MT | Master thesis

DM | Dissertação de mestrado

TFM | Treball de fi de màster

Integration projects of centralities of urban public transport networks in Rio de Janeiro city

Eloi Pallarès Escorial

Andréa Santos Souza | Rômulo Dante Orrico Filho

Rio de Janeiro, February 28th, 2023

MSCTM | Màster en Supply Chain, Transport i Mobilitat

Programa de Engenharia de Transportes_COPPE-UFRJ | ETSEIB_UPC | ETSECCPB_UPC

Abstract:

The current urban structure of Rio de Janeiro city and its metropolitan area, together with the socioeconomic reality of the area, makes the daily commuting times for a remarkable number of users of the public transportation network being extremely high and undesirable. The main aim of this present thesis is to create a model evaluating the feasibility and suitability of several proposals in order to deal with this problem by studying a scenario where Rio de Janeiro city and its metropolitan area turns from the current monocentric model to a multicentric one, specially focusing in the Grande Bangu area, located in Zona Oeste, in the western area of the city, becoming the case study of this project.

An analysis has been carried out in order to identify the background, strengths and weaknesses of the current city and metropolitan area, as well as its public transportation network. Afterwards, some strategies and proposals are about to be proposed in order to provide some guidelines to improve the SuperVia rail services, the ônibus network, the active mobility in the area and the urban planning and urban design.

For the SuperVia rail services, has been operationally and economically explored the possibility of introducing to the system semi-direct trains covering the Santa Cruz branch, with the idea of reducing the commuting times of the users of that line, as well as with the idea of extending this idea to the other branches of the existing commuter train network operating in the region.

Focusing in the Grande Bangu area, has been operationally and economically explored the feasibility and suitability of deploying a new ônibus network in the region, with the idea of a more local network, creating a public transportation cluster and reinforcing the new centrality. Two scenarios have been explored, with the feasibility of the introduction of a radial or an orthogonal network.

Staying in the Grande Bangu area, has been analyzed and explored the status quo of the active mobility in the region; which has been mainly given several solutions in the urban planning and urban design point.

Regarding the urban planning and urban design, this thesis has been devoted to solve the suitability of boosting and enlarging the current green infrastructure in the Grande Bangu area; as well as trying to improve using the architecture and urban planning knowledge and skills of the author of this thesis the status quo of the streets and avenues of the analyzed area, as well as one critical point.

Resumo:

A atual estrutura urbana da cidade do Rio de Janeiro e sua região metropolitana, juntamente com à realidade socioeconômica da região, faz com que os tempos de deslocamento diário de um número notável de usuários da rede de transporte público sejam extremamente elevados e indesejáveis. O principal objetivo desta presente dissertação é criar um modelo avaliando a viabilidade e adequação de várias propostas para lidar com este problema, estudando um cenário onde a cidade do Rio de Janeiro e sua região metropolitana passam do atual modelo monocêntrico para um modelo multicêntrico, com foco especial na área do Grande Bangu, localizada na Zona Oeste, tornando-se o estudo de caso deste projeto.

Foi realizada uma análise para identificar os antecedentes, pontos fortes e fracos da atual cidade e área metropolitana, bem como sua rede de transporte público. Em seguida, algumas estratégias e propostas serão propostas para fornecer algumas diretrizes para melhorar os serviços ferroviários da SuperVia, a rede de ônibus, a mobilidade ativa na área, e o planejamento urbano e o desenho urbano.

Para os serviços ferroviários da SuperVia, tem sido explorada operacionalmente e economicamente a possibilidade da introdução no sistema de trens semidiretos que cobrem o ramal de Santa Cruz, com a idéia de reduzir os tempos de deslocamento dos usuários daquela linha, mais também como com a possibilidade de estender esta idéia para os outros ramais da rede de trens metropolitanos existentes que operam na região.

Com o foco na região de Grande Bangu, tem sido explorada operacionalmente e economicamente a viabilidade e adequação da implantação de uma nova rede de ônibus na região, com a idéia de uma rede mais local, criando um cluster de transporte público e reforçando a nova centralidade. Dois cenários foram explorados, com a viabilidade da introdução de uma rede radial ou outra rede ortogonal.

Também, foi analisado e explorado o status quo da mobilidade ativa na região do Grande Bangu; a qual foi dada principalmente várias soluções no ponto de planejamento urbano e desenho urbano.

Com relação ao planejamento urbano e desenho urbano, esta dissertação foi também dedicada a resolver a adequação de melhorar e expandir a atual infraestrutura verde na área do Grande Bangu; mas também tentar melhorar, utilizando os conhecimentos e habilidades da arquitetura e planejamento urbano do autor desta dissertação, o status quo das ruas e avenidas da área analisada, assim como um ponto crítico.

Resum:

L'actual estructura urbana de la ciutat de Rio de Janeiro i la seva àrea metropolitana, juntament amb la realitat socioeconòmica de la zona, fan que els temps de desplaçament diaris d'un nombre notable d'usuaris de la xarxa de transport públic siguin extremadament elevats i indesitjables. L'objectiu principal d'aquesta tesi és crear un model d'avaluació de la viabilitat i idoneïtat de diverses propostes per fer front a aquest problema mitjançant l'estudi d'un escenari on la ciutat de Rio de Janeiro i la seva àrea metropolitana passa del model monocèntric actual a un actual a un altre de multicèntric, centrant-se especialment a la zona de Grande Bangu, situada a la Zona Oeste, a la zona oest de la ciutat, convertint-se en el cas d'estudi d'aquest projecte.

S'ha realitzat una anàlisi per tal d'identificar els antecedents, els punts forts i febles de la ciutat i l'àrea metropolitana actuals, així com la seva xarxa de transport públic. Posteriorment, s'han explorat algunes estratègies i propostes per tal de donar pautes per tal de millorar els serveis ferroviaris de SuperVia, la xarxa ônibus, la mobilitat activa a l'àrea i l'urbanisme i disseny urbà.

Referent als serveis ferroviaris de SuperVia, s'ha explorat de manera operacional i econòmica la possibilitat d'introduir al sistema trens semidirectes que cobreixin el ramal de Santa Cruz, amb la idea de reduir els temps de desplaçament dels usuaris d'aquesta línia, així com amb la idea d'estendre aquesta idea a la resta de ramals de la xarxa de trens de rodalies existents que operen a la regió.

Centrant-se a la zona de Grande Bangu, s'ha explorat operativa i econòmicament la viabilitat i idoneïtat de desplegar una nova xarxa d'ônibus a la regió, amb la idea d'una xarxa més local, creant un clúster de transport públic i reforçant la nova centralitat. S'han explorat els escenaris de la introducció d'una xarxa radial, o bé d'una xarxa ortogonal.

Focalitzant-se a la zona de Grande Bangu, s'ha analitzat i explorat l'status quo de la mobilitat activa a la regió; a la qual s'han donat diverses propostes en el següent punt referent a l'urbanisme i disseny urbà.

Pel que fa a l'urbanisme i el disseny urbà, aquesta tesi s'ha dedicat a resoldre la idoneïtat de potenciar i ampliar l'actual infraestructura verda a la zona de Grande Bangu; així com intentar millorar utilitzant els coneixements i habilitats d'arquitectura i urbanisme de l'autor d'aquesta tesi l'status quo dels carrers i avingudes de la zona analitzada, així com un dels punts crítics.

Acknowledgements:

I would like to thank the mentors of this thesis, Rômulo Dante Orrico Filho and Andréa Santos Souza for their time and dedication; but also, due their quick response in the initial e-mails in order to get accepted for my exchange program in COPPE-UFRJ.

I would also like to thank to all the administrative team in the offices for their jobs, and to all the office partners.

Agredecimentos:

Gostaria de agradecer aos mentores desta dissertação, Rômulo Dante Orrico Filho e Andréa Santos Souza pelo seu tempo e dedicação; mas também, pela sua rápida resposta nos e-mails iniciais para que eu fosse aceite para o meu programa de intercâmbio na COPPE-UFRJ.

Gostaria também de agradecer a todas as pessoas de administração no escritório pelos seus trabalhos, e a todos os parceiros do escritório.

Index:

1 | Introduction:

1.1 | Motivation:

One of the main drawbacks of the city of Rio de Janeiro is its huge area and low density, combined with a big number of inhabitants and an urban structure clearly American, where the vast majority of the jobs are located in the downtown, called “Centro” in Rio de Janeiro, and the inhabitants live in an urban fabric characterized by its sprawly low-density; creating several urban problems, among others, in the public transportation network and in the life of the users, specially related with the commuting times.

Along the history, several workers associations have claimed for the triple eight rule; where the three eights stand for eight hours a day of labor, eight hours a day of leisure and eight hours a day of sleeping. That movement became so big, that several governments even introduced in the legislation a maximum number of hours each worker can work along a day or week; even centuries ago. With the current structure of the city and its public transportation network, the motto introduced above, becomes such a challenging deal to fulfill for a big percentage of the population living in Rio de Janeiro and its metropolitan area.

The main aim of this thesis is to create a model or even a landmark, creating several strategies of how to tackle the problems in the life of the citizens of the city of Rio de Janeiro and its metropolitan area in the transportation engineering field, by improving the public transportation and the urban design quality, and therefore the life of the users, focusing in one of the neighborhoods of the city due the limited amount of time available to submit this project. The project will also take into account the climatic emergency we are experiencing worldwide and it is intended to contribute to mitigate the effects of that problem in-situ with all the treated fields in the project. Also, it is important to acknowledge and mention that this project will take into account as much variables and parameters on the ground as possible, but the big difficulties on the ground will make really hard to implement that model due the lack of experts of every single required field in order to tackle the issues found.

1.2 | Objectives:

This project aims to evaluate the feasibility and suitability of the implementation of a public transportation system adapted to a hypothetical future scenario where the city of Rio de Janeiro and its metropolitan area switches its monocentral pattern to a multicentrality layout. To fulfill that aim, three main fields are going to be deployed in this project, defined below:

- Operational feasibility of the new scenario, mainly focusing in the mathematics behind different services such as the SuperVia trains and the "ônibus".

- Economic field, looking for the feasibility and suitability of the implementation of the operations described in the previous point.

- Urban planning, urban design and architecture applied in the selected area of the city where this project is focusing the most.

In every single point depicted above, the main aim is intended to be the improvement of the welfare of the population, focusing in the riderships; but also, in the mitigation of the global warming emergency.

2 | Status quo; background, strengths and weaknesses:

2.1 | Background:

Rio de Janeiro and its metropolitan area is located in the Guanabara Bay, in the Brazilian state of Rio de Janeiro, having the capital of the state in the western side of the bay, and therefore, the main intensity of both inhabitants and jobs, as seen in *Fig1*, where the downtown, called “Centro” in Rio de Janeiro and the “Zona Sul” it is been pointed out as the main job location in the city. The thicker is the dotted line, the more jobs are located in that area, according to the inhabitants in that area. According to data available in 1970, the “Centro” area and the surrounding area accounts by 30% of the workforce accommodation and allocates over 59% of the jobs in the metropolitan area; the immediate periphery represents 38% of the labor despite allocates 20% of the jobs; and in the further periphery used to live a little bit over 32% of the workforce despite having a little bit below the 21% of the jobs in the area[211]. Despite the population of the current city is 57% larger than the city back in the 70’s, the job distribution pattern is still valid, as it is going to be depicted below, in the strategies point.

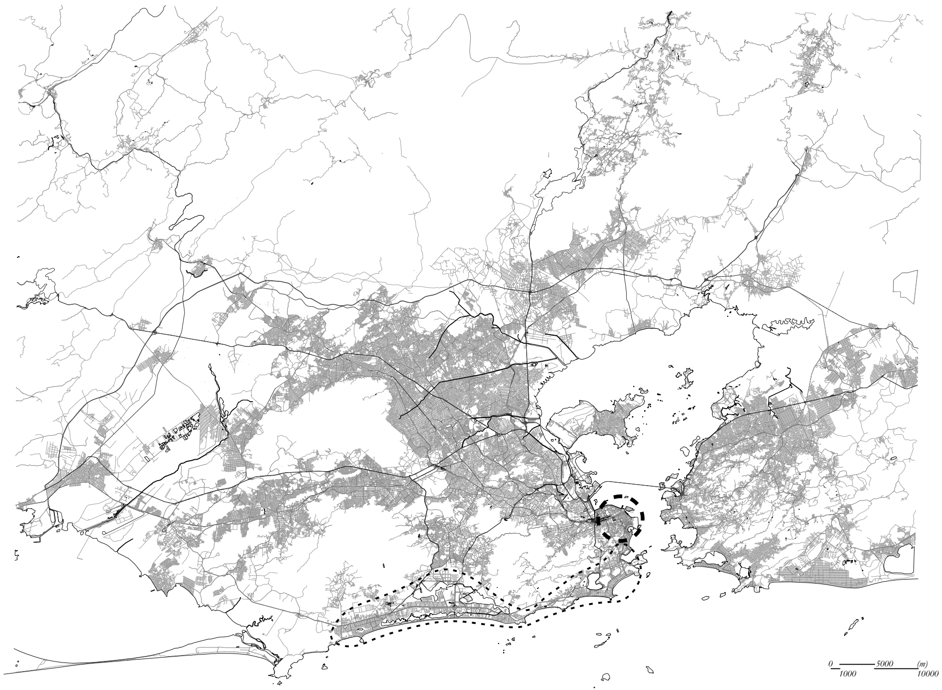

Fig1: Rio de Janeiro and its metropolitan area _ Guanabara Bay
Source: Own elaboration _[212]

Despite most of the neighborhoods or surrounding towns were created during the XVI century, the creation of the rail network and tramways[213] in the second half of the XIX century boosted the growth and acceleration of the surrounding towns and neighborhoods, shaping nucleus around some stations and boosting the industry in those areas.

That structure and urban fabric of the city is mainly given by the tree structure, seen in *Fig2*, several companies created heading “Centro” area. Most of the lines created by “Estrada de Ferro Leopoldina”, “Estrada de Ferro Dom Pedro II”, “Estrada de Ferro Rio d’Ouro” and “Estrada de Ferro Melhoramentos do Brasil” are currently owned by SuperVia (passenger rail company) having the main station in “Central do Brasil” terminal station and MRS[214] (freight rail company); few others such as the Niterói – São Gonçalo – Itaboraí line, that halted operation back in the 1990’s. The so-called “bondes”, tramways, also halted operation and were replaced by ônibus lines.

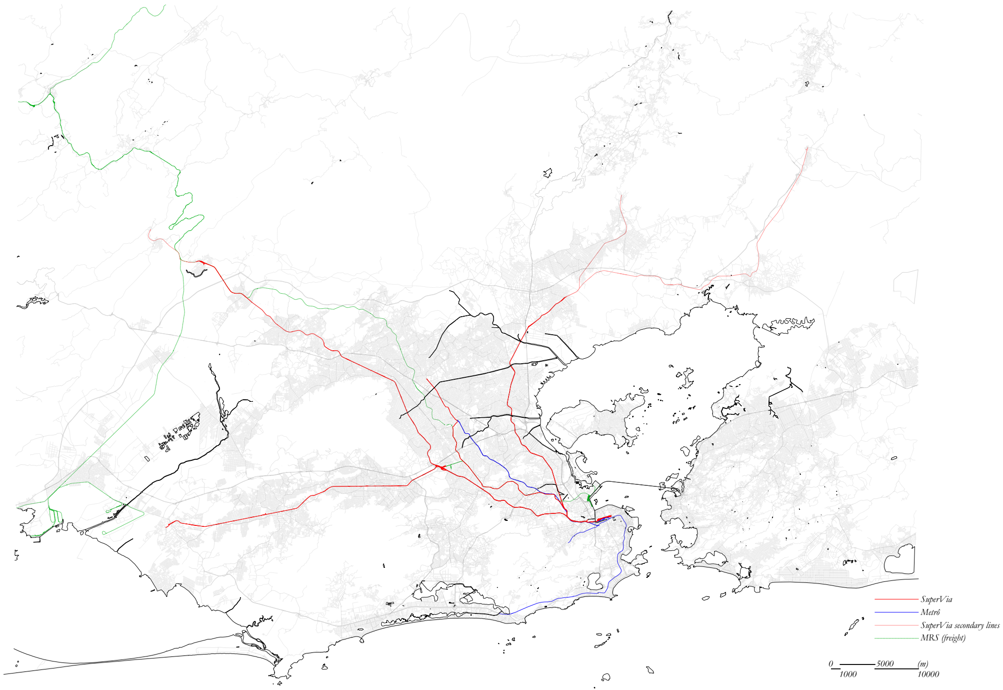

Fig2: Current rail network in Rio de Janeiro and its metropolitan area _ Guanabara Bay
Source: Own elaboration _[215]

The metrô network was created in the 70’s and afterwards enlarged until nowadays, mainly serving with an excellent service the so-called “Zona Sul”, southern area of the city; and becoming the busiest high-capacity public transportation infrastructure of the metropolitan area of Rio de Janeiro, excluding the Bus Rapid Transit netwok, BRT; despite just having two lines and not even leaving the capital premises.

According to the “PDTU - Plano Diretor de Transporte da Região Metropolitana do Rio de Janeiro”, released on September 2014 with 2012 data, the vast majority of Cariocas and Fluminenses use the public transportation system or walk (78,93%), being a minority, the ones using the private vehicle to commute; being the daily modal share as shown below in *Table 1* and *Table 2*.

Group	Subgroup	Mode	Trips	%
Active mobility	Walking	Walking	6.634.000	29,36
	Cycling	Cycling	546.000	2,42
Private vehicle	Private vehicle	Car	3.765.000	16,66
		Moto	170.000	0,75
Public transport	Private PT	Taxi	256.000	1,13
		Moto-taxi	39.000	0,17
	Collective PT	SuperVia	568.000	2,51
		Metrô	665.000	2,94
		Barcas	105.000	0,46
		Ônibus intermunicipal	1.781.000	7,88
		Ônibus municipal	6.671.000	29,52
		Ônibus executivo	70.000	0,31
		Ônibus pirata	16.000	0,07
		Transporte fretado	55.000	0,24
		Transporte escolar	428.000	1,89
Others	Others	Others	827.000	3,66
		Total	22.596.000	100

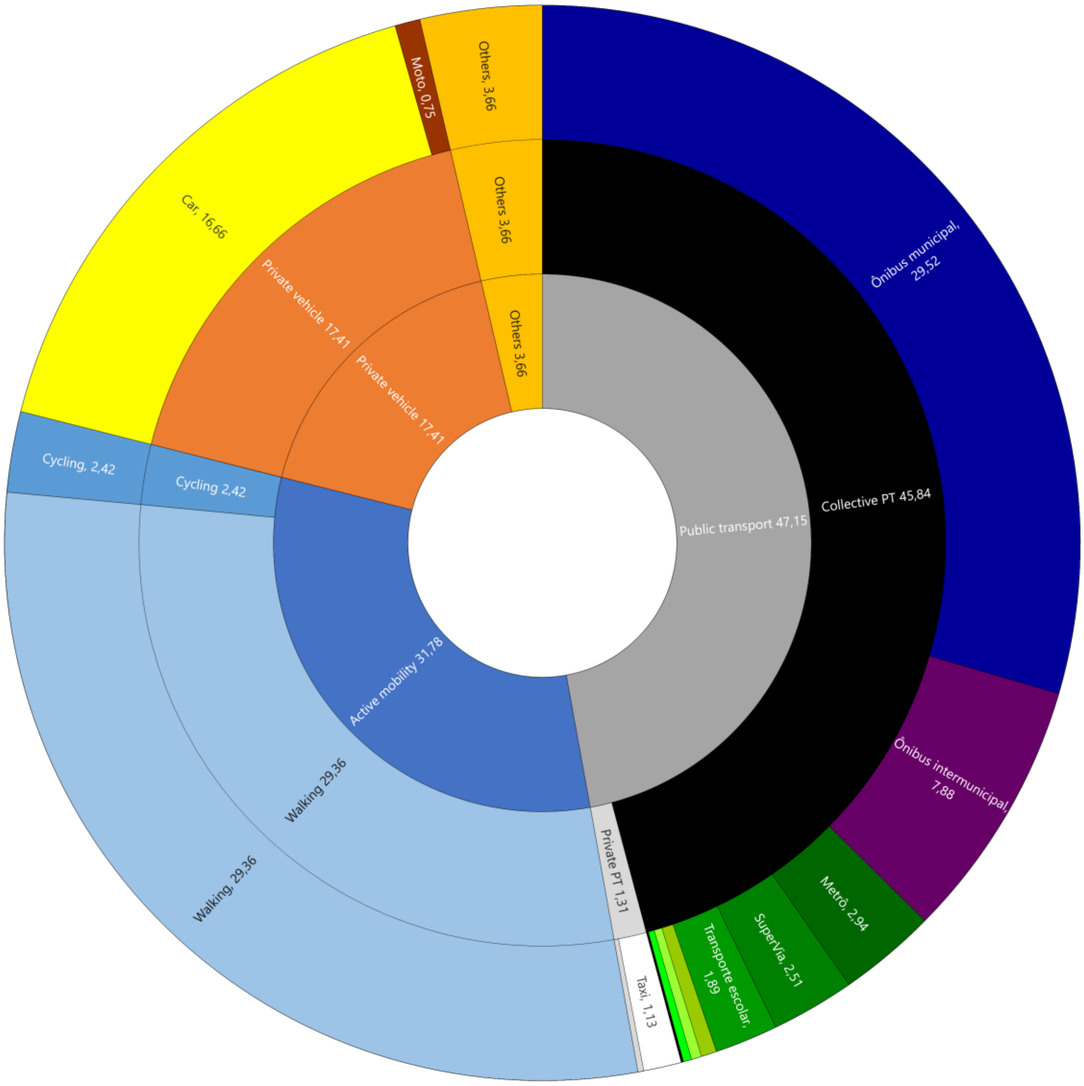

Table 1 | Table 2: 2012 daily modal split in Rio de Janeiro and Região Metropolitana
Source: PDTU - Plano Diretor de Transporte da Região Metropolitana do Rio de Janeiro _[216]

The data depicted in the *Table 1* and *Table 2* shows that the willingness of the users of Rio de Janeiro city and its metropolitan area to use the public transportation is really high. Rio de Janeiro city is the 3rd city in Brazil in terms of motorized public transportation usage, just after Manaus, in the state of Amazonas, and Salvador, in the state of Bahia. São Paulo or Curitiba, in the state of Paraná, with strong public transportation networks implemented, are 8th and 9th in the ranking, respectively. Campinas, in the state of São Paulo, is the last big city in that modal share ranking.

Another interesting point of that sample is the usage of the so-called "ônibus pirate", a network of unlicensed vans used as micro-buses that operates in certain areas of the city such as Bangu, that replaces the lack of public transportation controlled by the municipality, called "Prefeitura da Cidade do Rio de Janeiro". These vans are operated by local "milícias", criminal organizations; who control and sets the routes, timetables, schedules or headways, fees, revenues, among others. Once that van service is settled in a certain area, it is very tough to be replaced again by licensed public transportation due their operational methods, even with the possibility of becoming violent.

Keeping in mind the global warming scenario, it is also important to check the *Table 3* and *Table 4* to realize about the difference between the motorized trips and the free-carbonized trips done daily back on 2012 in the city of Rio de Janeiro and its metropolitan area.

Mode	Group	Trips	%
Motorized	Collective transport	11.016.000	48,76
	Individual vehicle	4.398.000	19,47
Not-motorized	Walking	6.634.000	29,36
	Cycling	546.000	2,42
Total		22.594.000	100

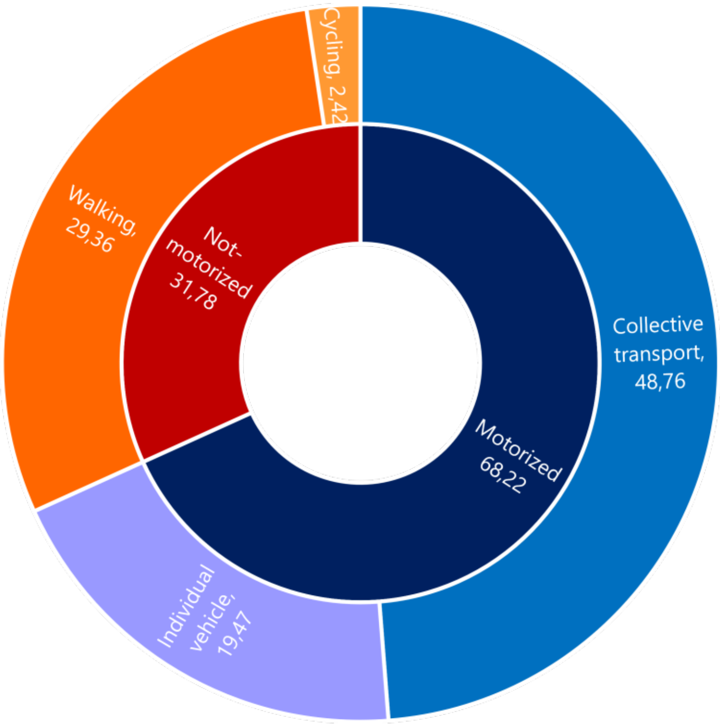

Table 3 | Table 4: 2012 daily modal split in Rio de Janeiro and Região Metropolitana (motorized and non-motorized)
Source: PDTU - Plano Diretor de Transporte da Região Metropolitana do Rio de Janeiro _[215]

Unfortunately, according to PDTU data, the motorized trips grew at a 2,33% yearly rate, growing from a little bit over 12,5M daily users in 2003, representing a 62,91%; to 15,4M daily users in 2012, representing a 68,22% as shown in the sunburst diagram right above.

It is important to remind that all the data depicted in the tables and diagrams right above, were collected back in 2012 to do the 2014 PDTU submission. Since then, the city and its public transportation network experienced remarkable changes and improvements, most of them boosted to host in the city of Rio de Janeiro both the 2014 FIFA World Cup and the 2016 Summer Olympics; being the most remarkable improvements the construction of medium-capacity modes of transport such as the VLT, BRT and gondola lift, all of them with different characteristics and purposes, somehow adapted to the conditions of the served areas.

BRT, capital letters standing for “Bus Rapid Transit”, it is a medium-capacity mode of transport that began operations in the city of Rio de Janeiro back in 2012, following the experience of many other cities worldwide, especially in Latin America, being the pioneer the Brazilian city of Curitiba, state of Paraná. It consists in a high-capacity bus fleet running along dedicated lanes, with high performance stations whose design and operation is way closer to the metro stations than the bus stops; allowing to reduce uncertainties to the minimum expression and becoming an infrastructure that requires an investment and maintenance cost remarkably below the cost of a metro or a tramway, getting similar performances in terms of riderships and commercial speeds, if it is operated properly. The BRT do Rio de Janeiro was designed to serve the peripherical areas of the city lacking of high-capacity public transportation services such as the trains of SuperVia and Metrô, at the same time that was associated to a redesign of the ônibus network in the city, creating feeding lines to the BRT that were mainly concentrated in several terminals scattered across the city. Also, the BRT helped to create a clear structure where the tree structure that the high-capacity public transportation created several years ago was put in jeopardy by creating a peripherical route linking several areas unserved by that network, but also linking several train and Metrô stations and creating transfer stations. With a brand new infrastructure and fleet, the “BRT do Rio de Janeiro” quickly gained many users, until reaching over 450.000[217] daily riderships with a remarkable commercial speed of 26 km/h and even reaching the 42 km/h[218] of commercial speed in the TransOlímpica stretch (to put it in a scale, the whole bus network system in Barcelona has an average daily commercial speed of 12,1 km/h[219] and the fastest metro line in Barcelona, L9 Sud, 37,7 km/h; being the average speed for the whole metro network 28,7 km/h), proving that all the areas served by the service, needed a mobility solution; but due a bad management and a lack of maintenance, the service remarkably decreased in many fields; including halting the construction of a main BRT corridor along Avenida Brasil, the busiest one in the city.

VLT, capital letters standing for “Veículo Leve sobre Trilhos”, “Light Vehicle on Rails” in English, it is a tramway system that began operation in the city back in 2016, serving the “Centro” and “Porto Maravilha” areas and linking several key points of the city and allowing to create several transfer points such as the airport Santos Dumont, Central do Brasil SuperVia station, Praça XV for the ferries to Niterói, the long-haul bus terminal and several other Metrô links. The service reached the 75.000 daily users[2110] and is still operating, the same way that there are several enlargement proposals[2111].

Another service that is worth mentioning, are the several gondola lifts, called "Teleféricos", services scattered through several areas of the city such as the "Providência" and "Complexo do Alemão", favelas with a hard penetration by conventional ground services such as buses or even microbuses due its physiognomy; not only regarding the width and shape of the streets but also due the steep slopes and even lack of tarmac on the ground, among other problems. Those services were projects linked with the revitalization and pacification of that neighborhoods, being designed together with some civic centers and the introduction to the area to the so-called "UPP – Unidades de Polícia Pacificadora" police stations, "Pacification Police Department" in English. Those projects had no touristic purposes such as the cable car for "Bondinho Pão de Açúcar", but public transportation services adapted to the physiognomy of the ground, linking and creating hubs with the VLT and with major train stations such as "Central do Brasil", in the case of "Teleférico da Providência"; and in "Bonsucesso", in case of "Teleférico do Alemão". Unfortunately, those services were in operation between 2014 until 2016 in the case of "Teleférico da Providência"; and between 2011 until 2016 in the case of "Teleférico do Alemão", despite having reached 10.000 daily riderships. The services halted operations due several reasons such as maintenance or ending of the concession, but several stations were abandoned and became ruins in the middle of the neighborhoods.

As said above, those new services created a new public transportation network in the city and allowed to transfer riderships from one mean of transport to other ones or even attracting new users, also creating new links, dynamics and centralities inside the city. The numbers depicted above are from 2012, which means that are a little bit outdated, the same way that do not take into account the COVID-19 pandemic and the consequences experienced for the public transport.

Below, it is going to be pointed out several strengths and weaknesses of the system, despite some of them could be considered both strengths and weaknesses.

2.2 | Strengths:

- Being obvious but important to mention, Rio de Janeiro and its Região Metropolitana is not starting from scratch; unlike other cities (many of them in Latin America), Rio de Janeiro already has an existing solid public transportation infrastructure, with several improvement and enlargement projects and research being undertaken, the same way Cariocas and Fluminenses are familiar with that means of transport.

- As seen above in the *Table 1*, *Table 2*, *Table 3* and *Table 4*; the use of public transportation or even active mobility is a widespread habit among Cariocas and Fluminenses. Not only in the percentage of daily commuters, but also in absolute numbers and compared with the population of the city of Rio de Janeiro, Baixada Fluminense, Leste Fluminense area and other municipalities of Grande Rio area.

- Nowadays the system is really struggling to carry an increasing number of users after the dramatic decrease during the toughest years of the pandemic, when several services such as SuperVia or many ônibus lines remarkably reduced their headways, or even halted operations such as the express train between "Central do Brasil" and "Deodoro"; specially during rush hour, it is hard to fulfill all the demand in the existing rolling stock. That situation leads to a scenario where is relatively easy to increase headways and bring back some of the rolling stock that used to serve the city before the COVID-19 pandemic outbreak. Nowadays, the operation of SuperVia has been dramatically reduced due the COVID-19 pandemic outbreak. The whole system went from 605.061 to 186.407 daily riderships, meaning that the daily users went down a whopping 69,2%. The latest data recorded until the end of September 2022 regarding daily riderships, according to SuperVia, shows that the demand went up to 349.539 daily riderships; which is a 46,7% more than the lowest point of the pandemic, but still 42,2% less than the average registered users before the pandemic outbreak.

- A remarkable part of the current city structure is due the creation of the railway lines during the second half of the XIX century, as well as many urban fabrics in Europe or in the US. Many rural areas such as Campo Grande or Bangu experienced remarkable growth and changes in their population, activities and urban fabrics; becoming more urban and even industrial, after the construction of the Santa Cruz rail stretch, belonging to the "Estrada de Ferro Dom Pedro II" company due the usage of the Emperor Dom Pedro II to get to his summer house out of the consolidated area of the city of Rio de Janeiro[221], specifically opening on 1878. Despite nowadays the urban fabric changed a lot since the inauguration of the line, many of that nucleus were built around the train lines and the stations, helping us to redesign the network without doing big changes in the current street configuration, especially as further we go from "Centro" and the southern area of the city.

- The city of Rio de Janeiro started operating advanced public transportation systems such as the BRS, capital letters standing for "Bus Rapid Service" and a system consisting in dedicated lanes for the ônibus, over 10 years ago, specifically on 2011; the same way also started operating the BRT back on 2012, being this one a high-performance public transportation system. That means that the city already has a lot of experience implementing and operating advanced public transportation systems, that can be replicated to other points and areas of the city. Also, since most of that infrastructures are not optimal or have drawbacks that can be easily identified, can be easily upgraded and create precedents to not replicate the same errors in the new implementation areas.

- Other proposals are being released such as the enlargement of the VLT network across the “Zona Sul”, but also the so-called “VLTzação do BRT”[222]; a project that is intended to substitute the existing BRT operations for tramways, using the same infrastructure to avoid expropriations and just substituting the existing ground for rails and power rails, the same way that some adaptations to the stations may be also required. That 15 year long project, according to the current “prefeito”, mayor in English, Eduardo Paes, it is being undertaken in order to tackle the several issues the city has with the BRT network and its companies; trying to get higher capacities, headways and reliability to the service and to key areas of the city.

2.3 | Weaknesses:

- It is important to mention the physiognomy of the city of Rio de Janeiro, with a very important presence of mountains and other geographical accidents that makes hard the interconnection between territories and areas of the city without the need of creating complex and expensive infrastructures such as tunnels and bridges. The geographical structure of the city became optimal to create radial corridors heading "Centro", creating a single centrality in the area. The only area in the city of Rio de Janeiro that can be considered mainly flat and where is easier the interconnection between districts is the one defined by the following natural borders: Guanabara Bay coastline, Parque Nacional da Tijuca ending in Santa Teresa and Glória neighborhoods, green corridor in Vila Militar linking Parque Nacional da Tijuca and Parque Natural Municipal da Serra do Mendanha, Parque Natural Municipal da Serra do Mendanha and Rio Pavuna.

As said above, another geographical drawback of the city of Rio de Janeiro is its enormous area into its premises. To give a scale, Rio de Janeiro city has an area[231] of 1.204 km^2, from which 600 km^2 of them can be considered urbanized areas, being almost 12 times bigger than Barcelona, with an area of 101 km^2; having the neighborhood of Barra da Tijuca alone over double of the coastal linear kilometers than the whole city of Barcelona, around 22 kms in Barra da Tijuca against 9kms in Barcelona.

- Being the average population density value a very generic number due the big disparity of numbers and values between neighborhoods, the city of Rio de Janeiro has a very low value in terms of population density, creating many problems in order to set a consistent generation and attraction model, unabling to set, for example, reasonable headways. In order to compare the city of Rio de Janeiro and Barcelona, some values are about to be compared:

The overall population density[231] of the city of Rio de Janeiro is 5.556 hab/km^2, being the Rocinha favela the neighborhood with the highest population density value, 48.258 hab/km^2. The carioca neighborhood of Copacabana has a population density of 35.858 hab/km^2. In the other hand, the overall population density[232] of the city of Barcelona is almost three times higher than the overall population density of Rio de Janeiro with a value of 16.157 hab/km^2; being l'Eixample district of the city the densest one, with a value of 36.105 hab/km^2, but having many neighborhoods with values that can surpass the value of 50.000 hab/km^2.

- The users of the public transport in the city of Rio de Janeiro and, specially, those ones commuting from and to other points of the metropolitan area; face several drawbacks such as the no integration of the trips between the different modes of transport and different companies operating in the area, but also inside same modes of transport such the BRT, where there are points such as the transfer between Recreio BRT Terminal and the BRT station of Salvador Allende is not integrated and the users have to pay twice.

- The separation of the ônibus and BRT network of the city of Rio de Janeiro in four different consortiums, splitting the city in four different geographical areas, as seen below in *Fig4*, becomes another drawback for the users and the fluidity of the system, that also splits main BRT corridors in several stretches, making transfer the riderships. For example, in the TransCarioca BRT line, the line began operation all the way from the international Tom Jobim airport in Galeão, located in the "Ilha do Governador" island, to Alvorada Terminal in Barra da Tijuca. After splitting the systems in different consortiums, the users need to transfer in Madureira station to keep with their planned trip, making the *Fig3* map, already outdated.

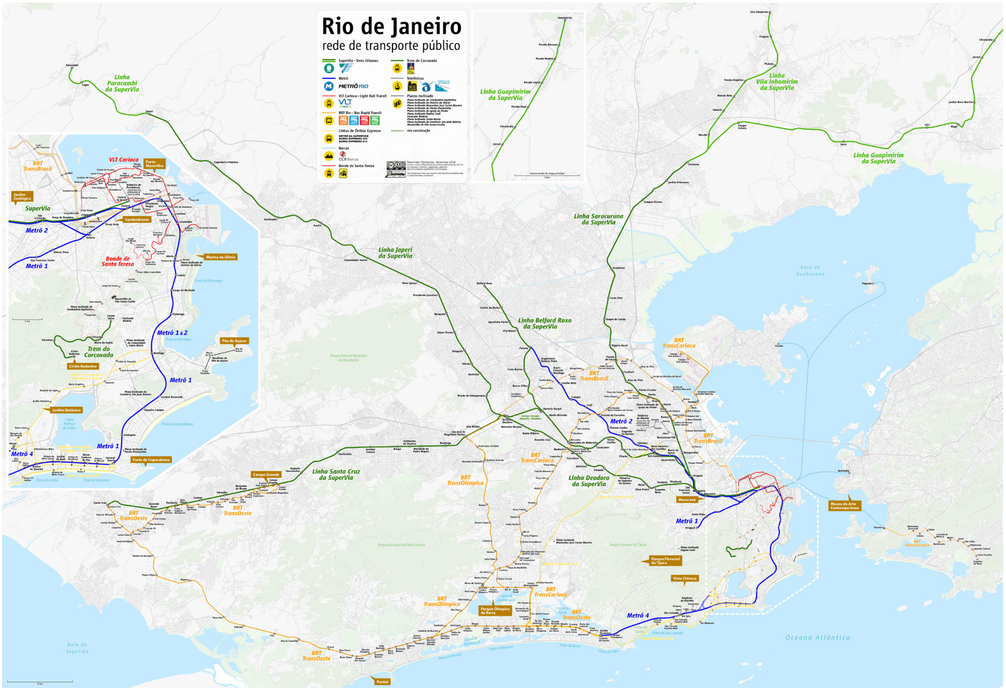

Fig3: Current public transportation network in Rio de Janeiro and its metropolitan area _ Guanabara Bay
Source: Prefeitura da Cidade do Rio de Janeiro _[233]

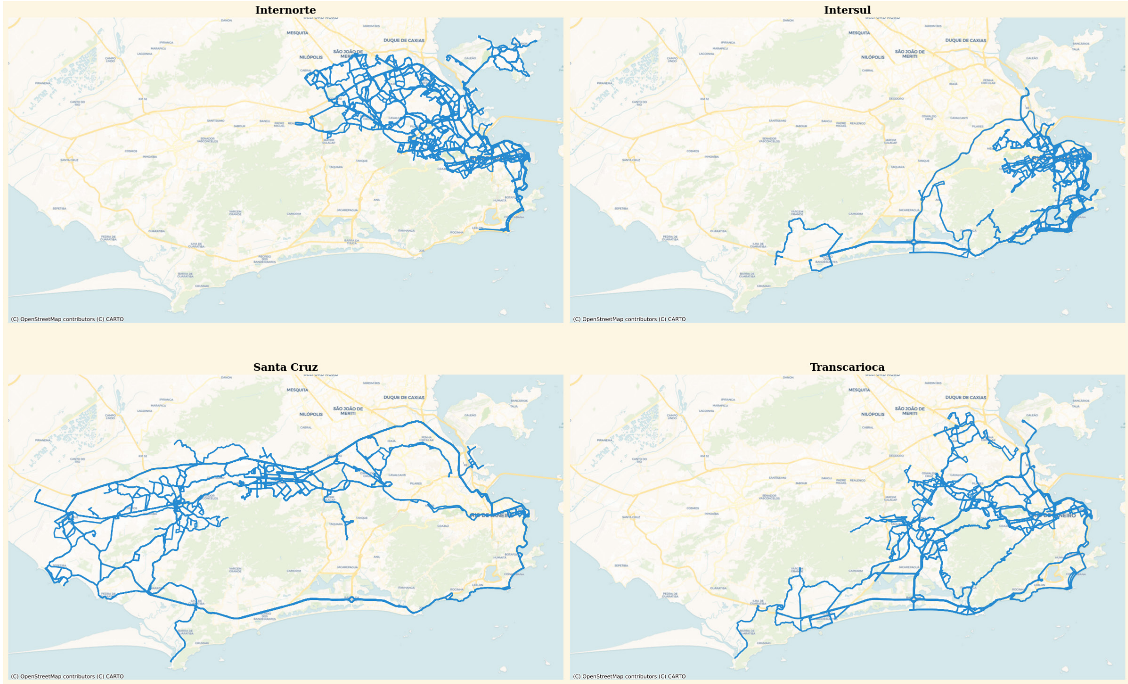

Fig4: Current ônibus and BRT network in Rio de Janeiro splitted by consortiums
Source: José Brandão de Paiva Neto _[234]

- Another major drawback many users face, especially in the western part of the city of Rio de Janeiro and other points of Baixada Fluminense area, is the extensive existence of several milícias controlling key points of the transportation network, specially operating with vans and creating an unfair competence to the regular services. In several points of the western part of the city, it is reported to be operating way more illegal vans than the licensed vans or buses[235]. These services have a unique fare, without reduction or other exemptions found in the licensed services for retired or handicapped people, students or other collectives; the same way that companies do not pay taxes, fills geographical gaps that the licensed companies cannot operate, the drivers lacks of the proper driving license and the vehicles do not follow the safety or hygienic required standards the licensed companies are supposed to fulfill; among other problems. That phenomenon is due the existence of several milícias controlling certain areas of the city, but also due the lack of regulated jobs among the population, leading several people to get self-employed by becoming van driver or an illegal moto-taxi, for example.

Apart of some of the issues depicted right above due the existence of the illegal van network, another remarkable drawback is the fact that many users stop using the regular services, that they are mainly sustained with the ticket fares of the users, and becoming the retired people, with fee exemptions, the main users of the service; putting in jeopardy the financial system and feasibility of the licensed services.

- Regarding high-capacity public transportation systems in the city of Rio de Janeiro, SuperVia train network consists has the characteristics of a commuter train service in terms of headway, total distance of the lines and configuration of the stations, among others, despite having the service of a regular metro in characteristics such as the average distance between stations, which is 1,65 kilometers in the Central do Brasil – Santa Cruz line, a service that stops in every single sation of the line or a commercial speed in the same line of 33,7 km/h[236 / 237].

- Due the lack of investment in the network, but also due the vandalism or due the areas where the lines run, where the railroad tracks became streets with houses, shops and people or other kind of animals walking around, among other causes, SuperVia trains have a big rate of delays or cancellations in the service. According to the company[238], during 2021, 1.492 incidents perturbed the normal service that affects the user, among that incidents, and to understand better the difficulties the company and its workers are facing, are reported shootings into the SuperVia premises or properties at a rate of a shooting every less than 2 weeks or bullets reaching SuperVia premises or properties at a similar rate; combined there is gun related incidents in SuperVia premises or properties at a rate of a little bit more than a week per year. Another major problem the company is facing, is the rollovers, being reported 83 rollovers during 2018, an average of 1,6 rollovers per week. In that 14.92 reported incidents, are not included other incidents that do not affect the perceived service by the users. Other sources[239], says that that rate can escalate up to a rate of over 1.800 incidents that affects the user every trimester, some of them not reported by the company.

- Since most of the income for the company comes from the users, the least passengers are being carried the least income for the company to be reinvested in the infrastructure, the same way it happens with the ônibus lines operating in milícia areas, where the illegal vans takes them most of the users. That phenomena was accentuated due the COVID-19 pandemic outbreak and the dramatic decrease of users of such networks, as seen before.

- Most of the weaknesses identified in the SuperVia are also shared with the regular ônibus or BRT network. The violence and vandalism[2310], lack of safety for the user, lack of maintenance in the stations, rolling stock and infrastructure are among the obvious causes; but also the inflation and the rise of the fees, that on 2017 a ride had a cost of R$ 3,40 and currently is R$ 4,05. Considering the lack of integration, makes the increase of the cost to R$ 2,67 per ride per user.

Considering the BRT as an almost brand new infrastructure, starting operations on 2012, the problems due lack of investment and the associated degradation rate skyrocketed right after both the 2014 FIFA World Cup and the 2016 Summer Olympics events were over. Some of that damages of the infrastructure were simply assumed by the operators instead; being an example the temporary reduction of speed from 70 km/h to 20 km/h on several stretches due the bad conditions of the tarmac, that melted due the heat, creating remarkable bumpy deformations or even holes on the ground. Also, the remarkable reduction in the headway degraded significantly the service and the user experience and even putting in jeopardy the safety of the users with overcrowded buses.

Another point is the abandonment of several stations due the invasion and vandalization, from stealing material to burning down stations or shooting it. Some stations became drug supermarket or even infra-homes for homeless people. The consequence is the bus drivers halting operation in several of those stations due the fear of the drivers itself, or due the inability of the users to even access to those stations. Not only the static infrastructure suffers from vandalism and lack of investment, but also the rolling stock, in an advanced state of degradation; even running with the doors open due lack of maintenance or overcrowded buses with so much people that are unable to fit inside the vehicle with the doors closed, as seen below in *Fig5*, or also with buses running with flat tires.

Fig5: Overcrowded BRT articulated bus circulating with the doors open in Rio de Janeiro city
Source: Estação Rio _[2311]

- All in all, and wrapping up all the treated drawbacks of the public transportation network in Rio de Janeiro and its metropolitan area, in *Fig6* displayed below, it is shown the main drawback that emerges from several of the topics depicted before, which is the commuting times of the people from any point of the Região Metropolitana do Rio de Janeiro until Carioca / Centro metrô station, located in “Centro” (downtown), considering that metropolitan region and the city itself as a monocentric organism.

As seen on the public transportation isochrone map from 2012, a remarkable part of the population of the western neighborhoods of Rio de Janeiro city needs between 2 to 3 hours to reach Carioca / Centro metrô station by public transportation; being over 3 hours ride for some public transportation users living in bordering cities of Rio de Janeiro. It is important to mention that most of that users do not live in remote areas of the city, but in areas served by SuperVia trains with headways that at the moment of the survey were of 10 minutes; nowadays that headways are half of what used to be, the same way other modes of transport such as BRT or ônibus also reduced considerably operations. One of those areas, is Campo Grande neighborhood, located in the western part of the city of Rio de Janeiro, considered the largest in population of the city with over 328.000 inhabitants registered in the 2010 census[2312]. That is one of the main topics it is intended to be tackled in this master thesis.

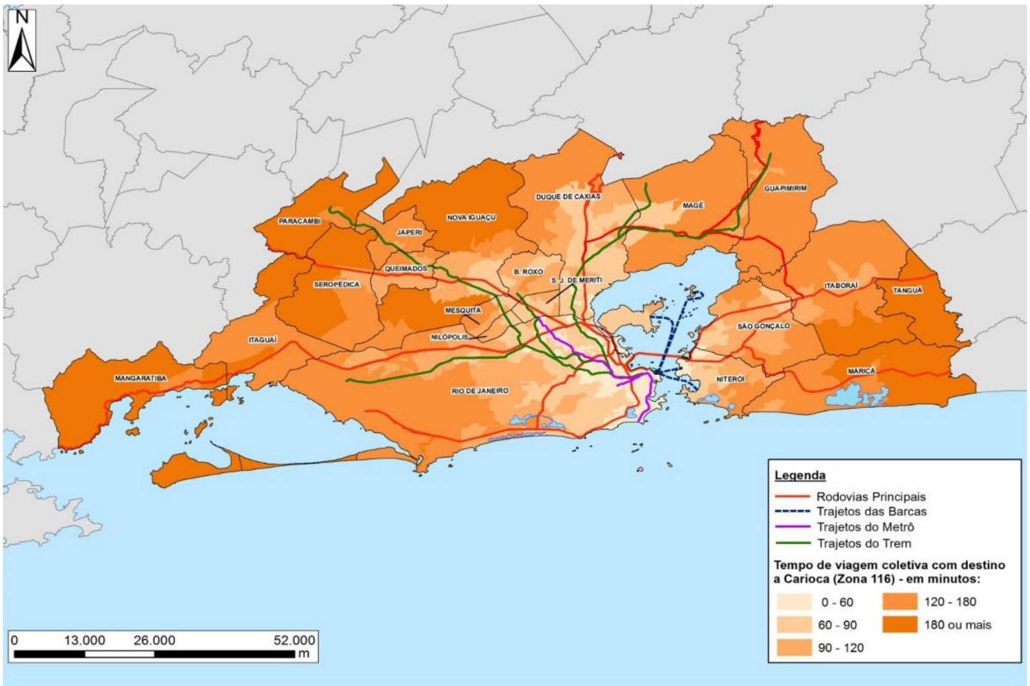

Fig6: Public transportation isochrones in Rio de Janeiro and its metropolitan area, from any point, heading Carioca / Centro metrô station

Source: PDTU - Plano Diretor de Transporte da Região Metropolitana do Rio de Janeiro _[215]

It is important to mention that a remarkable part of the structure public transportation network in Rio de Janeiro city and its metropolitan area it is designed as a monocentral structure where several public transportation corridors are bidirectional from and to the downtown area, Centro. That means that the most efficient movements into the system are going to be, mainly, following those directions, meaning that there is a big percentage of movements in that area that are not really thought to be done, or are not considered important enough to be included in the main network; situation that can lead to another isochrone map, where those movements may become even slower than the ones displayed above in *Fig6*.

The value of time for each user of the public transport is another variable that is also very important to point out, especially in the network we are analyzing.

3 | Strategies:

At the strategies point, it is intended to be explained a summary of the overall strategy, as well as the reason why a certain area it is been chosen for a closer analysis, and then depicting the specific ones from the mode of transport where each vehicle has the highest capacity until the mode of transport with the lowest capacity, ending with the urban planning and urban design.

As said before, this project is taking part of another larger project where the main aim, as seen below in the abstract *Fig7*, is to create several centralities across Rio de Janeiro city and its metropolitan area in order to avoid several issues Rio de Janeiro and its inhabitants are facing such as very long commuting times or excessive long traffic jams, especially during rush hour. Due time restrictions, this master thesis is going to focus in certain aspects and areas of the project; due the whole project requires a long time and multiple experts on several topics in order to tackle properly the overall problem, such as transportation engineers, architects, city planners, sociologists, environmental engineers, civil engineers and economists, among others.

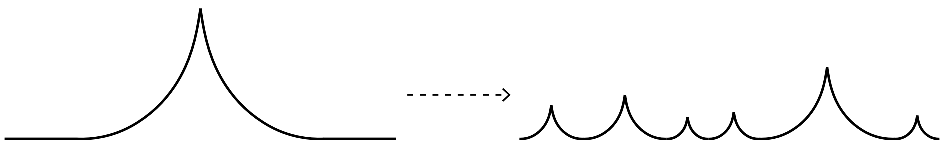

Fig7: Transition from monocentrality to multicentrality
Source: Own elaboration _[301]

As pointed out in the introduction points and as can be observed below in the *Fig8* and *Fig9*, the housing and employment location map of Rio de Janeiro city and its metropolitan area are not matching, even being pretty asymmetric.

As seen in the following figures, most of the housing is located in places such as Campo Grande, noth-east of Duque de Caxias or São Gonçalo. On the other hand, most of the jobs are located in “Centro”, Botafogo, Barra da Tijuca and Bonsucesso area.

With an official unemployment rate of a whopping 39,8%[302], according to 2013 data, the destination of 65,4% of the workers in the Rio de Janeiro metropolitan area is Rio de Janeiro City, being Niterói the second busiest destination with an 11,8% of the destinations, and being Duque de Caxias the third destination with a 6% sharp of the destinations, as seen in *Fig10* and *Fig11*, for a more accurate information of the origin-destination matrix. From those 60,2% of workers with job, only taking into account the workers from the metropolitan area, but excluding all of those workers from the capital; 44% of them work in their own municipality, 41% of them in another municipality, and only 15% of them in their own homes. It is important to remind that this numbers are made with the formal jobs in the Rio de Janeiro metropolitan area, but not taking into account all the other informal jobs in the area, being a remarkable percentage of the jobs carried out.

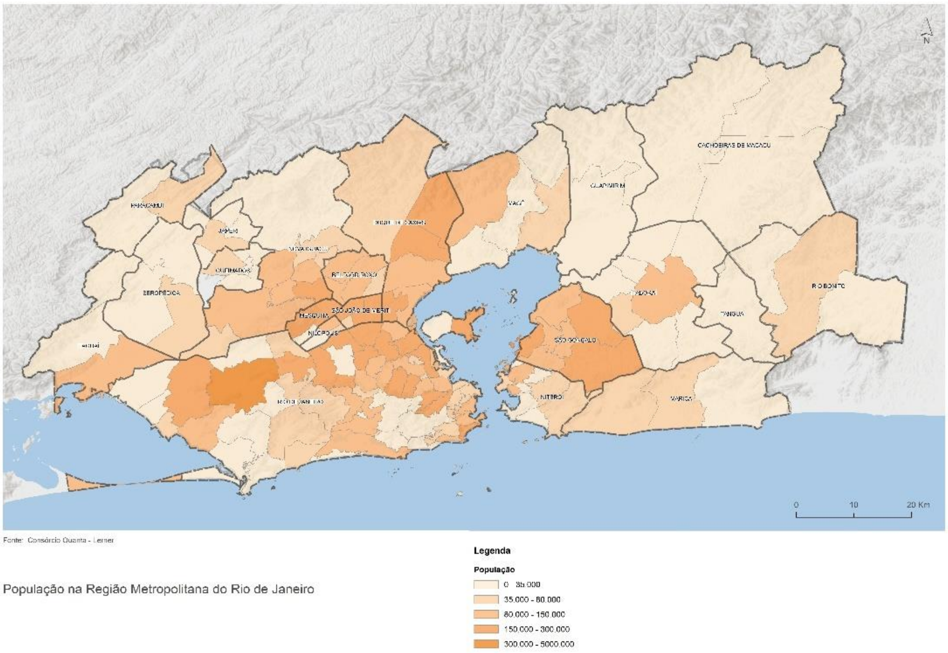

Fig8: Distribution of the population in Rio de Janeiro city and its metropolitan area _ Região Metropolitana do Rio de Janeiro
Source: PDUI - RMRJ _[303]

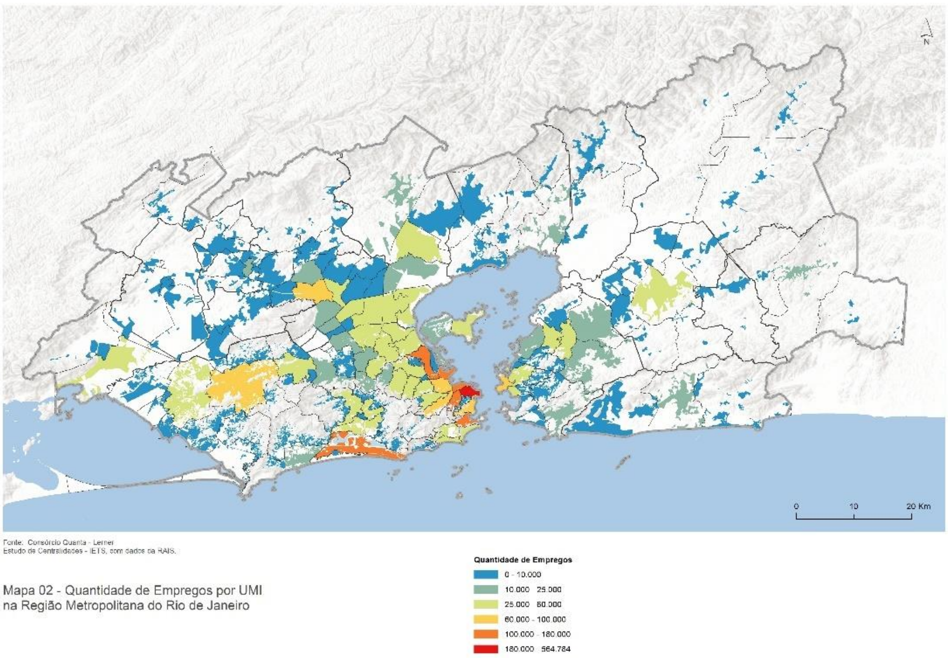

Fig9: Distribution of the labor in Rio de Janeiro city and its metropolitan area _ Região Metropolitana do Rio de Janeiro
Source: PDUI - RMRJ _[304]

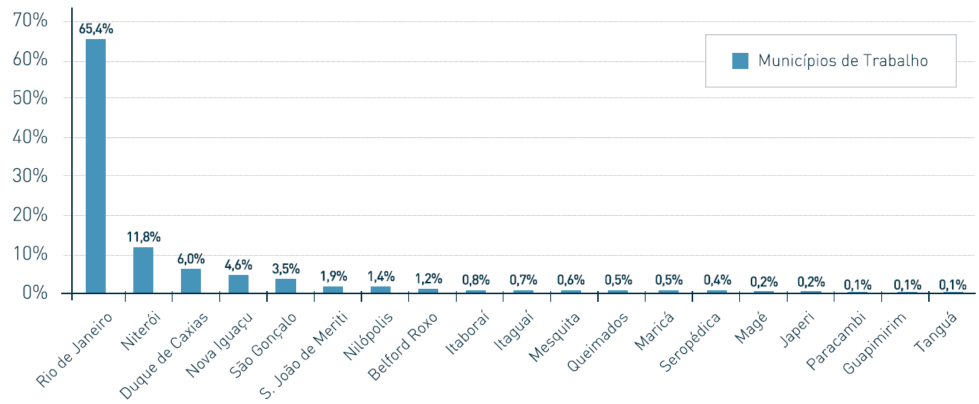

Fig10: Commuters daily destination due job location in Rio de Janeiro city and its metropolitan area
Source: SEBRAE _ Serviço Brasileiro de Apoio às Micro e Pequenas Empresas | Mobilidade Urbana e mercado de trabalho na Região Metropolitana do Rio de Janeiro. Estudo Estratégico _ Setembro 2013 _[302]

From the workers from Rio de Janeiro city living in the city, the distribution of the living areas is the following one: Centro, 2,6%; Zona Sul and Tijuca, 17,2%; Zona Norte, 39,1%; Jacarepaguá and Barra da Tijuca, 14,8%; Zona Oeste, 26,4%.

Município onde trabalha	**Município de residência**																					
	Belford Roxo	Cachoeiras de Macacu	Duque de Caxias	Guapimirim	Itaboraí	Itaguaí	Japeri	Magé	Maricá	Mesquita	Nilópolis	Niterói	Nova Iguaçu	Paracambi	Queimados	Rio Bonito	Rio de Janeiro	São Gonçalo	São João de Meriti	Seropédica	Tanguá	Total
Belford Roxo			1540			14	145	117		1084	432	58	4037	31	306		1291	169	1620	72		10.916
Cachoeiras de Macacu				108	164			21				57				8	21	42	12		10	443
Duque de Caxias	11215	13		314	254	154	189	6083	62	1020	933	1060	4001	40	470	37	13920	767	10135	49	23	50.739
Guapimirim		21	27		12			652				33		15				19				779
Itaboraí	21	424	20	58				253	144		11	778	23		89	511	216	3603	10	12	1251	7.424
Itaguaí	143		191		9		62	80	10	56	63	52	700	53	43		3498	58	173	1698		6.889
Japeri	23		42		9			9	12	121	104	22	451	149	427		169		54	72		1.664
Magé	88	33	1148	1391	221	12			13			130	15				142	382	117			3.692
Maricá		6	64		286			19			8	459	14				251	1030	20		34	2.191
Mesquita	738		75				199				779	12	2047		280		581		417	55		5.183
Nilópolis	535		171			19	232			3493		49	2927	57	388		1708	42	1564	48		11.233
Niterói	769	350	1453	269	11853	36	114	1107	5040	231	395		1280	26	219	340	7910	87877	1006	62	730	121.067
Nova Iguaçu	10386		1480	10	24	66	1692	156	19	6224	2568	185		439	3535	11	5339	47	3291	326		35.798
Paracambi						56	251			46	18		42		104		155		11	179		862
Queimados	365		113				692	41		244	112	11	2086	207			665	21	305	75		4.937
Rio Bonito		22			312			20	14		8	136	20				16	242			997	1.787
Rio de Janeiro	60338	391	86973	1729	9295	5996	12697	14414	7161	24973	24770	49878	85714	1482	17717	483		59855	69994	5628	459	539.947
São Gonçalo	37	150	224	158	8358			479	1856	10	49	8363	153	15	42	262	1350		70	24	586	22.186
São João de Meriti	5844		3137	40	12	11	103	68	40	1464	1354	44	2766		514		3559	41		89	10	19.096
Seropédica	17		20			347	257	13		33	41	27	455	397	25		1271		44			2.947
Tanguá					400							35				290	42	131				898
Total	90.519	1.410	96.678	4.077	31.209	6.711	16.633	23.532	14.371	38.999	31.645	61.389	106.731	2.911	24.159	1.942	42.104	154.326	88.843	8.389	4.100	850.678

Fig11: OD matrix commuters daily destination due job location in Rio de Janeiro city and its metropolitan area
Source: Uma análise da mobilidade urbana na Região Metropolitana do Rio de Janeiro a partir do censo demográfico de 2010 _[305]

In order to clarify and make the numbers more visual, in the *Fig12* depicted below are displayed the job location of the workers in the Rio de Janeiro metropolitan area. Being mild green the workers employed in their own home; mild blue the workers employed in their own municipality and in dark blue the workers employed in municipalities of the Rio de Janeiro metropolitan area not matching with their home location.

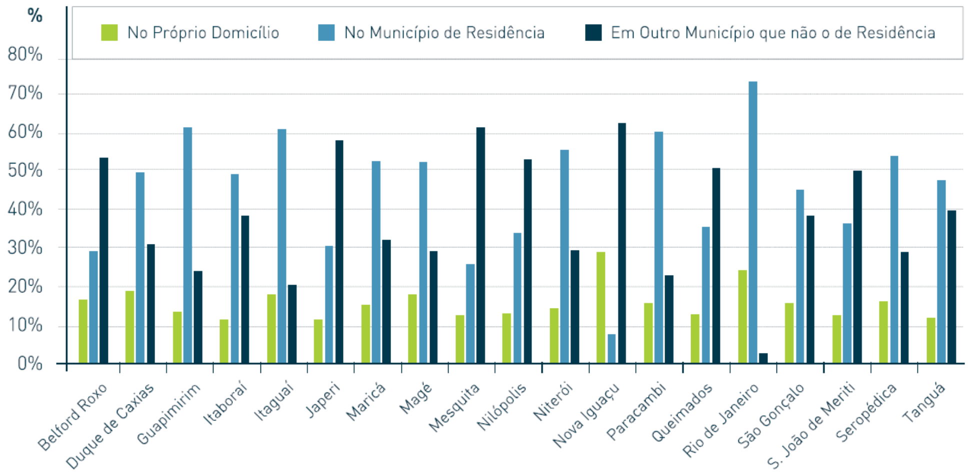

Fig12: Labor distribution based in the location of the municipality in Rio de Janeiro city and its metropolitan area
Source: SEBRAE _ Serviço Brasileiro de Apoio às Micro e Pequenas Empresas | Mobilidade Urbana e mercado de trabalho na Região Metropolitana do Rio de Janeiro. Estudo Estratégico _ Setembro 2013 _[302]

All in all, as seen below in *Fig13*, new feasible sub-centralities have been identified in order to start the project of a multicentral Rio de Janeiro metropolitan area, taking for granted that "Centro" and Zona Sul and Barra de Tijuca will keep playing a major role in that strategy.

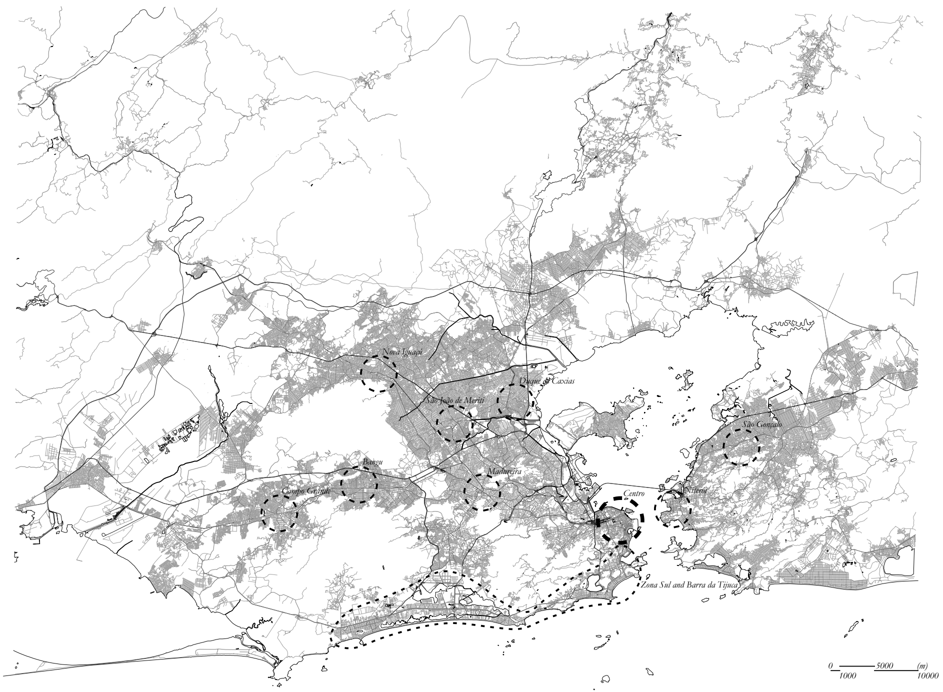

Fig13: Location of feasible new sub-centralities in Rio de Janeiro and its metropolitan area _ Guanabara Bay
Source: Own elaboration _[306]

That feasible new centralities are based in the fact that are located in places where there already exists a favorable environment where several key points already creates positive synergies that can be even boosted in order to improve their performance. That key points are the result of the combination of several key features such as areas with high population; high density; high job concentration; important hubs with a high number of daily riderships; combination of several infrastructures in a hub such as rail train station, metro station, bus terminal or BRT station, among others.

Fig14: Location of Bangu, in Rio de Janeiro city and its metropolitan area _ Guanabara Bay
Source: Own elaboration _[307]

Due the time restrictions of this project, the main efforts are going to be devoted in Grande Bangu area, located in the Zona Oeste (western area) of the city of Rio de Janeiro, being the carioca neighborhood of Bangu the main one, but also its surrounding neighborhoods. The configuration of all those neighborhoods consists in an area of consolidated built city of around 46 km^2. To give a scale, Barcelona has an area of 101 km^2, having a consolidated built city an area of around 63 km^2.

Neighborhood	Inhabitants
Magalhaes Bastos	24.430
Realengo	180.123
Padre Miguel	64.228
Bangu	220.552
Gericinó	13.564
Vila Kennedy	24.176
Jabour	30.000
Senador Camará	105.515
Santíssimo	41.458
Total	704.046

Table 5: 2010 population of the different neighborhoods conforming Grande Bangu area
Source: data.rio – População residente e domicílios segundo Bairros do Município do Rio de Janeiro - 2010 _[2312]

In the *Table 5* right above it is shown the total population of Grande Bangu and the inhabitants broken down of the different neighborhoods conforming this area[308] in the Zona Oeste of the city of Rio de Janeiro. All in all, Grande Bangu district has a population density[309] of 5.320 hab/km^2; being a little bit below the population density average of the city of Rio de Janeiro, which is 5.556 hab/km^2 and being over three times below the average population density of Barcelona, which is 16.157 hab/km^2. As said before, that average population density value of Barcelona takes into account the Collserona natural park, but normal values inside the city of Barcelona are around 45.000 hab/km^2, making Grande Bangu area around 8 times less dense than most of the neighborhoods in Barcelona.

Grande Bangu could be considered an urban island inside the city of Rio de Janeiro, since its urban fabric is barely linked with the surrounding districts such as Campo Grande, Jacarepaguá or Anchieta. Its borders are determined by Parque Estadual da Pedra Branca in the south and Parque Natural Municipal da Serra do Mendanha in the north; green corridor in Vila Militar linking Parque Nacional da Tijuca and Parque Natural Municipal da Serra do Mendanha in the east; and a weak urban fabric link between Campo Grande and Senador Camará via Santíssimo; all of that with a passing SuperVia train line with several stations linking Central do Brasil train station in "Centro" and Santa Cruz train station, located in the western-most district of the city of Rio de Janeiro. Due the time restrictions in order to carry out this project, the location conditions oferred by Grande Bangu area becomes optimal in order to simplify the mathematical calculus, especially with the ônibus network.

As pointed out above, in Zona Oeste surged several issues related with the illegal vans[235] controlled by milícias. That problem is especially extensive in Grande Bangu, where the vans create unfair competence to the regular services; being reported to be operating a larger number of illegal vans than the licensed vans or buses. These services have a unique fare, without reduction or other exemptions found in the licensed services for retired or handicapped people, students or other sensitive collectives; the same way that companies do not pay taxes, fills geographical gaps that the licensed companies cannot operate, the drivers lacks of the proper driving license and the vehicles do not follow the safety or hygienic required standards the licensed companies are supposed to fulfill; among other drawbacks.

Another motivation to work in Grande Bangu area is the fact that together with Campo dos Afonsos area, it is the warmest district in Rio de Janeiro city due its geographical location between the Parque Estadual da Pedra Branca in the south and Parque Natural Municipal da Serra do Mendanha in the north, creating a Foehn effect[310]; but also due the lack of a consolidated green infrastructure in the area. The Foehn effect is characterized for a sudden rise of the temperatures and a decrease of the environmental humidity due the crash of the downwind from the sea against a mountain system, in that case, the Parque Estadual da Pedra Branca, rising until reaching the top of that system while heating and raining or creating thick fog; and then going downhill hotter and dryer. All in all, makes Grande Bangu area, not only an urban island inside Rio de Janeiro city, but also a warm temperature island.

The temperature can easily reach values up to 7ºC above the temperatures registered in the meteorological station located in Santos Dumont airport; close to the Guanabara Bay, and therefore, a temperature way more regulated by the ocean water inertia[311].

Despite at night the temperature can go a little bit below the average of the city, the warm episodes worsened from the decade of the 1960's on, due the rapid growth of the population in that district, when the population grew from 222.669 inhabitants to 372.433 inhabitants[312] in 10 years. Afterwards, the population grew until reaching 704.046 inhabitants nowadays.

In order to reinforce the new sub-centralities, this project first will focus on the SuperVia rail network, trying to create semi-direct trains between those centralities and other busy train station. Afterwards, this project is going to focus on the ônibus network of Grande Bangu area, trying to treat it as an independent city designing the network for the inner area, and therefore trying to clean and simplify the existing one, only allowing inter-district lines between other regions of the city without high-capacity public transportation network available from and to Grande Bangu; the same way that creating a hierarchy of those lines, avoiding unnecessary overlapping in the network.

Due the overall situation, most of the strategies are going to be ruled by a low-cost policy, trying to take advantage as much as possible of the existing infrastructure. Another major strategy is the reinforcement of the built public transportation infrastructure, reshaping the amorphous public transportation network and introduction of the active mobility while adapting the urban space and urban design to the new reality. A new urban space and urban design it is going to be discussed, as well as the suitability of the introduction of the tactical urban design, the implementation of the classic urban design, or a combination of both. Despite the low-cost policy implemented in that project, it is going to be taken into consideration the suitability of investing money strategically when required and when it is proven that the return to the society can be economically bigger that the money invested in a certain project.

Most of that strategies are going to be designed taking into account the collaboration between the different public transportation operators in the city of Rio de Janeiro and its metropolitan area, instead of the fight between them. Furthermore, most of that strategies are going to be designed in a hypothetical future where the integrations between the different public transportation operators and modes of transport in the city of Rio de Janeiro and its metropolitan area, actually works.

3.1 | SuperVia:

3.1.1 | Operations:

3.1.1.1 | Overview:

As pointed out before, despite most of the neighborhoods or surrounding towns were created during the XVI century, the creation of the rail network during the second half of the XIX century boosted the growth and acceleration of the surrounding towns and neighborhoods, shaping nucleus around some stations and boosting the industry in those areas.

That structure and urban fabric of the city of Rio de Janeiro is mainly given by the tree structure several railway companies created heading “Centro” area. Most of the lines created by “Estrada de Ferro Leopoldina”, “Estrada de Ferro Dom Pedro II”, “Estrada de Ferro Rio d’Ouro” and “Estrada de Ferro Melhoramentos do Brasil” are currently owned by SuperVia (passenger rail company) having the main station in “Central do Brasil” terminal station and MRS (freight rail company). Nowadays Rio de Janeiro city and its surrounding area has a consolidated rail network, operated by SuperVia; a company that used to be owned by the State of Rio de Janeiro until 2011, that the public works company “Odebrecht” took control buying the majority of the shares. On 2019 the company was sold to the investing Japanese company Mitsui.

Fig15: Latest Rio de Janeiro and metropolitan area rail network diagram released by SuperVia
Source: SuperVia | Ramais e estações _ Mapa de linhas _[31111]

As seen above in the diagram of the *Fig15*, but also as seen at the beginning of this report in the map that can be found in the Fig2 of Pg. 10, the tree structure of the network consists in four main branches, where the highest demand is found. These branches are the Santa Cruz branch, Japeri branch, Belford Roxo branch and Gramacho and Saracuruna branch. All of the previous branches share the stretch between Central do Brasil station until Maracanã station. Due SuperVia latest rail network diagram was released a couple of years ago, the diagram shown above still shows the semi-direct line between the stations of Central do Brasil and Deodoro

station; line that used to operate during rush hours and halted operations due the COVID-19 pandemic outbreak and the sudden dramatic decrease of the daily riderships.
The main features of the branches, described from the western-most branch to the eastern-most branch:

- Gramacho and Saracuruna branch: is the third busiest line[31112] of the whole network. Shares the stretch between Central do Brasil station to Maracanã station with all the other lines; and until Triagem station, with the Belford Roxo line. Links Rio de Janeiro city with Duque de Caxias city center and the northern neighborhoods “Gramacho” and “Saracuruna” of the city of Duque de Caxias, of around a million of inhabitants.
Apart of the stations of the shared branch, the other main stations are Duque de Caxias and Gramacho, with an average daily demand of around 15.000 riderships during the working days. The line has double track until Gramacho, where some trains halt their operation and where the users willing to keep their trip until Saracuruna needs to change train, most of the times, since there are also trains between Central do Brasil and Saracuruna, another very important station with around 7.000 riderships during the working days; similar numbers than the Bonsucesso station, the other big station of the line. Between Gramacho and Saracuruna, the headway remains the same, despite the single track available. Once in Saracuruna, the line has two feeder lines heading Magé and Guapimirim, old line heading Teresópolis; and the line heading Vila Inhomirim, old line heading Petrópolis, that halted operation after linking Petrópolis and Rio de Janeiro with rack trains. Both of that feeder lines, that requires an extra fee to use them, account for the least busy rail lines of the whole network; and if we include the feeder lines, this branch could be considered the longest one in the SuperVia network.

- Belford Roxo branch: is the shortest and least busy line of the whole network and the one offering the poorest user experience due the state of conservation and maintenance of the tracks. Also, due the areas served, accounts for the largest number of reported shootings, with the average of a shooting every less than a month[31113]. Shares the stretch between Central do Brasil station to Maracanã station with all the other lines; and until Triagem station, with the Gramacho and Saracuruna line. Links Rio de Janeiro city with Belford Roxo city center, a city of around half a million inhabitants.
Apart of the stations of the shared branch, the other main stations are Belford Roxo, with around 10.000 daily riderships, and those ones with some kind of connection or transfer such as Pavuna, with around 2.000 daily users, with a Metrô transfer in the border between the city of Rio de Janeiro and São João de Meriti. Mercadão de Madureira, with over 3.000 daily users, is also a very important train station in this stretch, but also a important point with BRT lines and the major Madureira station (of the lines heading Japeri and Santa Cruz) 500 meters away; both of them, reinforcing the centrality that the neighborhood of Madureira has in the Zona Norte.

- Japeri branch: Not only being the longest and busiest one in the shared stretch from Central do Brasil until Deodoro with the Santa Cruz branch, but also the busiest one in the stretch between Deodoro and Japeri. Along the line, links several major stations and centralities such as Méier, Engenho de Dentro, Madureira (second most used station in the whole network, after Central do Brasil with over 32.000 daily users), Nilopolis, Nova Iguaçú (with over 23.500 daily users), Queimados and Engenheiro Pedreria; before getting to Japeri. Once in Japeri, the line has a feeder line heading Paracambi, that requires an extra fee for the usage. Also, the Japeri branch has a shared stretch with the freight rail company MRS, linking the harbor of Rio de Janeiro with other points in the Brazilian geography such as Minas Gerais and São Paulo.
The Japeri line it is the only one still offering a semi-direct service between Central de Brasil and Deodoro, giving service to the busiest stations of that stretch of the line such as São Cristovão, Maracanã, Estação Olímpica de Engenho de Dentro and Madureira; apart of the Silva Freire station during working days between 10:00h to 15:00h.

- Santa Cruz branch: The only line entirely running inside the city of Rio de Janeiro. Sharing the busiest stretch from Central do Brasil until Deodoro with the Japeri branch, but also the second busiest one in the stretch between Deodoro and Santa Cruz. Along the line, links several major stations and centralities such as Méier, Engenho de Dentro, Madureira (second most used station in the whole network and shared with the Japeri line, after Central do Brasil with over 32.000 daily users), Bangu, Campo Grande and Santa Cruz. Despite it is not the longest line, it has a remarkable total length of 54,6 kilometers[31114] and 34 stops, combined with the fact that the line is entirely running along a built city, having stops every relatively short distances without semi-direct trains, makes the Central do Brasil – Santa Cruz line the longest one in time with a total trip of 1h 40min. Due the fact that the district of Bangu is served by this branch, combined with all the points said above, this is the line that is going to be analyzed with a higher accuracy.

Nowadays, the operation of SuperVia has been dramatically reduced due the COVID-19 pandemic outbreak. According to SERTRANS[31115] data, the whole system went from 605.061 to 186.407 daily riderships, meaning that the daily users went down a whopping 69,2%. The latest data recorded until the end of September 2022 regarding daily riderships, according to SuperVia, shows that the demand went up to 349.539 daily riderships; which is a 46,7% more than the lowest point of the pandemic, but still 42,2% less than the average registered users before the pandemic outbreak.
That brought SuperVia to go from the situation depicted in *Fig16* to the situation depicted in *Fig 17*; both figures depict the running diagram of the SuperVia Santa Cruz rail branch.

It is important to point out that this is the only rail branch in the SuperVia network running entirely inside the premises of Rio de Janeiro city, and the only rail, and high-capacity mode of transport, serving Zona Oeste, with a total population on 2010 of almost 2,4 million inhabitants; also being the only one serving to all the stations in the busiest stretch of the whole SuperVia network between Central do Brasil and Deodoro, in Zona

Norte, since the Japeri line is serving the area with semi-direct trains skipping most of the stations.

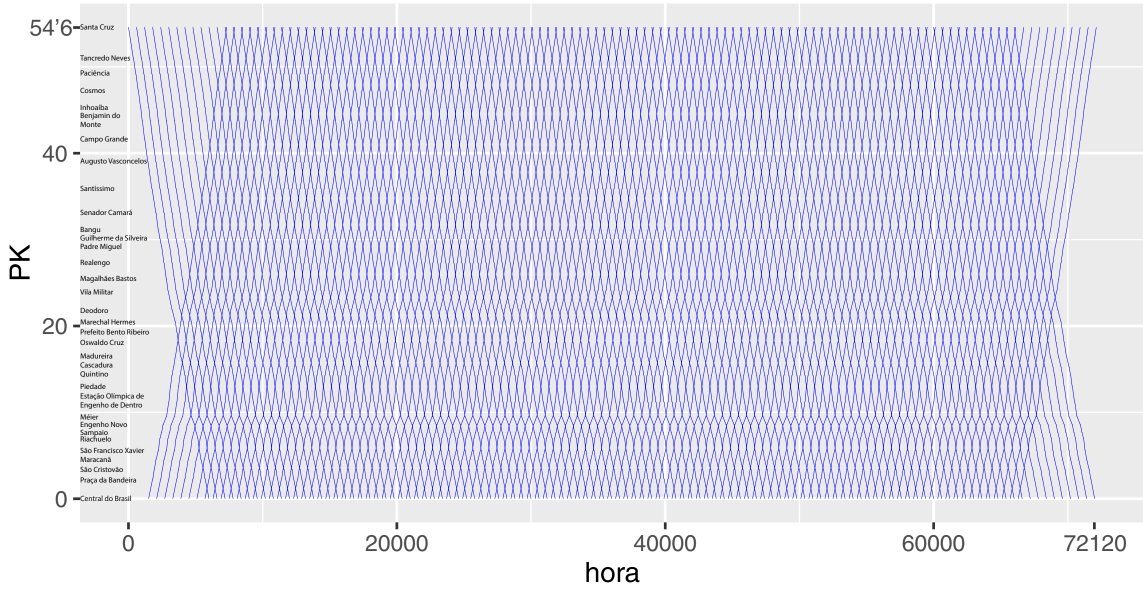

Fig16: Running diagram of the SuperVia Santa Cruz rail branch | Operation pre-pandemic
Source: Own elaboration _[31116]

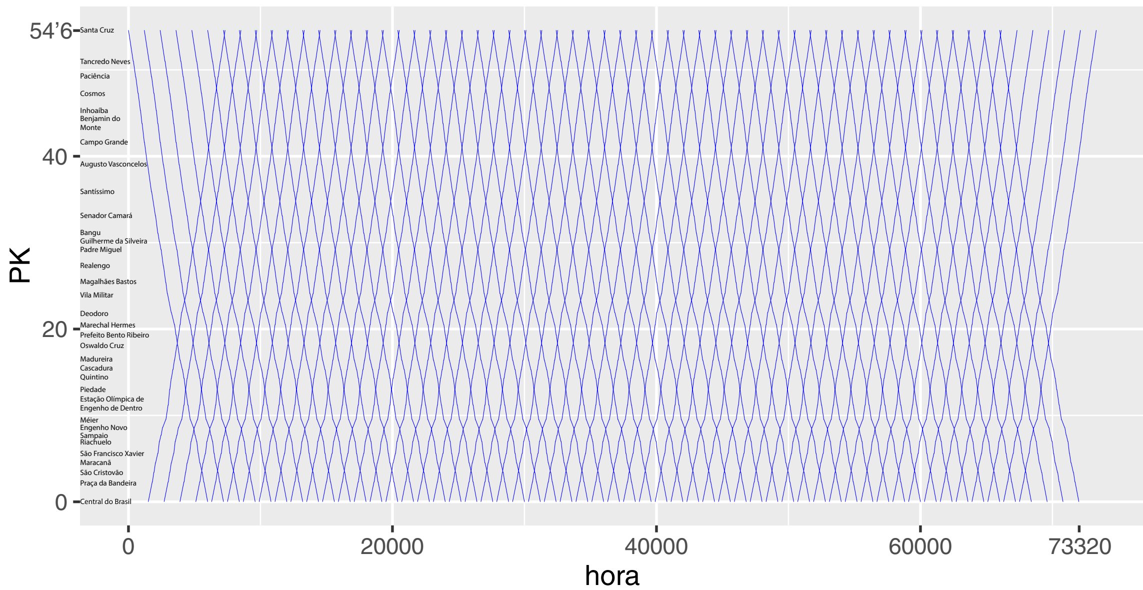

Fig17: Running diagram of the SuperVia Santa Cruz rail branch | Operation post-pandemic outbreak
Source: Own elaboration _[31117]

As seen in the figures *Fig16* and *Fig17* right above, the working days operations pre-pandemic were consisting in trains with a headway of 10 minutes each way, starting at 04:10h in the morning in Santa Cruz terminal, and running until 22:42h; with a total of 109 operations along the day between Central do Brasil and Santa Cruz, and 111 operations between Santa Cruz and Central do Brasil. From Central do Brasil, the first train used to leave at 04:35h in the morning heading Santa Cruz, until the last train at 22:42h.

The same timetables remained after the pandemic outbreak, in terms of opening and closing times, but instead the original headway of 10 minutes, that was decreased until the 20 minutes headway; consisting in 56 operations between Central do Brasil and Santa Cruz along the day, and also 56 operations between Santa Cruz and Central do Brasil.

3.1.1.2 | Proposals:

In order to reinforce the new centralities, but also to make them work together, the main strategy for the SuperVia is the introduction of semi-direct trains stopping in the busiest stations of the branch, in that case, the Santa Cruz branch, which is the one we are going to focus the most. All in all, the first strategy requires to identify the busiest train stations along the studied line.

Station	Users
Central do Brasil	136312
Praça da Bandeira	3622
São Cristovão	28248
Maracanã	13338
São Francisco Xavier	2429
Riachuelo	3937
Sampaio	1661
Engenho Novo	3748
Méier	13132
Estação Olímpica de Engenho de Dentro	11413
Piedade	2833
Quintino	2777
Cascadura	3498
Madureira	32158
Oswaldo Cruz	2923
Prefeito Bento Ribeiro	3141
Marechal Hermes	5426
Deodoro	7782
Vila Militar	1043
Magalhães Bastos	4345
Realengo	5276
Padre Miguel	3466
Guilherme da Silveira	3318
Bangu	14302
Senador Camará	3635
Santíssimo	3628
Augusto Vasconcelos	2703
Campo Grande	22658
Benjamin do Monte	2486
Inhoaíba	4408
Cosmos	4664
Paciência	5752
Tancredo Neves	1734
Santa Cruz	15400

Table 6: Daily riderships by stations in Santa Cruz SuperVia branch
*Source: SuperVia – Transparência | Dados operacionais _ Demanda Média Mensal de Passageiros por Estação_*[31112]

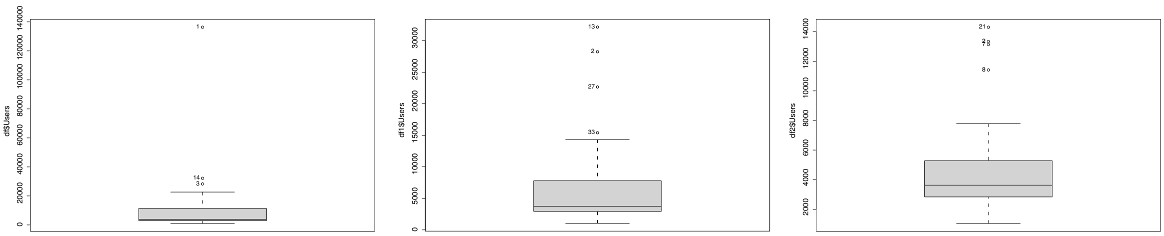

Fig18: Boxplots displaying the busiest train stations in Santa Cruz SuperVia branch
Source: Own elaboration _[31118]

As seen above in *Table 6* and *Fig18* above, RStudio software has been used in order to find out the busiest train stations along the Santa Cruz branch. The preliminary result is that the median, the middle value in the data set, riderships in the stations are 3842; while the mean, all the values added up and then divided by the number of values, are 11.094 daily riderships. In the other hand, the third quartile threshold, dividing the 75% of the lowest data, is set at 10.505 daily riderships.

Once we remove the main outlier, Central do Brasil station, with 136.312 daily riderships, the boxplots start showing us the busiest train stations. All in all, the busiest ones ordered from busiest to less busy, are Central do Brasil; Madureira, with 32.158 users; São Cristovão, with 28.248 users; Campo Grande, with 22.658; Santa Cruz, with 15.400 users; Bangu, with 14.302 users; Maracanã, with 13.338; Méier, with 13.132 users; and Estação Olímpica de Engenho de Dentro, with 11.413 users. All in all, all the stations have a value above the third quartile threshold.

Due the fact that the line is very long and the commercial speed is very low, currently set at 33,77 km/h, with the introduction of the semi-direct trains, it is needed to introduce some regularity into the line. Turns out that excluding the shared stretch between Central do Brasil until Maracanã, the two consecutive stations of Méier and Estação Olímpica de Engenho de Dentro and between Madureira and Bangu; all the busiest stations are disposed around 5 or 10 kilometers apart. For the two first cases, since the distances are very low, there is no need to mathematically worry that much; but in the case of the distance between Madureira and Bangu, in order to introduce some order in the calculus, Deodoro station is going to be needed, a station 5,5 km away from Madureira and 9,2 km away from Bangu. Deodoro, despite having a medium demand of passengers, it is the junction between the Santa Cruz and Japeri branches, having the availability of many tracks that nowadays are not really used for the regular operations.

The main aim of the current thesis is to propose low cost, even surgical, solutions in order to maximize the operations in the infrastructure. In order to do that, the strategy is to take advantage as much as possible of the existing infrastructure.

As seen below in *Fig19*, the intended overtaking train strategy it is divided in four steps. The train that is intended to keep the current operations of stopping at every station of the line is the first arriving to the overtaking station. The passengers willing to change to the semi-direct train, will have to leave from that first train and waiting for the semi-direct train few minutes. At the same time, that train will have the regular boarding and alighting operations of people interested to take that first train.

If possible, in the same platform but in the opposite track, the semi-direct train is intended to show up few minutes after the first train arrived in the station; so, apart of the regular boarding and alighting operation of every station, the people from the first train who is willing to take the second train and were waiting in the platform, will jump on the semi-direct one. At the same time, the people coming with the semi-direct train willing to take the one stopping at every station, will have enough time to transfer train; creating a bidirectional flow of users in the platform.

With that system, where no overtaking is carried out while the train stopping at every station is stopped in a station where the semi-direct train does not stop, both trains are feeders one of the other. With this system, an increase of the commercial speed and total travel time is going to be experienced by the train stopping at every station, but overall, the users will experience an upgraded service and a diminution of their travelling times, thanks to the new semi-direct trains.

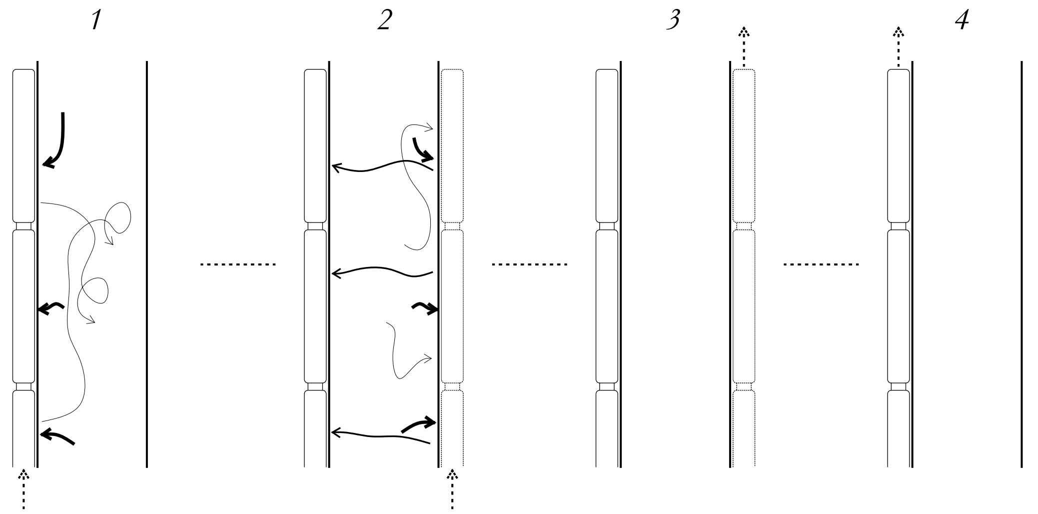

Fig19: Overtaking train strategy
Source: Own elaboration _31119

In order to carry out the operation depicted above, it is necessary to find out which of the busiest train stations chosen before have the needed infrastructure available, or has the feasibility of creating the needed infrastructure with the minimal investment possible. Since the line is not symmetrical, the overtaking stations from Central do Brasil heading Santa Cruz, it is assumed will not be the same of those ones from Santa Cruz heading Central do Brasil. Also, it is going to be simulated both scenarios with the current headway post COVID-19 pandemic outbreak, but also the pre-pandemic scenario, which means that the overtaking stations might change.

After evaluating the infrastructure and having created the semi-direct train models, four possible overtaking scenarios are about to be created:

· Overtaking stations Central do Brasil – Santa Cruz | status quo headway:

_ Deodoro and Campo Grande.

· Overtaking stations Santa Cruz – Central do Brasil | status quo headway:

_ Bangu and Madureira.

· Overtaking stations Central do Brasil – Santa Cruz | pre-pandemic headway:

_ Deodoro, Bangu and Campo Grande.

· Overtaking stations Santa Cruz – Central do Brasil | pre-pandemic headway:

_ Bangu, Deodoro and Madureira.

Below, is going to be explained, but also graphically, with the same scale and the north heading the top of the page, analyzed the reason why those stations are the optimal for the crossings, from eastern-most to western-most.

_Madureira:

Madureira, with 32.158 users, becomes an optimal overtaking station for the trains from Santa Cruz heading Central do Brasil in both pre-pandemic and status quo scenarios due the volume of daily riderships, its geographical situation and its existing infrastructure.

From all the other overtaking stations, is the station requiring the most aggressive and expensive intervention, needing two new switches before and after the platform; but also invading the one of the existing tracks, currently devoted to the Japeri line. The operations of the Japeri lines can be easily reallocated in the other northern existing tracks, as seen below in *Fig20*.

Fig20: Graphic overtaking train strategy | Madureira
Source: Own elaboration _311110

_ Deodoro:

Deodoro, with 7.782 users; despite the low volume of daily users, has the potential to become an optimal overtaking station for the trains for every scenario but for the trains from Santa Cruz heading Central do Brasil status quo scenario due its geographical situation and its existing infrastructure. After the Central do Brasil staion, Deodoro is the station with the largest infrastructure in the Santa Cruz branch, and it is located almost in the middle of the stretch; at the kilometric point 21,9 km from Central do Brasil station, out of the 54,6 km of the whole branch. In a future, Deodoro it is supposed to allocate the link between the TransOlímpica and TransBrasil BRT stretches, boosting its daily users.

The current operations of Deodoro stations are quite complex, with overlapped tracks and flows between the Santa Cruz and Japeri lines; so looking at the ground floor map, below in *Fig21*, could seem like the operations are quite messy, but with the addition of a new switch after the platform of the trains heading Central do Brasil station, the situation can be easily fixed. Due the existing infrastructure and the overlapped tracks and flows, unfortunately, the transfer between the train that stops at every single station and the semi-direct train is infeasible to be done on the same platform, so the users will be required to move from platform to platform through the existing upper corridor.

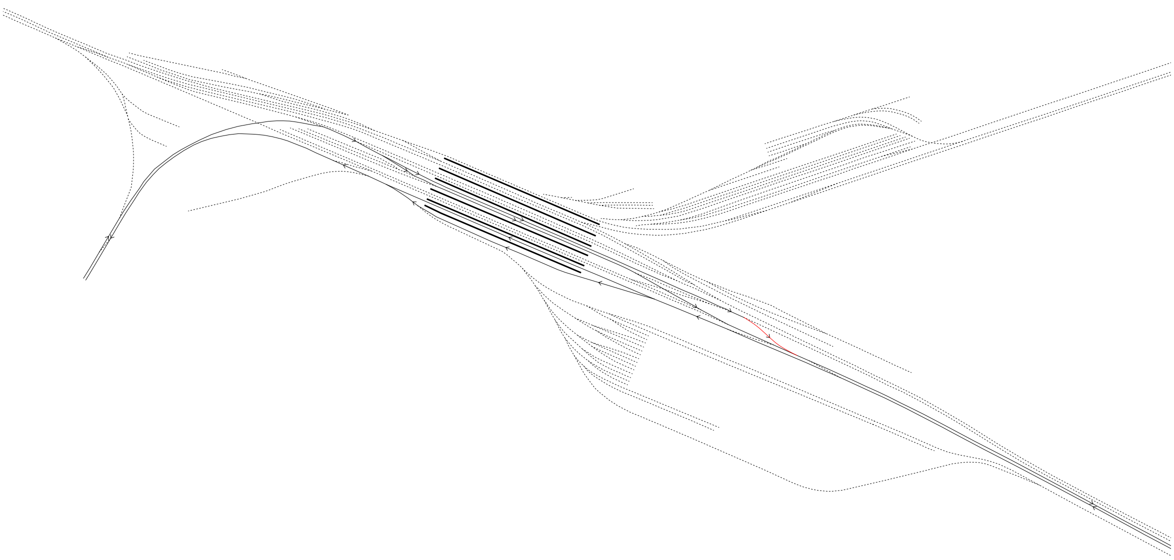

Fig21: Graphic overtaking train strategy | Deodoro
Source: Own elaboration _[311111]

_ Bangu:

Bangu, with 14.302 users, becomes an optimal overtaking station for the trains for every scenario but for the trains from Central do Brasil heading Santa Cruz status quo scenario due its geographical situation and its existing infrastructure. due the volume of daily riderships, its geographical situation and its existing infrastructure.

As seen below in *Fig22*, the addition of a new switch after the platform of the trains heading Santa Cruz station, can accommodate the required operations for the Central do Brasil – Santa Cruz pre-pandemic scenario.

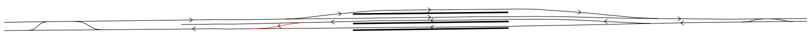

Fig22: Graphic overtaking train strategy | Bangu
Source: Own elaboration _311112

_ Campo Grande:

Campo Grande, with 22.658 users, becomes an optimal overtaking station for the trains from Central do Brasil heading Santa Cruz in both pre-pandemic and status quo scenarios due the volume of daily riderships, its geographical situation and its existing infrastructure.

As seen below in *Fig23*, no extra works are required in order to accommodate the new operations, making Campo Grande the easiest and cheapest station in terms of investment required in order to make feasible the semi-direct trains strategy.

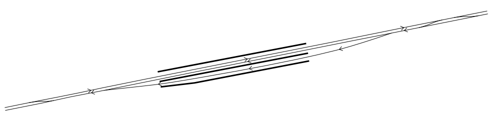

Fig23: Graphic overtaking train strategy | Campo Grande
Source: Own elaboration _311113

In order to improve the user experience of the riders, the strategy of the semi-direct trains is going to be to avoid as much as possible to have to stop the trains at stations or in the middle of the tracks if there is not the need to do so. For that, the semi-direct

train rides have been computed with variable speeds, being always as high as possible; but also considering that is better a rolling convoy than a stopped one in order to improve the sensation of motion of the users and avoiding the sensation of wasting dwelling times, despite the average speed between stations is very low.
As pointed out before, the Santa Cruz line is not symmetrical in terms of mileage between stations, demand and infrastructure; that is the reason why it is going to be depicted in the following figures the different operations in the branch with the introduction of semi-direct trains in the status quo situation. The following figures are showing the introduction of a semi-direct train in the status quo situation between Central do Brasil and Santa Cruz, depicted below in *Fig24*; the introduction of a semi-direct train between Santa Cruz and Central do Brasil, depicted below in *Fig25*; and the overlapping of both operations, depicted below in *Fig26*.

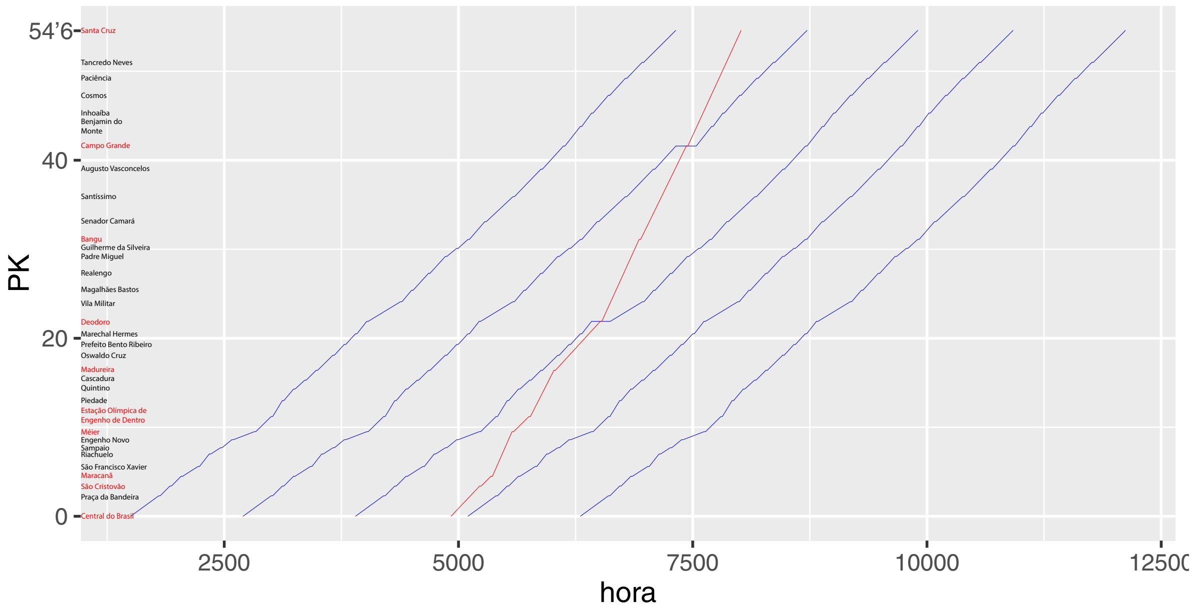

Fig24: Running diagram semi-direct train Central do Brasil – Santa Cruz | Status quo scenario
Source: Own elaboration _311114

As seen above in *Fig24*, with the introduction of a semi-direct train between Central do Brasil to Santa Cruz with the status quo scenario, two overtaking are required, one in Deodoro train station, with a 3 minutes and 18 seconds stop of the train in front of the semi-direct train; and another one in Campo Grande, with 3 minutes and 36 seconds stop of the train in front of the semi-direct train.

The density of busy stations in the shared stretch between Central do Brasil and Deodoro, even with consecutive stations, makes that the commercial speed between some stations remains the same as the train stopping everywhere and barely improves between certain stops, also in order to avoid a crash with the preceding train. It is only after surpassing Deodoro until reaching Santa Cruz, that the commercial speed between stations is always between 75 km/h to 80 km/h.

As said before, that strategy improves a lot the performance of the system because of the introduction of the semi-direct trains, at the same time that worsens the performance the trains stopping at every station. Also, the introduction of semi-direct trains, creates perturbances in the existing operations in terms of higher dwelling times in the overtaking stations, perturbances that are dissipated after three trains. In order to better understand that perturbances, some numbers are about to be given. The regular operation of the current trains between Central do Brasil and Santa Cruz takes 97 minutes, 1h and 37 minutes, performing at a commercial speed of 33,77 km/h, with an average distance between stops of 1,65 kilometers. The first train to be overtaken by the semi-direct train, due the new dwelling time in Deodoro, will need 100,06 minutes, a little bit more of 1h and 40 min, performing at a commercial speed of 32,74 km/h. The second train to be overtaken by the semi-direct train, due the new dwelling time in Campo Grande, will need 100,36 minutes, a little bit more of 1h and 40 min, performing at a commercial speed of 32,64 km/h.

All in all, the new semi-direct train will perform the same stretch with the following values. Semi-direct trains between Central do Brasil to Santa Cruz will cover the 54,6 kilometers at a performing commercial speed of 63,48 km/h; almost the double of the existing trains. The whole ride is computed to take 51 minutes and 36 seconds, being the new average distance between stations of 6,07 kilometers.

In summary, the introduction of this semi-direct train implies an important reduction in the ride of 45 minutes and 24 seconds.

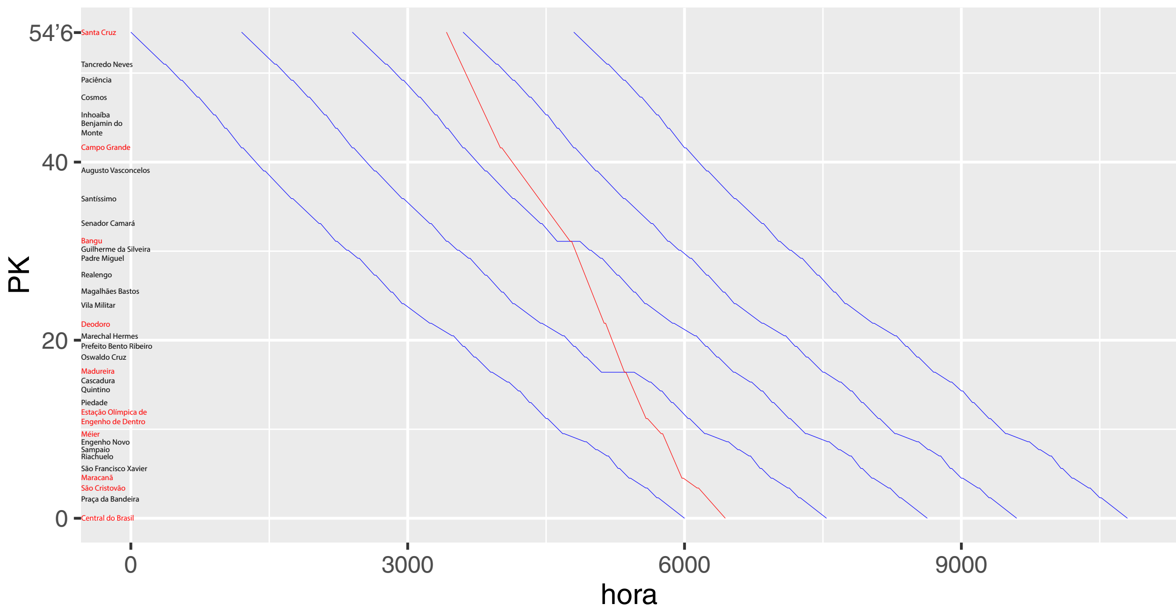

Fig25: Running diagram semi-direct train Santa Cruz - Central do Brasil | Status quo scenario
Source: Own elaboration _311115

As explained before, and as seen above in *Fig25*, the train line is not symmetrical, so several values are different than the previous scenario, as it is going to be explained below.

As seen above, with the introduction of a semi-direct train between Santa Cruz to Central do Brasil with the status quo scenario, two overtaking are required, one in

Bangu train station, with a 4 minutes and 6 seconds stop of the train in front of the semi-direct train; and another one in Madureira, with a 5 minutes and 54 seconds stop of the train in front of the semi-direct train.

The density of busy stations in the shared stretch between Central do Brasil and Deodoro, even with consecutive stations, makes that the commercial speed between some stations remains the same as the train stopping everywhere and barely improves between certain stops, also in order to avoid a crash with the preceding train; despite being better than the trains heading Santa Cruz from Central do Brasil. Between Campo Grande and Bangu, the semi-direct train needs to slow down to 50 km/h in order to avoid a crash with the preceding train.

As said before, that strategy improves a lot the performance of the system because of the introduction of the semi-direct trains, at the same time that worsens the performance the trains stopping at every station. Also, the introduction of semi-direct trains, creates perturbances in the existing operations in terms of higher dwelling times in the overtaking stations, perturbances that are dissipated after three trains. In order to better understand that perturbances, some numbers are about to be given. The regular operation of the current trains between Santa Cruz and Central do Brasil takes 3 more minutes than in the previous scenario, specifically, 100 minutes, 1h and 40 minutes, performing at a commercial speed of 32,76 km/h, with an average distance between stops of 1,65 kilometers. The first train to be overtaken by the semi-direct train, due the new dwelling time in Bangu, will need 103,85 minutes, a little bit more of 1h and 43 min, performing at a commercial speed of 31,55 km/h. The second train to be overtaken by the semi-direct train, due the new dwelling time in Madureira, will need 105,65 minutes, a little bit more of 1h and 45 min, performing at a commercial speed of 31,01 km/h.

All in all, the new semi-direct train will perform the same stretch with the following values. Semi-direct trains between Santa Cruz to Central do Brasil will cover the 54,6 kilometers at a performing commercial speed of 65,04 km/h; almost the double of the existing trains. The whole ride is computed to take 50 minutes and 24 seconds, being the new average distance between stations of 6,07 kilometers.

In summary, the introduction of this semi-direct train implies an important reduction in the ride of 49 minutes and 36 seconds.

All in all, the new operations, combining both ways, the detailed running diagram will look as seen below in *Fig26*. In the economic feasibility, it is going to be researched the needed rolling stock in order to carry out these new operations, as well as the willingness of the operator to replicate this new strategy along the whole day, or only during peak hour, as well as the headways of the new semi-direct operations.

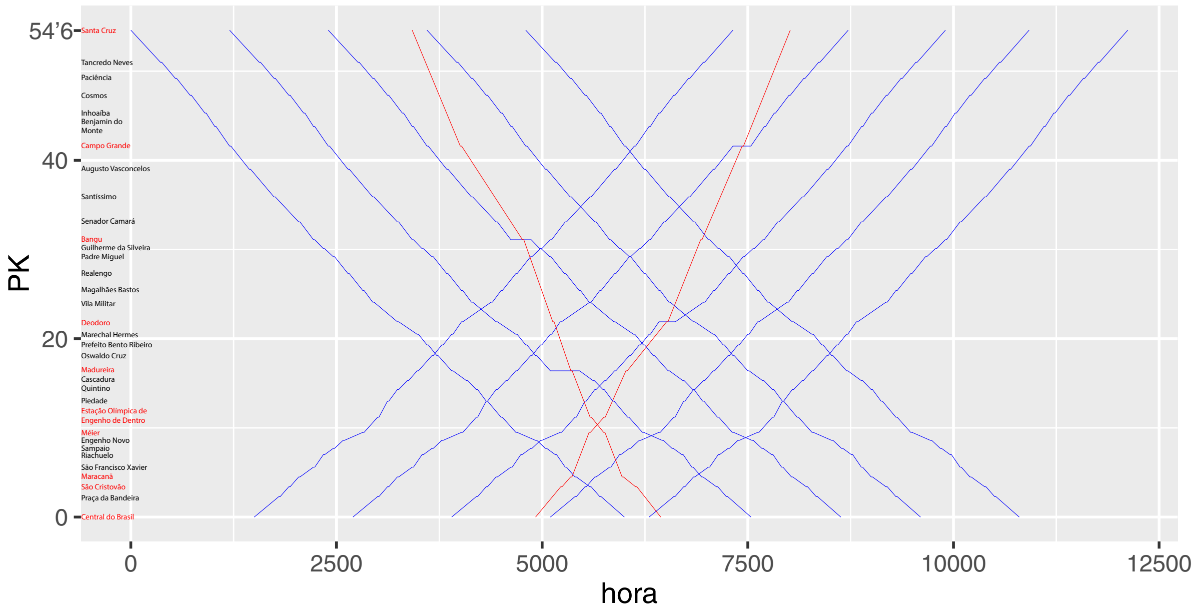

Fig26: Running diagram semi-direct train Santa Cruz branch _ overlapping both ways | Status quo scenario
Source: Own elaboration _311116

The following figures are showing the introduction of a semi-direct train in the pre-pandemic situation between Central do Brasil and Santa Cruz, depicted below in *Fig27*; the introduction of a semi-direct train between Santa Cruz and Central do Brasil, depicted below in *Fig28*; and the overlapping of both operations, depicted below in *Fig29*.

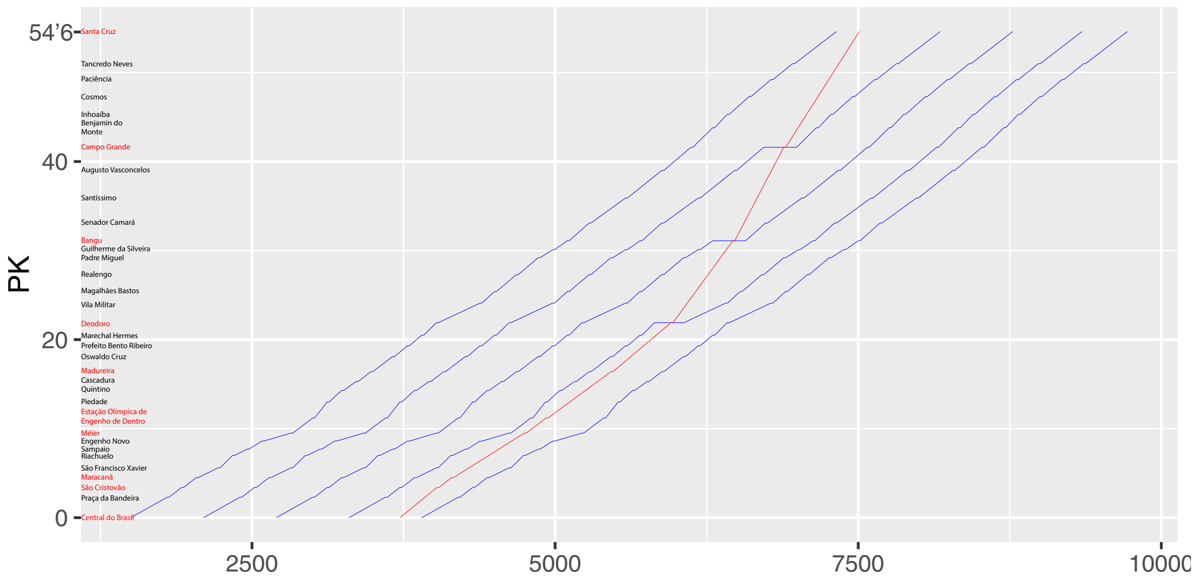

Fig27: Running diagram semi-direct train Central do Brasil – Santa Cruz | Pre-pandemic scenario
Source: Own elaboration _311117

As seen above in *Fig27*, with the introduction of a semi-direct train between Central do Brasil to Santa Cruz with the pre-pandemic scenario, three overtaking are required, one in Deodoro train station, with a 4 minutes stop of the train in front of the semi-direct train; another one in Bangu, with a 4 minutes and 30 seconds stop of the train in front of the semi-direct train; and another one in Campo Grande, with 4 minutes and 30 seconds stop of the train in front of the semi-direct train.

The density of busy stations in the shared stretch between Central do Brasil and Deodoro, even with consecutive stations, makes that the commercial speed between some stations remains the same as the train stopping everywhere and barely improves between certain stops, also in order to avoid a crash with the preceding train. It is only after surpassing Deodoro until reaching Santa Cruz, that the commercial speed between stations is always above 65 km/h, even reaching 90 km/h.

As said before, that strategy improves a lot the performance of the system because of the introduction of the semi-direct trains, at the same time that worsens the performance the trains stopping at every station. Also, the introduction of semi-direct trains, creates perturbances in the existing operations in terms of higher dwelling times in the overtaking stations, perturbances that are dissipated after four trains. In order to better understand that perturbances, some numbers are about to be given. The regular operation of the current trains between Central do Brasil and Santa Cruz takes 97 minutes, 1h and 37 minutes, performing at a commercial speed of 33,77 km/h, with an average distance between stops of 1,65 kilometers. The first train to be overtaken by the semi-direct train, due the new dwelling time in Deodoro, will need 100,76 minutes, a little bit more of 1h and 40 min, performing at a commercial speed of 32,51 km/h. The second train to be overtaken by the semi-direct train, due the new dwelling time in Bangu, will need 101,26 minutes, a little bit more of 1h and 41 min, performing at a commercial speed of 32,35 km/h. The third train to be overtaken by the semi-direct train, due the new dwelling time in Campo Grande, will also need 101,26 minutes, a little bit more of 1h and 40 min, performing at a commercial speed of 32,35 km/h.

All in all, the new semi-direct train will perform the same stretch with the following values. Semi-direct trains between Central do Brasil to Santa Cruz will cover the 54,6 kilometers at a performing commercial speed of 51,87 km/h. The whole ride is computed to take 63 minutes and 7 seconds, being the new average distance between stations of 6,07 kilometers.

In summary, the introduction of this semi-direct train implies an important reduction in the ride of 33 minutes and 50 seconds.

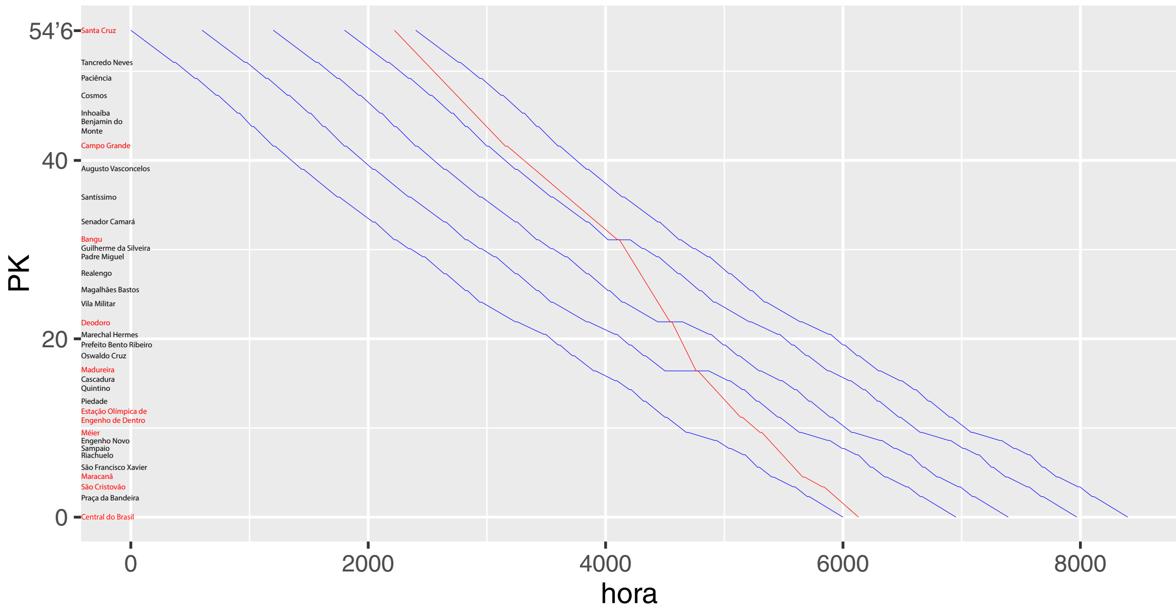

Fig28: Running diagram semi-direct train Santa Cruz - Central do Brasil | Pre-pandemic scenario
Source: Own elaboration _311118

As explained before, and as seen above in *Fig28*, the train line is not symmetrical, so several values are different than the previous scenario, as it is going to be explained below.

As seen above, with the introduction of a semi-direct train between Santa Cruz to Central do Brasil with the pre-pandemic scenario, three overtaking are required, one in Bangu train station, with a 3 minutes and 6 seconds stop of the train in front of the semi-direct train; another one in Deodoro, with a 3 minutes and 28 seconds stop of the train in front of the semi-direct train; and another one in Madureira, with a 6 minutes and 8 seconds stop of the train in front of the semi-direct train.

The density of busy stations in the shared stretch between Central do Brasil and Deodoro, even with consecutive stations, makes that the commercial speed between some stations remains the same as the train stopping everywhere and barely improves between certain stops, also in order to avoid a crash with the preceding train; despite being better than the trains heading Santa Cruz from Central do Brasil. Between Campo Grande and Bangu, the semi-direct train needs to slow down to 40 km/h in order to avoid a crash with the preceding train.

As said before, that strategy improves a lot the performance of the system because of the introduction of the semi-direct trains, at the same time that worsens the performance the trains stopping at every station. Also, the introduction of semi-direct trains, creates perturbances in the existing operations in terms of higher dwelling times in the overtaking stations, perturbances that are dissipated after four trains. In order to better understand that perturbances, some numbers are about to be given. The regular operation of the current trains between Santa Cruz and Central do Brasil takes 3 more minutes than in the previous scenario, specifically, 100 minutes, 1h and 40 minutes, performing at a commercial speed of 32,76 km/h, with an average distance between stops of 1,65 kilometers. The first train to be overtaken by the semi-direct train, due the new dwelling time in Bangu, will need 102,85 minutes, almost 1h and 43 min, performing at a commercial speed of 31,85 km/h. The second train to be overtaken by the semi-direct train, due the new dwelling time in Deodoro, will need 103,21 minutes, a little bit more of 1h and 43 min, performing at a commercial speed of 31,74 km/h. The third train to be overtaken by the semi-direct train, due the new dwelling time in Madureira, will need 105,89 minutes, almost 1h and 46 min, performing at a commercial speed of 30,94 km/h.

All in all, the new semi-direct train will perform the same stretch with the following values. Semi-direct trains between Santa Cruz to Central do Brasil will cover the 54,6 kilometers at a performing commercial speed of 50,26 km/h. The whole ride is computed to take 65 minutes and 11 seconds, being the new average distance between stations of 6,07 kilometers.

In summary, the introduction of this semi-direct train implies an important reduction in the ride of 34 minutes and 49 seconds.

All in all, the new operations, combining both ways, the detailed running diagram will look as seen below in *Fig29*. In the economic feasibility, it is going to be researched the needed rolling stock in order to carry out these new operations, as well as the willingness of the operator to replicate this new strategy along the whole day, or only during peak hour, as well as the headways of the new semi-direct operations.

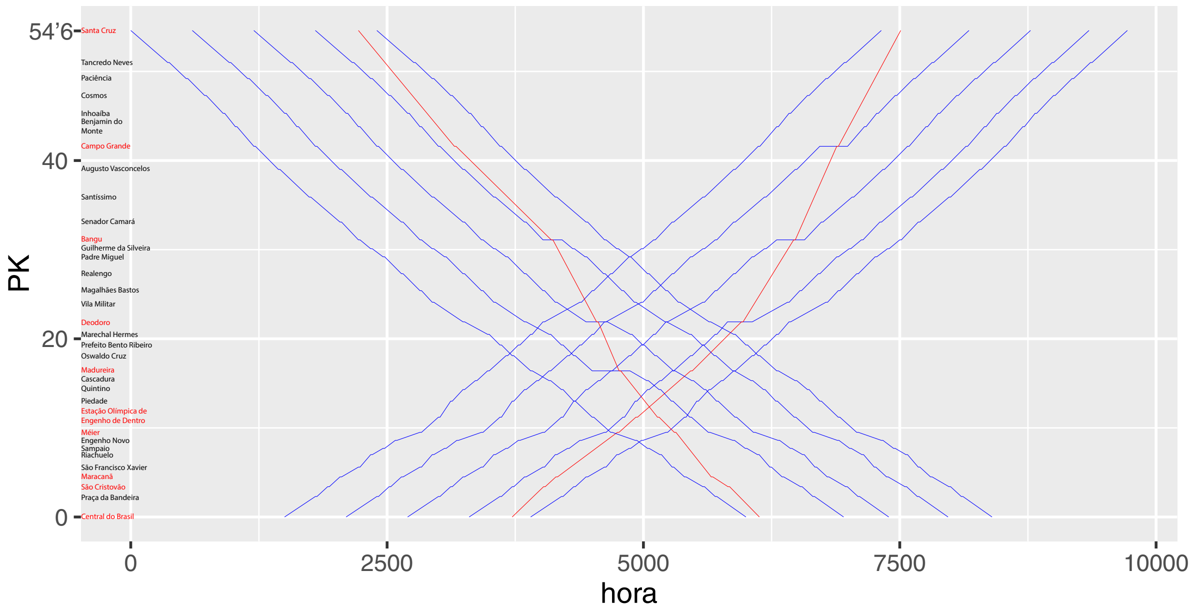

Fig29: Running diagram semi-direct train Santa Cruz branch _ overlapping both ways | Pre-pandemic scenario
Source: Own elaboration _311119

As seen above, due the density of trains and the complexity of the operations with the pre-pandemic scenario, the introduction of semi-direct trains is substantially worst than the semi-direct trains in the status quo scenario, with a lower headway.

The regular operation of the current trains between Central do Brasil and Santa Cruz takes 97 minutes, 1h and 37 minutes, performing at a commercial speed of 33,77 km/h. With the new semi-direct trains with the status quo scenario, the train will perform the stretch between Central do Brasil to Santa Cruz at a commercial speed of 63,48 km/h; almost the double of the existing trains. The whole ride is computed to take 51 minutes and 36 seconds. In summary, the introduction of this semi-direct train implies an important reduction in the ride of 45 minutes and 24 seconds.

With the pre-pandemic scenario, the semi-direct trains between Central do Brasil to Santa Cruz will cover the 54,6 kilometers at a performing commercial speed of 51,87 km/h. The whole ride is computed to take 63 minutes and 7 seconds. In summary, the introduction of those semi-direct train implies an important reduction in the ride of 33 minutes and 50 seconds.

Wrapping the whole topic up, that means that with the status quo scenario, a semi-direct train can cover the same stretch between Central do Brasil and Santa Cruz up to 12 minutes faster than with the pre-pandemic scenario, as seen below in *Table 7*. Of course, due the introduction of the semi-direct trains, the trains stopping at every station, worsens their performance, making the introduction of the semi-direct trains even more competitive.

The regular operation of the current trains between Santa Cruz and Central do Brasil takes 3 more minutes than the current trains covering the stretch between Central do Brasil to Santa Cruz, specifically, 100 minutes, 1h and 40 minutes, performing at a commercial speed of 32,76 km/h. With the new semi-direct train with the pre-pandemic scenario, the train will perform the stretch between Santa Cruz to Central do Brasil at a commercial speed of 65,04 km/h; almost the double of the existing trains. The whole ride is computed to take 50 minutes and 24 seconds. In summary, the introduction of this semi-direct train implies an important reduction in the ride of 49 minutes and 36 seconds.

With the pre-pandemic scenario, the semi-direct trains between Santa Cruz to Central do Brasil will cover the 54,6 kilometers at a performing commercial speed of 50,26 km/h. The whole ride is computed to take 65 minutes and 11 seconds. In summary, the introduction of this semi-direct train implies an important reduction in the ride of 35 minutes and 49 seconds.

Wrapping the whole topic up, that means that with the status quo scenario, a semi-direct train can cover the same stretch between Central do Brasil and Santa Cruz up to 14 minutes faster than with the pre-pandemic scenario, as seen below in *Table 7*. Of course, due the introduction of the semi-direct trains, the trains stopping at every station, worsens their performance, making the introduction of the semi-direct trains even more competitive.

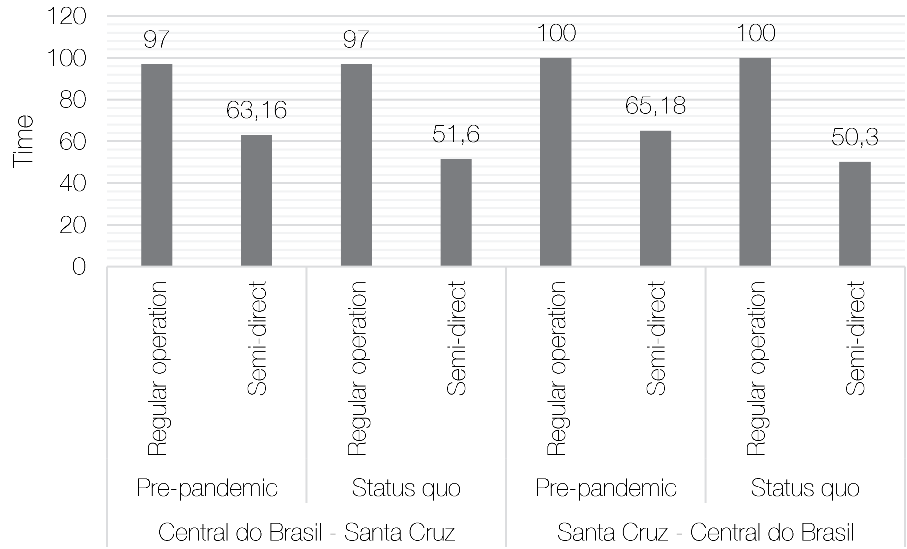

Table 7: Different scenario time comparison in Santa Cruz SuperVia branch
Source: Own elaboration _[3111110]

In order to perform the depicted running diagrams, there are several issues to be tackled, especially in terms of signalization, blocking and margins.

According to the UIC file 451-1, from December 2000, it is required to take into account several concepts in order to define the running speed of a train[3111111], such as the base speed, regularity margin and supplementary margin, that are about to be explained below.

The base speed is the minimum possible time to travel a given section of the line while towing a certain load; depending on the technical specifications of the rolling stock, power supply, adhesion, rolling resistance and maximum allowed speed; having exclusive dependence on technical and commercial factors.

The regularity margin is the additional time to compensate for delays due to occurrences such as periodic conservation works; possible loss of time due technical incidents, adverse weather conditions or other inconveniences in the operation. According to the table provided by the UIC file 451-1, with the performing speed in the Santa Cruz branch, it is intended to take into account a 4 minutes margin.

The supplementary margin is the additional time to account for the maneuvers in the track infrastructure configuration in urban nodes such as switches or traffic lights, as well as considering work in the superstructure and installations.

Summing up the base speed, the regularity margin and the supplementary margin, we get the type speed, which could be defined as the speed to be considered between two points as a train schedule.

Another important point to mention, is the capacity of the line, defined as the number of trains that can run through a given stretch in a given time frame, normally being defined by hourly circulations, especially in urban and suburban lines. Normally, the capacity of the most restrictive element, considered as a bottleneck, gives the total capacity. According to the UIC, in suburban lines, the potential capacity of a line during rush hour is the 85% of the maximum capacity, whereas during the whole day is the 70% of the maximum capacity; in order to absorb potential occurrences in the line in order to avoid the saturation of the line. The saturation of the line can be reached due bad regularity in the circulation of the convoys, lack of punctuality in the services, difficulties in order to fit new trains or delayed trains in the train paths, serious alterations in the exploitation due to light incidents or difficulties in obtaining working intervals to carry out the maintenance of the line, among others. Due the current conditions of the network, nowadays SuperVia operations still has too many inner and outer uncertainties leading to the saturation of the line too often, as seen before.

In order to improve the service and even increase the capacity, SuperVia has several options to improve the inner issues such as improving the superstructure and the installations in the SuperVia premises. From sleepers, to rails, but also the platforms or the gaps between the platforms and the wagons. Another important point in order to upgrade the performance of the line, is the implementation of the latest signaling technology in the trains and in the superstructure.

The choice and implementation of the signaling and blocking technology in a rail line is one of the most challenging and tricky points for the companies. To give a scale of the magnitude, in the Europe, it is starting to be a homogenization of the signaling after many years of technical issues related to the vast variety of technologies implemented in the European network; where not only each country has its own system, but several countries even have several technologies.

Currently, SuperVia runs with the signaling and blocking ATP system, capital letters standing for "Automatic Train Protection". That technology, which has different sub-systems depending on the country and the company providing the system, has the main aim of preventing the reach of two different trains warning the driving with information via side markings, but also in-cabin information. Another feature of the ATP technology is to prevent the incorrect driving behavior of the driver and minimizing the possible consequences such as skipping red traffic lights or avoiding overspeeding episodes, with the ability of activating the emergency brakes in case of exceeding the limit speed; Also, the driver is provided in advance of possible hazards or possible instructions.

Considering the available technologies and the transition towards a greener future, having the backbone of the decarbonization of the cities and countries worldwide, meaning that the rail transportation is called to become one of the main actors in the future so it is expected to experience a remarkable growth; nowadays it is considered that in the major rail lines there is no point of not implementing any other signaling and blocking technology than the moving block. The several technologies associated with the moving block are the latest systems in rail signaling and blocking and have several advantages compared with the previous ones, at the same time that are very useful in order to increase capacities in the lines where it is implemented[3111112].

The moving block technology it is not associated with static points on the track or superinfrastructure because the blocking section moves along with the running train. The separation between trains depends on the position of the preceding convoy and the required braking distance, depending on the speed, weight and wagons, among others.

With the moving block technology, the train calculates the instantaneous speed in each point according to the data transmitted by the static installation, but also with the data provided by the other convoys; having a continuous communication that allows to know and manage at all times the position and speed of the convoys running along the stretch; having a safety braking curve continuously following a mobile target. All in all, the distance between trains, so also the headway, can be reduced to its minimum.

As said before, Europe started a homogenization of the signaling and blocking technologies back in the 1990's[3111113]. The ERTMS, capital letters standing for "European Rail Traffic Management System", was the chosen technology, despite it is being also implemented in many other continents. Since the research and development of new technologies is constantly going on and on, that ERTMS technology has several levels, from zero to three; where the larger is the number of the level, the more capacity and speed is allowed, and the less distance between trains and less on-track equipment is required. The third level of the ERTMS technology, the most advanced one, is the one having the ability of having the moving block technology, where the transmission of the signals is mainly done by GSM-R[3111114].

In order to compute all the semi-direct trains depicted above, a 3 minutes margin was given to all the convoys leaving the terminus stations. That means that every semi-direct train deployed in the branch is supposed to leave three minutes before the train stopping at every single station of the line, meaning that depending on the scenario, there are trains leaving 17 minutes (for the status quo scenario) after the previous train stopping at every station, or trains leaving 7 minutes (for the pre-pandemic scenario) after the previous train stopping at every station. In order to compute the required extra dwelling time for the overtaken train stopping at every station in the overtaking stations, 1 minute and 30 seconds of safety margin after the semi-direct train leaving the station was given.

When a semi-direct train is overtaking another train in an overtaking station, it is supposed to run at the highest range of the expected average speeds in the line, around 75 km/h to 80 km/h. That means that with 1 minute and 30 seconds margin, when the train that stops at every station starts running again behind the semi-direct train, the semi-direct train is already 2.000 meters ahead.

Especially due the traffic congestion, but also the high density of stations close to Central do Brasil terminus station, the semi-direct trains leaving the terminus stations are not supposed to run at very high speeds, maybe reaching values of less than 40 km/h. Considering an commercial speed of 35 km/h, with a 3 minutes margin, the train that stops at every station starts running again behind the semi-direct train will start running once the semi-direct train is 1.750 meters ahead. If we consider the terminus station of Santa Cruz, where the semi-direct trains can start running at the higher range of expected commercial speeds in the branch, considering it 80 km/h, the train that stops at every station starts running again behind the semi-direct train will start running once the semi-direct train is 4.000 meters ahead.

Those values depicted above can be easily optimized for a better performance of the network with the implementation of the proper signaling and blocking system; which is somehow feasible, considering that in rush hour in the highest demanded stretch of the metrô in Rio de Janeiro, the headway is even below the 90 seconds. That is the reason why, the implementation of those new systems is not only suitable for the SuperVia infrastructure, but also reasonably feasible.

3.1.2 | Economic feasibility:

In order to compute the economic feasibility, some previous theoretical calculus[3121] are needed.

In order to compute the fleet size (M), the following expression has been used:

$$M = \frac{2L}{v_c}\frac{1}{H} \text{ (veh-h)}$$

In order to compute the total distance travelled by the fleet per hour (V), the following expression has been used:

$$V = \frac{2L}{H} \text{ (veh-km/h)}$$

In order to compute the commercial speed of the vehicles (V_{cx2}) with the lay-over time included, has been computed from the expression:

$$v_{cx2} = \frac{a_l}{\left(\frac{a_l}{cruisevel + \tau \frac{a_l}{s} + a_l \, \Lambda' \, h \frac{\frac{\tau'}{2}}{L} + \frac{t_{layover}}{3600}}\right)} \text{ (km/h)}$$

Headway can also be considered as:

$$\frac{\partial_Z}{\partial_H} = H \rightarrow H^*$$

After doing the derivative, we will get the following expression:

$$H^* = \sqrt{\frac{4L\left[R\$_V + R\$_M\left(\frac{1}{v} + \frac{v}{sa}\right)\right]}{\Lambda \beta_T}} \text{ (min)}$$

In order to compute the total cost, as a result of the cost of the distance travelled by the fleet in one hour plus the cost of the total hours worked by the drivers in one hour, the following expression is about to be used in an optimization iterative process:

$$\min_{s,H}\{Z_A\} = R\$_V V + R\$_M M \text{ (R\$)}$$

Objective function, being subject to:

$$CG \leq CG_{max}$$

$$s \geq 0; H \geq 0$$

$$CG \leq CG_{max} \rightarrow T \leq T_{max}$$

Being:

$R\$_V$: Unit distance cost (R$/veh-km).

$R\$_M$: Unit temporal cost (R$/veh-h).

Z_A : Hourly agency cost **α.**

CG: Average generalized cost per passenger.

CG_{max} : Maximal generalized cost per passenger.

T: Mean door-to-door travel time per trip

T_{max} : Maximal door-to-door travel time per trip

According to the SuperVia operational data, it is going to be considered that the peak hour is at 17:00h, carrying during that hour the 40.155 users, but for the Santa Cruz branch it is going to be considered 12.000 users, considering that is the second most used branch of the whole network.

It is important to point out that temporal cost are related to the fixed costs; many of these items are negotiated under a monthly base.

In order to run the macro of the excel, several values are about to be explained below.

The capacity of the trains is going to be set at 1.560 users, taking into account seated and standing passengers.

The acceleration rate for the vehicles it is set at 0,85 m/s^2, and the maximal cruising speed is set at 80 km/h.

The boarding and alighting operation, so the time lost per stop, it is set at 1 second per passenger. The average walking speed has been set at 3 km/h.

Transferring European economical values to a country like Brazil it has been a challenge, so the unit distance cost has been set at 95 R$/veh-km; and the unit vehicle cost has been set at 980 R$/veh-h.

The value agreed for the value of time, it is 0,36 **€**/pax-h. This value comes from the recommendation of the World Bank[32127], where it is agreed to be the 30% of the average nationwide wage. In the Brazilian context follows the following expression:

$$Value\ of\ time = \left(\frac{Average\ wage}{Monthly\ working\ hours}\right) \cdot 0'3 = \left(\frac{R\$\ 1200}{176}\right) \cdot 0'3 = R\$/pax \cdot h\ \ 2'05 \approx 0'36€/pax \cdot h$$

Despite can also be computed 220 monthly working hours; 176 working hours has been finally set as the most suitable value for the calculations.

It has been set 150 meters of distance in order to describe the transferring distances between lines in the network.

In time perception weight terms, the following numbers have been set. 1 for the travelling time perception, 1,1 both for access time perception and waiting time perception; and 1,2 for the transferring time perception.

As a constraint, has been set that the minimum time headway cannot be below 10 or 20 minutes.

Wrapping the whole thing up, and taking into consideration that this is a theoretical exercise, all the values explained above and the peak hour demand value, the following output has been obtained after running the excel:

_ For the headway constrained at 10 minutes, representing the pre-pandemic scenario:

The total operational cost for the Santa Cruz branch in the status quo scenario, defined by the expression seen above “min Z”, becomes 61.591 R$/h, being the optimal value found by the iterative process, and being the sum between the user cost, 24.670 R$/h; and the agency cost, 36.921 R$/h. If we do a simple calculus dividing the total operational cost (61.591 R$/h) by the expected users during peak hour (12.000), we end up having an expected fare of R$ 5,13 per trip. Currently, the actual fare for the SuperVia rail services is R$ 5.

Of course, the model used above follows the economic model from several cities in Europe, being quite distant of the economic model followed in most of the cities in Brazil, where almost the whole cost is assumed by the user, which at the same time is mainly assumed by the employer of every individual. Specifically, every company with 10 or more employees, the company is supposed to assume the value of the commuting ride done by the employee, in case that the monthly cost of the rides is over 6% of the wage of the employee. In that case, where the influence of the Prefeitura or the State Government (regional government, not federal government), is just in the retired commuters and students, we can almost assume that almost all the cost will be assumed by the user, being almost the whole value obtained by the "min Z" iterative process.

As seen before, the disparity of fares between the peak and the off-peak hour and the lack of subsidies of the tender process of the Prefeitura da Cidade do Rio de Janeiro, brings us to the "Câmara de Compensação system where the inequalities between lines and operators are intended to be sorted by the unification of the fares, where the surplus of the most profitable ones compensates the least busy ones.

The total distance travelled by the fleet per hour (V), it has been found to be 264,7 veh-km/h; with a total fleet (M) of 11,5 veh-h, which rounded up becomes 12 veh-h. Due operational reasons, according to the running diagram depicted above, the actual rolling stock used to be 21 veh; running with an expected occupancy of 680 users.

The average access time has been found to be 7 minutes; the average waiting time, 12,4 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 39,2 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 58,5 minutes.

_ For the headway constrained at 20 minutes, representing the status quo scenario:

The total operational cost for the Santa Cruz branch in the pre-pandemic scenario, defined by the expression seen above "min Z", becomes 56.010 R$/h, being the optimal value found by the iterative process, and being the sum between the user cost, 28.707 R$/h; and the agency cost, 27.269 R$/h. If we do a simple calculus dividing the total operational cost (56.010 R$/h) by the expected users during peak hour (12.000), we end up having an expected fare of R$ 4,66 per trip. Currently, the actual fare for the SuperVia rail services is R$ 5.

The total distance travelled by the fleet per hour (V), it has been found to be 188,5 veh-km/h; with a total fleet (M) of 9,2 veh-h, which rounded up becomes 10 veh-h. Due operational reasons, according to the running diagram depicted above, the actual rolling stock needed is 11 veh; running with an expected occupancy of 955 users.

The average access time has been found to be 6,6 minutes; the average waiting time, 17,4 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 44 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 68 minutes.

For the economic outlook for the introduction of semi-direct trains I both scenarios above, it is going to be assumed a very simple modal split between the existing trains stopping at every station and the semi-direct trains. Due the limited amount of available time to do this master thesis, will not be possible to do neither an induced demand forecast nor a modal split projection, so it is going to be assumed that the demand is going to be the same as the current one, and that the users are going to be evenly distributed along the services pointed out below; only changing into the excel macro the speed and the demand in order to get the new values and sum them up. Also, due the lack of time, it is going to be computed the introduction of the semi-direct trains as an independent element, not collaborating with the current operations; which is not the most accurate method. It is not going to be taken into account the value of all the externalities, positive or negative.

It is important to take into account that the previous used formulas, which are going to be used in this point as well, does not take into account the difference between the fixed and variable costs, which makes them not the most solid ones in order to compute the introduction of the semi-direct trains into the system.

Since the units of measure are the following ones:

Total cost, min Z (R$/h).

Total distance travelled by the fleet per hour, V (veh-km/h).

Total fleet, M (veh-h).

It is not going to be considered the overall daily cost. Also, due the lack of information in terms of forecasted induced demand or forecasted modal split, it is going to be given some tips, but the operator is going to be the one deciding which is the most feasible solution for the network.

_ For the pre-pandemic scenario:

Since the headway of the trains that stops at every station is 10 minutes, considered a remarkably good headway in the conditions of the Santa Cruz brunch, it is going to be performed the excel with two possible scenarios, which are the introduction of semi-direct trains between 20 and between 30 minutes, and the results are going to be compared.

_ Introduction of semi-direct trains every 20 minutes:

It is going to be considered that every hour there are going to be 9 trains running, 6 trains that stops at every station, and 3 semi-direct trains; so it is going to be considered that 2/3 of the demand is going to be assumed by the regular trains, and 1/3 of the demand is going to be assumed by the semi-direct trains; being 8.000 users the 2/3 of 12.000 users, and 4.000 users the remaining 1/3 of 12.000 users.

_ Pre-pandemic operation adapted to the new demand:

The total operational cost becomes 51.254 R$/h, being the optimal value found by the iterative process.

The total distance travelled by the fleet per hour (V), it has been found to be 264,7 veh-km/h; with a total fleet (M) of 10,3 veh-h, which rounded up becomes 11 veh-h; running with an expected occupancy of 453 users.

Since the current compositions of the rolling stock are two coupled convoys, and considering the low expected occupancy of the semi-direct trains, it it has been computed the operation with half of the seats, despite the new economical values are not going to be very accurate. The result has been found to be the same, which of course, it is not true since the system is saving one convoy for each deployed service.

The average access time has been found to be 7,7 minutes; the average waiting time, 12,4 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 35 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 55,1 minutes.

Since the current compositions of the rolling stock are two coupled convoys, and considering the low expected occupancy of the semi-direct trains, it has been computed the operation with half of the seats, despite the new economical values are not going to be very accurate. The result has been found to be the same, which of course, it is not true since the system is saving one convoy for each deployed service.

_ Pre-pandemic operation adapted to the new demand with the introduction of the semi-direct trains:

The total operational cost becomes 31.521 R$/h, being the optimal value found by the iterative process.

The total distance travelled by the fleet per hour (V), it has been found to be 188,5 veh-km/h; with a total fleet (M) of 5,6 veh-h, which rounded up becomes 6 veh-h; running with an expected occupancy of 318 users.

The average access time has been found to be 9,9 minutes; the average waiting time, 17,4 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 26,9 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 54,2 minutes.

Since the current compositions of the rolling stock are two coupled convoys, and considering the low expected occupancy of the semi-direct trains, it it has been computed the operation with half of the seats, despite the new economical values are not going to be very accurate. The result has been found to be the same, which of course, it is not true since the system is saving one convoy for each deployed service.

All in all, the combination of both services, has the following output:

Total operational cost: R$ 82.775

Total distance travelled by the fleet per hour (V): 453,2 veh-km/h

Total fleet (M) of 17 veh-h

_ Introduction of semi-direct trains every 30 minutes:

It is going to be considered that every hour there are going to be 8 trains running, 6 trains that stops at every station, and 2 semi-direct trains; so it is going to be considered that 3/4 of the demand is going to be assumed by the regular trains, and 1/4 of the demand is going to be assumed by the semi-direct trains; being 9.000 users the 3/4 of 12.000 users, and 3.000 users the remaining 1/4 of 12.000 users.

_ Pre-pandemic operation adapted to the new demand:

The total operational cost becomes 53.760 R$/h, being the optimal value found by the iterative process.

The total distance travelled by the fleet per hour (V), it has been found to be 264,7 veh-km/h; with a total fleet (M) of 10,6 veh-h, which rounded up becomes 11 veh-h; running with an expected occupancy of 509 users.

The average access time has been found to be 7,5 minutes; the average waiting time, 12,4 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 36 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 55,9 minutes.

_ Pre-pandemic operation adapted to the new demand with the introduction of the semi-direct trains:

The total operational cost becomes 24.782 R$/h, being the optimal value found by the iterative process.

The total distance travelled by the fleet per hour (V), it has been found to be 146,4 veh-km/h; with a total fleet (M) of 4,3 veh-h, which rounded up becomes 5 veh-h; running with an expected occupancy of 307 users.

The average access time has been found to be 10 minutes; the average waiting time, 22,4 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 26,7 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 59,1 minutes.

All in all, the combination of both services, has the following output:

Total operational cost: R$ 78.542

Total distance travelled by the fleet per hour (V): 411,1 veh-km/h

Total fleet (M) of 16 veh-h

_ For the status-quo scenario:

Since the headway of the trains that stops at every station is 20 minutes, it is going to be performed the excel with just one possible scenario, which is the introduction of a semi-direct trains between 20 minutes.

_ Introduction of semi-direct trains every 20 minutes:

It is going to be considered that every hour there are going to be 6 trains running, 3 trains that stops at every station, and 3 semi-direct trains; so it is going to be considered that 1/2 of the demand is going to be assumed by the regular trains, and 1/2 of the demand is going to be assumed by the semi-direct trains; being 6.000 users the 1/2 of 12.000 users.

_ Status-quo operation adapted to the new demand:

The total operational cost becomes 39.051 R$/h, being the optimal value found by the iterative process.

The total distance travelled by the fleet per hour (V), it has been found to be 188,5 veh-km/h; with a total fleet (M) of 7,8 veh-h, which rounded up becomes 8 veh-h; running with an expected occupancy of 477 users.

Since the current compositions of the rolling stock are two coupled convoys, and considering the low expected occupancy of the semi-direct trains, it has been computed the operation with half of the seats, despite the new economical values are not going to be very accurate. The result has been found to be the same, which of course, it is not true since the system is saving one convoy for each deployed service.

The average access time has been found to be 7,3 minutes; the average waiting time, 17,4 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 37,2 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 61,9 minutes.

Since the current compositions of the rolling stock are two coupled convoys, and considering the low expected occupancy of the semi-direct trains, it it has been computed the operation with half of the seats, despite the new economical values are not going to be very accurate. The result has been found to be the same, which of course, it is not true since the system is saving one convoy for each deployed service.

_ Status-quo operation adapted to the new demand with the introduction of the semi-direct trains:

The total operational cost becomes 35.575 R$/h, being the optimal value found by the iterative process.

The total distance travelled by the fleet per hour (V), it has been found to be 188,5 veh-km/h; with a total fleet (M) of 5,7 veh-h, which rounded up becomes 6 veh-h; running with an expected occupancy of 477 users.

The average access time has been found to be 9,8 minutes; the average waiting time, 17,4 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 27,4 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 54,6 minutes.

Since the current compositions of the rolling stock are two coupled convoys, and considering the low expected occupancy of the semi-direct trains, it has been computed the operation with half of the seats, despite the new economical values are not going to be very accurate. The result has been found to be the same, which of course, it is not true since the system is saving one convoy for each deployed service.

All in all, the combination of both services, has the following output:

Total operational cost: R$ 74.626

Total distance travelled by the fleet per hour (V): 377 veh-km/h

Total fleet (M) of 14 veh-h

It is important to point out that the model is not the most accurate one in terms of calculating that several scenarios, having one of its main weaknesses in the computation of the average access time, average waiting time, in-vehicle travel times, and in consequence, the expected door to door travel time.

As seen below in *Fig30*, the daily demand experiences remarkable jumps between 04:00h and 05:00h, and between 18:00h, 19:00h and 20:00h. Also, can be considered that the morning peak demand is between 05:00h and 08:59h; and the afternoon peak demand is between 16:00h and 18:59h.

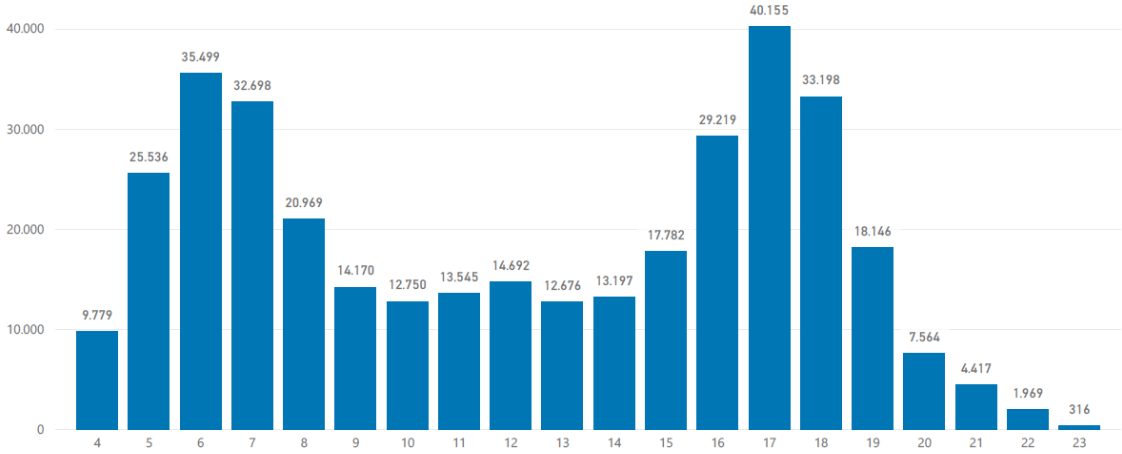

Fig30: Daily demand profile. X axis representing the hours of operation and Y axis representing the riderships
Source: SuperVia _32125

Below, between the *Table 8* and *Table 15*, are depicted the results shown above, comparing all the different analyzed scenarios.

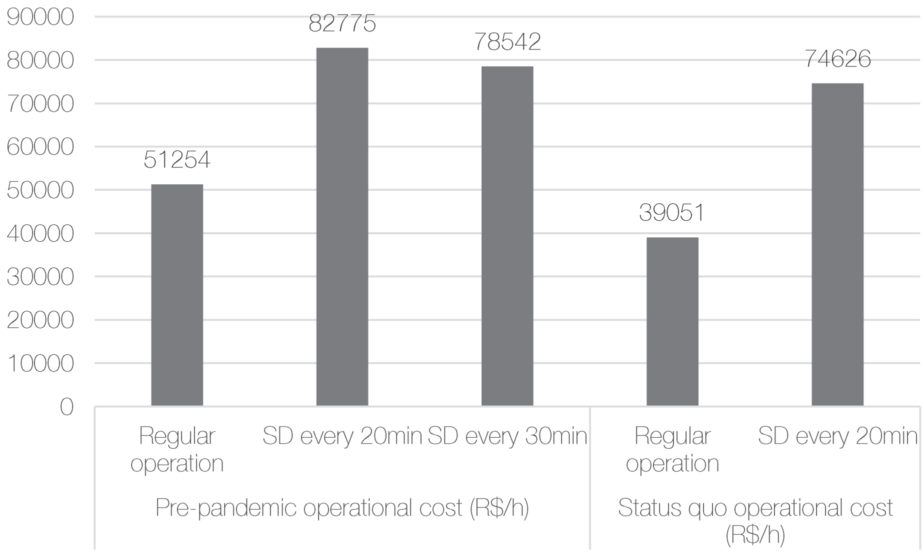

Table 8: Operational cost comparison between scenarios
Source: Own elaboration _3122

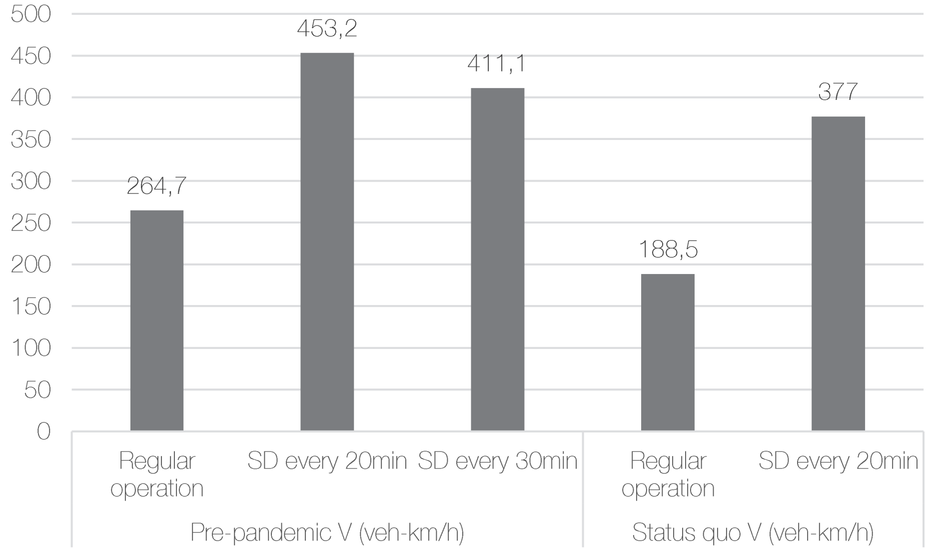

Table 9: Total distance travelled by the fleet per hour comparison between scenarios
Source: Own elaboration _[3123]

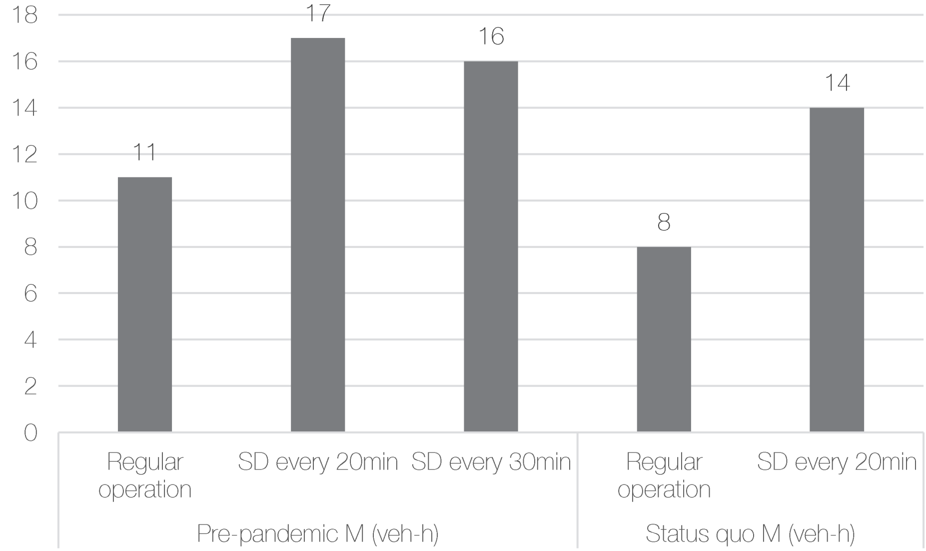

Table 10: Fleet comparison between scenarios
Source: Own elaboration _[3124]

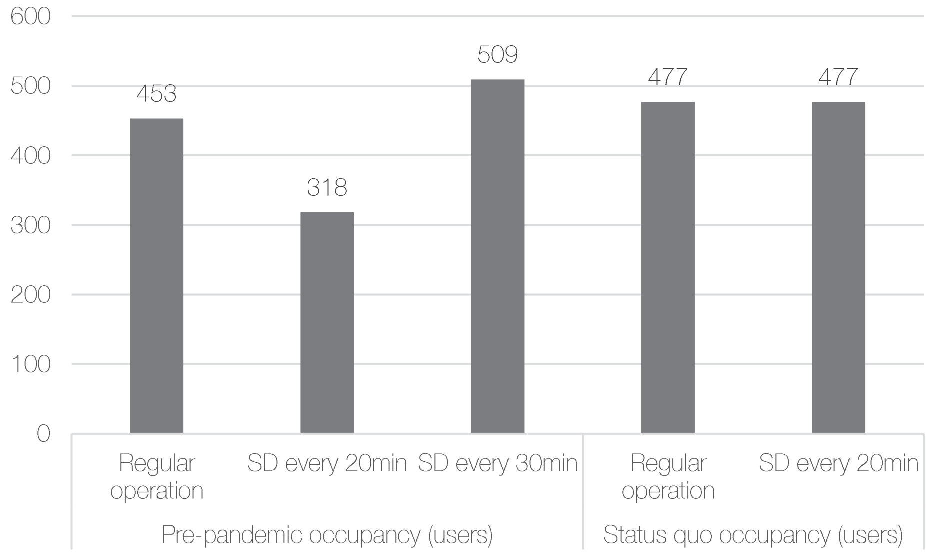

Table 11: Occupancy comparison between scenarios
Source: Own elaboration _[3125]

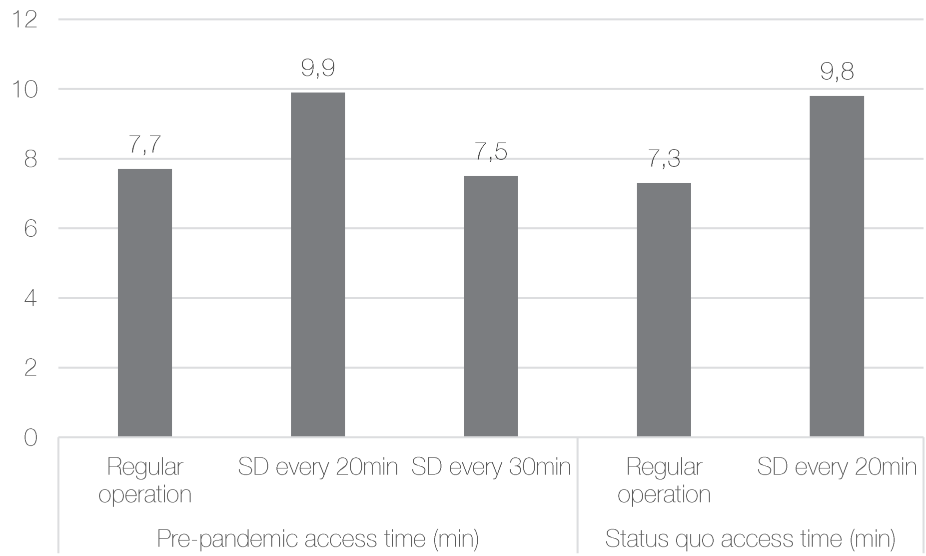

Table 12: Access time comparison between scenarios
Source: Own elaboration _[3126]

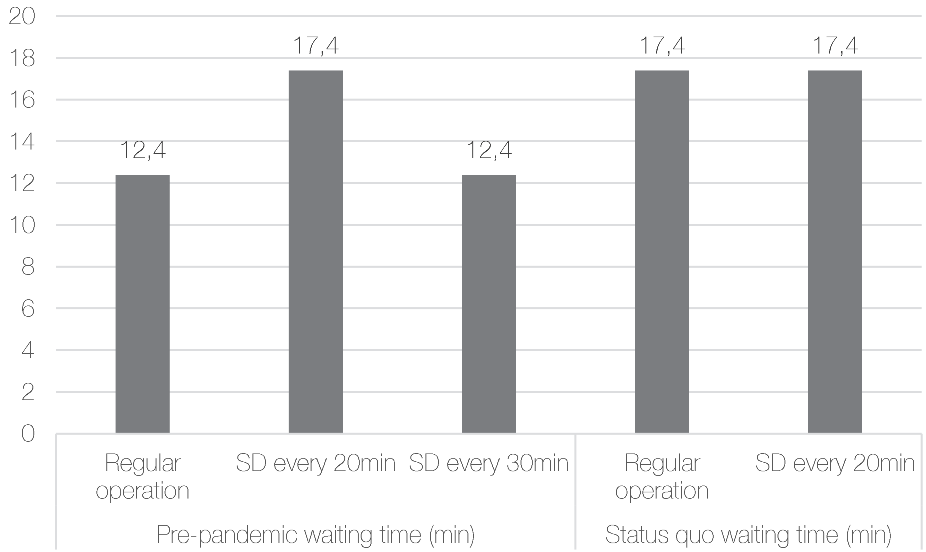

Table 13: Waiting time comparison between scenarios
Source: Own elaboration _[3127]

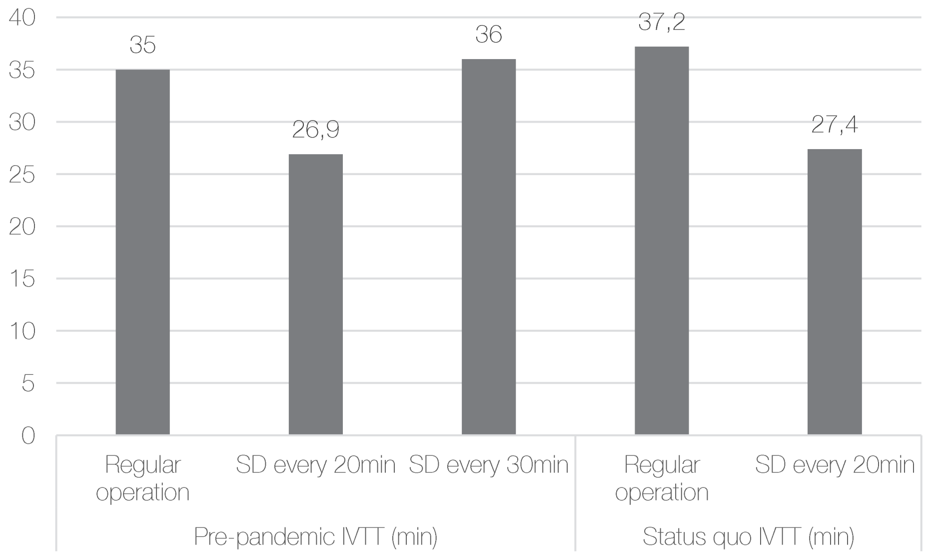

Table 14: In-vehicle travel time comparison between scenarios
Source: Own elaboration _[3128]

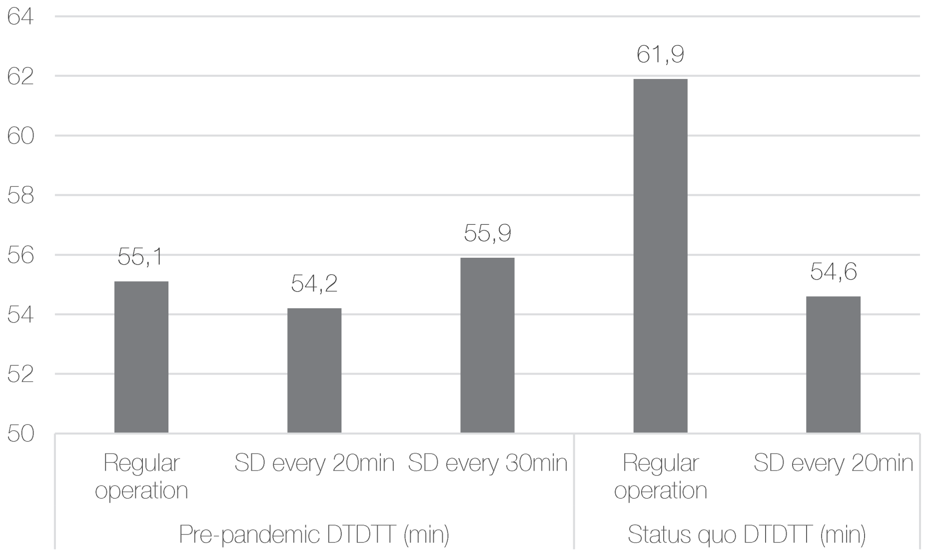

Table 15: Door-to-door travel time comparison between scenarios
Source: Own elaboration _[3129]

All in all, the operator has the power to assess the feasibility and suitability of the introduction of semi-direct trains in the following three possible scenarios:

_ Introduction of semi-direct trains during the whole day.

_ Introduction of semi-direct trains between 05:00h and 18:59h or 19:59h.

_ Introduction of semi-direct trains in the time span between 05:00h and 08:59h, and then halting operations until the time span between 16:00h and 18:59h or 19:59h.

3.2 | Ônibus:

3.2.1 | Operations:

3.2.1.1 | Overview:

As seen in previous points, ônibus plays a major role in the mobility of Rio de Janeiro city and its metropolitan area. Being the public transportation the 47,15% of the modal share in the area, just the municipal ônibus and the intermunicipal ônibus combined, account for the 37,4% of the total mobility of the area; meaning that combined, they carry over 8,4 million daily riderships. Just to better understand the scale of those values, the buses of the municipal operator from Barcelona, TMB[218], carries daily a little bit more than 400.000 users daily, with the 2022 recorded data, despite before covid used to be above half a million daily users.

The ônibus network in Rio de Janeiro city and its metropolitan area it is a gigantic network conformed by 202 operators, 3.260 lines and a fleet of 22.500 ônibus running through a 22.966 kilometers network[32111]; making many times the whole network a truly labyrinth for the users, being really hard to easily understand, even with the new available tools such as the "Moovit" and "Google Maps" cell phone apps. From the previous numbers, Rio de Janeiro city has 697 municipal lines operated by a fleet of over 9.000 vehicles, divided in four different consortiums.

The ônibus implementation is so widespread due its investment and operational costs, despite not being the most optimal one in terms of operations, especially in a city like Rio de Janeiro. The cost by kilometer is around R$ 3 million and has an immediate implementation; whereas the BRT has a cost of R$ 20 million per kilometer and an average of 2 years of construction; the VLT, R$ 80 million per kilometer and an average of 5 years of construction; and the metro, R$ 200 million per kilometer and an average of 10 years of construction. The ônibus network has a weak BRS system, created between the years 2011 and 2014, in the main corridors of Zona Sul, Centro and in Engenho Novo and Riachuelo area; despite in this last area, after works in the pavement, the bus segregation lines have been withdrawn. It is important to point out the tiny area served by this BRS system, compared with the overall vast area of the city of Rio de Janeiro; despite where this system has been implemented, the total travel time of the rolling stock is decreased in a rate of 65%, with a really good approval from the users. All in all, due the big events occurred in the Carioca city during the years 2014 and 2016, the ground transportation in the city was remarkably boosted with the arrival of the BRT and the VLT, which were a game-changer for the mobility; despite later on, especially the BRT, fell into a really quick decadence and degradation.

Nowadays the ônibus system is really struggling to carry an increasing number of users after the dramatic decrease during the toughest years of the pandemic, when several services remarkably reduced their headways and rolling stock.

As said before, it is also interesting to point out the difficulties to connect some points of the city of Rio de Janeiro with other areas, due its complicated physiognomy of the local orography, hard to connect territories without expensive infrastructures such as tunnels and viaducts. Another major drawback for the public transportation, and specially the ônibus network, is the vast area that the city occupies and its low density, especially compared with most of the European cities; but also, the distribution of the population and the location of the jobs.

Once has been analyzed the suitability and feasibility of deploying semi-direct trains stopping in Bangu train station in order to reinforce this possible new centrality; the next step in the chosen area, is to focus the study of the reorganization of the ônibus network in the Grande Bangu area, an area specially affected by the illegal van phenomena, excessive heat episodes, and a geographical location remarkably distant from the downtown. The distance by car from Bangu to Cinelândia metro station, in Centro, is around 44 kilometers, that without issues in the traffic, which has a really low likelihood to happen, can be covered by public transportation in around 1 hour and 30 minutes. If another destination is chosen such as Copacabana, the commuting time can easily go up to 2 hours.

As explained before, this strategy is intended to be as low-cost as possible and is going to be designed in a hypothetical future where the integrations between the different public transportation operators and modes of transport in the city of Rio de Janeiro and its metropolitan area, actually works.

3.2.1.2 | Proposals:

The main aim of these proposals is to deploy an intelligible network for the user, at the same time a hierarchy is created in order to reinforce the new centralities. In the case of Grande Bangu area, it is intended to treat it as an independent city due its geographical conditions, but also to reinforce the multicentrality project I am working on. It is not intended to be treated in this project, but the idea is to create ônibus lines getting into and out of the area, only when there is no other alternative. To clarify, if there is an existing link between Bangu and another area by train, between Bangu and Campo Grande, for example, will be considered that is not a priority to deploy a bus line between these two points; but between Bangu and Jacarepaguá, for example, an ônibus line is going to be needed due the lack of alternatives. The main aim of that action is to optimize the network and avoiding creating the existing overlappings in the network, where in several points, a single ônibus stop is used by over 100 ônibus lines, some of them, with and extremely long route; to put a scale, that is almost all the bus lines of Barcelona, all of them stopping in the same bus stop. In Avenida do Brasil, for example, several lines runs several kilometers overlapping each other doing the same route heading to Avenida Presidente Vargas and Candelária in a tree structure; where those lines are being added to Avenida do Brasil from the several areas that avenue runs through, or because that avenue becomes the only way to get to Centro. That phenomena could be avoided creating those new centralities, but also trying to create a hub and spoke system, with main lines running through the main arteries of the city being feeded by some feeder lines.

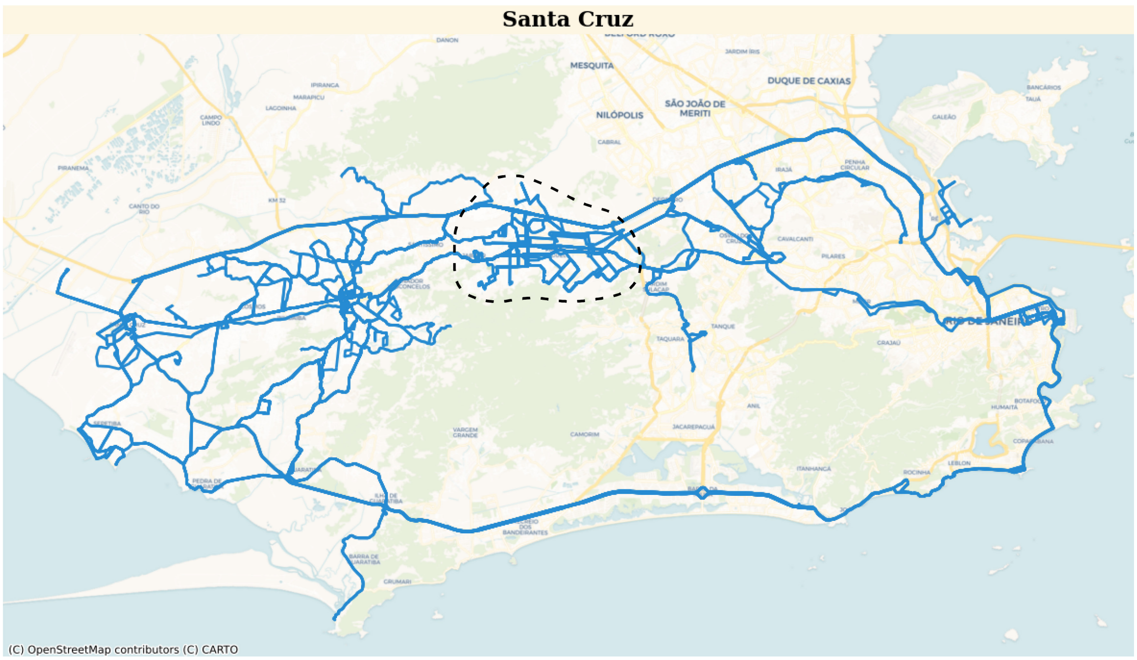

Fig31: Current ônibus and BRT network in Rio de Janeiro | Santa Cruz consortium, focusing in Grande Bangu area
Source: José Brandão de Paiva Neto _[234]

As seen above in the *Fig31*, with the available data, the ônibus lines belonging to the Santa Cruz consortium, which is the only one operating in the area, going through the Grande Bangu area are mainly organized as passing services in the east-west axis, most of them going through Avenida do Brasil. Of course, the map depicted above shows the official lines, excluding the illegal vans, giving service more locally in the area. In the map can be clearly seen how most of the lines mainly follows the same path as the SuperVia rail line between Central do Brasil to Santa Cruz. It is intended to completely change the existing layout, as explained before.

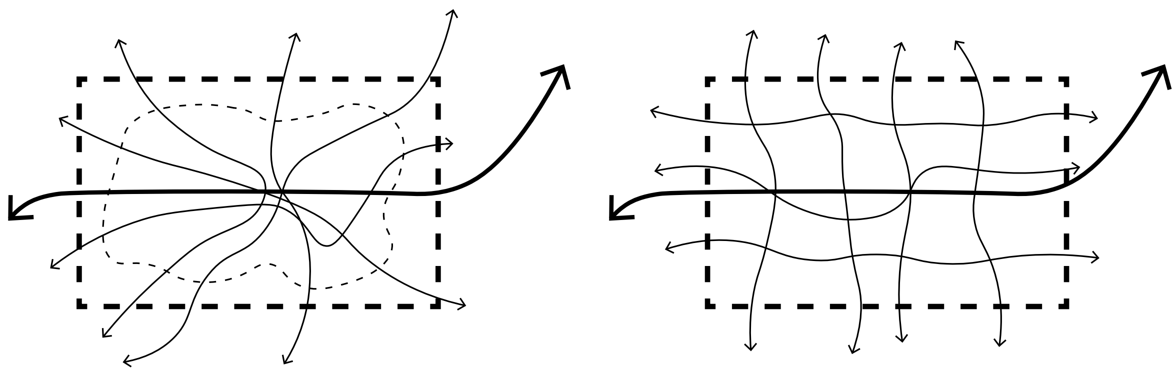

Fig32: Feasible future ônibus scenarios in Grande Bangu area
Source: Own elaboration _[32121]

Two possible scenarios are proposed in order to tackle the status quo scenario in Grande Bangu area, the radial network and the orthogonal network, as seen in *Fig32*.

As explained before, being the SuperVia rail line the backbone of the mobility between the surrounding served areas of Grande Bangu, the radial ônibus network arises as one of the feasible solutions, having the hardcore in the current Bangu train station, close to Bangu Shopping mall, former fabric factory "Fábrica de Tecidos Bangu". That option might reinforce the center of Bangu, at the same time that if it is not deployed correctly, can create a bus saturation in the center, as well as bottlenecks. In order to avoid that, it is intended to have passing ônibus lines, not being Bangu central the terminus of any of those lines, in order to increase the fluidity. This solution requires a certain urban fabric in order to accommodate the network in an efficient way, the same way that as closer to the center the network becomes denser and denser, whereas in the outskirts the system can suffer lack of service due vast areas unserved; which could be solved with a circular line running close to the district boundaries that never reaches the center of the system, despite also requires a certain urban fabric in order to be as efficient as possible. Furthermore, with this solution, several stations in Grande Bangu, where the semi-direct trains does not stop, might be quite underserved by the ônibus network.

In the second scenario proposed, the orthogonal network solution, the SuperVia rail line also arises as the backbone of the mobility between the surrounding served areas of Grande Bangu. It is important to point out that the urban fabric of the Great Bangu area is more suitable for that scenario than the radial one. Despite this is a system that can arise as an asymmetric layout, where some lines have a higher headway than others, for example; this is a system where the physiognomy allows a better distribution of the passengers along the territory and the served area, allowing to create sub-sub-centralities in the other train stations where the semi-direct trains does not stop. It is important to point out the difficulties to cross by ground transportation from the northern part of the SuperVia tracks to the southern part, and vice-versa due the existing infrastructures in shape of bridges over the tracks; being specially challenging for the orthogonal scenario, due the rigidity of this system. Another feature of this system is that can decentralize the area, with the surrounding routes closer to the outskirts of Grande Bangu area.

Other points or areas that can be interesting to take special care of, is Avenida do Brasil and Avenida Santa Cruz, that can help distributing or collecting passengers coming or heading from SuperVia unserved areas; as well as Magalhães Bastos SuperVia and BRT hub, that can link the passengers with all the TransOlímpica BRT axis, mainly heading towards Taquara, Curicica, Jacarepaguá and Barra da Tijuca. Also, in a future, TransOlímpica BRT is supposed to be linked with the TransBrasil BRT stretch, boosting even more the decentralized connections.

In order to have an idea of the potential ônibus users of the new network in Grande Bangu area, it is about to be computed some simple calculations.

As seen before, Grande Bangu area has a total population of 704.046 inhabitants, with a population density of 5.320 hab/km^2. 64,7% of that group belongs to the active population[32122]; which has an official unemployment rate of 39,8%. That means that there are 275.069 workers in the area. 19% of them work from home, meaning that there are 222.806 workers commuting daily.

The seniors over 65 years, representing the 10,2% of the population, which are 71.812 inhabitants, they have got the public transportation for free. 25,1% of the population is under 18, meaning that there are 180.236 inhabitants in that layer, who mostly uses the “Escolar” transportation.

From the previous data, 47,15% of the people commuting use the public transportation. In order to round up numbers, despite the computed people working from home and the unemployed people, it is going to be considered a number of 300.000 users in the working active age, 25.000 seniors and 20.000 people under 18 that are potential users. All in all, it is going to be considered 345.000 potential users in the Grande Bangu area.

_ Radial structure analysis:

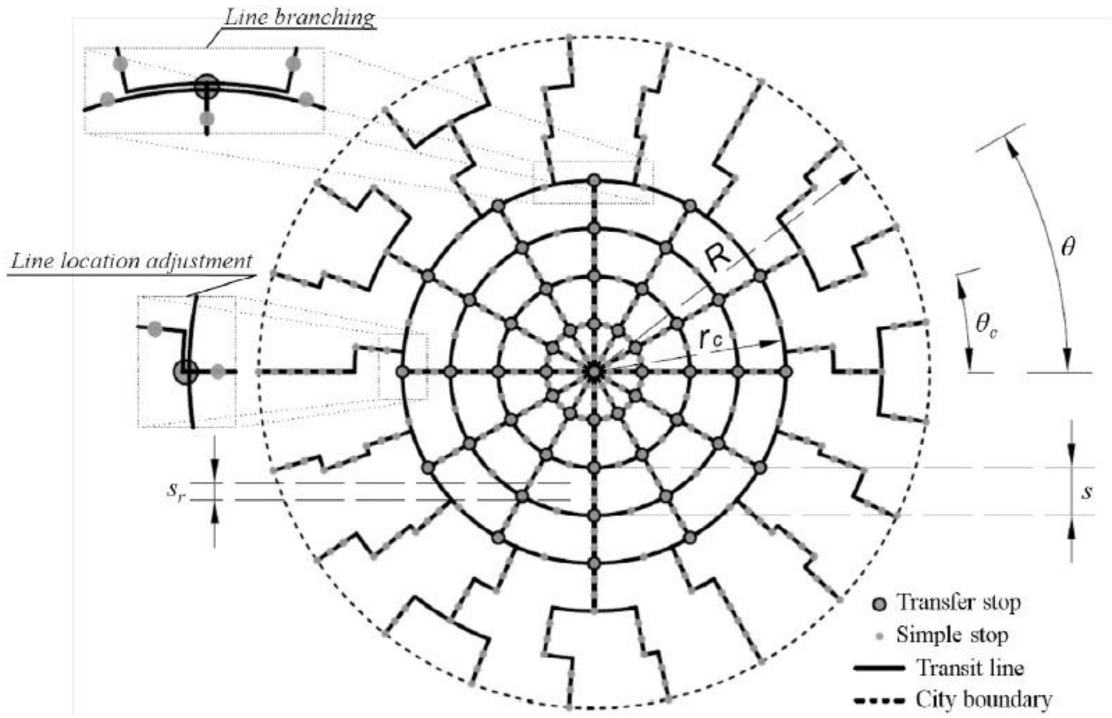

Fig33: Network scheme, geometric decision variables and parameters of the radial hybrid model.

Source: Competitive transit network design in cities with radial patterns _ Badia, H. et al (2011) _[32123]

As seen above in *Fig33*, this model is aimed to be suitable in cities composed with radial axes and concentric rings. The network consists of two types of bidirectional corridors; radial axis, periphery-center-periphery; and circular or ring lines, concentric to the center.

The resulting network configuration is defined by six decision variables. Five of these are spatial variables that determine its topology: the angle between radial lines in the central area Θ (rad), stop spacing in radial lines s_r (km), circular line spacing s (km), the angle between stops of circular lines Θ_c (radians) and the central area size $\alpha= r_c/R$, where r_c (km) is the radius of this area and R (km) of the city. The sixth variable is the headway of service H (h) in the center. The spacings, which are referenced throughout the paper, are equivalent to a linear distance between circular lines or radial stops, and an angle between radial lines or circular stops.

The model seeks to minimize an objective function where the different costs, that the two system stakeholders (agency and users) have to face, are included. All these costs are estimated with geometric probability tools and are expressed in terms of decision variables and characteristics of the territory (size of radius R), transport technology (vehicle capacity C (pax/veh), speed v (km/h), dwell time τ (h) and boarding time τ' (h)), users (demand in rush hour Λ (pax/h) or average hourly λ (pax/h), value of time μ (R$/h) and walking speed w (km/h)), and unit costs of infrastructure $R\$_L$ (R$/km h), operative $R\$_V$ (R$/veh km) and fleet $R\$_M$ (R$/veh h).

In order to compute the network length (L), the following expression has been used:

$$L = \frac{\pi\left[4s\left((1+\alpha^2)R+(1-\alpha)s\right)+\theta\alpha R\left((1+3\alpha^2)R+(1+3\alpha)s\right)\right]}{4\alpha s\theta} \text{(km)}$$

In order to compute the total distance travelled by the fleet per hour (V), the following expression has been used:

$$V = \frac{\pi R[4s+\alpha\theta(2s+(1+\alpha)R)]}{\theta s H} \text{ (veh-km/h)}$$

In order to compute the commercial speed of the vehicles for corridors (V_{com}) without lay-over times, the following expression has been used:

$$V_{com} = \frac{1}{\frac{1}{v}+\frac{\tau}{l_S}+\frac{\tau\prime\Lambda(1+e_T)}{V}} \text{ (km/h)}$$

Being l_s (km) the infrastructure length for each stop; and e_T the average number of transfers that have to be performed by a user to complete his trip.

In order to compute the number of vehicles required (M), the following expression has been used:

$$M = \frac{V}{v_{com}} \text{ (veh-h)}$$

Below, it is about to be analytically computed several useful service variables in order to design the new network.

_ Access time "A": it is computed in function of the spacing of the stops and the walking speed, according to the following expression:

$$A = \frac{\left[40\pi R^2\left[3Rs\left(\frac{2s_r}{s-\theta(1-\alpha^2)}\right)+\alpha\theta(2R^2(3-\alpha^2)-s^2)\right]-(4-\theta)\left[\left(\frac{1-\theta_c}{\theta}\right)\alpha\theta\left(4R^2\left(5s^2(2\alpha^2-1)+4\alpha^2R^2(5-3\alpha^2)\right)-7s^4\right)-\left(1-\frac{s_r}{s}\right)30\alpha^2Rs(2R^2(2-\alpha^2)+s^2\right]\right]}{480\pi wR^3}$$

_ Waiting time "W": it is computed in function of the headway. However, the average waiting time will also have to take into account the passengers that make transfers. The resulting expression is shown below:

$$W = H\left[\frac{2+\alpha^3}{3\alpha} + \frac{(1-\alpha^2)^2}{\pi} - \frac{\theta\alpha^2(2-\alpha^2)}{2\pi} - \frac{\theta(4-\theta)\alpha s(2\alpha^2R^2+3\alpha Rs+s^2)}{12\pi^2R^3}\right]$$

_ Riding in-vehicle, "T":

$$T = \frac{E}{V_{com}}$$

_ Expected number of transfers "e_T":

$$e_T = 1 + \frac{2(1-\alpha^2)^2}{\pi} - \frac{\theta(4-\theta)\alpha s(2\alpha^2R^2+3\alpha Rs+s^2)}{6\pi^2R^3} - \frac{\theta\alpha^2(2-\alpha^2)}{\pi}$$

The optimization model will contain the components described previously, which are computed in function of the decision variables. The objective function would look as follows:

$$min\left\{Z = C_A + C_U = \frac{R\$_L L + R\$_V V + R\$_M M}{\lambda\mu} + \left[W_A A + W_W W + W_T T + W_t\left(\frac{\delta}{w}\right)e_T\right]\right\}$$

Objective function, being subject to:

$$s > 0; H \geq H_{min}; \frac{s}{R} \leq \alpha \leq 1$$

$$O \leq C$$

Despite the remarkable possibilities of the radial structure, the main aim of these expressions is to adapt the hybrid model to become suitable for radiocentric cities with a street pattern composed of radial axes and concentric rings, such as in Moscow, Paris, Madrid, Amsterdam, Milan or Berlin. Grande Bangu could fit this model but with remarkable difficulties due its urban fabric and street pattern. Also, unlike some other areas of the city of Rio de Janeiro and its metropolitan area such as Campo Grande or

Duque de Caxias; Bangu does not have any bus terminal, as well as the remarkable scarcity of available soil in the key points of the district in order to fit the required terminals for that model, which could lead to several bottlenecks and cul-de-sacs in operational terms.
Also, especially in the outskirts of the Grande Bangu area, the new lines may create an excess of turns in the urban fabric, creating major inefficiencies and loss of performance of the new ônibus lines.
Due the reasons exposed above, it is considered highly infeasible and unsuitable to implement this model in the Grande Bangu area.

_ Orthogonal structure analysis:

Due the orography and the urban fabric of Grande Bangu area, with some neighborhoods such as Vila Kennedy, Padre Miguel or some Senador Camará areas being ramifications of the main Grande Bangu area body; the calculus for the orthogonal network is about to be computed like a hybrid bus network structure, as also seen above in the expressions of the radial structure strategy, in order to make sure that the new network is covering as much area as possible, and therefore, as much potential users as possible.

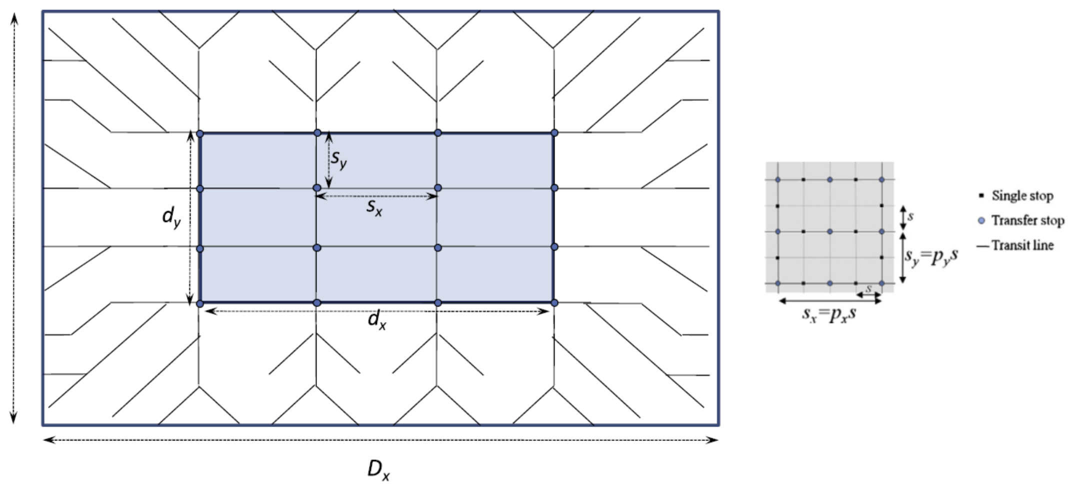

Fig34: Concept for an urban HPB network in a rectangular area | Assymetric lattice of lines and stops.

Source: Design and implementation of efficient transit networks: Procedure, case study and validity test _ Tr Part A. Estrada et al (2011) _[32124]

As seen above in *Fig34*, the service area of the HPB, capital letters standing for "High Performance Bus", is a rectangle of sides D_x and D_y(km), and where $D_x \geq D_y$. The system's core is a bidirectional grid of transit lines with spacing s_x and s_y (km), which covers a rectangle concentric with the service area; as shown in the blue rectangle, it is defined by $d_x \times d_y$. The dimensions of the central rectangle are denoted $d_x \leq D_x$ and

$d_y \leq D_y$. They will be expressed in terms of the dimensionless ratios: $\alpha_x = d_x / D_x$ and $\alpha_y = d_y / D_y$.

The provided information is enough to configure the idealized system and set an operating plan; only five decision variables need to be chosen: H (headway), s, s_x, s_y, α_x, α_y.

In order to compute the network length (L), the following expression has been used:

$$L = \frac{D_x D_y}{2 s_x s_y} \left(s_x + s_y\right)(\alpha_x \alpha_y) \text{ (km)}$$

In order to compute the total distance travelled by the fleet per hour (V), the following expression has been used:

$$V = \frac{2\alpha_x D_x D_y}{s_y H} \left[1 + \frac{D_x}{2D_y}(1 - \alpha_x)\right] + \frac{2\alpha_y D_x D_y}{s_x H} \left[1 + \frac{D_y}{2D_x}(1 - \alpha_y)\right] \text{ (veh-km/h)}$$

In order to compute the gross commercial speed of the vehicles for the vertical and horizontal corridors (V_{cb}) without lay-over times, the following expression has been used:

$$\frac{1}{v_c} = \left[\frac{1}{v} + \frac{\tau}{s}\right] + (1 + e_T)\frac{\Lambda}{V_{\tau'}} \text{ (km/h)}$$

The passenger demand is assumed to be uniformly and independently distributed over the service region with average trip generation rates: Λ (pax/h) during the rush period.

Other important parameters are the trip time added per stop due to bus door operation, deceleration and acceleration, τ (h/stop); and trip time added per boarding passenger τ' (h/pax).

In order to compute the net commercial speed of the vehicles for the vertical and horizontal corridors (V_{cn}) considering lay-over times, the following expression has been used:

$$v_{cgross} = \frac{1}{\left(\frac{1}{cruisevel + \frac{\tau}{s} + \tau'(1+et)\frac{\Lambda}{V} + \frac{laytime}{\frac{3600\,L}{ncorr}}}\right)} \text{ (km/h)}$$

In order to compute the number of vehicles required (M), the following expression has been used:

$$M = \frac{V}{v_{cgross}} \text{ (veh-h)}$$

Below, it is about to be analytically computed several useful service variables in order to design the new network.

_ Access time "A": it is computed in function of the spacing of the stops and the walking speed, according to the following expression:

$$A = \frac{\frac{S_x + S_y}{4} + \frac{S}{2}}{V_w}$$

_ Waiting time "W": it is computed in function of the headway. However, the average waiting time will also have to take into account the passengers that make transfers. The resulting expression is shown below:

$$W = (1 + P_1) \cdot \left(\alpha^2 + \frac{2(1 - \alpha^3)}{3\alpha}\right) \cdot \frac{H}{2} + P_2 \cdot \frac{H}{2}$$

_ Expected number of transfers "Et": the possible transfers in our network are 0, 1 or 2, so the expression to calculate the average value is the following:

$$Et = \frac{s(D_x + D_y)}{D_x \cdot D_y} \cdot \left(-1 + \frac{\alpha}{2} - \frac{\alpha^3}{2}\right) + \frac{1}{2} \cdot (3 - 2\alpha^2 + \alpha^4) + \frac{s^2\alpha^2}{D_x \cdot D_y}$$

_ In-vehicle travel time "IVTT": it is computed with the average trip length of users and the commercial speed. It is important to mention that the commercial speed used does not take into account the layover time at terminals, as users do not perceive these operational time losses. The formula is shown below, where the numerator computes the average trip length:

$$IVTT = \frac{\left(\frac{\alpha^2 d_v^2 + \alpha^2 d_h^2 + 4\alpha^2 d_h d_v}{4\alpha(d_h + d_v)} + \frac{\alpha(d_h + d_v) \cdot \left(1 - \frac{\alpha^2}{2}\right)}{12\alpha^2 d_h d_v}\right) \cdot (1 - \alpha^4) + \frac{\alpha^5(d_h + d_v)}{3} + \frac{(2 - 3\alpha + \alpha^3) \cdot (d_h + d_v)}{4}}{V_c}$$

The optimization model will contain the components described previously, which are computed in function of the decision variables. The objective function would look as follows:

$$min\ Z\ =\ (\pi_v V + \pi_M M + \pi_L L) + \mu \cdot \Lambda \cdot (A + W + T + \frac{\delta}{V_w} Et)$$

Objective function, being subject to:

$$s > 0;\ s_x = p_x s;\ s_y = p_y s;\ p_x, p_y\ integer;\ \frac{s_x}{D_x} \leq \frac{\alpha_x s_y}{D_y} \leq \alpha_y H \geq H_{min}$$

$$O_x \leq C;\ O_y \leq C$$

$$\frac{\alpha_x D_x}{s_x} + \frac{\alpha_x D_x}{s_x} \leq N$$

The coefficients are:

_ π_v: unit distance cost in R$/veh-km
_ π_M: unit vehicle cost in R$/veh-h
_ π_L: unit infrastructure cost in R$/km
_ μ: value of time in R$/pax-h
_ Λ: hourly demand in pax/h
_ δ: equivalent penalty time per transfer (km)
_ V_w: walking speed (km/h)

Lastly, it is required to take into account that the occupancies, both in vertical and horizontal corridors, cannot exceed the capacity of the vehicles. These constraints are introduced in the model as follows:

$$O_v =\ max\ \left\{\frac{\Lambda s(1-\alpha^2)}{4\alpha D_x};\ \frac{\Lambda(1-\alpha^2)^2}{32} + \frac{\Lambda s(3+2\alpha^2-3\alpha^4)}{8\alpha D_x}\right\} \leq\ C$$

$$O_h =\ max\ \left\{\frac{\Lambda(1-\alpha^2)}{4\alpha D_x s};\ \frac{\Lambda(1-\alpha^2)^2}{32} + \frac{\Lambda s(3+2\alpha^2-3\alpha^4)}{8\alpha D_y}\right\} \leq\ C$$

As pointed out before, it is going to be considered 345.000 potential daily users in the Grande Bangu area. According to the SuperVia operational data[32125], it is going to be considered that the peak hour is at 17:00h, carrying during that hour the 11,22% of the daily demand. Off-peak hour is going to be considered around 10:00h to 14:00h, where each hour, the system is carrying the 3,4% of the daily demand. For the Grande Bangu area numbers, 11,22% of the daily demand represents 38.709 users per hour during peak hour; in the other hand, 3,4% of the daily demand represents 11.730 users per hour during off-peak hour. The average demand is going to be considered the potential daily users divided by the total amount of hours the system is running, 20; all in all, that gives us a value of 17.250 hourly users.

In order to run the macro of the excel, several values are about to be explained below.

The dimensions of Grande Bangu area are considered 10,5 kilometers in the "X" axis per 6 kilometers in the "Y" axis.

The capacity of the buses is going to be set at 80, taking into account seated and standing passengers, according to the most used ônibus models in Rio de Janeiro city, the Caio Apache[32126] and Marcopolo Torino.

The cruising speed is defined as the speed between stations, including stops due to traffic and pedestrian interference, it is set at 22 km/h. It is important to not mix "cruising speed" and "commercial speed" concepts. The acceleration rate it is set at 0,5 m/s^2, and the maximal cruising speed is set at 45 km/h.

The boarding and alighting operation, so the time lost per stop, it is set at 28 seconds, after computing a 3 seconds opening and closing doors operation and a 1,5 second boarding and alighting time per passenger. The average walking speed has been set at 3 km/h.

Transferring European economical values to a country like Brazil it has been a challenge, so the unit infrastructure cost has been set at 328 R$/km-h. Meanwhile, the unit distance cost has been set at 22 R$/veh-km; and the unit vehicle cost has been set at 219 R$/veh-h.

The value agreed for the value of time, it is 0,36 **€**/pax-h. This value comes from the recommendation of the World Bank[32127], where it is agreed to be the 30% of the average nationwide wage. In the Brazilian context follows the following expression:

$$Value\ of\ time = \left(\frac{Average\ wage}{Monthly\ working\ hours}\right) \cdot 0'3 = \left(\frac{R\$\ 1200}{176}\right) \cdot 0'3 = R\$/pax \cdot h\ \ 2'05 \approx 0'36€/pax \cdot h$$

Despite can also be computed 220 monthly working hours; 176 working hours has been finally set as the most suitable value for the calculations.

It has been set 100 meters of distance in order to describe the transferring distances between lines in the network.

In time perception weight terms, the following numbers have been set. 1 for the travelling time perception, 1,1 both for access time perception and waiting time perception; and 1,2 for the transferring time perception.

As a constraint, has been set that the minimum time headway cannot be below 5 minutes. Also, both for the horizontal and vertical corridor, it has been set a maximum of 3 kilometers spacing between corridors, the same way that the lay-over time at the end of the lines have been set at 3 minutes, which has the equivalent value of 180 seconds. That constraints are very important in order to get reasonable values, for example in the number of corridors, being super low if we decrease the minimum headway value and rising if we increase the minimum headway value, for example; or decreasing a lot the bus stop spacing with a very low headway, but getting reasonable stop spacing values with a higher headway.

Wrapping the whole thing up, and taking into consideration all the values explained above and the peak hour demand value, the following output has been obtained after running the excel:

A total of 11,54 horizontal corridors, which rounding up, are going to be 12 horizontal corridors. In the other hand, 10 vertical corridors have been found to be the optimal number of lines, having the network a total length of 181,73 kilometers and having transfer stations at every station of the horizontal corridor and every two ônibus stops in the vertical corridor. These lines, are supposed to have an optimal headway of 5 minutes, which was a value constrained by the model, despite without the constraint would have gone way below. The commercial speed is supposed to be 13,68 km/h, which is a very reasonable value, considering other ônibus networks. The optimal spacing between ônibus stops it has been set between 0,52 kilometers.

The capacities that have been found by the excel, is that the average occupancy of the buses running through the horizontal corridors are going to be 80 persons for each vehicle and 70 users for each vehicle running through the vertical corridors.

The average access time has been found to be 13 minutes; the average waiting time, 4,56 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 22,16 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 39,72 minutes. The expected amount of transfers required for each user, is set to 0,82 transfers per user and trip; having a likelihood of 17,7% of not having to do any transfer and a likelihood of 82,3% of having to do one transfer. The likelihood of having to do 2 transfers is 0%.

Considering the off-peak hour demand value, the following output has been obtained after running the excel:

A total of 3 horizontal corridors. In the other hand, 3,57 vertical corridors have been found to be the optimal number of lines, which rounding up, are going to be 4 vertical corridors; having the network a total length of 53,57 kilometers and having transfer stations every two ônibus stops of the horizontal corridor and every three ônibus stops in the vertical corridor. These lines, are supposed to have an optimal headway of 5 minutes, which was a value constrained by the model, despite without the constraint would have gone way below. The commercial speed is supposed to be 15,33 km/h, which is a higher value than in the peak hour scenario. The optimal spacing between ônibus stops it has been set between 0,98 kilometers.

The capacities that have been found by the excel, is that the average occupancy of the buses running through the horizontal corridors are going to be 68 persons for each vehicle and 80 users for each vehicle running through the vertical corridors.

The average access time has been found to be 34,3 minutes; the average waiting time, 3,71 minutes; and regarding the in-vehicle travel time, has been found that the average is going to be 19,48 minutes. All in all, the expected door to door travel time, which accounts for the sum of the access time, waiting time and the in-vehicle travel time, it is supposed to be 57,49 minutes. The expected amount of transfers required for each user, is set to 0,48 transfers per user and trip; having a likelihood of 51,5% of not having to do any transfer and a likelihood of 48,5% of having to do one transfer. The likelihood of having to do 2 transfers is 0%.

As we can see, the network becomes less developed, with just 7 corridors. The stop spacing almost doubles, and the headway does the same reaching a new value of 5 minutes, due the constraint value. These found differences in the optimal network design regarding peak and off-peak demands requires to adapt the service for different periods of the day. To do so, operators can implement different measures such as reducing headways in the off-peak hours, something quite easy as only requires to keep part of the fleet in the depot during the required time. Altering the design of the network during the day would cause confusion in the users, so it is considered as not feasible. It is important to point out that the strategy that the optimization model gives at the output is the most efficient one in economic terms. However, it is feasible to introduce different network designs at nights or at weekends, where the demand is significantly lower than in working days and the users would not have much trouble in getting adapted to the changes.

This calculus has been made in order to give an idea of the general layout of the whole network in the served area, but is not getting into detail of each line. Of course, the number of corridors found, neither the horizontal nor the vertical are intended to be symmetric between them, since it is obvious that the demand and characteristics of each line will change depending on the served areas and the points where it stops, so of course, each line requires to be analyzed individually and be fine-tuned in order to get the best possible performance for each line, but also for the whole network. In summary, the asymmetry is required in order to get the best service in the Grande Bangu area.

Another interesting point would be to analyze the influence of the SuperVia rail services in the area, that have not been taken into account in the model. With the obtained values, some horizontal lines are going to perform as mere back-up services supporting the rail services or lines giving service in the in-between areas of the stations, which would be quite unlikely due the different radius of the influence areas of the train stations and the influence areas of the bus stops. The same way, would be interesting to analyze all the ônibus passing lines through the Avenida Brazil corridor, the backbone of the Carioca private and public transportation network.

Since the headways are quite reasonable, it has not been considered the option of introducing the cadenced schedules in order to soften and make easier the transfers between lines and other means of transport such as the SuperVia rail sevices, reducing the total travel time value. The transferring points between ônibus and SuperVia rail services is one topic that has to be properly treated in order to find a system to get the best solution to get soft transfers, trying to avoid creating confusion to the users willing to transfer.

As explained before, this strategy is intended to be as low-cost as possible and has been designed in a hypothetical future where the integrations between the different public transportation operators and modes of transport in the city of Rio de Janeiro and its metropolitan area, actually works.

In order to improve the whole network, other tougher and expensier actions would be recommended to carry out. The actions that area about to be pointed out below have not been taken into account before to run the calculus seen above in this project.

Regarding the rolling stock, most of the fleet, Brazilian conceived and manufactured, is adapted to the reality of the country, with bumpy roads lacking of maintenance; also, the durability of the vehicles and its devices is conceived to be more important than the comfort for the user, due the general lack of maintenance in the depots. That makes that most of the buses are made with a high floor, making the user go upstairs to jump into the bus during the boarding operation, and making them go downstairs during the alighting operation; making increase the value for the required time for each user to do the boarding and alighting time, worsening the performance of whole system; not to mention the difficulties the handicapped individuals have to face when using the public transportation. Also, the fact that many vehicles only have one, especially the “Executivo” services, or two doors, combined with the intended path the users need to make inside the bus between their boarding operation and their alighting operation, makes the boarding and alighting time slower than it could be. Few vehicles have been acquired so far with three or more access doors available in order to make these operations smoother and faster, increasing the speed of the lines.

Another weak point of the rolling stock is regarding the card validation process, with a complex turnstile device at the entrance in the front of the vehicle. Omitting the point that still many vehicles still have the seat and the needed structure for the seller staff of the operator, when many times the seller is the driver itself, also creating inefficiencies in the system; only the required structure of the turnstile is excessively space-consuming, not only for the device (or tow devices) itself, but also for the anti-fraud structure created around it, creating beam and glass walls that ends up consuming very valuable space into the vehicle, as well as worsens the performance of the system by making the whole validation process excessively slow; playing also a big role the slow speed of the validation machine and the transmission of the information between that device and the turnstile.

Another fact that worsens the system is the lack of semaphoric priorization along the lines, especially in several of the critical points of the city of Rio de Janeiro and its metropolitan area; the same way that the lack of devoted lanes for the public transportation in the vast majority of the city of Rio de Janeiro and its metropolitan area, makes a system that is artificially worsened at the will of the general traffic of the city and its peak and off-peak periods.

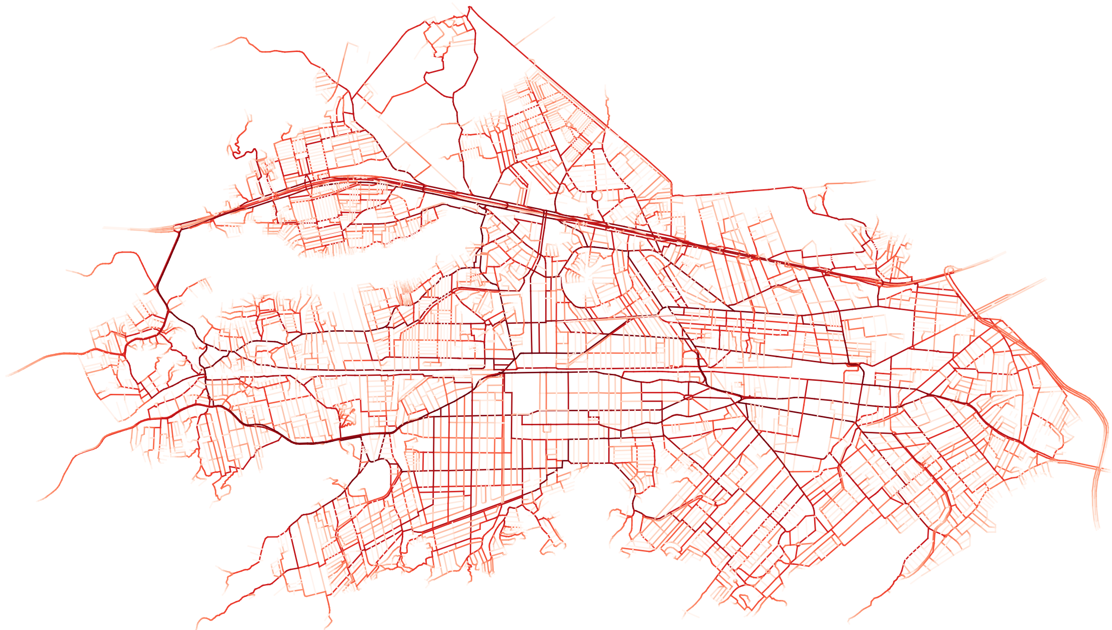

Fig35: Network betweenness analysis of Grande Bangu area.

Source: Katarzyna Sowińska featuring Eloi Pallarès _[32128]

As seen above in *Fig35*, a network betweenness analysis has been performed using QGIS in order to find out which are the most suitable routes for the new bus corridors. The tool has been performed without the pedestrian bridges in the area and with a radius equivalent to 5.500 meters, which is approximately half of the distance between the eastern-most and the western-most side of the analyzed area. The network betweenness analysis is a mathematical tool where through an algorithm, the shortest paths in a network can be found.

With the same tool, it can also be observed the reason why the hybrid orthogonal ônibus network has been selected over the radial ônibus network. The configuration of the streets and the urban fabric makes the hybrid orthogonal network more efficient and avoids several problems, especially in terms of bus traffic jam in the central region of the Grande Bangu area, at the same time that can reach further territories to be served, especially in the periphery.

As seen, the movements between the eastern-most and the western-most territories are remarkably easier than the movements between the northern-most and the southern-most territories. This phenomenon is originated due the tough horizontal existing barriers in the territory such as the Avenida Brasil and the SuperVia railroad tracks, with just five bridges suitable for cars available, with odd geometries, as seen in dark red in the image above. Crossing from the northern to the southern side of the tracks is not easy either, with also very few pedestrian bridges available. The same way, crossing Avenida Brasil in the north-south axis, is not easy either; specially for pedestrians, since most of the times the most feasible option is to get into the Avenida de Brasil central highway and drive until one of the half roundabouts (“retorno”) in order to reach your destination, creating big detours in the possible routes inside the district. In summary, the whole district can be divided in three big horizontal slices; the area in the south of the SuperVia railroad tracks, the area between Avenida Brasil and the SuperVia railroad tracks, and the area in the north of the Avenida Brasil.

All in all, makes the deployment of the new orthogonal network remarkably tricky and challenging, especially the new corridors in the north-south axis, especially in the rush hour scenario; where the vehicles will need to do big detours and challenging routes in order to get to the closer bridge from the expected corridor, as well as the right bridge, considering that not all the bridges in the area have two ways for the cars.

It is important to mention that due lack of time and available tools, this project has not been able to research and perform neither an induced demand model nor a new generation and attraction mathematical model in order to get a higher accuracy on the new ônibus network outputs; which is one of the reasons why does not make sense to run a model in order to find out the precise output of one particular line of the new network. The lack of data to fine-tune the model makes it very unsuitable to run, the same way that the operator must balance the options of the number of corridors and fleet size between the peak hour and the off-peak hour scenario, the same way that the high asymmetry in the new corridors makes it even harder.

Despite all the paragraphs above, a good start in order to fine tune the corridors of the new network, is using the QGIS tool used below in the *Fig36*.

Fig35: Walking attraction reachability analysis of Grande Bangu area.

Source: Katarzyna Sowińska featuring Eloi Pallarès _[32129]

As seen above in the map, a walking attraction reachability analysis has been performed using QGIS in order to find out which are the most powerful potential sub-centralities in the region, taking into account the walking speed and its reachability. The tool has been performed with a radius equivalent to 1.000 meters. As seen, the denser is the network, the strongest is the reachability, the same way that can be observed how weak is the effect of the several pedestrian bridges in the area, despite the bridges itself becomes interesting links, as seen above in dark blue.

Another point that is interesting to take into account in order to reorganize the city in order to have a more efficient ônibus network, is the way the streets are organized and how many turns the ônibus needs in order to fulfill their route. With routes going along one-way streets, the routes from point A to point B are quicker, so the vehicle can do a higher mileage per hour, than the routes going along double-way streets; despite this other option can be improved if the route avoids having left turns in the double-way streets[321210].

In order to have a more accurate idea both of the actions and the economic feasibility and suitability, would be strongly recommended to take into account other parameters and consequences of the implementation of the new ônibus network such as the externalities, positive and negative ones or the greenhouse gas emissions and its possible reduction by the implementation of the new network. Also, would be very convenient to give details of the output of the computation of the values of the creation of at least one single line, which becomes very complicated due the reasons explained above, but also due the difficulty to find accurate routes for the new corridors, in the framework of this project. Unfortunately, due the limited amount of available time and the vast variety of topics treated in this thesis, makes very unfeasible to give answer to all of these very interesting and necessary topics.

3.2.2 | Economic feasibility:

As said before, it is important to point out that the strategy that the optimization model gives at the output is the most efficient one in economic terms. It is not going to be taken into account the value of all the externalities, positive or negative.

Just to remind what has been pointed out before, the unit infrastructure cost has been set at 328 R$/km-h. Meanwhile, the unit distance cost has been set at 22 R$/veh-km; and the unit vehicle cost has been set at 219 R$/veh-h.

The value agreed for the value of time, it is 0,36 **€**/pax-h. This value comes from the recommendation of the World Bank[32127], where it is agreed to be the 30% of the average nationwide wage. In the Brazilian context follows the following expression:

$$Value\ of\ time = \left(\frac{Average\ wage}{Monthly\ working\ hours}\right) \cdot 0'3 = \left(\frac{R\$\ 1200}{176}\right) \cdot 0'3 = R\$/pax \cdot h\ \ 2'05 \approx 0'36€/pax \cdot h$$

Despite can also be computed 220 monthly working hours; 176 working hours has been finally set as the most suitable value for the calculations.

With the value of time of the workers depicted above, it is clear that in this model the operational cost is going to be more relevant than the value of the time of the workers in Rio de Janeiro city and its metropolitan area.

_ Taking into consideration all the expressions explained above and the peak hour demand value, the following output in terms of economic feasibility has been obtained after running the excel:

The total operational cost, defined by the expression seen above “min Z”, becomes 251.255 R$/h, being the optimal value found by the iterative process, and being the sum between the user cost, 24.773 R$/h; and the agency cost, 226.483 R$/h. If we do a simple calculus dividing the total operational cost (251.255 R$/h) by the expected users during peak hour (38.709), we end up having an expected fare of R$ 6,49 per trip. Currently, the actual fare for the ônibus services is R$ 4,05.

The total distance travelled by the fleet per hour (V), it has been found to be 4.361,5 veh-km/h; with a total fleet (M) of 319 veh-h.

_ Taking into consideration all the expressions explained above and the off-peak hour demand value, the following output in terms of economic feasibility has been obtained after running the excel:

The total operational cost, defined by the expression seen above “min Z”, becomes 100.150 R$/h, being the optimal value found by the iterative process, and being the sum between the user cost, 35.616 R$/h; and the agency cost, 64.530 R$/h. If we do a simple calculus dividing the total operational cost (100.150 R$/h) by the expected users during off-peak hour (11.730), we end up having an expected fare of R$ 8,54 per trip. Currently, the actual fare for the ônibus services is R$ 4,05.

The total distance travelled by the fleet per hour (V), it has been found to be 1.285,7 veh-km/h; with a total fleet (M) of 84 veh-h.

Of course, the model used above follows the economic model from several cities in Europe, being quite distant of the economic model followed in most of the cities in Brazil, where almost the whole cost is assumed by the user, which at the same time is mainly assumed by the employer of every individual. Specifically, every company with 10 or more employees, the company is supposed to assume the value of the commuting ride done by the employee, in case that the monthly cost of the rides is over 6% of the wage of the employee. In that case, where the influence of the Prefeitura or the State Government (regional government, not federal government), is just in the retired commuters and students, we can almost assume that almost all the cost will be assumed by the user, being almost the whole value obtained by the "min Z" iterative process.

As seen before, the disparity of fares between the peak and the off-peak hour and the lack of subsidies of the tender process of the Prefeitura da Cidade do Rio de Janeiro, brings us to the "Câmara de Compensação"[3221] system where the inequalities between lines and operators are intended to be sorted by the unification of the fares, where the surplus of the most profitable ones compensates the least busy ones.

3.3 | Active Mobility:

Another key point in order to reinforce the new centralities in Rio de Janeiro city and its metropolitan area is the active mobility; not only to commute straight from the origin to the destination, but also to create new little hub and spoke sub-systems, allowing a better flexibility and enabling the user to get quicker commuting times by segmenting its ride by the most suitable modes of transport for each occasion. As seen above in the *Table 1*, *Table 2*, *Table 3* and *Table 4*; the use of public transportation or even active mobility is a widespread habit among Cariocas and Fluminenses. Not only in the percentage of daily commuters, but also in absolute numbers and compared with the population of the city of Rio de Janeiro, Baixada Fluminense, Leste Fluminense area and other municipalities of Grande Rio area.

As seen below in *Fig37*, like many other modes of transport, the bike lane system is way much developed in Zona Sul and Barra da Tijuca than in the other areas of the city of Rio de Janeiro and its metropolitan area, where the density and the quality of the infrastructure is remarkably more mature than in Zona Norte and Zona Oeste. Despite that fact, even in Zona Sul area, the bike lane system lacks of a clear structure and interconnectivity in order to be clearly understood and used as a major player in the overall mobility of the city, other than a leisure mean of transport; specially the further the user goes from the seafront.

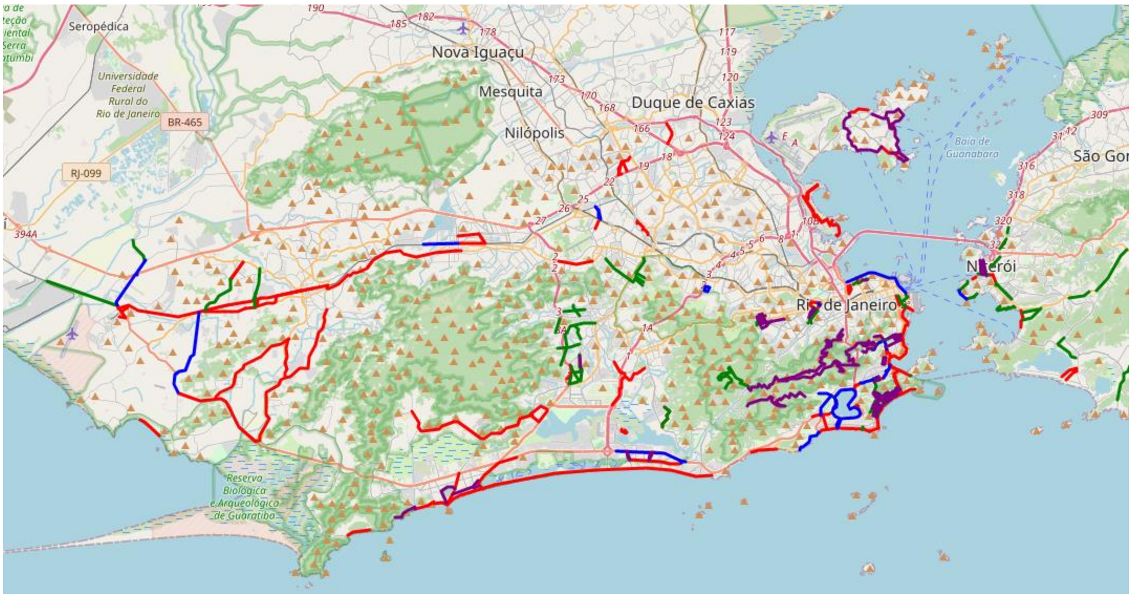

Fig37: Current bike lane system in Rio de Janeiro city and its metropolitan area.

Source: Transporte ativo | Mapa Cicloviário do Rio de Janeiro _[331]

The situation in Zona Norte and Zona Oeste is even more dramatic, even completely lacking of a single bike lane, or just having an unconnected axis linking vast areas without any kind of capillarity into the region in order to make more attractive the use of the bike. Also, many times the drawn lines, are just shared lanes with the motorized vehicles, making the ride even more uncomfortable and even dangerous for the bike users. It is also important to mention than in the existing bike lanes, many times becomes hard to ride the bike due the lack of clarity in terms of distinguishing the pedestrian and the biking area, as well as the everlasting trash mountains present in the marked tracks.

As seen below in *Fig38*, the Grande Bangu area is not an exception in the Zona Oeste area, so only has two unlinked bike lanes not really connecting any key point of the area, other than the main SuperVia station in Bangu and the main shopping mall in the area. Also, the parking infrastructure is extremely weak in the whole region, only with a decent bike parking density close to the main SuperVia station in Bangu and the main shopping mall in the area. It is important to mention, just to give a scale of the status quo of the active mobility in the region, that the area displayed below, is larger than the built area of the city of Barcelona.

Fig38: Current bike lane system in Grande Bangu area.

Source: Transporte ativo | Mapa Cicloviário do Rio de Janeiro _[331]

Since the shared biking service is not still active in the Grande Bangu area, the best option so far to boost the active mobility in the region is the creation of big safe private bike stations in key areas of the area in order to boost the multimodality. Before the pandemic, SuperVia used to offer a service called "Bicicletários"[332] in few stations of its network such as Japeri, Santa Cruz, Engenheiro Pedreira and Saracuruna; but also in the train stations of Bangu and Realengo, both in the Grande Bangu area. The service used to be free of charge for those users willing to use the train services, but with a cost of a daily R$ 1 for those individuals only willing to use the bike stations without being users of the rail services; and the registration was made via the existing public transportation card "Riocard Mais". The current SuperVia legislation is extremely restrictive in terms of boarding bikes into the convoys.

Reopening these bike stations in the key points of the city becomes an urgent action in order to boost the active mobility in the new sub-centralities, but also opening new ones becomes a must in this strategy.

Fig39: Current shared bike system network in Rio de Janeiro city.

Source: Bike Itaú _ tembici | Rio de Janeiro _[333]

As seen above in *Fig39*, the current shared bike system in Rio de Janeiro city is only available in Zona Sul, Centro, Barra da Tijuca and Tijuca (located in Zona Norte), apart of two stations in Madureira area. The location of the stations has a direct correlation with the location of the highest household income of the city, but also with the development of the bike lane system in the region. Unlike many other cities, where leisure is a marginal activity in the shared bike service, in Rio de Janeiro, the leisure plays an important role in the usage of the service, specially during weekends and days off.

Grande Bangu area becomes a really interesting case, as well as challenging, in the city of Rio de Janeiro due its orography, mainly flat and with barely geographical accidents present in the area. To give an idea, the longitudinal section describes a virtually flat slope, going from 34 meters above the sea level in the eastern SuperVia train station of Realengo to an elevation of 45 meters above the sea level in the SuperVia train station of Senador Camará, located 6 kilometers western the first station. In terms of transversal section, mainly being the SuperVia rail tracks the lowest point of the valley, and the western the user goes the more tough is the topography, the highest points in the northern and southern points of the area are around 60 meters above the sea level. All in all, makes Grande Bangu area a very suitable region to boost the active mobility. Due the current low density of population, area, distances and low density of services in the vast majority of the area, it is considered that the most feasible active mobility mode of transport to be incentivized is the bike, rather than walking.

The expansion of the shared bikes to the other parts of the city, could play a major role in the strategy of boosting the active mobility in the new centralities, helping to create an idea of the five or fifteen minute city that turns the neighborhoods into a more livable and with added value areas. Of course, the introduction of this service, but also with the introduction of new private bike parkings, must be linked with the improvement of the biking infrastructure in the region, in order to make the rides easier and safetier. This concern is going to be treated in the upcoming "Urban planning and urban design" point of this project.

Another important point in order to boost the active mobility, as said before in this project, is he integration with the other public transportation services of the city. Currently Bike Itaú can be linked with the metrô card "GIRO", but not with the integrated card "Riocard Mais"; forcing the users to have two cards if they need to use several modes of transport. This topic brings us to the introduction of the so-called "Mobility as a Service, MaaS", where in order to make more attractive and pleasant the journeys and their planification, it is proposed the introduction of technological tools, mainly apps providing continuous information to the user that helps him or her to commute in an intermodal and integrated public transportation network and system. In summary, making the user experience easier using the new digital tools in terms of planning the optimal ride, paying or even sharing information. Currently, most of the information regarding the public transportation in Rio de Janeiro city and its metropolitan area is splitted between several apps such as Moovit app, Cartão Digital + Riocard Mais app, Riocard Mais app, Giro Metrô app, Bike Itaú app, Google Maps app, Waze app, 99 app and Uber app, among others. Trying to gather most of this apps in just one, at least the public ones, would help the user planning its ride, the same way would be convenient to create a solid and reliable public app in order to look for the optimal ônibus and BRT ride.

All in all, the actions explained above would be convenient not only to reinforce the new centralities, but also to help decreasing the greenhouse gas emissions (GHG), but also in order to help fighting the sedentary lifestyle of the average population, having remarkable benefits for the healthcare of each individual, but also helping to decrease the tension of the healthcare system by boosting a sportier lifestyle among the inhabitants of these regions; all in all, positive externalities for the whole system.

As said before, some of the solutions of the problems pointed out in this point, are going to be treated in the upcoming "Urban planning and urban design" point of this project, right below.

3.4 | Urban planning and urban design:

This point is going to be fully devoted to the urban planning and urban design of the Grande Bangu area, intrinsically linked with the local weather in the area, which as said before, its remarkably warm; but also to the biodiversity of the area and the active mobility. In summary, the main aim of this point is to tackle some of the active mobility and the warm episode issues in the area, all in all, trying to upgrade the welfare of the inhabitants by upgrading the urban design.

Most of the actions are intended to be as low-cost as possible, in order to have an immediate application and effect on the ground; but some other proposed actions will require a larger budget, complex solutions and a longer implementation time; specially those ones related with the biodiversity, due the advanced state of degradation of the current green infrastructure and its water streams in several fields of study.

3.4.1 | Green corridors:

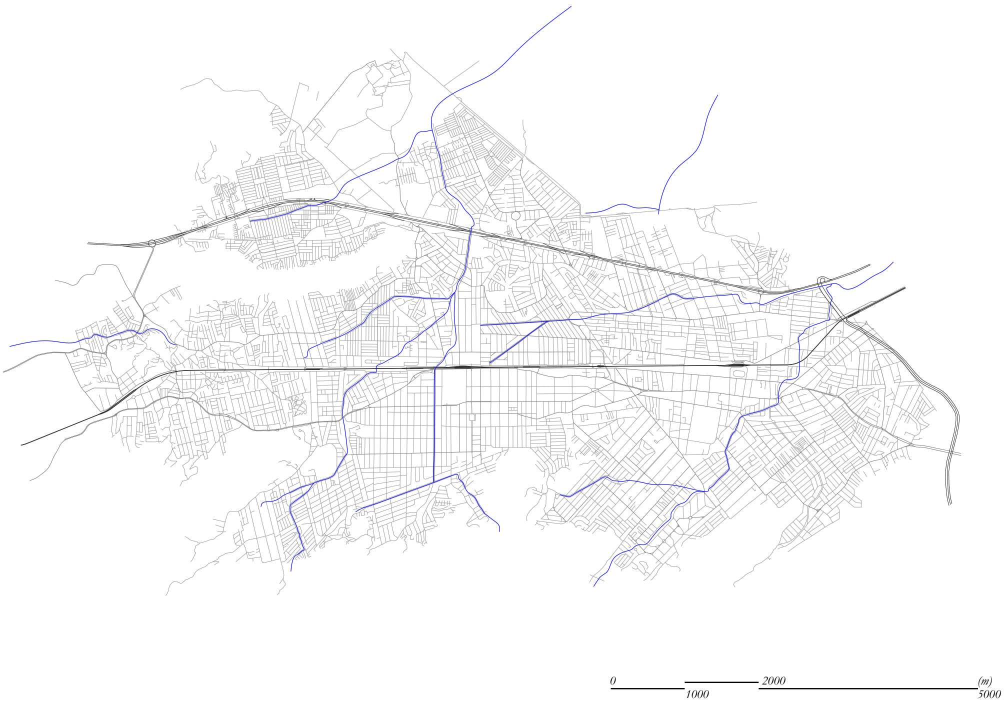

Fig40: Grande Bangu area and its rivers and tributaries.

Source: Own elaboration _[3411]

Despite Grande Bangu area it is surrounded by big green areas such as the Parque Estadual da Pedra Branca in the south and Parque Natural Municipal da Serra do Mendanha in the north, the built area has a really high construction density; which means that the area really lacks of green areas.

After analyzing the area, as seen above in *Fig40*, several rivers were found running through the neighborhoods, all of them, with high levels of pollution and contamination due the lack of respect to the nature and, in some cases, due the lack of sewer infrastructure. Most of these rivers and tributaries, end up flowing into the Guanabara Bay in the border between Rio de Janeiro city and Duque de Caxias, or in Gramacho, a neighborhood in Duque de Caxias.

Some of the stretches were already integrated in the urban fabric of Grande Bangu area by turning them into some kind of canal, many times, even covered, not having a proper urban design for the inhabitants to enjoy them, but some other were just forgot, letting the people leaving there to build their homes very close to the rivers, without respecting the biodiversity that a river can bring to the area, but also without respecting the needed safety distance in case of a flooding emergency. In summary, there is two identified scenarios for the rivers in the Grande Bangu area; in one hand the case where the Prefeitura assumed the management of the river by turning it into a canal-like structure; and in the other hand, the river just raffling between the poorly planned buildings in the area.

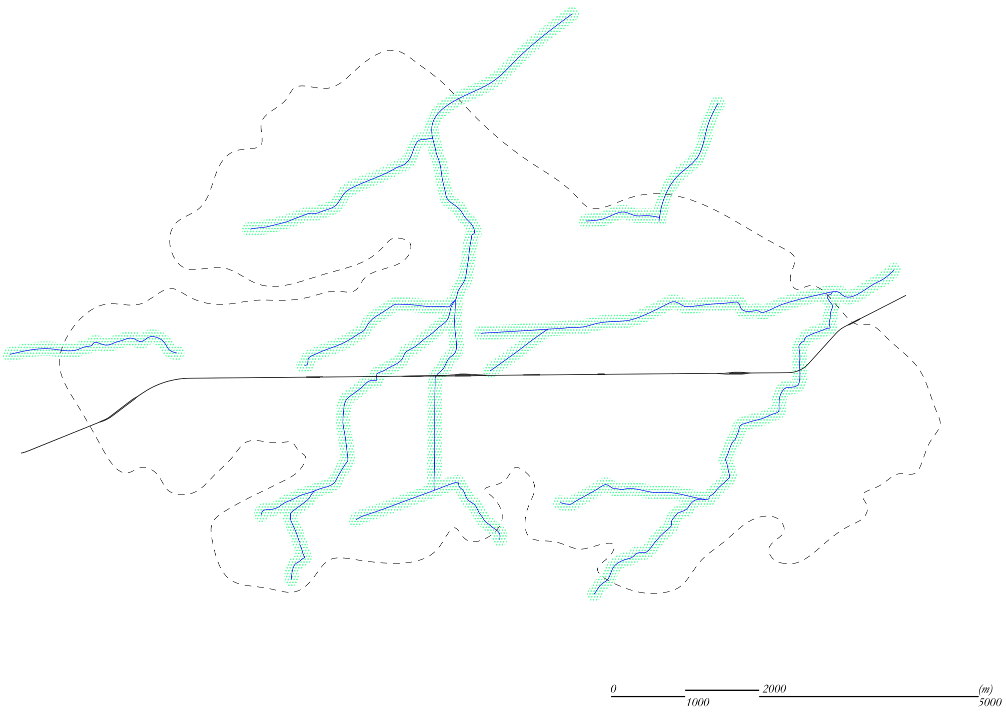

Fig41: Grande Bangu area and its current green corridors.

Source: Own elaboration _[3412]

As seen above in *Fig41*, the rivers in the Grande Bangu area enables the region to create a new layer of infrastructure, green, in that case; by having green corridors not only linking both parks in the northern and southern boundaries of the district, but also enabling the inhabitants to enjoy this infrastructure, but even becoming a new structure for the active mobility in the region. Of course, a big valorization work is required to make these corridors attractive to the inhabitants in the area and to the biodiversity, capillarizing the nature into the region. Of course, the introduction and valorization of these rivers, is not only linked to the water management, but also to the associated vegetation; all in all, helping to create climatic shelters, but also contributing to decrease the overall temperature in the region.

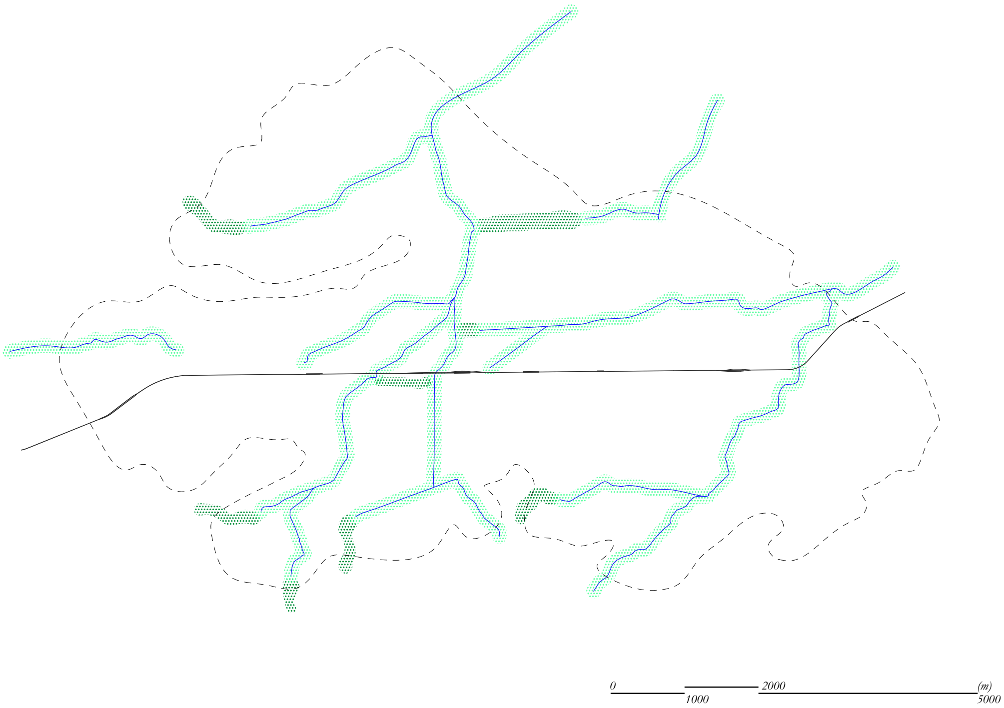

Fig42: Grande Bangu area and its feasible green corridor connections.

Source: Own elaboration _[3413]

In order to reinforce this new infrastructure, two clear actions are proposed.

First of all, the extension of those corridors that currently ends close to the boundaries of the district, until reaching the big natural areas surrounding Grande Bangu area. That action will not be easy at some points, specially in these ones close to the Parque Estadual da Pedra Branca, in the south; but will enable the link between the biodiversity in the north and the south, as seen above in *Fig42*.

Second of all, when possible, linking the corridors into the built area in order to create new biodiversity links and new active possibilities for the inhabitants in the area, boosting the capillarity of these green areas into the district.

These actions, not only will create new northern-southern and eastern-western axis and logics, but also new diagonals and new axis and possibilities in the area.

The actions described above needs to be linked to the sanitation of the water, as well as the surrounding areas, which requires actions in the water stream of the river, but a whole new structure in terms of sewers of some of the surrounding buildings. Also, has to be linked with the garbage management of the area in order to avoid turning the water streams into landfills. Linked to those actions, has to be also performed a recheck of the flora and fauna associated tot the rivers, in order to clean the area of non-vernacular species, and the reintroduction of those ones belonging to the natural environment of the area. These similar experiences have been carried out in other points of the planet such as in the Besòs river, in the outskirts of Barcelona; or in downtown Seoul, with the urban renewal of the Cheonggyecheon river.

The total length of the Grande Bangu area river system is 42.193 meters, which would require a whole team of architects, urban planners and engineers in order to carry out an exhaustive renewal plan. In this project are about to be given some pattern ground floor and section plans in order to try to solve tackle that problem.

Different scenarios are about to be given in order to tackle the status quo and propose different possible pattern solutions, which are going to be as accurate as possible, at the same time that as dimensionless as possible to fit as many places as possible. The optimal final solution is intended to be one of the proposals, or a combination of some of them.

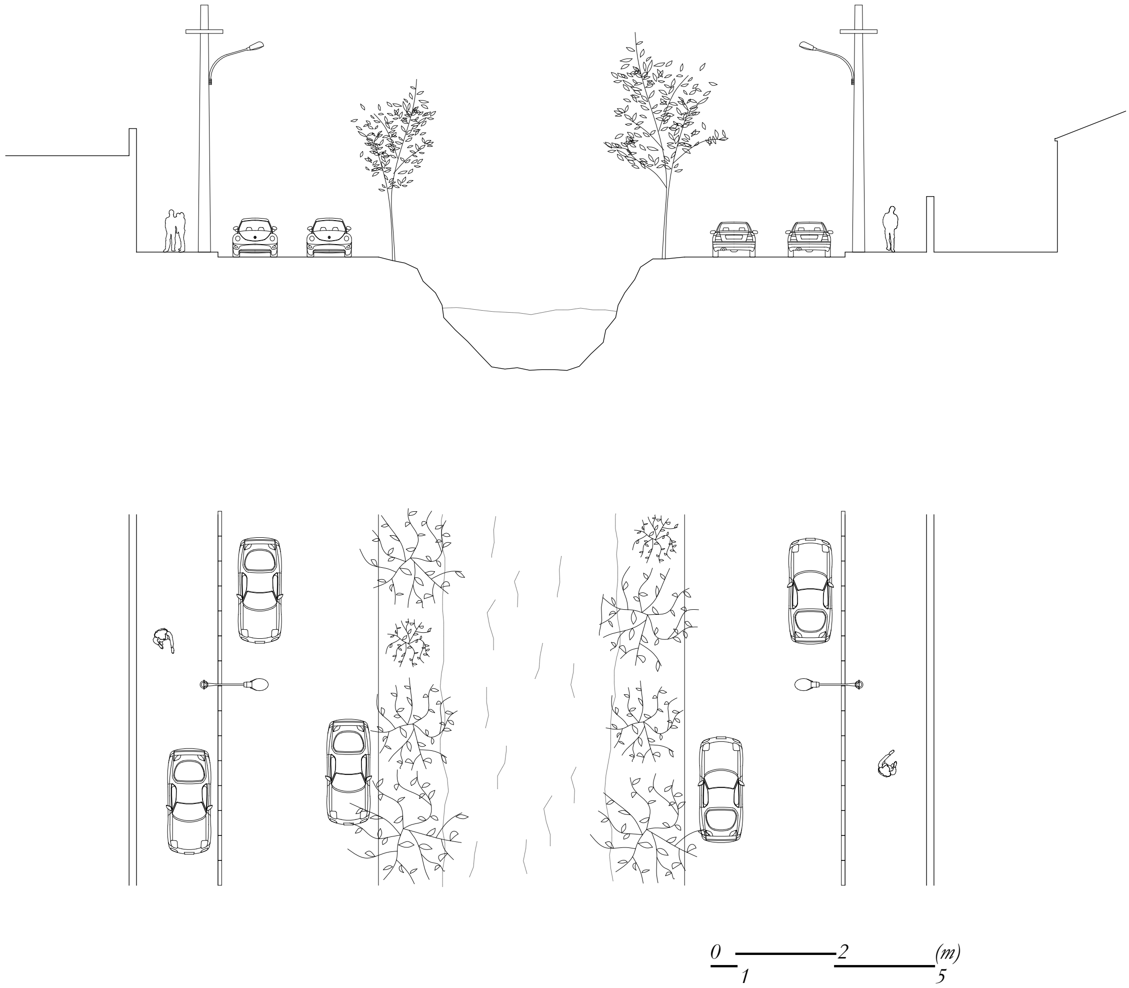

Fig43: Scenario 1 _ Status quo.

Source: Own elaboration _[3414]

As seen above in the *Fig43*, a first scenario was identified with the water stream in the middle of the section of the street without any canalization on any structure carrying the water. In this scenario, the river and the surrounding green it is treated like a mere leftover in the section of the street and in the urban design. This kind of water stream can be found in places such as in the “Rua André João Antonil”, in Realengo.

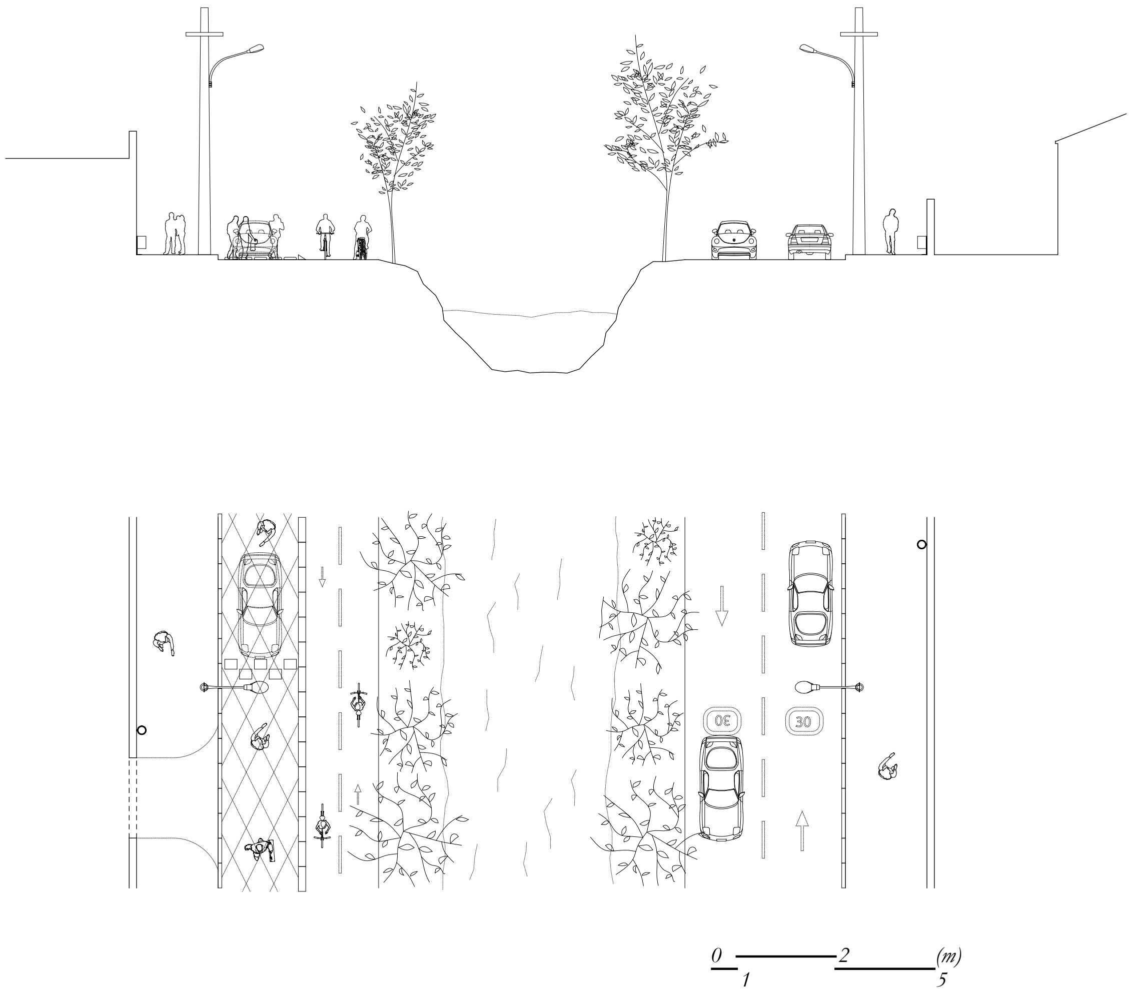

Fig44: Scenario 1 _ Proposal.

Source: Own elaboration _[3415]

As seen above in the *Fig44*, the proposal for the first scenario becomes a low-cost re-organization of the street, combined with some tactical urbanism. Currently, the car infrastructure is doubled and the double lane with of both sides of the river is not actually used as a double lane street, but as an anarchic one lane street. With the reorganization, just one of the sides becomes a double way street in order to free the other side of the water, where the closest lane becomes a double way bike dedicated lane, and the lane that is closer to the homes becomes an extended sidewalk for pedestrians, with the possibility of access to the emergency vehicles and the neighbors owning a parking spot in their homes.

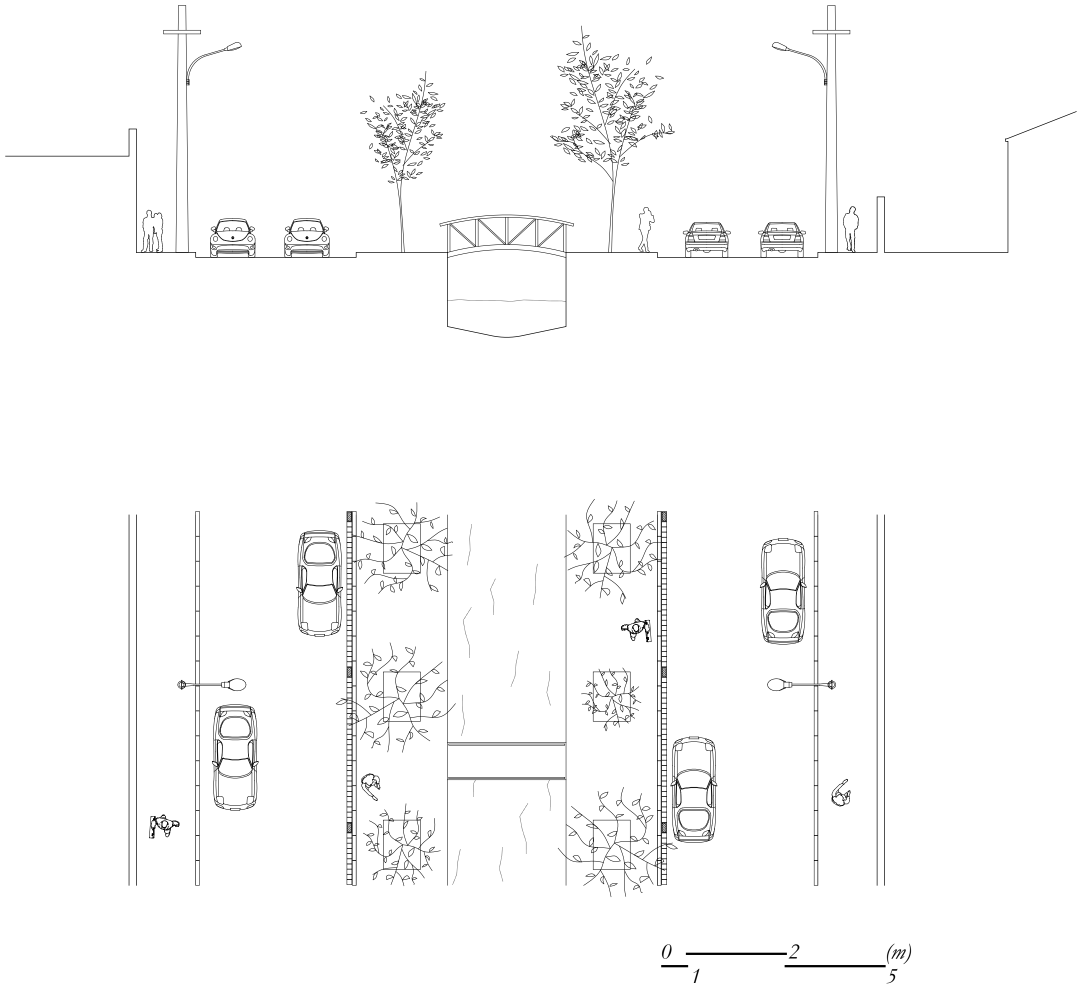

Fig45: Scenario 2 _ Status quo.

Source: Own elaboration _[3416]

As seen above in the *Fig45*, a second scenario was identified with the water stream in the middle of the section of the street with a trench-like concrete canalization carrying the water. In the design of that section, there is a little bit more of sensitivity for the user experience and not only we can find sidewalks, but also little pedestrian bridges to go from one side to the other of the river. This kind of water stream can be found in places such as in the "Avenida Ribeiro Dantas", in Bangu.

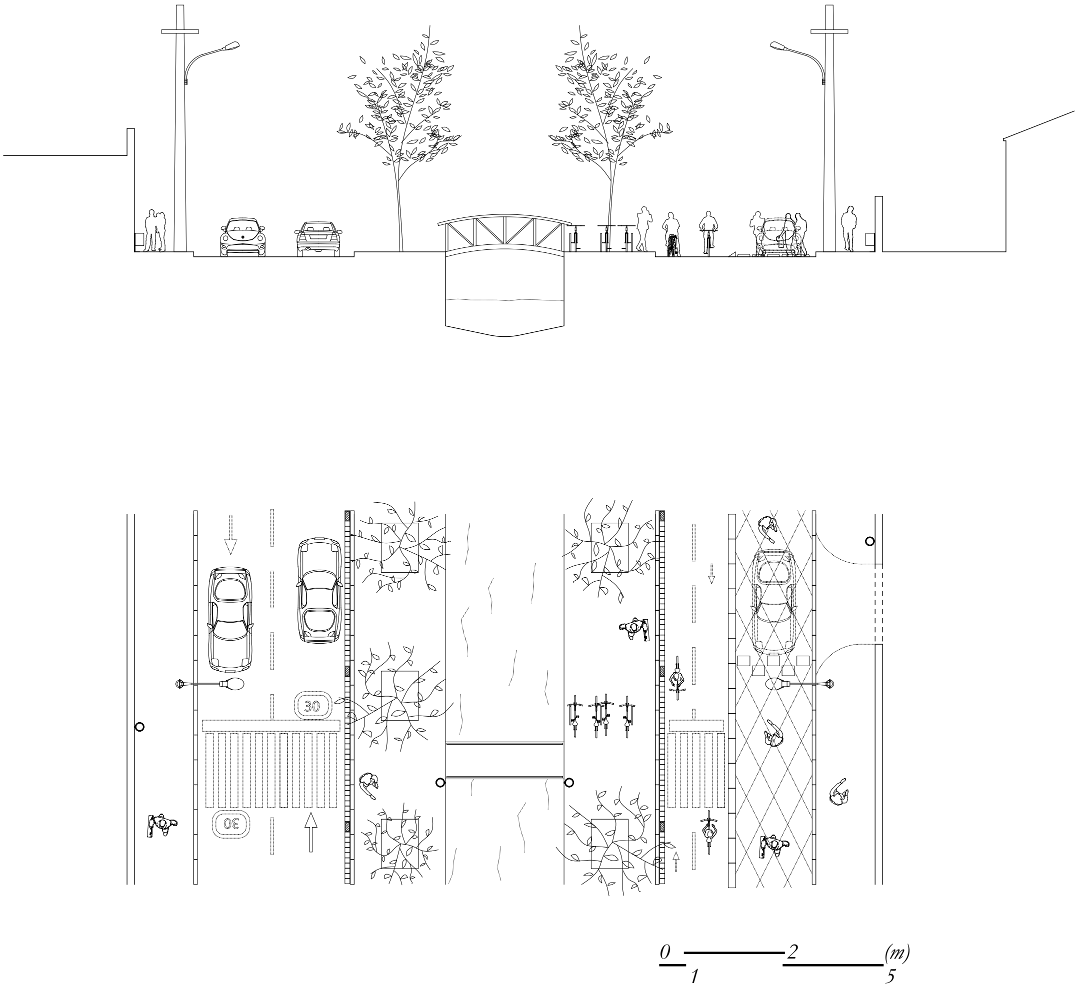

Fig46: Scenario 2 _ Proposal 1.

Source: Own elaboration _[3417]

As seen above in the *Fig46*, the first proposal for the second scenario becomes a low-cost re-organization of the street, combined with some tactical urbanism. Currently, the car infrastructure is doubled and the double lane with of both sides of the river is not actually used as a double lane street, but as an anarchic one lane street. With the reorganization, just one of the sides becomes a double way street in order to free the other side of the water, where the closest lane becomes a double way bike dedicated lane, and the lane that is closer to the homes becomes an extended sidewalk for pedestrians, with the possibility of access to the emergency vehicles and the neighbors owning a parking spot in their homes. All in all, enables the pedestrians to better enjoy their walks close to the river, but also makes easier and safer to cross the available bridges. This would be the cheapest proposal for this scenario.

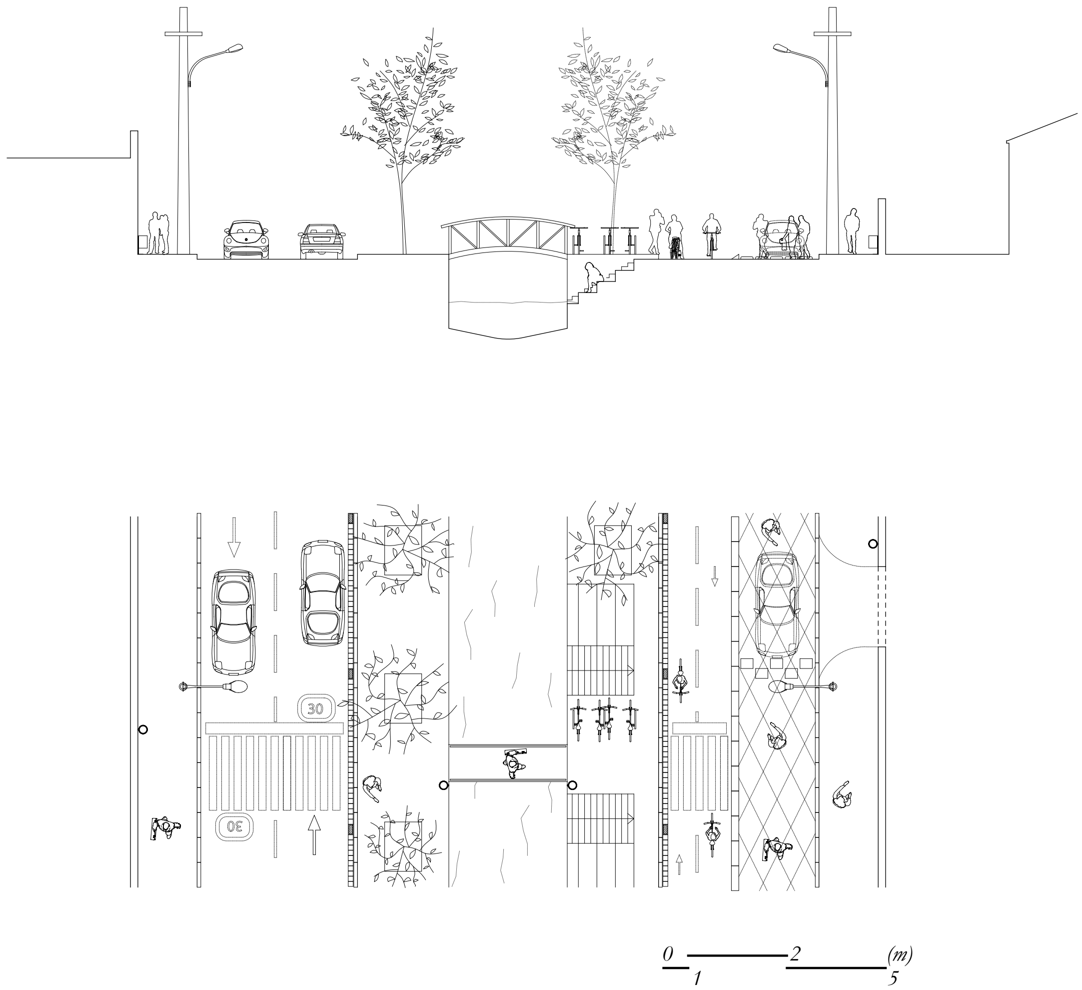

Fig47: Scenario 2 _ Proposal 2.

Source: Own elaboration _3418

As seen above in the *Fig47*, the second proposal for the second scenario shares many characteristics with the first proposal in terms of reorganization of the street and car managing, but adds the possibility to create stadium-like bleachers by subtracting part of the existing concrete, and of course, if needed, the introduction of new materials, preferentially biomaterials in order to reduce the greenhouse gas emissions. That action is intended to be an attraction strategy for new users in order to use the public space in a more active way, understanding it not just a place to go through, but also a place to rest and enjoy. This would be the expensiest proposal for this scenario. Of course, both proposals of scenario 2 can be combined in order to get a better result.

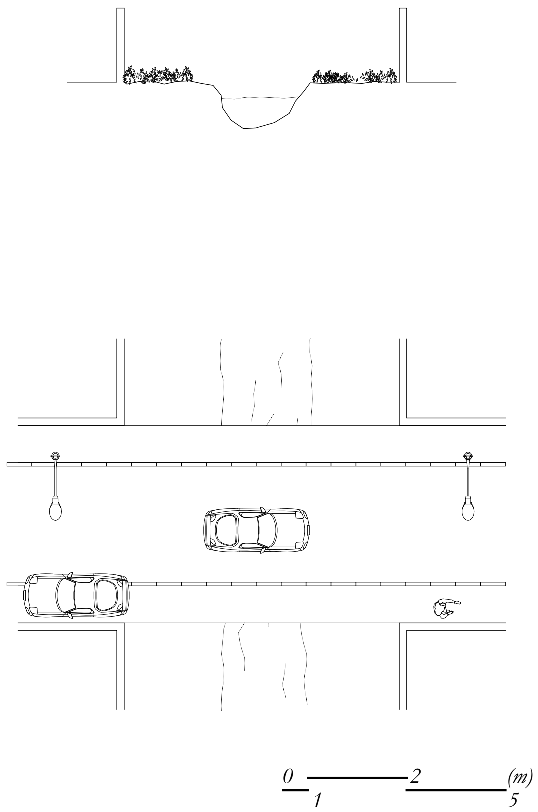

Fig48: Scenario 3 _ Status quo.

Source: Own elaboration _[3419]

As seen above in the *Fig48*, a third scenario was identified with the water stream crossing transversally the street without any canalization on any structure carrying the water, having a river bed wide enough to allocate something else than just mud and vegetation. This kind of water stream can be found in places such as in the “96 R. D.”, in Senador Camará; specially in the periphery of the studied area, so with a very low population and activity density, and where there is an obvious lack of urban design and where the water is understood as an urban leftover.

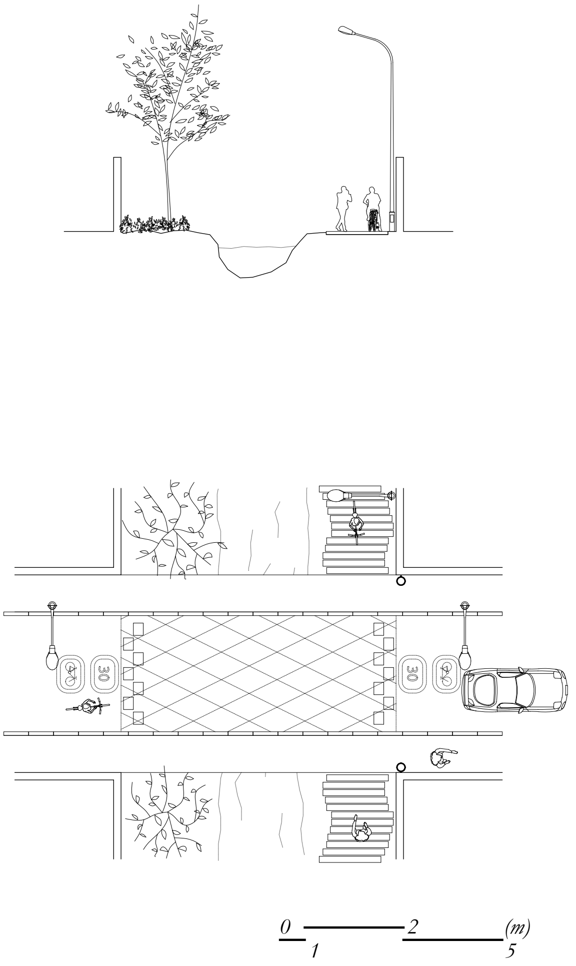

Fig49: Scenario 3 _ Proposal.

Source: Own elaboration _[34110]

As seen above in the *Fig49*, the proposal for the third scenario becomes a low-cost re-organization of the crossing street, combined with some tactical urbanism. Currently, the car infrastructure consists in a double lane with street which is not actually used as a double lane street, but as an anarchic one lane street. With the reorganization, the street becomes a one-way street with a bike prioritization and with special protection for the pedestrians willing to cross the street in order to use the riverbed as a boulevard. One of the sides of the river bed becomes a leisure boulevard in order to create new routes and possibilities to the inhabitants of the area and other users.

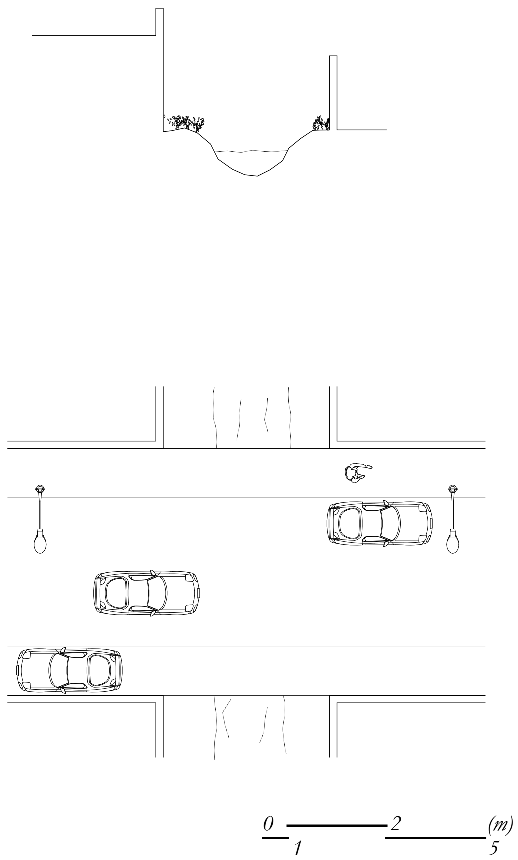

Fig50: Scenario 4_ Status quo.

Source: Own elaboration _[34111]

As seen above in the *Fig50*, a fourth scenario was identified with the water stream crossing transversally the street without any canalization on any structure carrying the water, having a river bed not wide enough to allocate something else without a major architectural or engineering intervention. This kind of water stream can be found in places such as in the “Rua Birigui”, in Realengo; specially in the periphery of the studied area, so with a very low population and activity density, and where there is an obvious lack of urban design and where the water is understood as an urban leftover.

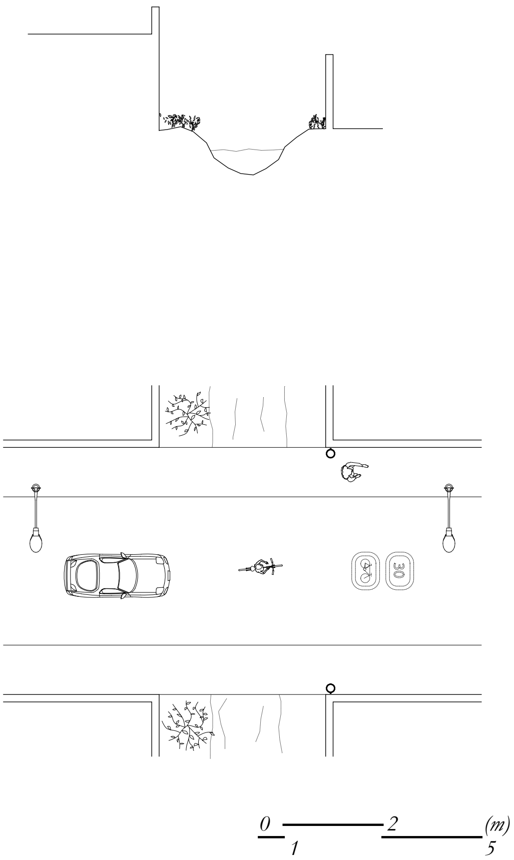

Fig51: Scenario 4 _ Proposal 1.

Source: Own elaboration _[34112]

As seen above in the *Fig51*, the first proposal for the fourth scenario becomes a very low-cost re-organization of the crossing street, combined with some tactical urbanism. Currently, the car infrastructure consists in a double lane with street which is not actually used as a double lane street, but as an anarchic one lane street. With the reorganization, the street becomes a one-way street with a bike prioritization. The water stream of the river and its river bed remains the same, further than the required cleaning of the river and the river bed, as well as the autochthonous fauna cataloguing and, if needed, reintroduction.

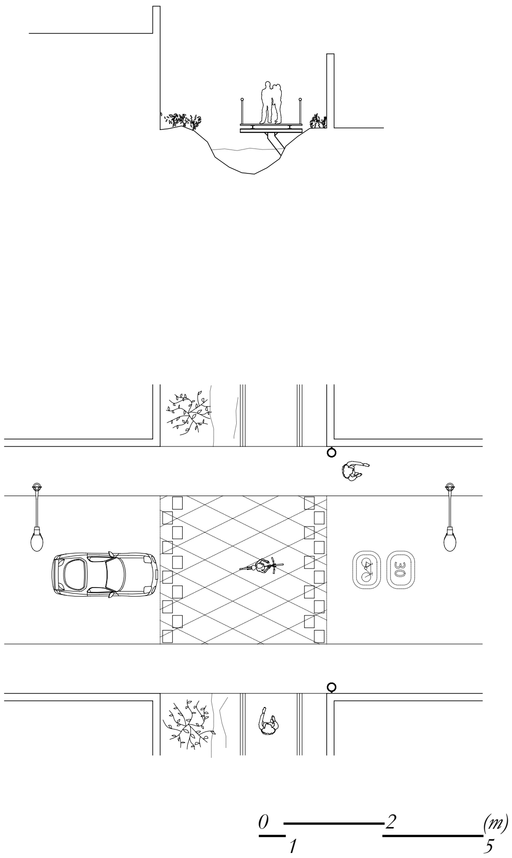

Fig52: Scenario 4 _ Proposal 2.

Source: Own elaboration _[34113]

As seen above in the *Fig52*, the second proposal for the fourth scenario becomes a low-cost re-organization of the crossing street, combined with some tactical urbanism. Currently, the car infrastructure consists in a double lane with street which is not actually used as a double lane street, but as an anarchic one lane street. With the reorganization, the street becomes a one-way street with a bike prioritization and with special protection for the pedestrians willing to cross the street in order to use the riverbed as a boulevard. A bridge-like platform is intended to be installed over the river in order to become a leisure boulevard creating new routes and possibilities to the inhabitants of the area and other users. This bridge-like platform, of course, it is the most expensive proposal from the ones proposed so far. Of course, both proposals of scenario 4 can be combined in order to get a better result.

3.4.2 | Streets:

As seen above in the previous point, not only the green corridors have been analyzed and have proposals, but also, since some of these green corridors belongs to existing streets or crosses other streets, also some of the street scenarios have been already treated; so, in this point it is intended to analyze and give proposals for other street typologies that can be found in the Grande Bangu area. As said above, the Grande Bangu area is larger than the built city of Barcelona, which means that there is a plenty of scenarios that can be found; in this point it is going to be researched some patterns that can classify different streets. Different scenarios are about to be given in order to tackle the status quo and propose different possible pattern solutions, which are going to be as accurate as possible, at the same time that as dimensionless as possible to fit as many places as possible. The optimal final solution is intended to be one of the proposals, or a combination of some of them.

The main bottlenecks in order to improve the streets is, in one hand, the width of most of the streets, which are very narrow, even the main ones, having a more or less standard width no matter if the street is located in the center or in the outskirts of the analyzed area. Another bottleneck, in the other hand, is the lack of continuity in the network and how many streets that are supposed to have continuity, are splitted by the railroad tracks or by an apple. Another major drawback that has been tried to sort out is the lack of regularity in the sections of the streets, having random widths for the lanes and sidewalks along the analyzed stretches.

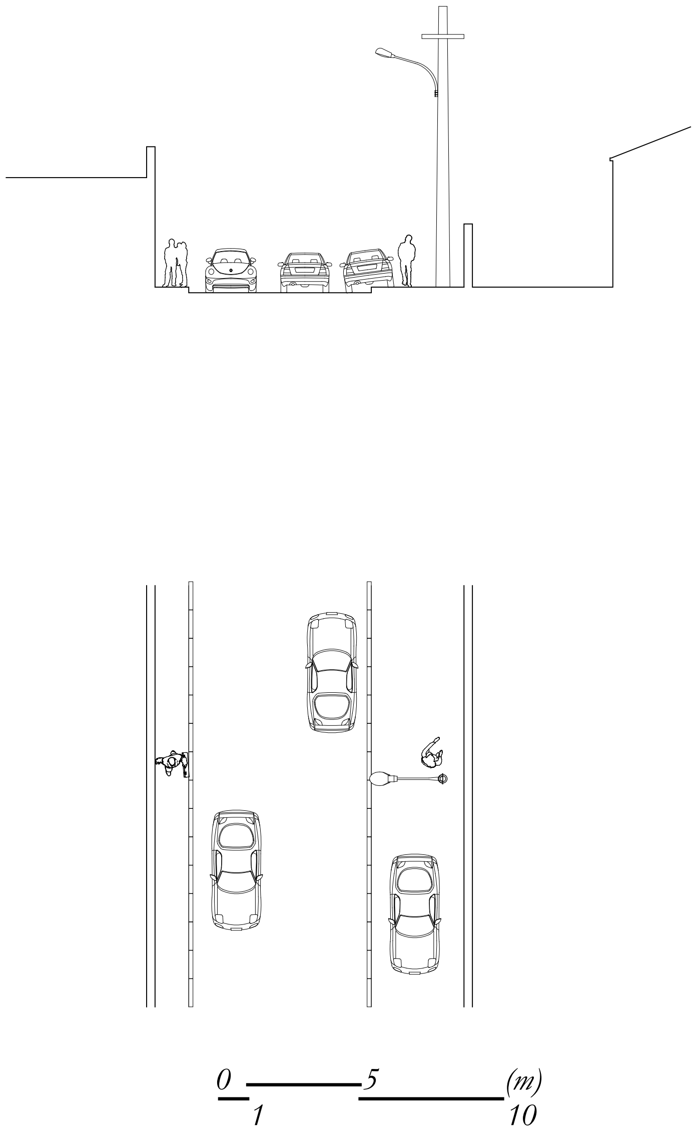

Fig53: Scenario 1 _ Status quo.

Source: Own elaboration _[3421]

As seen above in the *Fig53*, a first scenario was identified. It consists to a simple street with a narrow section, where the sidewalks have an anarchic and irregular width, and the asphalt area it is intended to be a double way street. The facilities and the urban design are really weak

Despite the scenario depicted above represents the vast majority of the streets in the analyzed area, this kind of section can be found in places such as in the “Rua Belisário da Souza”, in Padre Miguel.

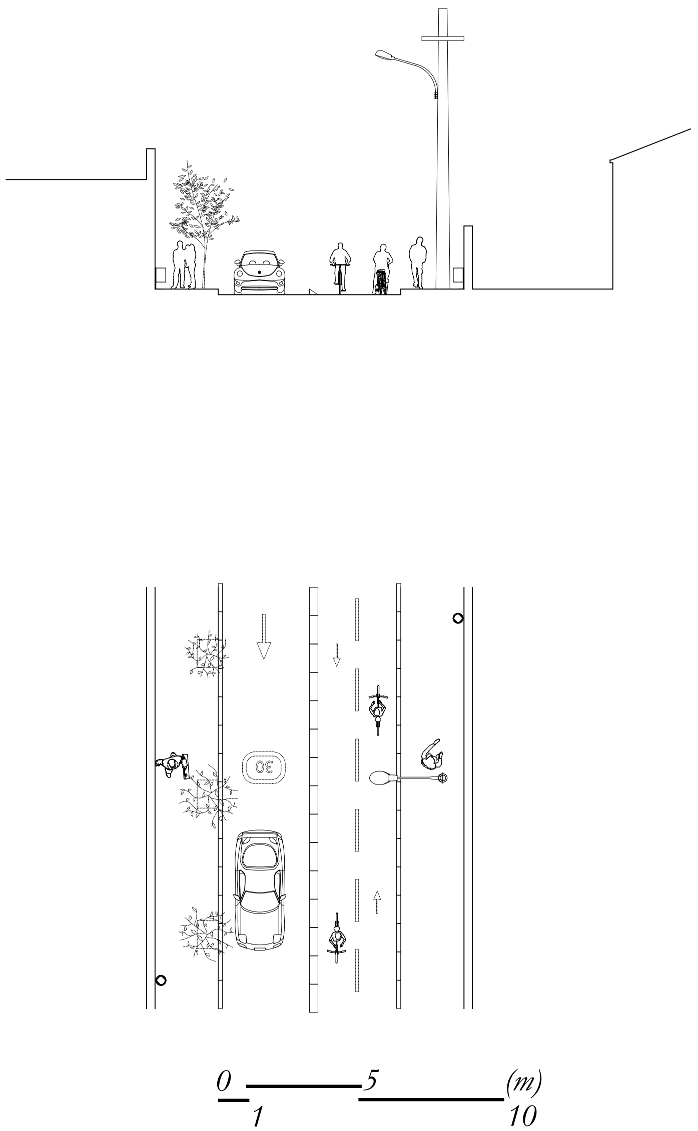

Fig54: Scenario 1 _ Proposal 1.

Source: Own elaboration _[3422]

As seen above in the *Fig54*, the first proposal for the first scenario emerges as a low-cost re-organization of the street, combined with some tactical urbanism. Currently, the car infrastructure is dominating the section of the street. With the reorganization, half of the asphalt area, which has been centered, is devoted to cars, whereas the other lane becomes a double way bike dedicated lane. Also, by centering the tarmac area, a new dimension of the sidewalks emerges, allowing to even plant some trees in order to give shade to the users, as well as breaking the monotonous vision of the current street.

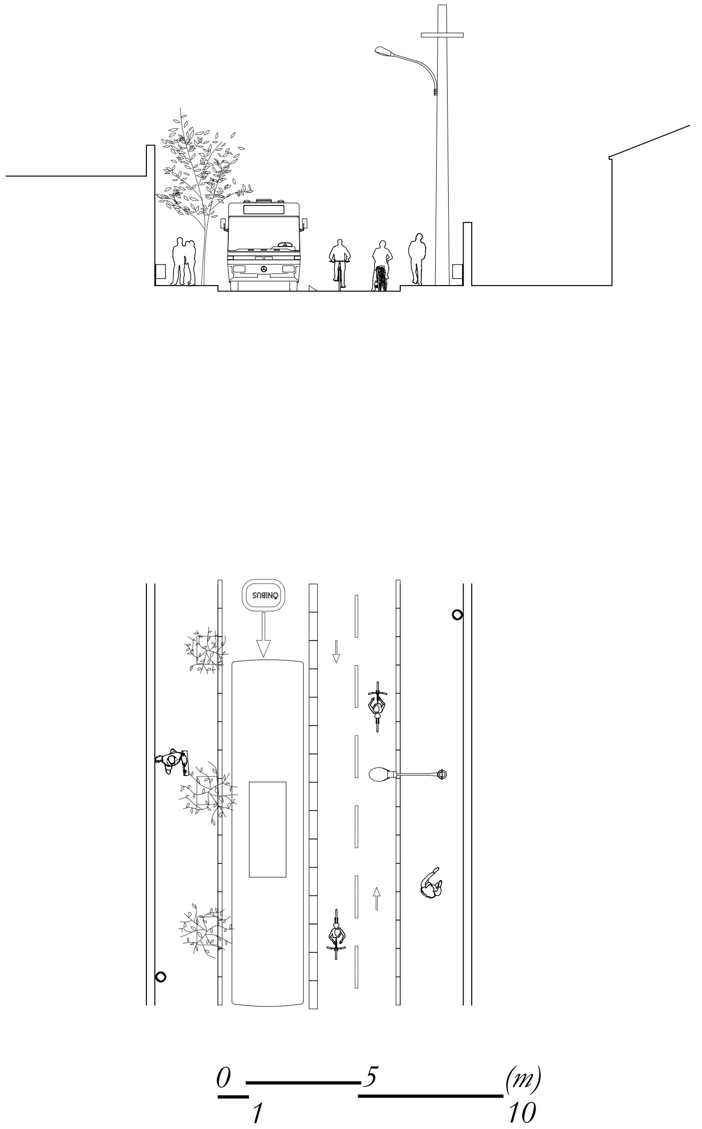

Fig55: Scenario 1 _ Proposal 2.

Source: Own elaboration _3423

As seen above in the *Fig55*, the second proposal for the first scenario emerges as another low-cost re-organization of the street, combined with some tactical urbanism. With the reorganization, half of the asphalt area, which has been centered, is now devoted to an ônibus dedicated lane; whereas the other lane becomes a double way bike dedicated lane. Also, by centering the tarmac area, a new dimension of the sidewalks emerges, allowing to even plant some trees in order to give shade to the users, as well as breaking the monotonous vision of the current street.

This sample could be replicated in more central areas of the region, boosting both the public transportation and the active mobility.

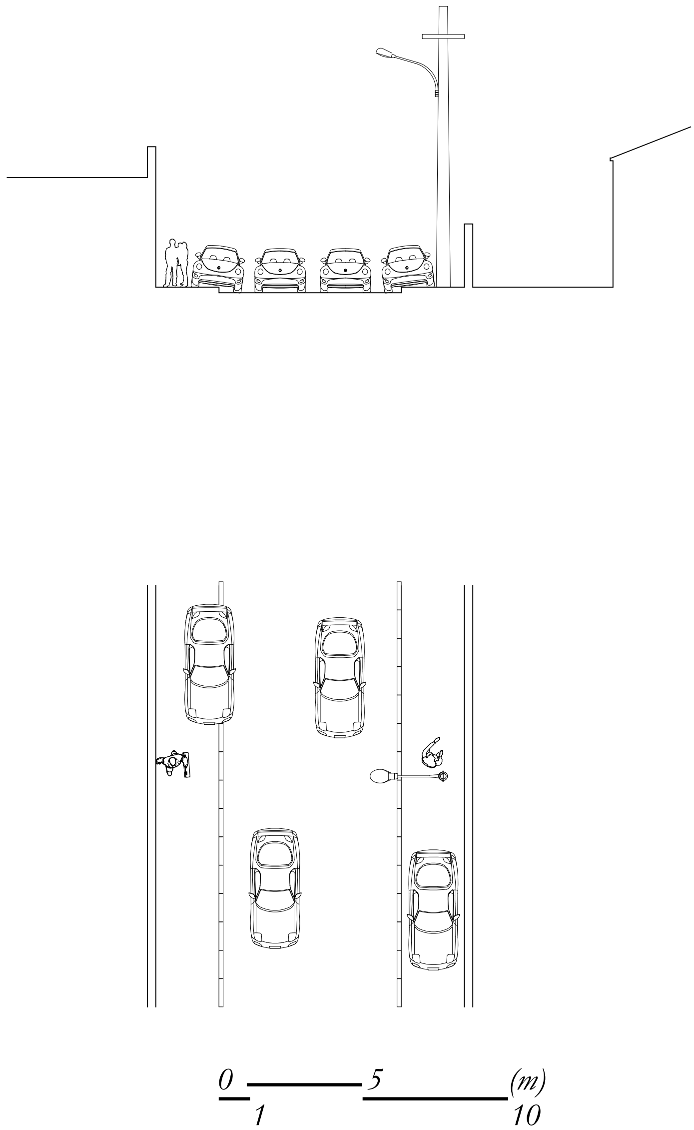

Fig56: Scenario 2 _ Status quo.

Source: Own elaboration _[3424]

As seen above in the *Fig57*, a second scenario was identified. It consists to a simple street with a narrow section, where the asphalt area it is intended to be a double lane one-way street. The facilities and the urban design are really weak

The scenario depicted above represents a big number of the streets in the analyzed area. This kind of section can be found in places such as in the “Rua Boiobi”, in Bangu.

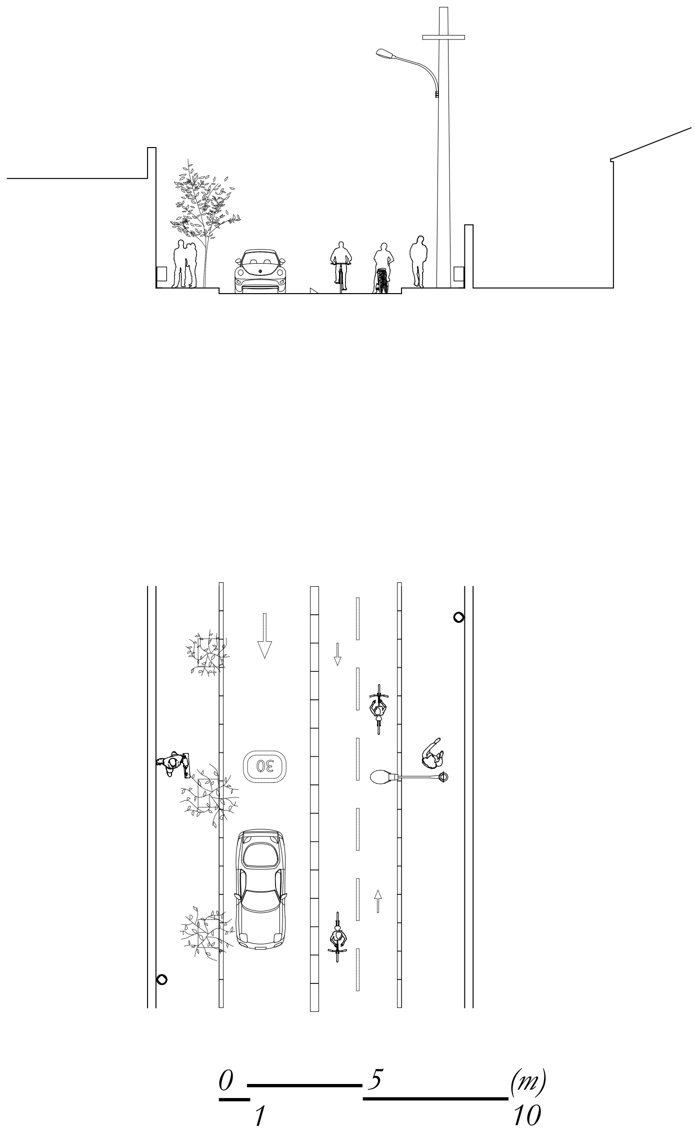

Fig57: Scenario 2 _ Proposal 1.

Source: Own elaboration _[3425]

As seen above in the *Fig57*, the first proposal for the second scenario emerges as a low-cost re-organization of the street, combined with some tactical urbanism. Currently, the car infrastructure is dominating the section of the street. With the reorganization, half of the asphalt area, is devoted to cars, whereas the other lane becomes a double way bike dedicated lane. Also, some trees are introduced in order to give shade to the users, as well as breaking the monotonous vision of the current street.

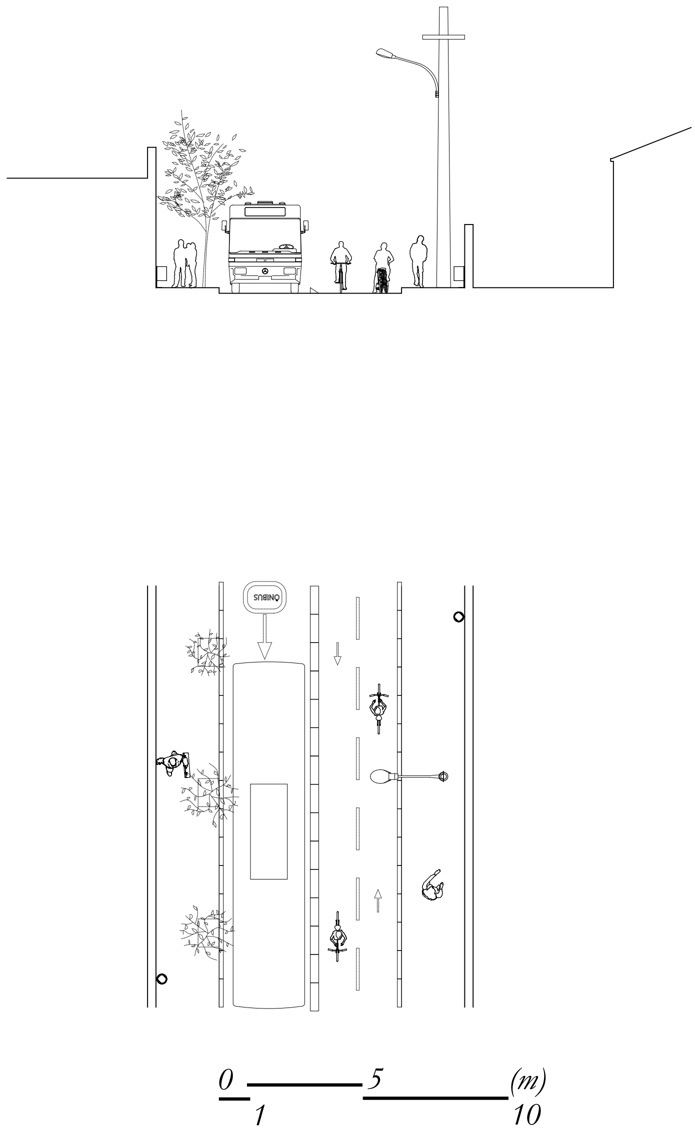

Fig58: Scenario 2 _ Proposal 2.

Source: Own elaboration _[3426]

As seen above in the *Fig58*, the second proposal for the second scenario emerges as another low-cost re-organization of the street, combined with some tactical urbanism. With the reorganization, half of the asphalt area, is now devoted to an ônibus dedicated lane; whereas the other lane becomes a double way bike dedicated lane. Also, some trees are introduced in order to give shade to the users, as well as breaking the monotonous vision of the current street.

This sample could be replicated in more central areas of the region, boosting both the public transportation and the active mobility.

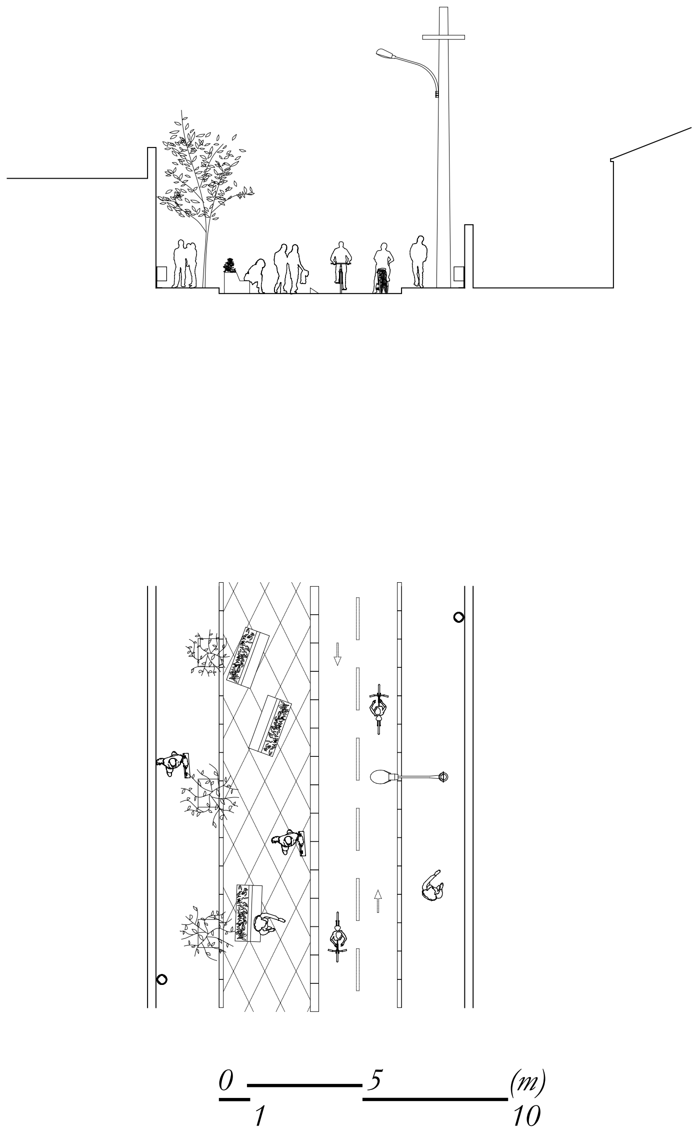

Fig59: Scenario 2 _ Proposal 3.

Source: Own elaboration _[3427]

As seen above in the *Fig59*, the third proposal for the second scenario emerges as another low-cost re-organization of the street, combined with some tactical urbanism. With the reorganization, half of the asphalt area, is now devoted to the pedestrians, with some furniture with plants on it; whereas the other lane becomes a double way bike dedicated lane. Also, some trees and vegetation are introduced in order to give shade to the users, as well as breaking the monotonous vision of the current street.

This sample could be replicated in even more central areas of the region, boosting the active mobility and making the city more liveable.

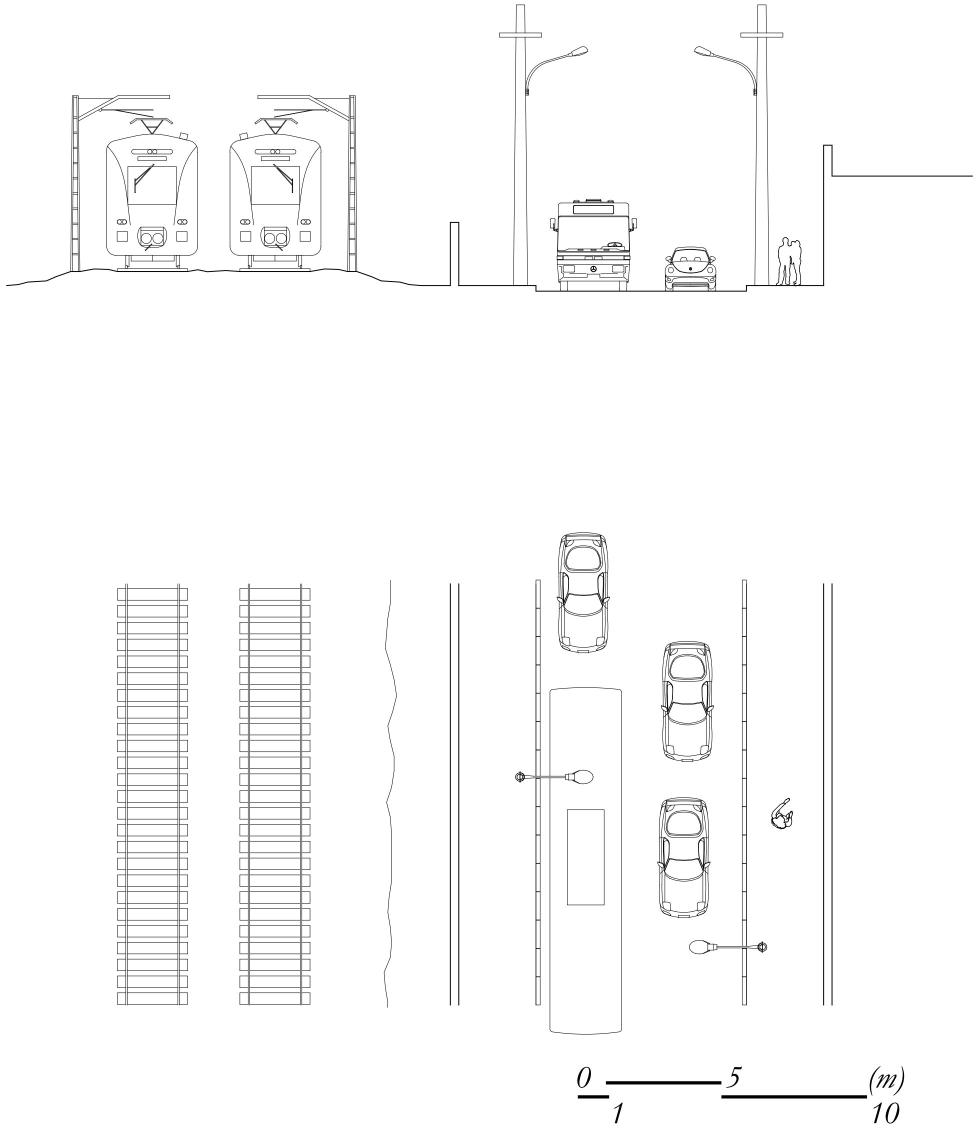

Fig60: Scenario 3 _ Status quo.

Source: Own elaboration _[3428]

As seen above in the *Fig60*, a third scenario was identified. It consists to a very sensible street in the region, specifically the "Avenida Santa Cruz" in the central area of Bangu.

Consists in a simple street with a narrow section, where the sidewalks have an anarchic and irregular width, and the asphalt area it is intended to be a double lane one-way street. The facilities and the urban design are really weak, despite is one of the main arteries of the region.

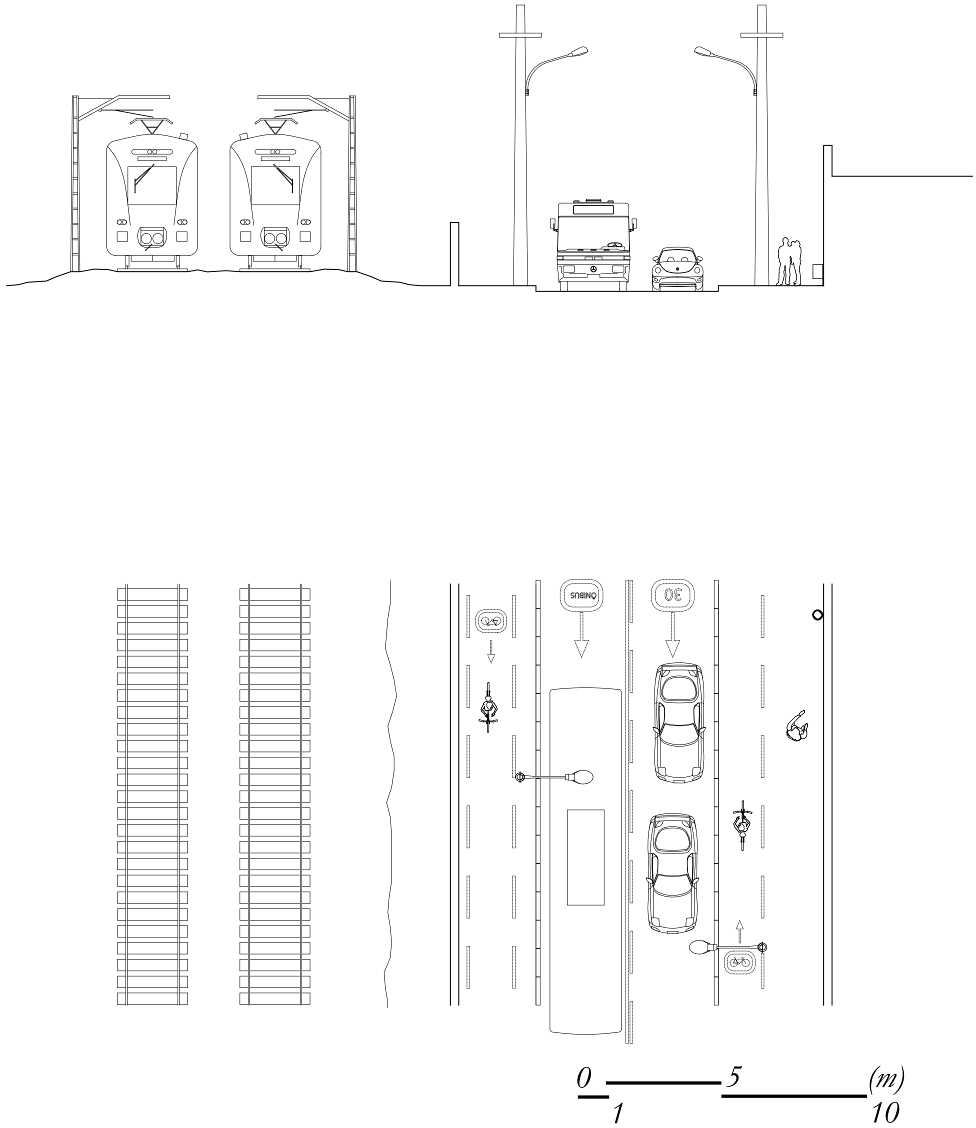

Fig61: Scenario 3 _ Proposal 1.

Source: Own elaboration _[3429]

As seen above in the *Fig61*, the first proposal for the third scenario emerges as a low-cost re-organization of the street, combined with some tactical urbanism. Currently, the car infrastructure is dominating the section of the street. With the reorganization, half of the asphalt area, is now devoted to an ônibus dedicated lane; whereas the other half is devoted to cars. Also, two bike lanes are painted on the ground of both sidewalks, one per direction, due lack of space.

This proposal is intended to be the least radical of the ones proposed for this scenario.

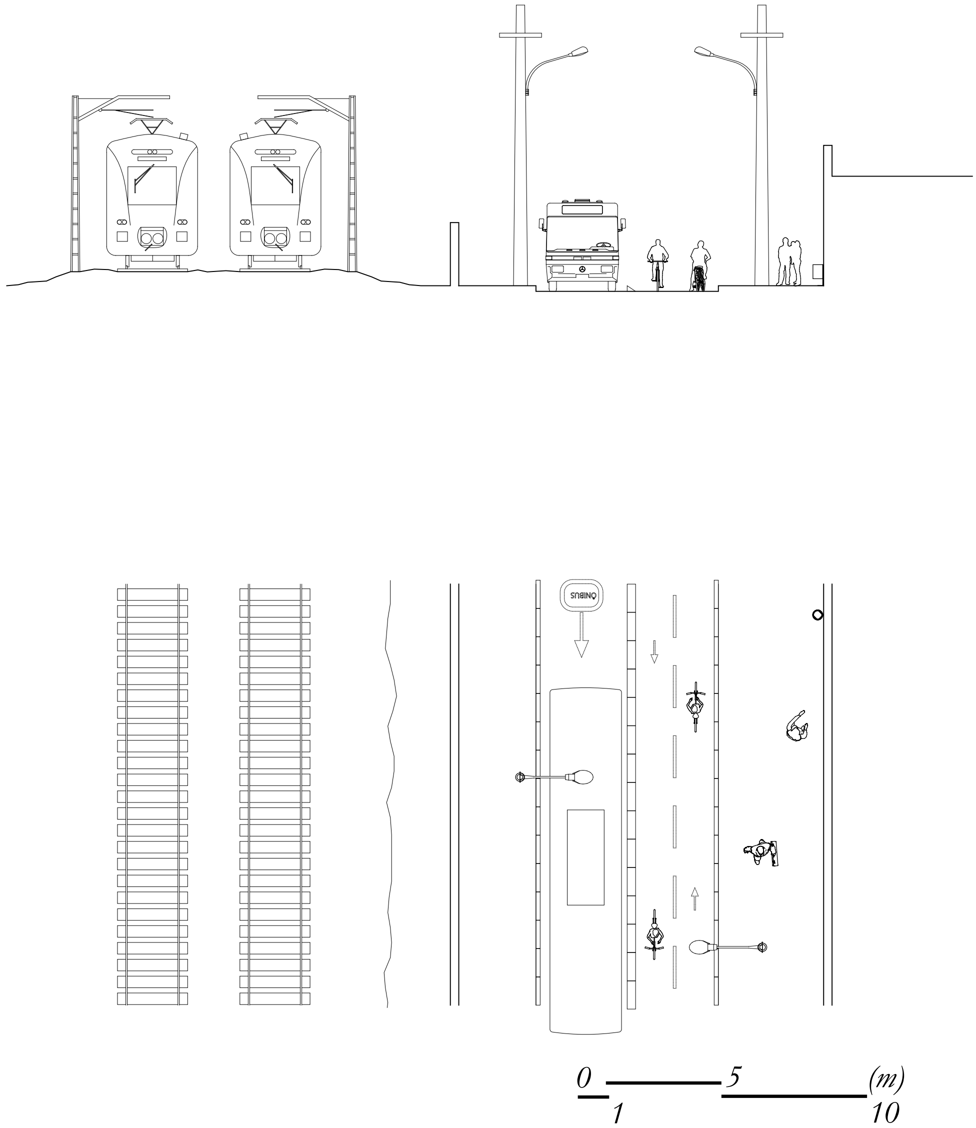

Fig62: Scenario 3 _ Proposal 2.

Source: Own elaboration _[34210]

As seen above in the *Fig62*, the second proposal for the second scenario emerges as another low-cost re-organization of the street, combined with some tactical urbanism. With the reorganization, half of the asphalt area, is now devoted to an ônibus dedicated lane; whereas the other lane becomes a double way bike dedicated lane.

This sample could be understood as a radical measure in order to boost both the public transportation and the active mobility in the center, trying to make more liveable the center of Bangu, in order to boost the new centrality. Bangu could be the pioneer in Rio de Janeiro in terms of pacification of its city center in terms of traffic.

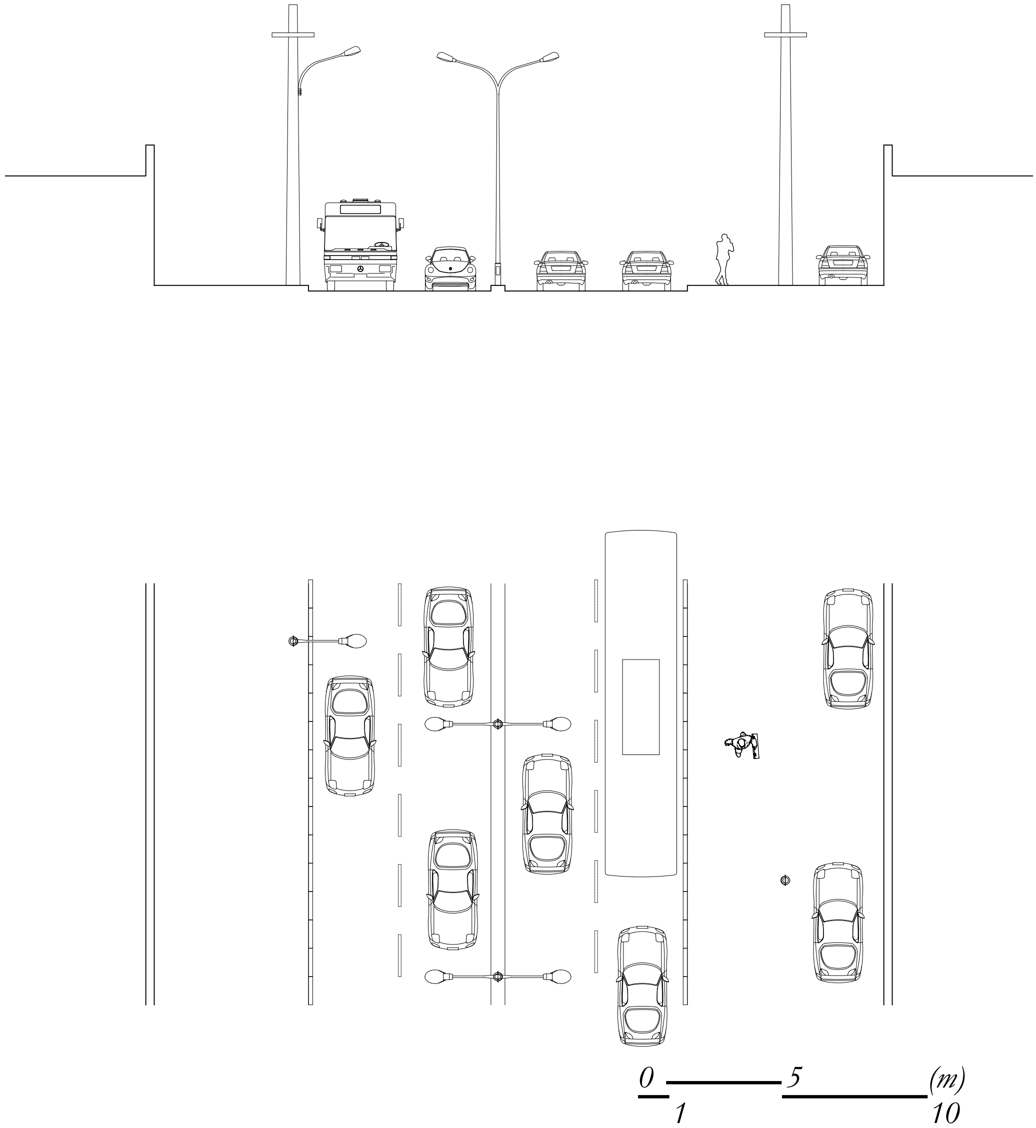

Fig63: Scenario 4 _ Status quo.

Source: Own elaboration _[34211]

As seen above in the *Fig63*, a fourth scenario was identified. It consists to a very sensible street in the region, specifically the “Avenida Santa Cruz” in the Senador Camará area.

Consists in a complex street with a wide section, where the sidewalks have an anarchic and irregular width, and the asphalt area is a double lane double way street. The facilities and the urban design are really weak, despite is one of the main arteries of the region.

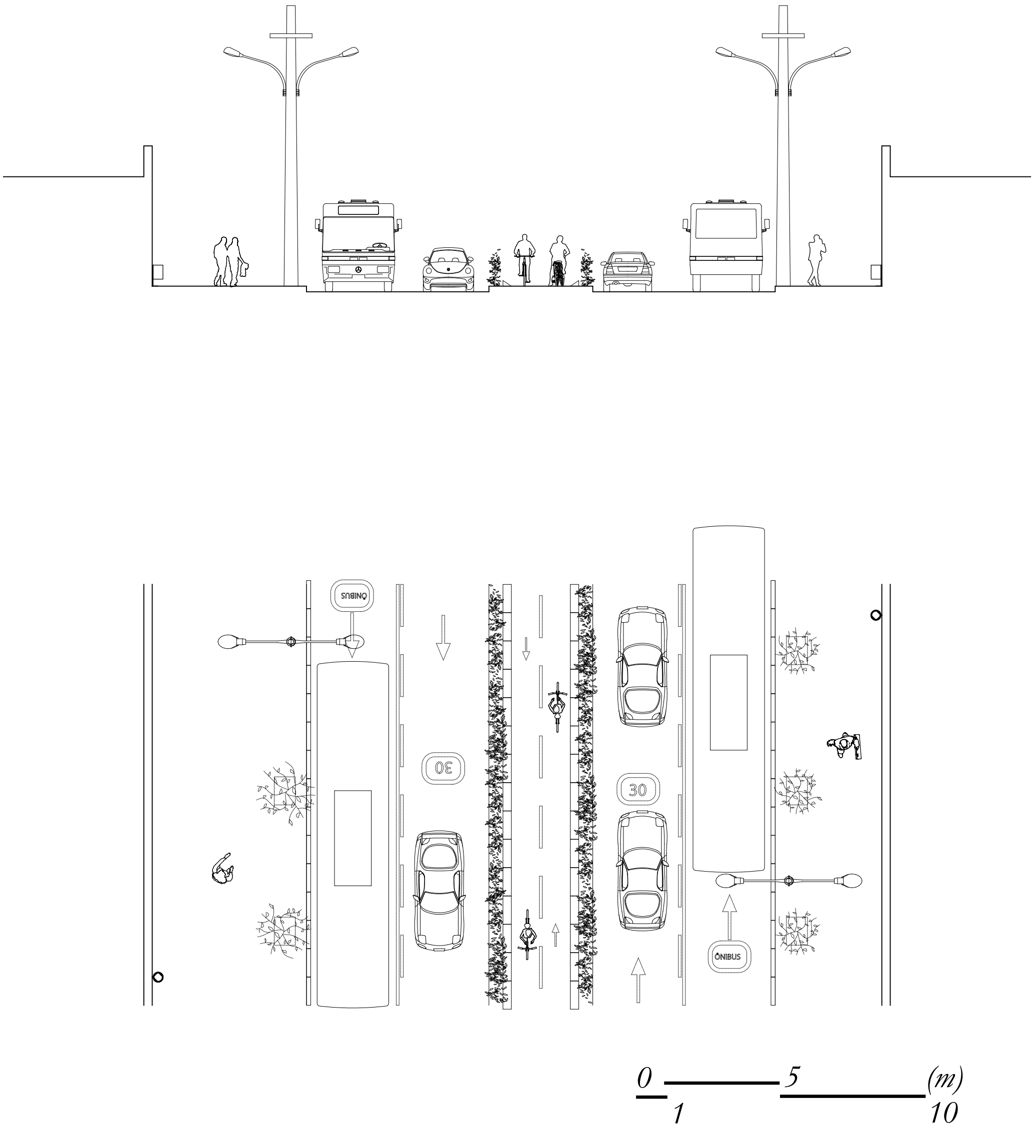

Fig64: Scenario 4 _ Proposal.

Source: Own elaboration _[34212]

As seen above in the *Fig64*, proposal for the fourth scenario emerges as a low-cost re-organization of the street, combined with some tactical urbanism. Currently, the car infrastructure is dominating the section of the street. With the reorganization, the right-most lanes of the asphalt area, are now devoted to the ônibus dedicated lanes; whereas the left-most lanes are devoted to cars. Also, a central two-way bike lane is deployed, protected by the vegetation.

Also, some trees and vegetation are introduced in order to give shade to the users, as well as breaking the monotonous vision of the current street.

3.4.3 | Critical points:

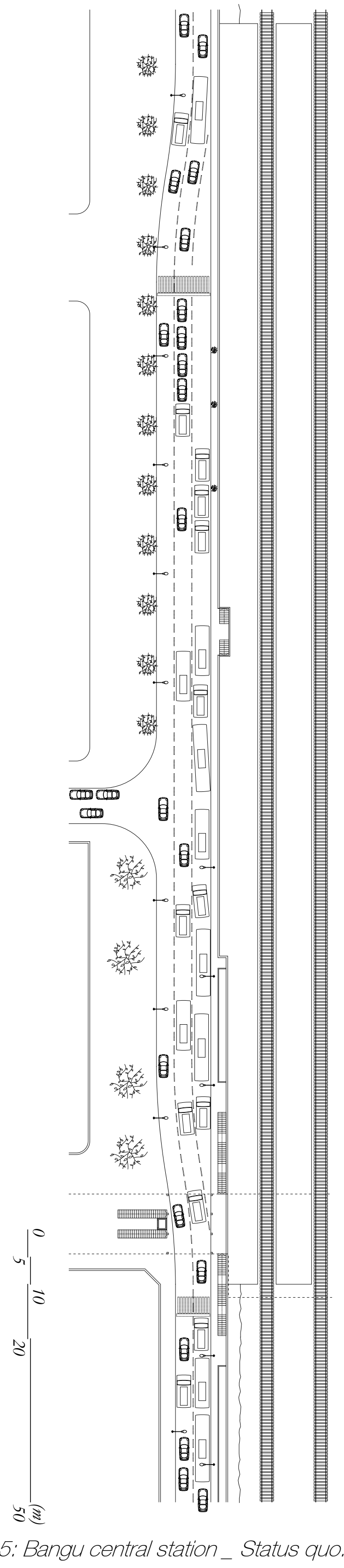

Fig65: Bangu central station _ Status quo.

Source: Own elaboration _[3431]

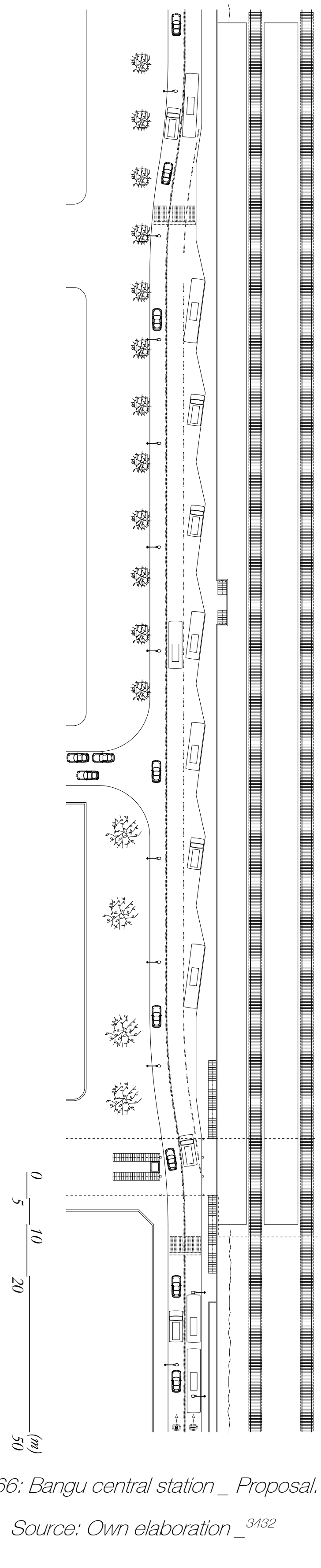

Fig66: Bangu central station _ Proposal.

Source: Own elaboration _[3432]

As seen above in *Fig65*, currently the closest streets from the central station of Bangu such as the Avenida Santa Cruz, in the ônibus operation perspective, have several drawbacks such as the very limited space in the section, specially in the access from the eastern area. Another major drawback is the very limited width of both sidewalks and the relationship between these key parts of the street with the rest of the city.

Of course, the lack of a dedicated lane for the ônibus, creates several inefficiencies in the operations of the lines, as well as the existing major problem of the illegal vans in that region of the city.

The current ônibus terminal in central Bangu, is extremely confusing due the lack of signalization of the lines and the messy "parallel parking" of the ônibus serving those bus stops, where many times the vehicles gets partially stuck due the parking position of the other vehicles. That also creates major several inefficiencies in the operations of the lines due the lack of dedicated special spots for each official ônibus line serving the area.

Regarding the access to the SuperVia Bangu train station, it is easy, intelligible and dignified enough, having several staircases or electric stairs, and even elevators, to reach the upper walkway giving access to the platforms. There is another secondary exit for the users of the southern-most platform.

As seen above in the proposal depicted in *Fig66*, most of the efforts were devoted to the improvement of the ônibus operations in this critical point. Due the scale of the plan, it has not been possible to also draw the possibility of the introduction of bike lanes, and other key parts of the urban design; elements that can be found in deeper detail above in the *Fig61* and *Fig62*. As many of the actions carried out in this project, that is intended to be as low-cost as possible.

The main actions carried out are the following ones:

- Introduction of the ônibus dedicated lane in order to smooth the operations in the street and terminal.

- Enlargement of the northern-most sidewalk, getting rid of some of the existing stores and taking some squared meters from the existing southern-most SuperVia platform. That enlargement has the main objective to allocate the new high-performance ônibus platforms.

  In terms of bureaucracy, it is possible that taking space from the southern-most sidewalk would have been easier, but the pedestrians and the city deserve having wide sidewalks, very scarce in the region; so taking square meters from that sidewalk becomes very infeasible. Also, taking space from the southern-most sidewalk would have meant a restructuration of the asphalt area, with sharper turns in the trajectory of the cars.

- Introduction of the new high-performance ônibus platforms, as seen below in *Fig67*.

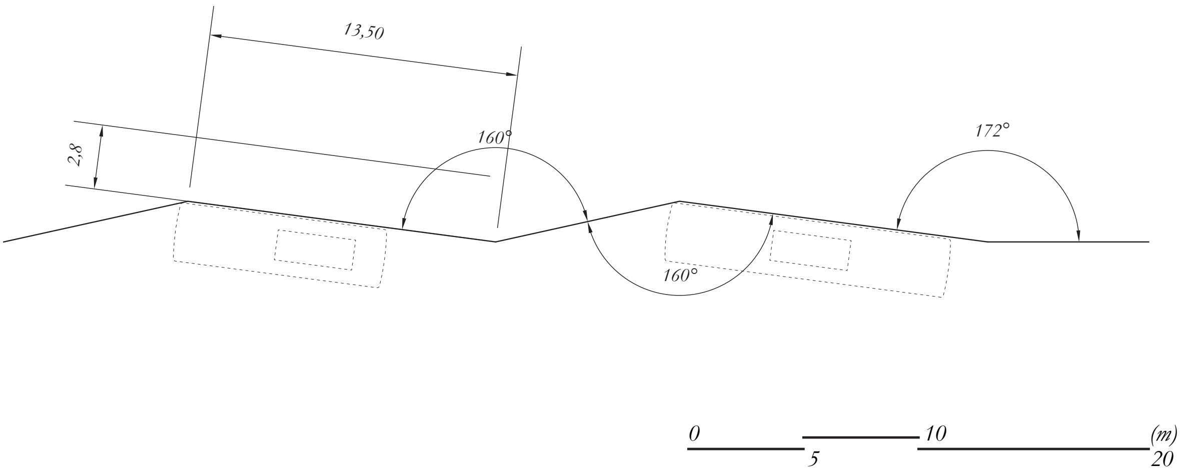

Fig67: Bangu central station _ Bus stop strategy.

Source: Own elaboration _[3433]

As seen in the detail above, the high-performance ônibus platforms consists in a saw-like very linear space-consuming system, that allows, due the very wide angles of the platform, a quicker access and exit to the bus, with a very easy maneuverability; at the same time that clarifies to the user at the moment of looking for the right platform. This system has been already applied in places such as the new Tapiola hub, in Espoo; in the metropolitan area of Helsinki[3434], and can be replicated not only in the central Bangu rail station, but in many other critical points of the region with a remarkable lack of width in the sections of the streets.

Due the limited amount of available time to do this thesis, only the central Bangu area has been tackled, but the Grande Bangu area is plenty of other critical points that needs to be solved such as the new transferring points between the new horizontal and vertical corridors, the critical points pointed out with the contact and the links between the northern and southern sides of the SuperVia tracks or the Avenida de Brasil; among others.

4 | Conclusions:

This thesis is intended to be a tiny piece in the enormous project to turn Rio de Janeiro city and its metropolitan area from the current monocentric model to a multicentric one; a project that not only requires the participation of the local politicians and the neighbors, but also a multidisciplinary team of professionals from a wide range of fields such as transportation engineers, architects, city planners, sociologists, environmental engineers, civil engineers and economists, among others; as well as a longer time than the one devoted in this project. Despite the previous words, this thesis already covered a wide variety of knowledge fields in order to tackle the multicentric project.

The main aim of that project was to propose low-cost, even surgical, solutions in order to maximize the operations in the infrastructure. In order to do that, the strategy is to take advantage as much as possible of the existing infrastructure; but also, the reinforcement of the built public transportation infrastructure, reshaping the amorphous public transportation network and introduction of the active mobility while adapting the urban space and urban design to the new reality and challenges. The low-cost policy has the aim to have an immediate application and effect on the ground; but few other proposed actions will require a larger budget, complex solutions and a longer implementation time; specially those ones related with the biodiversity.

This thesis provided several analytical, mathematical, operational and economical tools in order to carry out the project; but it is also important to point out that only with that answers and tools, it is not enough. It is also needed the will of the administration, civil society, law enforcement corps and politicians in order to make this project a success. None of the answers and tips provided in this thesis makes sense if there is no integrations between the different public transportation operators and modes of transport in the city of Rio de Janeiro and its metropolitan area or if there is no collaboration between them; all the mathematics and good will behind the calculus of the rail services and the ônibus network are useless if the illegal vans operating in the Grande Bangu area carries on with their operations or if the surrounding premises of SuperVia keeps hosting thousands of non-regulated houses or shops, turning the tracks into non regulated streets; all the mathematics and good will be in vain if the weekly shootings into the SuperVia premises does not halt, among other issues yet to tackle. Unfortunately, Rio de Janeiro already have several great projects such as the “Teleférico” services in Providência and Complexo do Alemão, that ended up becoming big disappointments due some of the topics explained in the previous lines; big investments that became steel trash in the middle of the city. Also, not only investments in the region are needed in order to implement new services, but also long-term maintenance policies in order to keep with the required and needed standards to run the system and avoiding cases like the quick rise and fall phenomena the whole BRT system experienced since its launchment, ten years ago.

Also, all of that efforts will end up being undesirable for the users if there is not the required investment in the intelligibility of the physical network, but also in the user experience; an investment in the so-called Mobility as a Service, MaaS", is needed in order more attractive and pleasant the journeys and their planification, making the user experience easier using the new digital tools in terms of planning the optimal ride, paying or even sharing information; as well as the integration of all the current mobility apps and cards.

All in all, in this thesis has been discussed the feasibility and suitability of the implementation of several policies, working with the status quo of the city, but trying to go towards a more decentralized city and metropolitan area, which is one of the backbones of the current problems; but in a future it is also strongly recommended to tackle with other major issues such as the low housing density, the whopping distances into the city and the metropolitan area and the inequalities between individuals and neighborhoods, which creates urban fabrics and behavioral tendences in the city that does not do anything else but damaging the whole system and society.

5 | Bibliography:

211_ From: Abreu, Mauricio de Almeida. (1987). 2.3.3. Como se compõe a Estrutura Metropolitana | Pg. 25. Evolução Urbana do Rio de Janeiro - Prefeitura da Cidade do Rio de Janeiro. Livraria Pereira Passos.

212_ From: Own elaboration

213_ From: Abreu, Mauricio de Almeida. (1987). 3.3. Bondes e trens: A cidade cresce em direções qualitativamente distintas | Pg. 53. Evolução Urbana do Rio de Janeiro - Prefeitura da Cidade do Rio de Janeiro. Livraria Pereira Passos.

214_ From: (2014). Fundamento Legal | Pg. 13. Proposições para solução de conflitos ferroviários urbanos. ANTT - Agência Nacional de Transportes Terrestres.

215_ From: Own elaboration

216_ From: Prefeitura da Cidade do Rio de Janeiro – PDTU | Plano Diretor de Transporte da Região Metropolitana do Rio de Janeiro (2012): http://www.rio.rj.gov.br/dlstatic/10112/5333332/4139325/25PDTUGovEstado092014.pdf

217_ From: data.rio | Passageiros transportados no sistema BRT, segundo as estações, no Município do Rio de Janeiro entre 2012-2021: https://www.data.rio/documents/c6f240be8491426e8634ff8702b0785e/about

218_ From: Instituto de Políticas de Transporte & Desenvolvimento – ITDP | Avaliação BRT Rio TransOlímpica: http://itdpbrasil.org.br/wp-content/uploads/2017/08/avaliac%CC%A7a%CC%83o-BRT-transolimpica-01-08-2017.pdf

219_ From: Transports Metropolitans de Barcelona – TMB | InfoTMB, dades bàsiques 2022: https://www.tmb.cat/documents/20182/94438/Dades+basiques+2022+CA-EN/617a88d1-0818-4aaf-a3a7-836a201c364f

2110_ From: data.rio | Passageiros transportados no sistema VLT, segundo as estações, no Município do Rio de Janeiro entre 2016-2021: https://www.data.rio/documents/passageiros-transportados-no-sistema-vlt-segundo-as-esta%C3%A7%C3%B5es-no-munic%C3%ADpio-do-rio-de-janeiro-entre-2016-2021/about

2111_ From: Alstom | Alstom anuncia novo contrato para expansão do VLT do Rio de Janeiro: https://www.alstom.com/pt/press-releases-news/2022/7/alstom-anuncia-novo-contrato-para-expansao-do-vlt-do-rio-de-janeiro

221_ From: SuperVia – Ramais e estações | Conheça as estações: https://www.supervia.com.br/pt-br/estacao/santa-cruz

222_ From: O Globo – VLTzação do BRT: sai ônibus, entra bonde; prefeitura promete 251 km de trilhos nos corredores nos próximos 15 anos:
https://g1.globo.com/rj/rio-de-janeiro/noticia/2022/07/07/prefeitura-do-rio-anuncia-vltzacao-do-sistema-brt.ghtml

231_ From: data.rio | Rio em Síntese:
https://www.data.rio/pages/rio-em-sntese-2

232_ From: Ajuntament de Barcelona | Estadística i Difusió de Dades:
https://ajuntament.barcelona.cat/estadistica/catala/Estadistiques_per_territori/Barris/Poblacio_i_demografia/Poblacio/Padro_municipal_habitants/a2022/cp01.htm

233_ From: Prefeitura da Cidade do Rio de Janeiro:
https://www.rio.rj.gov.br/web/pmus/mapa-da-rede-de-transportes

234_ From: José Brandão de Paiva Neto | From data.rio:
https://www.data.rio/

235_ From: (Junho 2021). Transporte ilegal ameaça serviço regular, vida dos passageiros e segurança pública | Pg. 13. Edição 113. Revista ônibus.

236_ From: SuperVia – Transparência | Dados operacionais _ Quadro de Distância entre as Estações:
https://www.supervia.com.br/sites/default/files/quadro_de_distancias_entre_estacoes.pdf

237_ From: Own elaboration

238_ From: SuperVia – Transparência | Dados operacionais _ Balanço 2021:
https://www.supervia.com.br/pt-br/balanco-2021-0

239_ From: O Globo – Em três meses, trens da SuperVia atrasaram mais de 1800 vezes, segundo relatório da Agetreansp:
https://g1.globo.com/rj/rio-de-janeiro/noticia/2022/09/27/em-tres-meses-trens-da-supervia-atrasaram-mais-de-1800-vezes-segundo-relatorio-da-agetransp.ghtml

2310_ From: (Junho 2021). BRT Rio: Do reconhecimento ao colapso | Pg. 24. Edição 113. Revista ônibus.

2311_ From: Estação Rio – Rodoviários afirmam não haver segurança nos articulados do BRT:
https://estacaorio.com/2022/09/20/rodoviarios-afirmam-nao-haver-seguranca-nos-articulados-do-brt/

2312_ From: data.rio | População residente e domicílios, segundo Bairros do Município do Rio de Janeiro - 2010:
https://www.data.rio/documents/71a7a8f734c542d5b9c147c0907fe079/explore

301_ From: Own elaboration

302_ From: SEBRAE _ Serviço Brasileiro de Apoio às Micro e Pequenas Empresas | Mobilidade Urbana e mercado de trabalho na Região Metropolitana do Rio de Janeiro. Estudo Estratégico _ Setembro 2013:
https://www.sebrae.com.br/Sebrae/Portal%20Sebrae/UFs/RJ/Menu%20Institucional/SEBRAE_EPG_set13_mob_urb_merc_trab_rj.pdf

303_ From: Modelar a metrópole | PDUI / RMRJ _ Plano Estratégico de Desenvolvimento Urbano Integrado da Região Metropolitana do Rio de Janeiro:
https://www.modelarametropole.com.br/wp-content/uploads/2017/01/Popula%C3%A7%C3%A3o.jpg

304_ From: Modelar a metrópole | PDUI / RMRJ _ Plano Estratégico de Desenvolvimento Urbano Integrado da Região Metropolitana do Rio de Janeiro:
https://www.modelarametropole.com.br/wp-content/uploads/2017/03/02-Empregos-REV-01.jpg

305_ From: Soares Bueno, R. & Soares Bertho, A. C. (2010). Uma análise da mobilidade urbana na Região Metropolitana do Rio de Janeiro a partir do censo demográfico de 2010:
http://abep.org.br/xxencontro/files/_paper/608-308.pdf

306_ From: Own elaboration

307_ From: Own elaboration

308_ From: data.rio | Mapa dos Bairros do Município do Rio de Janeiro:
https://www.data.rio/documents/mapa-dos-bairros-do-munic%C3%ADpio-do-rio-de-janeiro-2017/explore

309_ From: IBGE – Instituto Brasileiro de Geografia e Estatística | População residente, por sexo e situação do domicílio:
https://sidra.ibge.gov.br/tabela/202#/n102/3304557099/v/all/p/last%201/c2/all/c1/all/d/v1000093%202/l/v,p+c2,t+c1/resultado

310_ From: de Oliveira Lemos, L. & Oscar Júnior, A. C. (2021). O campo térmico em episódio de inverno no bairro Bangu, Rio de Janeiro (RJ). Universidade de São Paulo:
https://www.revistas.usp.br/rdg/article/view/176065

311_ From: José de Lucena, A. (2005). O campo térmico na zona oeste do Rio de Janeiro / RJ: Uma contribuição ao estudo do clima urbano. Universidade do Estado do Rio de Janeiro:
https://www.e-publicacoes.uerj.br/index.php/geouerj/article/view/1320

312_ From: Abreu, Mauricio de Almeida. (1987). 2.3. Formação social e espaço: A área metropolitana do Rio de Janeiro | Pg. 27. Evolução Urbana do Rio de Janeiro - Prefeitura da Cidade do Rio de Janeiro. Livraria Pereira Passos.

31111_ From: SuperVia – Ramais e estações | Mapa de linhas:

https://www.supervia.com.br/sites/default/files/diagrama_de_linhas_-_horizontal_-_site_-_rev_jan_20_impresso_e_visualizacao_0.pdf

31112_ From: SuperVia – Transparência | Dados operacionais _ Demanda Média Mensal de Passageiros por Estação: https://www.supervia.com.br/pt-br/demanda-media-mensal-de-passageiros-por-estacao

31113_ From: (Ano 2022). Pelo sossego da sua viagem: Como contar tiros pode salvar o trabalhador? | Pg. 3. Edição 03. Revista "Ó, o trem" | Observatório dos trens.

31114_ From: SuperVia – Transparência | Dados operacionais _ Quadro de Distância entre as Estações: https://www.supervia.com.br/sites/default/files/quadro_de_distancias_entre_estacoes.pdf

31115_ From: SERTRANS – Secretaria de Transportes do Governo do Estado do Rio de Janeiro | Dados consolidados da Região Metropolitana do Rio de Janeiro _ Abril 2020: https://secretarias.rj.gov.br/secretaria/Default.aspx?sec=TRANSPORTES

31116_ From: Own elaboration and SuperVia: https://www.supervia.com.br

31117_ From: Own elaboration and SuperVia: https://www.supervia.com.br

31118_ From: Own elaboration

31119_ From: Own elaboration

311110_ From: Own elaboration

311111_ From: Own elaboration

311112_ From: Own elaboration

311113_ From: Own elaboration

311114_ From: Own elaboration

311115_ From: Own elaboration

311116_ From: Own elaboration

311117_ From: Own elaboration

311118_ From: Own elaboration

311119_ From: Own elaboration

3111110_ From: Own elaboration

3111111_ From: Morata, M. & Casas, C. (2021). Line planning and capacity | Rail Transport. ETSECCPB | Universitat Politècnica de Catalunya.

3111112_ From: Morata, M. & Casas, C. (2021). Signalling and protection | Rail Transport. ETSECCPB | Universitat Politècnica de Catalunya.

3111113_ From: Morata, M. & Casas, C. (2021). ERTMS | Rail Transport. ETSECCPB | Universitat Politècnica de Catalunya.

3111114_ From: European Union Agency for Railways – European Union | European Rail Traffic Management System - ERTMS: https://www.era.europa.eu/domains/infrastructure/european-rail-traffic-management-system-ertms_en

3121_ From: Estrada, M. (2018). 2. Network design I | Public Transport. ETSECCPB | Universitat Politècnica de Catalunya.

3122_ From: Own elaboration

3123_ From: Own elaboration

3124_ From: Own elaboration

3125_ From: Own elaboration

3126_ From: Own elaboration

3127_ From: Own elaboration

3128_ From: Own elaboration

3129_ From: Own elaboration

32111_ From: (Ano 2014). 2.3.3. As cidades do Século 21 | Pg. 18. Guia da Mobilidade Sustentável 2014. FETRANSPOR.

32121_ From: Own elaboration

32122_ From: IBGE – Instituto Brasileiro de Geografia e Estatística | Pirâmide etária: https://educa.ibge.gov.br/jovens/conheca-o-brasil/populacao/18318-piramide-etaria.html

32123_ From: Badia, H. et al (2011). Competitive transit network design in cities with radial patterns: https://www.sciencedirect.com/science/article/abs/pii/S0191261513002154

32124_ From: Tr Part A. Estrada et al (2011). Design and implementation of efficient transit networks: Procedure, case study and validity test: https://www.sciencedirect.com/science/article/pii/S187704281101069X

32125_ From: SuperVia – Transparência | Dados operacionais _ Perfil Horário da Demanda – Média Mensal:

https://www.supervia.com.br/pt-br/perfil-horario-da-demanda-media-mensal

32126_ From: Caio – Apache V | Catálogo do produto:
https://caio.com.br/apachev/assets/apachevipv_catalogo.pdf

32127_ From: World Bank – Infrastructure notes | The Value of Time In Economic Evaluation of Transport Projects:
https://documents1.worldbank.org/curated/en/759371468153286766/pdf/816020BRI0Infr00Box379840B00PUBLIC0.pdf

32128_ From: Katarzyna Sowińska featuring Eloi Pallarès | From OpenStreetMap:
https://www.openstreetmap.org/export#map=13/-22.8700/-43.4628

32129_ From: Katarzyna Sowińska featuring Eloi Pallarès | From OpenStreetMap:
https://www.openstreetmap.org/export#map=13/-22.8700/-43.4628

321210_ From: Ortigosa, J., M. Menendez, and V.V. Gayah. (2015) Analysis of Network Exit Functions for Various Urban Grid Network Configurations. Transportation Research Record: Journal of the Transportation Research Board , No. 2491, 12-21.
https://www.researchgate.net/publication/284705667_Analysis_of_Network_Exit_Functions_for_Various_Urban_Grid_Network_Configurations

3221_ From: Dante Orrico Filho, Rômulo. (1996). 2.3.2. Formas de ressarcimento | Pg. 200. Ônibus urbano | Regulamentação e Mercados – L.G.E.

331_ From: Transporte ativo | Mapa Cicloviário do Rio de Janeiro:
http://www.ta.org.br/ciclorio/

332_ From: SuperVia – Serviços | Serviços para o cliente _ Bicicletários:
https://www.supervia.com.br/pt-br/bicicletarios?accept-cookies

332_ From: Bike Itaú _ tembici | Rio de Janeiro:
https://bikeitau.com.br/rio/

3411_ From: Own elaboration

3412_ From: Own elaboration

3413_ From: Own elaboration

3413_ From: Own elaboration

3414_ From: Own elaboration

3415_ From: Own elaboration

3416_ From: Own elaboration

3417_ From: Own elaboration

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3428_ From: Own elaboration

3429_ From: Own elaboration

34210_ From: Own elaboration

34211_ From: Own elaboration

34212_ From: Own elaboration

3431_ From: Own elaboration

3432_ From: Own elaboration

3433_ From: Own elaboration

3434_ From: Tapiolan keskustan kehittämisen liikenteelliset tarkastelut: https://docplayer.fi/63067073-Tapiolan-keskustan-kehittamisen-liikenteelliset-tarkastelut.html