in Antananarivo:

- "les Coopératives de Taxis Be" owning some bus lines. They are considered a private and family type of business since presidents are nominated by their predecessor without consultation;
- "l'Union des cooperatives des transports suburbains" (UCTS), gathering over 50 independent cooperatives and controlling a total of 74 bus lines.

We can conclude from this organization that the cooperatives manage as they wish the routes and it is not rare to see a bus making a detour for the convenience of a family member or a friend. This organization cannot be qualified as rigorous and the management does not fit with an urban context but more with a village.

Thanks to a partnership between "la Région Ile-De-France" (France) and Antananarivo, the institution "Institut des métiers de la ville" (IMV) has been created in order

to train people of Antananarivo to good habits about the management of a big city. Among other activities, there is one concerning the transportation organization. It gives this institution the ability to lead discussions and most of all to ease exchanges between ATT and CUA entities.

The existing transportation network within the city is shared between buses and taxis. A railway network exists and its infrastructure is used for Merchandise activities managed by Madarail. Apart from those public transportations mentioned, personal vehicles are used to move around the city (owning a car is seen as a personal achievement). Walking is also by far the first means of transportation as showed in the following figure.

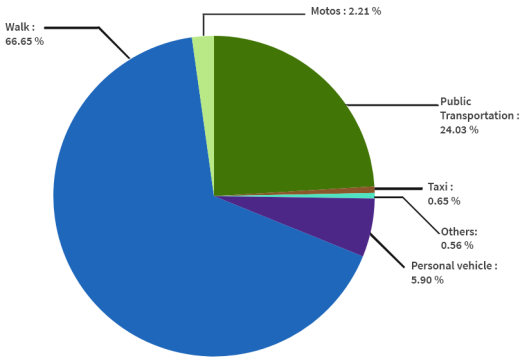


Diagram 1: Types of transportation in Antananarivo

2.1. Taxis network

Over 7700 taxis flood the streets of Antananarivo. The taxi license is delivered by the City Hall and represents half of the traffic of light vehicles.

They are part of the chaos since they stop anywhere to pick up passengers or wait for new ones. It is not uncommon to see a taxi stopping in the middle of the street to do so. They are also the only means of transportation between Antananarivo airport and the city center which is around 12 km away.

2.2. Bus network

The bus network as mentioned previously is entirely managed by many small companies. Therefore, we can find 5 types of transportation means:

- taxi Be: Buses with routes within the Urban community of Antananarivo (CUA);

- suburban transport: buses with routes between Antananarivo and the cities around it;
- regional transport: buses with routes between Antananarivo and cities in the region of Antananarivo;
- rational transport: Transportation network between Antananarivo and the five other regions of the country;
- private transport: Buses that ensures particular missions such as school rides for children, companies staff transport.

There are 1 790 Taxis Be, the size of a minivan that can carry 20 people although it is not unusual to see them with over 30 passengers. They are spread out on 82 lines with thousands of bus stops.

2.3. Personal vehicle

In addition to buses, there is a significant circulation of private cars in the city. It is estimated at around 7.5 % of the total of vehicles in Antananarivo, which is already over 110,000 cars.

Since very few investments have been made on the road infrastructures over the last three decades, the congestion has become extremely unbearable for both cars and buses.

As a conclusion to this insight on the transportation system network, we can say that infrastructures and the transportation network do not fit the commuters' needs.

3. The route and the transportation system: a four-step model

3.1. Generation

This step describes the hubs where traffic is significant. The analysis shows 4 areas within the city where the transportation offer is not enough:

- the university of Antananarivo with more than 20,500 people who need to reach Ambohitsaina hill;
- the city center of Antananarivo which is the focal point of many roads. It also takes the whole traffic north-south or west-east. The district contains multiple hotels, embassies, administrative building and commercial activities;
- "the road of the dam and the road of the hydrocarbons" in the west and the north of the city are important industrial areas with over 30,000 jobs in different areas of expertise. The roads are mainly blocked by merchandise traffic in addition to the daily commutes.

3.2. Distribution

The allocation of urban travel divided by reasons shows the two most important types of flows:

- home – work;
- home – school.

Moreover, 59% of movements are done within the six districts of Antananarivo and travels are done from the peripheral districts to the city center. We will analyze these following routes in the four-step model:

- route 1: Home – School;
- route 2: Home – Work;
- route 3: within the city center.

3.3. Transportation through a multi-criteria analysis (MCA)

The next step is to determine a range of possible transportation systems. It is done following the multi-criteria analysis method. The alternatives considered for the study are light rail (metro or tramway), Metrocable and BRT. All of them will be assessed following 3 types of criteria: quality, quantity and setup complexity.

The conclusion of the analysis shows that a Metrocable system has the most positive results compared to the other two systems. Indeed, the BRT and the light rail systems have each only two out of three types of criteria.

Criteria/System	Light Rail	Metrocable	BRT
Quantity	17	17	17
Quality	30	37	19
Setup complexity	6	33	35

Table 1: Simplified table result for the MCA

3.4. Choice of a route using a multi-criteria analysis

The route is derived from the distribution step and has to be consistent with the choice of the transportation system. The criteria taken into account were approved by our contact at the IMV, which gives high credibility to our analysis. It has been decided that the most important are:

- education;

- break of the congestion;
- to relieve the city center.

The route that got the best results is the one between Soarano Old Central Station and the university. Especially because education is considered one of the top priorities and the other two alternative routes did not offer relevant benefits from an education point of view.

4. The chosen route

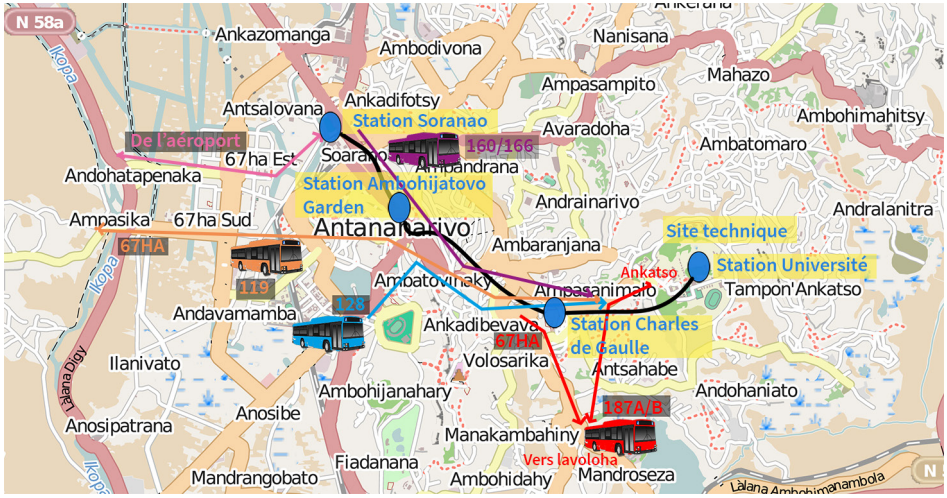


Figure 1: The detailed chosen route: Soarano - University - Source : © les contributeurs d'OpenStreetMap, CC-BY-SA

The final route for the Metrocable system is an opportunity to create several multimode hubs. It would merge buses network around the metrocable route especially the ones towards university.

The concerned buses would be the 119, 128A/B, 160/166, 187A/B: they all have a different starting point but a common route to the university at Charles De Gaulle Avenue.

5. The chosen system

5.1. Principle

The chosen system is a gondola lift system which would, as stated previously, meet the requirements of the selected route. In a more precise approach, next step is to choose a type of metrocable to install for the project. To do so, the requiring capacity

has been calculated: the system must give quality service for **3,477 People per Hour per Direction** (PPHPD).

A benchmarking among the existing gondola lift systems in the world shows that the one used in Medellin (Columbia) is the closest one that we can use as reference for our project. The system will be featured with a single cable and a continuous move of a steal haul rope which slows down at each station arrival. The single cable will ensure both functions for haulage and support. Moreover, the grip holding the aerial lift will be detachable, in order to use the slow down motion function for station arrival.

Now, it is also required to provide the size of the interval between two cable cars according to estimated PPHPD. Numeric application gave an **interval of 15 s between 2 vehicles**. This number will be used to determine the number of lift needed for the operation.

The main operation functions that would be used for the project are the following:

- "classical mode" where the roundtrip are decided in advance, according to a timetable;
- "rush hour" mode where the system will be usually used at its maximum capacity following the interval;
- "off Peak hour" mode where the system will allow two types of operating modes:
    - departure-on-demand by the customer who can wait for the next departure or request an immediate departure;
    - departure on order from the Operating Control Center (OCC) where the departure is given by the operator thanks to a remote command from his workstation.

The following diagram shows the principle of the chosen gondola lift system. We can find in the upstream terminal station the device that will ensure the cable tension. On the other side, in the downstream terminal station, there are motors that will ensure the cable movement.

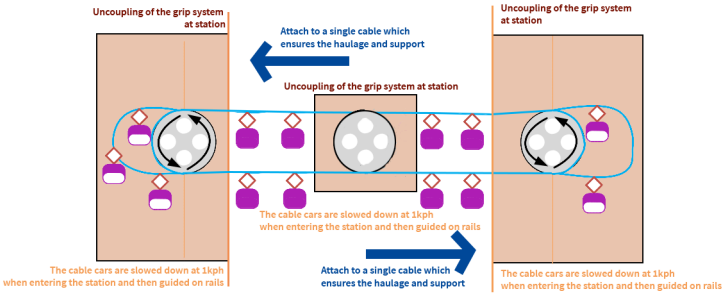


Diagram 2: Gondola lift system with single rope and a detachable grip

5.2. Infrastructures



Downstream Terminal Station

Function :
-Technical room for the cable tension devices
-Customer reception area
-Storage for 87 lifts



Intermediate station

Function :
-Customer reception area
- « Pocket track » for 3 lift



Intermediate station

Function :
-Customer reception area
- « Pocket track » for 3 lift



Upstream Terminal station

Function :
-Technical room for the motors
-Customer reception area
-Storage for 85 lifts
-Maintenance hall
-OCC

Diagram 3: Overall equipment diagram

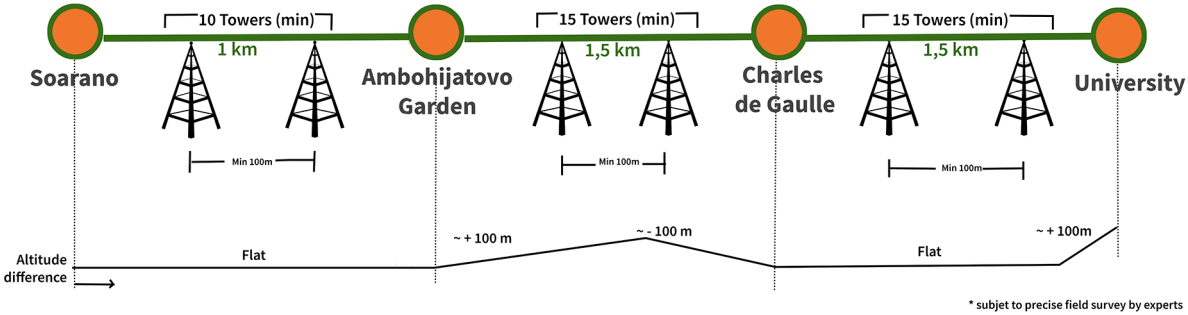


Diagram 4: Overall infrastructure diagram

5.2.1. Tower

Depending on the altitude difference, there are 3 types of tower:

- support tower which is used mainly to maintain the longitudinal profile;
- compression tower which is used to allow a breakage to reduce the altitude on the longitudinal profile;
- support-Compression tower is a tower that has both functions.

The diameter of tower base is around 1 m and it cannot be higher than 40 m. Moreover, a tower is needed every 100 to 300 meters. For the study and the calculation of the project cost, the worst case will be taken into account.
In our case, the project will need for every 100 m a tower implantation:

- 10 towers between stations Soarano and Ambohijatovo Garden (about1 km long interstation);
- 15 towers between stations Ambohijatovo Garden and Charles de Gaulle (about1.5 km long interstation);
- 15 towers between stations Charles de Gaulle and Université (about 1.5 km long interstation).

5.2.2. Stations

Each station is a group of building and structures including technical equipment and areas for boarding and alighting. Depending on the architecture chosen and the required organization, there could be a customer reception zone with or without a shelter. Depending on the type of station, the required dimension for the each would be:

- for terminal stations: 25 to 30 m long and 10 m wide;
- for intermediate stations: 50-60 m long and 10 m wide.

5.2.3. Aerial lift

The single cable metrocable type maximum speed has been set at 21 kph according to benchmarks. However, the commercial speed observed on other projects is 18 kph with a capacity of 15 s.

Those inputs allow us to determine the duration of a roundtrip, by assuming a 1.5 min transition at station. We get these numbers:

- time between Soarano and Ambohijatovo Garden: 3 min 20 s;
- time between Ambohijatovo Garden andCharles de Gaulle and between Charles de Gaulle and University: 5 min;
- transition duration at station: 1 min 30 s which is 9 min in total (2 stops at terminal station and 4 stops at intermediate station);
    - total duration for a trip: 19 min 20 s;
    - total duration for a roundtrip: 38 min 40 s;

The required fleet would be 143 aerial lifts for the operation. A 10% extra has to be added to take into account maintenance needs. Therefore the total required fleet would be **158 lifts.**

5.2.4. Power supply

Power supply consumption need has been provided through data from Medellin Metrocable system.

The average (theoretical) consumption for a single-rope metrocable with a low drop along the line is estimated at 1,200 kWh for a 19-hour operation per day and an average speed of 5 m / s. The estimated need in terms of electricity load would be **204 MW per year.**

5.2.5. Initial investment for the construction of the Antananarivo Metrocable

Cost Breakdown in euros (excluding taxes)			
Type	**Equipment**	**Price per equipment**	**Total price**
Stations	Haul station	€2.5 to €3M	€3 M
	Intermediate station	€2 M to €2.5 M	2.5 × 2 = €5 M
	Support station	€1 M	€1 M
Cables	Cable haul / support	€50 M per meter	12 km × 50 = €0.6 M
Lifts	Lift 8-15 persons	€30 k	158 × 30 = €4.74 M
Tower	Tower for single-cable system	€100 k	40 × 100 = €4 M
System	Control-Command, CCTV, PA/PIS, ticketing system	€1.5 k	€1.5 M
Miscellaneous equipment	UPS, Miscellaneous equipment	€300 k	€0.3 M
		SUB-TOTAL	€20.14 M
		Fees (10 % of sub-total)	€2,014 M
		TOTAL	€22,154 M

Table 2: Cost Breakdown for metrocable construction - Source: CETE de Lyon

5.2.6. Operation and maintenance

The system will work for 17 hours a day during 358 days. It would require 2 types of staff, a technical team to manage maintenance of the system and an operating team to manage operation on the line.

Concerning maintenance, we planned a daily visual control of all technical equipment, completed by an annual inspection lasting 7 days straight. The estimation of time spent on the daily inspection would be 2,500 hours.

In addition, the system will have to go through 2 other types of inspection:

- multi-year inspection program depending on the operator (usually < 10th year of functioning);
- important inspections program, recommended after 10 years of functioning.

6. Project lifecycle cost

6.1. Travel general cost

Travel general cost is defined as ticket price and costs related to time spent travelling. Then social value of time is needed to be able to calculate the cost of transportation time.

To estimate social time value in Antananarivo, we based our calculations on "The value of travel time saving", a research report made for the Department of Transport in *Policy Journals*. This report proposes to distinguish values for travel during leisure time from the value related to professional trips. Working time value depends on the type of jobs, and wages.

Our study will use average wages and propose a hypothesis on the relation between job qualification and the level of population education. The value we got for working time value is €0.8/ h. In order to figure out leisure time value, we estimated that an adult with an average job considers the value of its leisure time as half the value of its time travelling due to professional reasons. Although unemployed and retired people will consider it even lower, we took average working people as reference. So leisure time value used for our project is €0.4/ h.

When we look at reasons causing people to travel, we realize that only 0.17 % of total movements are made for professional reasons. We can conclude that social time value should be the same as leisure time value: **€0.4/ h**.

The last step is to calculate travel general cost. We made several hypotheses regarding ticket price, speed and average time spent waiting and travelling using every transportation alternative available in Antananarivo at morning peak hour for the itinerary between the town center and the university. We deduced that metrocable is the less expensive from a social point of view compared to Taxi-Be buses (about 40 % less) and private vehicles (about 60 % less).

6.2. System lifecycle cost

The considered costs for the system are the ones related to:

- staff for the operation and maintenance of the system;
- electricity consumption;

- maintenance costs for equipment repair or replacement.

It has been determined the following costs per year:

System lifecycle cost breakdown	
Staff	€134,220 / yr
Electricity	€209,111 / yr
Maintenance spares & repair	€90,000 / yr
TOTAL	€433,331 / yr

Table 3: System Lifecycle cost breakdown synthesis

6.3. System lifecycle revenue

The main income of the system is from the tickets which are divided as follow:

- single Ticket;
- monthly pass

The estimated income from the tickets with several traffics scenario would be **€1,117,246.**

6.4. Net Present Value

First, we will talk about earnings from travel time saving. Modal shift from walking to metrocable is negligible, whereas modal shit from buses and private vehicles to metrocable would be equivalent to 50 % (1 out of 2 commuters would choose the new system)

As it was explained in section 5.1 above, travel general costs for metrocable is significantly less expensive than those for buses or private vehicles. Therefore the estimated earnings from travel time saving correspond to **€1.45 M.**

For this study, the estimation for the external help has not been considered from the equation since we are going to assess cost effectiveness of the project with an unfavorable scenario. Besides, there would be a huge uncertainty estimating factors such as the cost of unknown figures about CO_2 and different kinds of pollution in Madagascar.

We could have taken the given values used in France (see Quinet report) but it would not have been significant for our study considering the gap between both countries in regards to quality of life and how it is valued. Concerning public finance, when we subtract operational and maintenance costs from income due we get from tickets, we get: **€0.85 M.**

Finally, if we assume that the residual value of the investment is €4.5 M (investment cost after it has paid off), **the Net Present Value is estimated at €0.6 M**. It means that even in a really unfavorable scenario, the project would be cost-efficient.

Our calculations show that the internal profitability rate is equal to 5 % which is over the discount rate of 4.5 %. It means that, from a socio-economic standpoint, the metrocable project would have a positive outcome.

6.5. Project funding

One of the major concerns is to find an entity that would take in charge the management of such a construction. From our perspective, the CUA helped by the IMV seem to be the best partnership to accomplish this mission. But Madagascar government must show that it will back up every decision. To do so, it must show that it really intends to launch the project by using part of the funds from the IDA.

The project can also turn to other funding partner from all around the world such as the Japanese fund, the Arab bank or the African bank. It can also involve international associations such as the French development agency in addition to the IDA.

7. Key to success

The study shows many positive outcomes to ease the transportation for people of Antananarivo and to put Madagascar in such a project. The metrocable system would significantly decrease travel time for students all around Antananarivo, improve the consistency of the existing bus routes, and therefore limit pollution by limiting congestion.

However, the key to success for this project is to properly define a public transport authority to manage the construction and then to supervise the transport operator. It must ensure the consistency of the transportation plan between the gondola lift and the buses. Even if the decision granting people access to more mobility is not profitable, this public service must have a strong political wish to serve the population.

In the end, this new system must be the first step of the revival of the capital city of Madagascar, the main target of this study being students and therefore this country's future.