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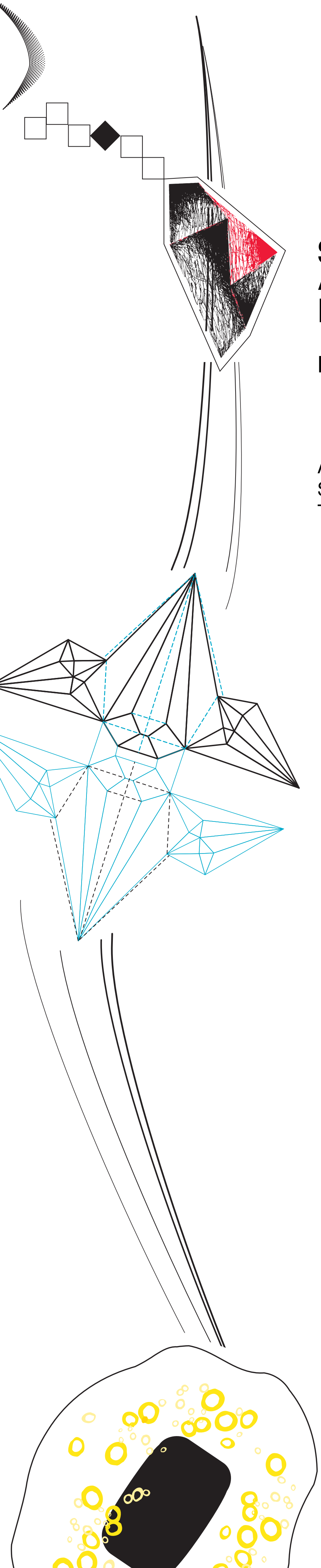

SHARED CYCLING INFRASTRUCTURE AS A FEEDER SYSTEM FOR PUBLIC TRANSPORT IN SÃO PAULO

BACHELOR THESIS

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Title:
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Preface

At the University of Twente it is common to finish a three-year bachelor program with a thesis. This thesis can either be done for one of the many chairs within UTwente and is carried out inside a (research)company outside of this university. The bachelor (Bsc) assignment takes 10 weeks after which the product is a report. Before this there is a pre-thesis-phase of 10 week, in which the student writes this very research proposal in front of you.

I would like to take this chance to thank all the GeoLab colleagues for their resourcefulness, ARCgis tutorials and discussions about all aspects off the project. Besides my supervisors, especially Diego Tomassielo, Nuno Graça and Gabriel Mormilho have been of great contribution to the thesis and my time in Brazil in general.

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Abstract

This research project was carried out at Universidade de São Paulo , Brazil as a part of the Civil Engineering bachelor program. It examines the current use of shared cycling in the city of São Paulo and the connection of this to public transport.

São Paulo , like other large cities, has to deal with increasing city size and seeks for ways to fit the new traffic flows in its busy streets. Promoting a shift to other modes as for instance public transport or (shared) cycling. This would improve accessibility in the city.

The report examines the current state of cycling in São Paulo by looking at the available systems and current master plan of the municipality. Also, the use of the shared cycling system is analysed in depth to determine succes factors for stations as well as areas where these do not cover yet.

The main aim of this thesis is: To analyse the use of bike sharing and its effect on the catchment area of public transport stations in the São Paulo region.

The catchment area describes the region around a transit station where potential riders are drawn from. This is related to the modality used to travel to the station. Considering the hilly character of this city improvements have been made for accurately determining the catchment area by bike. Slope depended cycling speeds have been implemented in the network and are validated by means of google maps trip comparison. Analysis shows an increase of 650% in people reached by bike compared to by foot.

Cycling is in a stage of development in Brazil. Current generations are more growing up with bicycles around them whereas their parents are starting to see the bike as a proper way of transport. Earlier years showed a concentration of bike trips in daytime and weekends where the previous years have shown an increase in rush hour use. The municipality of São Paulo has put the improvement of cycling infrastructure in the strategic master plan; committing itself to installing more (separate) bike lanes in the future and expanding the bike sharing infrastructure. As a guide for indicating areas that are suitable for cycling, this report contains a new bikeability index. Taking into account topography, the traffic stress and the availability of cycling lanes at this moment. The bikeability index shows explanation for why stations in some areas are less succesful.

Ohter factors that have been found to have a positive correlation with

bike use are: the income, commercial density and job density.

At this point, shared cycling in São Paulo is lacking behind when compared to other large cities. Bikes do not make it to 1.5 trip per day whereas Paris (7) and Barcelona (11) are scoring way higher. Improving he bike-ability of São Paulo as well as traffic education will help in increasing bike use and confine traffic congestion. For making bike sharing a success, the connection with residential neighbourhoods could be improved as well as the general performance and maintenance of the system.

1 Introduction

The use of bike sharing as an acces mode to public transport in large cities might contribute to the decrease of traffic problems. Also, it can add to the social equality of accessibility to employment or functions. Groups that benefit from high density of functions, opportunities and transport generally are not the ones that carry the burden of for instance pollution and congestion. As large cities like São Paulo (11,97 million inhabitants, 2014) keep increasing in size and population density, car roads are congesting more and more and approach their limits. The global traffic index released by TomTom shows São Paulo as the 6th most congested city in the world.

This thesis project, executed at Universidade de São Paulo looks into accessibility segregation and the use of bike sharing as a mode of transport and as an access mode to public transport. The paper has a clear structure, starting with a peek into the existing literature, followed by data gathering and the results that follow from this.

2 Research aims

This research is done as a contribution to the larger, international ASTRID (Accessibility, Social justice and TRansport emission Impacts of TOD strategies) project. The research group investigates disparity and social injustice in job accessibility and the effects of air-pollution in metropolitan areas. ASTRID also assesses the value of Transit Oriented Development (TOD) for promoting social justice; for instance when it comes to accessibility of jobs for different socio- economic groups. The team aims to do this by means of an international comparison of metropolitan areas in the UK, The Netherlands and Brazil (ASTRIDteam, 2016). This thesis will focus particularly on shared cycling as a mode for the first and last mile of public transport trips in the São Paulo region. It therefore adds valuable information about accessibility to the ASTRID project and the municipality of São Paulo .

The main aim is:

To analyse the use of bike sharing and its effect on the catchment area of public transport stations in the São Paulo region

The aim was broken down into sub-aims which gave guidance to the analysis, these are the following:

1. **How can the catchment area of public transport be measured?**
   - How do urban planning and transit oriented development (TOD) influence this area?
   - What is the role of the bike in the catchment area?
2. **What is the behaviour of shared cyclists in São Paulo ?**
   - How has the use of cycling changed over time?
   - What are the characteristics of successful bike sharing regions?
3. **What is the effect of a bike rental scheme on the catchment area of public transport in São Paulo ?**
   - How do the locations of bike sharing coincide with those of residential areas PT-stations and other destination areas?
   - In what new locations will bike sharing have the largest influence?
   - For what socio- economic group would bike sharing be most beneficial?

3 Theoretical framework

3.1 Bike sharing around the globe

In the past decade, the number of cities operating a bike sharing program (BSP) has increased from 13 in 2004 to 855 as of 2014 (Fishman, 2016). Since their introduction, bicycle sharing programs have evolved dramatically. From just non locked bikes indicated as public property, via a shopping cart coin system to the smart, connected, and dockless systems that are developing now. Roughly the evolution can be divided in four generations characterized in figure 1 the fourth generation is currently developing, already at least one US-based operator operates systems in which on-board solar-powered GPS replaces docking stations (Fishman, 2016).

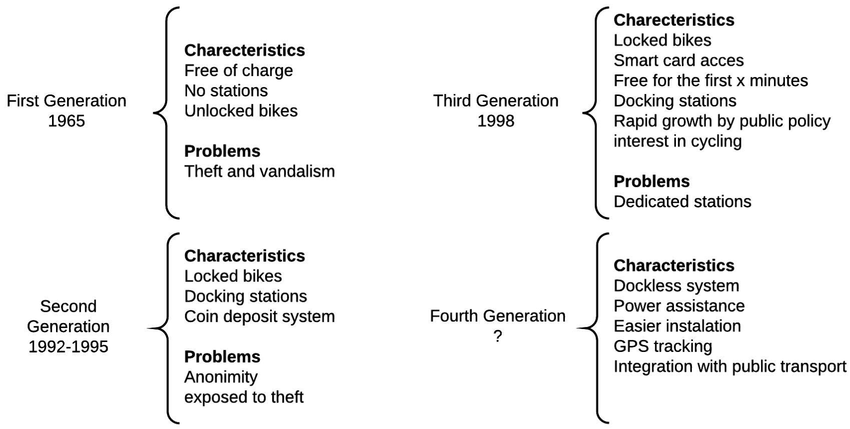

Figure 1: Characterizing the bike sharing schemes in four generations (combined and adapted from Fishman (2016) and Midgley (2011))

To be considered as an alternative to city residents for their access trips, the bike-stations should be located close to the transport stations as well as in residential neighbourhoods very close to their home. Fishman et al. (2013) discovered this is an even more powerful motivational factor then the natural tendency to ride a bike. For instance Fishman (2016) states that Montreal respondents living within 500m of a bike docking station were 3.2 times more likely to have used bike share then those who did not have this facility. Other motivating factors from the Melbourne research that scored big in the same survey have been: convenience (score 3.2/4), docking stations close to work (score 2.7/4) and health benefits (score 2.6/4).

Challenges with regard to shared cycling presented by Midgley (2011) and

Chataway et al. (2014) besides the city's topology are: theft, vandalism, the helmet culture or obligation in some countries, the perception of safety and the lack of experience or fear of people to ride a bike. Although other cities' examples can serve as useful guides, there is no single model of bike-share (ITDP, 2013).

In cities with an insufficient metro coverages a good bike sharing infrastructure can fill the gap on either side of the trip by having bikes available on the beginning and end to travel the first respectively last mile (Rietveld, 2000). Making the metro accessible to more people will stimulate the use and reduce traffic jams above ground.

3.2 The current state of cycling infrastructure in São Paulo

The previous municipal government (it changed with the start of the new year) had a target of 400 km of bike lanes by the end of 2015 . Up until 2016, 526km of separated bike lanes have been build in the city (fig. 2). An example or the type of cycling lanes in the city is shown in figure 3. Accompanying this plan, it was decided that a bike sharing system would be implemented called 'Bike sampa'. Building 100 stations per year up to a total of 3000 bikes.

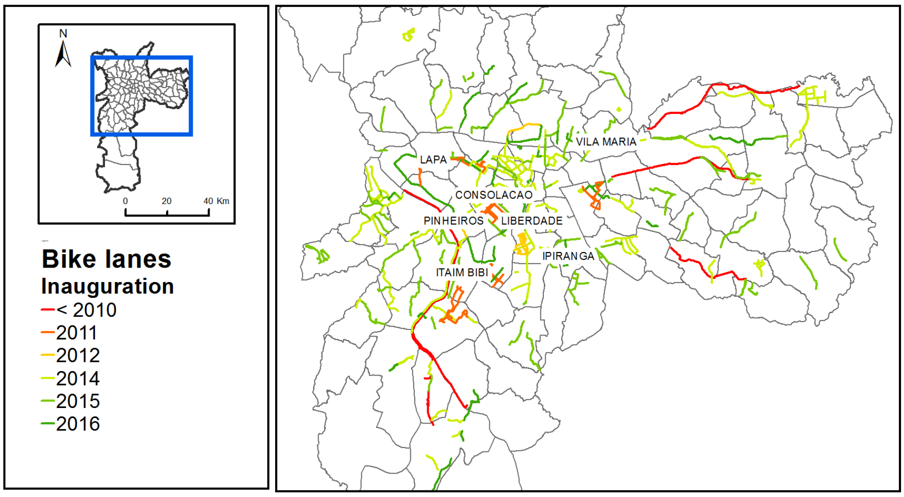

Figure 2: The development of bike lanes throughout the years

Figure 3: The separated cycling lane in Avenida Paulista

The contract for this was between the municipal council of transport, operating company Sertel and private sponsor Itaú, one of Brazils banks. The current contract with this operator will end in 2017 and chances are there will come a new operator. Reasons for this change are the: lack of reliable information regarding the available bicycles in the system, the lack of proper maintenance and the unavailability of the system at times because of damaged bikes or the terminal being unable to communicate with the network in order to release a bike (Cesar et al., 2016). The current contract has no incentives or fines for keeping up the network quality.

Physical and operational integration with other modes of transport, in particular the subway system, through the implementation of bike racks, enabling the carrying of a bike on the metro and promotion of shared cycling formed an important role in the 2014 and 2016 master plan of the municipality. Citizens are now for instance allowed to take their own bike on the subway in weekends during off peak hours whereas car speeds have been reduced in areas where cycling was dangerous.

The municipality's interest is in developing areas close to axes of public transport and good infrastructure, especially to promote a new pattern of urban mobility; the search for higher urban and environmental quality, strengthening the commitment to the environmental agenda and improve the quality of life for the population (Prefeitura de São Paulo, 2014).

At the current moment the Sampa bike sharing program counts 285 stations with 1600 bicycles divided over the city. Nothing compared to successful cities like Paris (17.900 bikes) or London (9.900 bikes) that have far less inhabitants. To stimulate the number of trips per bike per day, the first hour of rental is free after which a charge of 5R$ is taken. Payment is possible only by credit card, this acts as a form of security deposit and eliminates the anonymity that led to the demise of earlier, less technologically advanced bike sharing programmes (Fishman, 2016). 80% Of the population is however excluded by this limitation when looking at card ownership data (figure 4) for Latin America, making the use of bike share something that is for the rich.

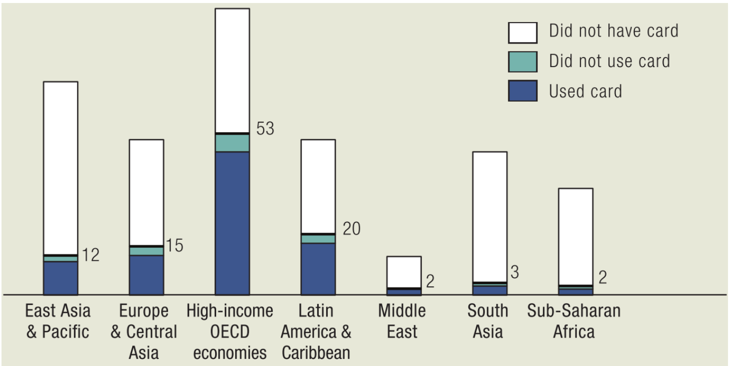

Figure 4: Credit card ownership and use in different regions as % of all adults (Demirgüç-Kunt et al., 2015)

Despite the recent efforts the bikes in São Paulo fail to make 1,5 trip per bike per day which can be seen as alarming. Rio for instance has twice as many (ITDP, 2016) and healthy European systems are between 7 (Paris) and 11 (Barcelona) trips per day per bike (ITDP, 2013). A competitive program was started by Bradesco, another large bank in São Paulo . This system exists of 17 docking stations, focused around the main avenue near the city center: Paulista [1]. Both systems need separate accounts and registration. Besides this small competitor, the largest public park in the city offers their own bike sharing service at a kiosk near the entrance. São Paulo is a city where bike-share does not share.

Research done by ativo (2016) shows interesting numbers on the general bike use in Brazilian cities [2] table 1.

Important to note is that 27,8% of bike users make mixed-mode trips and traffic education, for cyclists as well as car owners, is the highest graded barrier to cycling. Brazilians mostly did not cycle their entire youth like

[1]No data was made available by this carrier

[2]When considering these numbers it must be taken into account that the survey was conducted among 5012 cyclists spread over 10 regions of Brazil. Non cyclists are not measured, also those who cycle more often are more likely to be surveyed.

Table 1: Survey results of cyclists in Brazil compared to São Paulo . Edited from ativo (2016)

Statistic	Brazil	São Paulo
Use the bike in combination with another mode	26,4%	27,8%
Cycling more then 5 days per week	73,2%	73,6%
Motivation to start cycling		
Sports	42,9%	47,6%
Health	22,8%	24,2%
Cost	19,6%	17,9%
Others	10,5%	9,9%
Environment	2,2%	1,3%
Destinations		
Work	88,1%	91%
Leisure	76%	73,9%
Shopping	59,2 %	44,2%
Education	30,5%	23,9%
Barriers		
Traffic education	34,6%	36,8%
Available infrastructure	26,6%	24,1%
Traffic safety	22,7%	19,5%
Others	4,6%	7,9%
Public security	7,4%	7,2%
Lack of traffic signalling	3,3%	3,9%

youngsters in Eurpean countries like Holland and Denmark. Therefore education in riding a bike and dealing with the heavy traffic in São Paulo is wanted (ativo, 2016).

3.3 Catchment area of public transport

The service area or catchment area, describes the region around a transit station where potential riders are drawn from Hochmair (2014). The distance that a passenger is willing to travel to access public transport means is related to the type of feeder mode.

The area of influence in its simplest form can be a circular Euclidean buffer (Seskin et al., 1996), often it is expressed as a distance decay function (Martens, 2004), (El-Geneidy et al., 2014), (Gutiérrez et al., 2011). Both assume no difference in impedance of roads. Whereas for walking this might be an appropriate simplification because of the low speed and. Hilly conditions like those in São Paulo in combination with cycling ask for a different approach. As (Midgley, 2011) mentioned; *"for cycling, slopes between 4 and 8 percent are a significant constraint and those above 8 percent are impractical"*. The hilly character of São Paulo is visualised in figure 5, where it can be seen that the slope of 26% of roads is above 8%.

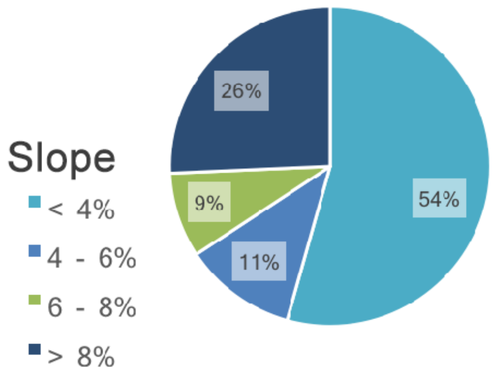

Figure 5: Statistical presentation of slopes in the city of São Paulo

A possible solution can be found in using travel time as a method of determining the catchment area. Considering the topography, this would lead to a more accurate estimate in the conditions.

The types and mix of land uses also influences the demand for transit as well as the use of non motorized modes. It is however difficult to sort out the effects of land use mix and urban design because they are strongly correlated with density (Seskin et al., 1996). This proves that taking the bike in mind when thinking about transit oriented development can increase the bike use in a city.

Transit Oriented Development (TOD) was first introduced as: "moderate and high density housing along with complementary public uses, jobs, retail and services in mixed-use evelopment along the regional transit system" by Calthorpe in 1993 (Lee et al., 2016). The goal of this concept is to reduce the need for long trips, therefore also reducing the amount of trips made by car. In the typical transit oriented development walking has been considered the major access mode to transit. Several critics exist for the concept of TOD such as the difficulty to implement sufficient public transportation options without reorganizing the urban structure of an existing area. Also, the community opposition to land use changes are mentioned by Lee et al. (2016). In recent years the amount of trips by bicycle as well as the multi-modal trips (with the bike as either a feeder or egress method) have grown rapidly. According to Pucher and Buehler (2009) after a case study in 8 large North American cities an increase in the number of racks as well as improvements in the convenience, security, and shelter of bike parking are the reason for this. A case study has also been conducted by Puello and Geurs (2015), characterizing transit area's by means of the 5 D's: density, diversity, design, distance to transit and destination accessibility. The case study indicated facilities and service level for cycling to and from the areas as highly important factors. Lee et al. (2016) combined available data to analyse the share of cycling as a feeder to public transport in different parts of the world (fig 6).

		Korea	Japan (Tokyo)	Netherlands	Denmark	Sweden	Copenhagen	Munich
Bicycle share of total trips (%)		2.5	14	27	14	10	26	13
Bicycle	Regional train						25	16
+ PT	suburban train						22	10
	express bus	0.2	13	35	25	9	12	—
	(city)bus						4	4
	Metro						—	5

Figure 6: The share of bike use as a feeder system to public tansport arround the world (Lee et al., 2016)

As in other researches by Martens (2007) and Pucher and Buehler (2008) this shows the Netherlands and Copenhagen again as the top cycling places. The multitude of TOD efforts that the municipality of São Paulo is currently applying to improve bicycle infrastructure, including bike lanes, combined bus/bike lanes, off-street paths, signed bicycle routes, cyclist-activated traffic signals or bike boxes, is shown to increase levels of cycling (Hochmair, 2014).

4 Research methods

4.1 Indicators for analysing the catchment area

Factors for reviewing catchment areas can be classified into three types according to Gutiérrez et al. (2011): built environment, socio-economic factors and characteristics of the stations. A summary of those taken into account is shown () after which the variables that ask for a more in depth explanation are deepened. The hypothesis is that there will be correlation between these variables and shared bike usage.

Built environment

Factor	Definition	Source
Entropy index	Land mixture index where 0 stands for a single use and 1 for a rich mixture	Secretaria Municipal de Finanças 2016, equation 2
Bike-ability index	Indication of the bike-ability of an area depending on topography, traffic stress and availability of (sperate) bike lanes	DTM-, network-, cyclovia-/ciclorota- maps

Socio-economic

Factor	Definition	Source
Population density	Inhabitants/km^2	OD zonal data 2007
Job density	Jobs/km^2	OD zonal data 2007
Income	Household income	OD zonal data 2007

Station characteristics

Factor	Definition	Source
Metro stations	Number of accessible stations within a 15 minute catchment area from the zones' centroid	GeoSampa, Cycling network
Bike sampa flow	trip OD use data	Bike sampa user data september 2014 & 2016
Bike station availability	Number of accessible bike stations within a 15 minute catchment area from the zones' centroid	GeoSampa, cycling network

4.2 Data collection

4.2.1 Cycle speed network

As proposed because of the hilly character of the study region a time measurement of catchment area would be more appropriate then an euclidean distance area. Several steps are taken to reach this new speed model.

1. The DTM raster map of the region is translated into a slope map that shows the elevation of São Paulo . This map is directly used in determining the bikeability index (figure 8c).

2. The slope map is categorized per percent (0-1, 1-2...20+) and clipped to the existing road network. This is to make it possible for one road to exist of multiple sections with different slope levels.

3. Point maps for both the start and end of each road section are exported. The elevation level of both is added as a field to the road sections allowing for the calculation of the slope including its direction. Simply considering the clipped percentage as slope will miss direction.

4. Downhill speed is modelled by the AASHTO (American Association of State Highway and Transportation Officials) (1999) (fig. 7) as well as uphill speed by means of the following equation (1) for a standard person and bike.

$$P = K_r M s + K_a A s v^2 d + g i M s \tag{1}$$

Var.	Definition	Value
P	power delivered assuming 20km/h on a flat surface(CROW, 2007)	65,6 W
k_r	rolling resistance coefficient, bike on asphalt	0,005
M	mass of bike + rider	90 kg
s	speed of the bike on the road	variable $[m/s]$
k_a	wind resistance coefficient	0,5 (no wind)
A	the frontal area of the bike and rider	0,6 m^2
v	speed of the bike through the air	same as speed
d	air density	1,226 kg/m^3
g	gravitational constant	9,81 m/s^2
i	gradient	variable [%]

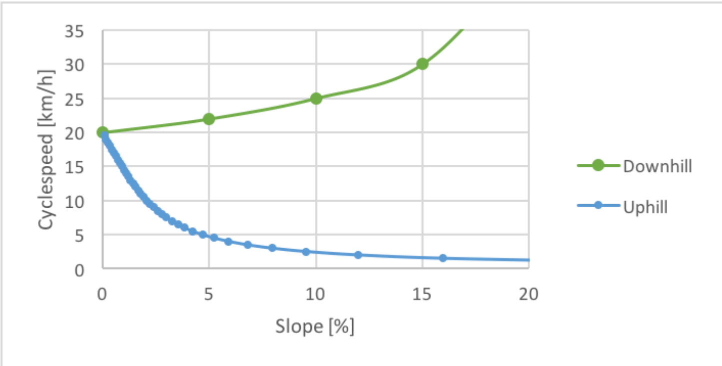

Figure 7: Implementation of cycling speeds on slopes

5. Speed is cut off at 3 and 35 km/h because at steep hills people would get of the bike and walk up slowly or use the brakes to maintain a relatively safe speed in the city.

6. Validation is done by comparison of the average speed between the model and Google Maps. For this purpose 2.000 random routes between 500m and 10km were generated in ARCgis and used in an automated python script that calculates these routes in Google Maps. [3] A paired T-test on the output gives a confidence interval of -1,8 to - 1,6 which is accepted for the purpose of catchment area determination.

   Google is the most reliable available source for travel times on the city network. It takes into account more variables than the created speed model in this thesis, for instance the time of day and historic trip information is used. For these reasons, google maps is chosen for validation of the model.

4.2.2 Bikeability index

In cities like São Paulo where cycle lanes are not as common as in our European countries, large differences exist in the bikeability of roads. To investigate relations between the suitability of an area for cycling and the use of the bike Winters et al. (2013) suggested the use of a bikeability index. Also Sustrans (2014) and Mekuria et al. (2012) use indexes that are comparable to that of Winters to determine cycle friendly design (Sustrans, 2014) and stress levels (Mekuria et al., 2012). Empirical research on important factors

[3] This script is written by the GeoLab team at Universidade de São Paulo for research purposes, it takes coordinates of start and endpoints as input. Google has set a limitation on trip generations in google maps per day per computer at 2500.

was done by Winters et al. (2013) in the region of Vancouver, Canada. Focus groups gathered by Winters in 2008 discussed physical factors that are modifiable through TOD planning and zoning of which the following are used in our index (table 2). Other elements that came up but had a significantly smaller influence where: environment, destination density and population density. The three considered variables together scored 91 out of 130 total assigned points which justifies the selection of just these 3 for a general index. An elaboration on these three factors and their implementation method follows.

Table 2: Ranking of built environment factors, adjusted from Winters et al. (2013)

Factor	**Score winters**	**Adjusted weight**
Bicycle facilities	50	54%
Traffic	25	27%
Topography	16	19%
	91/130	**100%**

Table 3: Stress level on the road network

Level	**Traffic** $[km/h]$	**Bicycle facilities**	**Topography** [%]
1	100+	no seperate lane	10+
2	60 to 100		3 to 10
3	40 to 60	Ciclorota (made suitable)	1 to 3
4	up to 40	Ciclovia (physically separated)	0 to 1

Bicycle facilities The availability of a seperated or indicated bike lane drastically reduces the stress level experienced by riders. Cyclists are even willing to detour their route when a bike lane is offered in the vicinity (Winters et al., 2013). For the São Paulo region, 2 types of bike lanes are mapped. Namely, ciclovia: lanes physically separated from car roads;

and ciclorota: car lanes that are marked or otherwise made more bike-friendly.

In the process of generating the heat map a search radius buffer of 400m was applied on the 2016 CET (Companhia de Engenharia de Trafego) bike facility map to incorporate the detour effect (Winters et al., 2013). The map (fig. 8b) shows the formation of islands of high bikeability that are not in all cases connected.

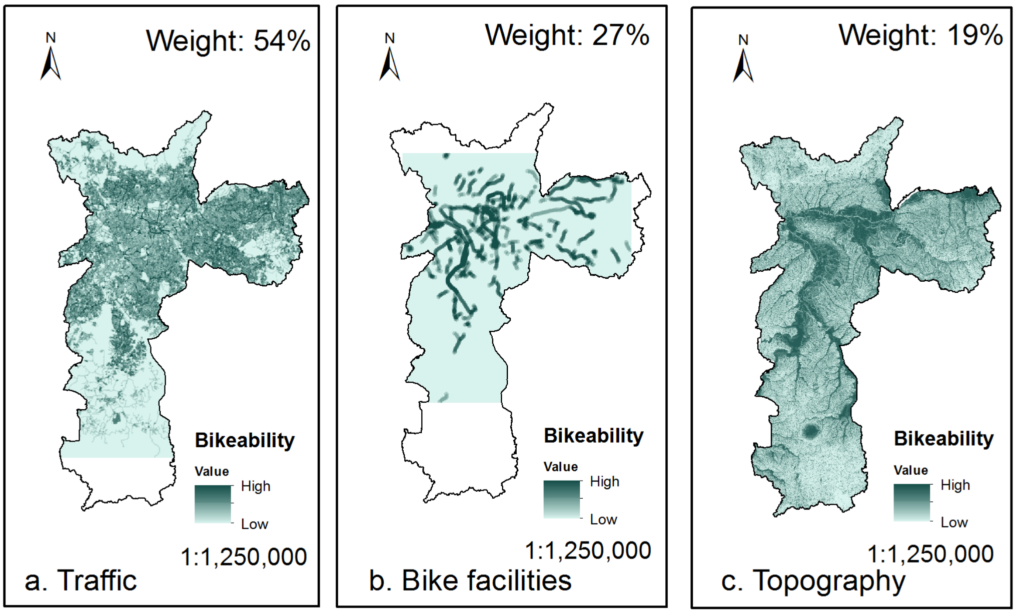

Figure 8: Individual bikeability factors and their weights

Traffic The intolerance of cyclists to traffic stress is one of the factors explaining the difference between South American and European bike use (Mekuria et al., 2012). One way of expressing this traffic stress level is by analysing the speed limit on the road network for roads not containing separate lanes. The resulting heat map derived from the available network is shown in fig. 8a.

Topography As mentioned earlier, slopes between 4 and 8 percent form a severe restriction for cycling whereas higher slopes are almost impossible to ride. Using GIS tools the cities DTM map was converted to the slope map shown in figure 8c

The traffic, bike facilities and topography map are aggregated to a bike ability score by multiplying them with their weights before adding them. The result is a high resolution (10 m) bikeability raster for the region, depicting bicycle-friendly areas and areas that do not invite to ride a bike (fig 9)

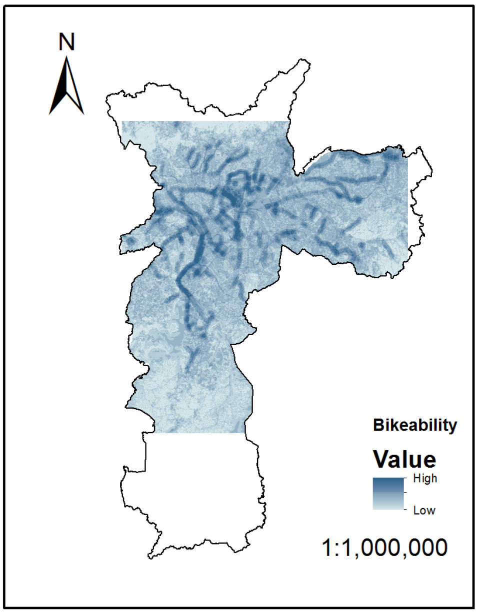

Figure 9: Aggregated bikeability of the municipality of São Paulo

4.2.3 Entropy index

The entropy index as described by Cervero et al. (1995) will be used to include diversity of the built environment in our study areas. The hypothesis is as Seskin et al. (1996) explained earlier that where numerous activities are accessible within a small area, the likelihood of walking or cycling increases. Mixed-use suburban centres have been successful in generating higher transit use than the typical suburban area (Advani and Tiwari, 2006). The case of Curitiba, Brazil is a great working example of this and Transit Oriented Development in general where mixed-use areas around well designed bike and BRT-lanes support dense growth of the area and generate bi-directional flows on the network. The land use entropy map follows from the application of equation 2 on the land use map.

The landuse map provided comprises 15 categories that where grouped in the following way (table 4)

Table 4: Grouping of land use types

Education
Education
Residential
Resid. horizontal low standard
Resid. horizontal medium/high standard
Resid. vertical low standard
Resid. vertical medium/high standard
Residential
Commercial
Residential and commercial
Commercial and industry
Industry and warehouses
Commercial and services
Public space
Public space
Vacant land
Others
No dominant use
Garage
Others

$$E = -\sum_{i=1}^{k} \frac{P_i * ln(P_i)}{ln(k)} \tag{2}$$

Where P_i is the proportion of land area in land-use category i, and k is the number of land-use categories. The index ranges between 0 and 1, where 0 signifies land devoted to a single use and 1 meaning all land area evenly spread among all use. As an input to this model the predominant land use map of Secrectaria Municipal de Finances (2016) is used. Calculation is done on the scale of ODzones as this is the scale where most of the other indicators are available on. It features 320 zones in the municipality of São Paulo with decreasing size near the city centre.

5 Results

Important insights are given by analysing the available use data. The availabe data consits of trip data about all bike sharing trips in São Paulo for September 2014 and September 2016. Data includes date, time and location of both pick-up and drop-off. For 2014 the company also released the gender of the user riding the bike.

5.1 Gender neutral

Whereas European cycling culture does not differ for male and female trips (table 5) countries in the UK, USA and also Brazil are less gender-neutral (Pucher, 2008). Figure 10 shows the gender split for the bike sharing data of São Paulo 2014.

Table 5: Female cycling participation in Europe as a percentage of the total bike trips (Pucher and Buehler, 2008)

Country	Female trips
The Netherlands	55%
Germany	49%
Denmark	45%

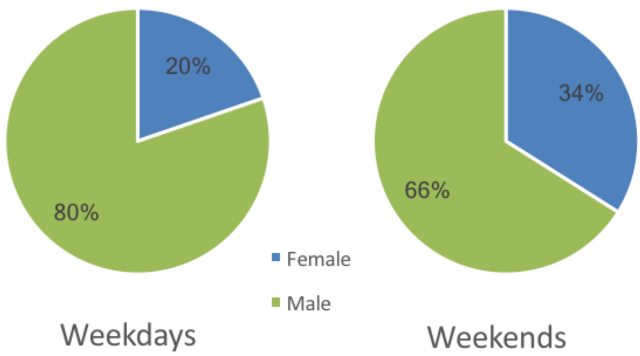

Figure 10: Bike sharing use by male and female

The interview with cycling activism group 'oGangorra' and field research showed several reasons for this gender-inequality.

- Conservative male/female roles. Brazil, more than Europe, sticks to classic distribution of chores in the household. Therefore the amount of trips per day of men (home-work-home), is less than that of woman (bringing children to school, shopping, household tasks, work)
- Women accept a lower level of traffic stress (Mekuria et al., 2012). As the stress level is high and general bikeability is low (previously presented bikability maps in figure 8 and 9) in Brazil this makes it a more masculine activity to engage in cycling. The conservative roles also play a role in this avoidance of risks and gender inequality.

It is for a reason that weekdays and weekends are split up in the following figures.

5.2 Trip purpose

Although a survey is not part of the research, the trip purpose can be extracted from the available use data. Especially when plotted on a map. More than in Europe, cycling is seen as a form of leisure and sports whether that is on a city bike or mountain bike. The split in week- and weekend days or even rush versus normal hours shows this. Figure 11 shows the difference between the time of use of bike sharing in 2014 and 2016.

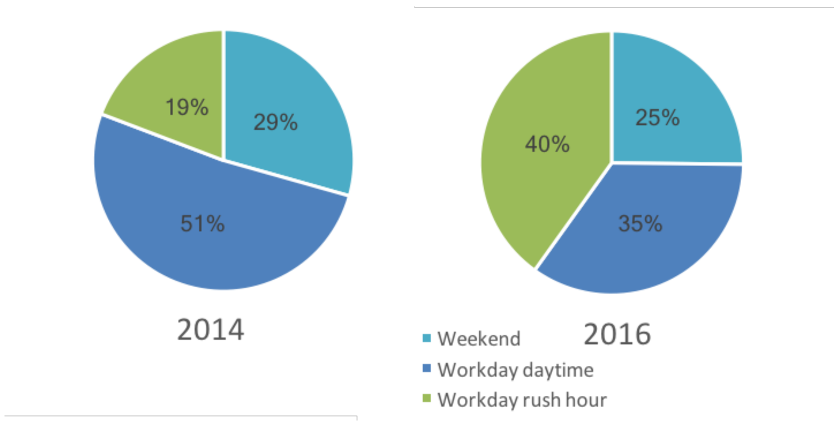

Figure 11: Bike sharing use by time of day

Use has shifted from weekends and daytime, which is likely to be seen as leisure or free time use, to rush hour use. With caution, it can be said that the people have started to accept the bike as serious transport mode. It is an important measure for the success of the municipality's investments in bike lanes and cycling promotion. Assuming a large part of rush hour trips is work related this means the bike is used as an alternative to another mode of traffic.

A study of the most popular station, Faria Lima (named after the metro station next to it), was done in ARCgis. 5% Of the total bike sharing trips in the municipality went from this station. The OD map (fig 12) shows over 80% of these trips going to commercial places and a university.

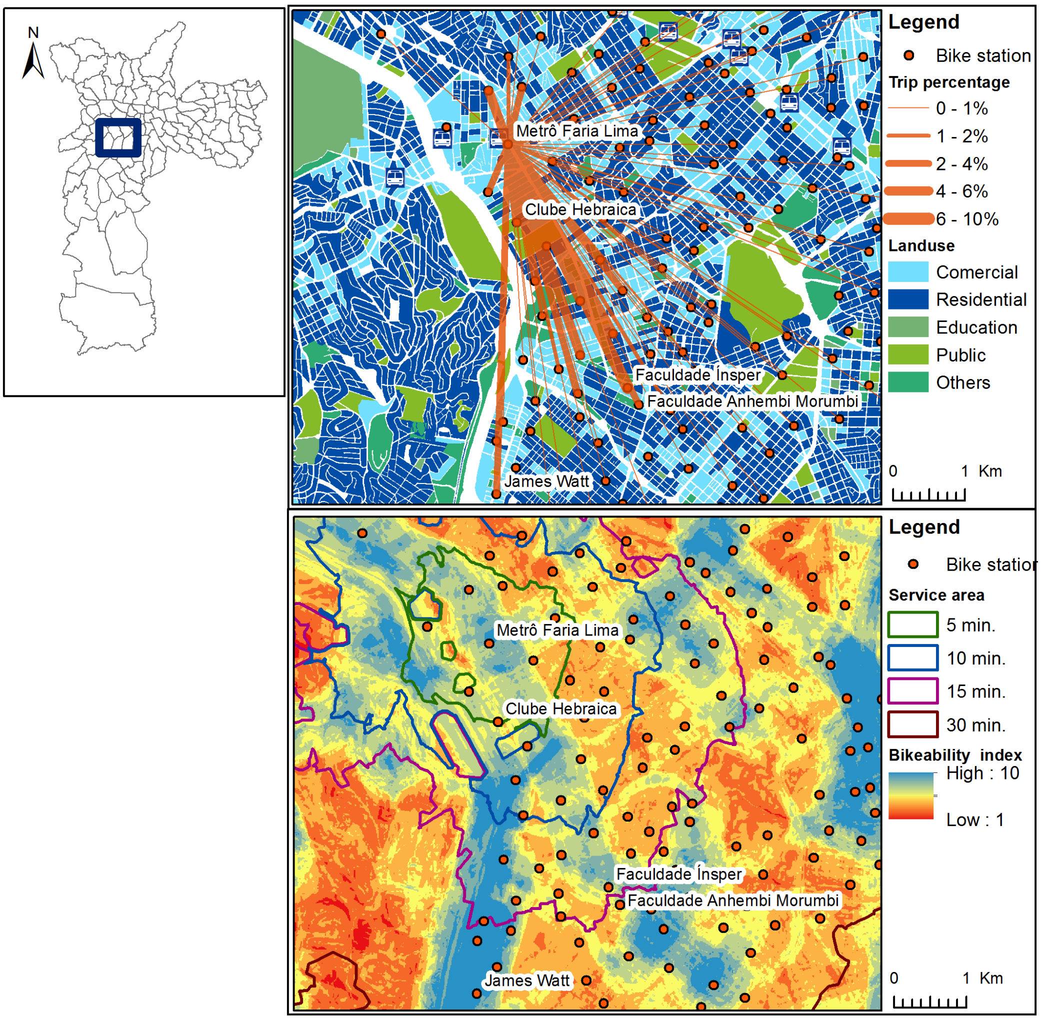

Figure 12: Faria lima trip destinations and catchment area

A lot of the movements are towards the south side of the station, this area of Jardins and Itaim Bibi is seen as an important commercial district, companies like Facebook, Apple and Google hold office here. Commuting to the area by metro is not easy since the closest station is Faria Lima. This is the example of a location where bike sharing made the use of the metro more attractive by filling the last mile of commuters. The bikeability map also implies the suitability of this region for bike sharing; all regions of interest are connected by high bikeability areas.

The area around most bike sampa stations is focussed on commercial use. This is seen throughout the city (fig 13), residential areas that don't draw much external visitors are missing out on access to the shared bikes.

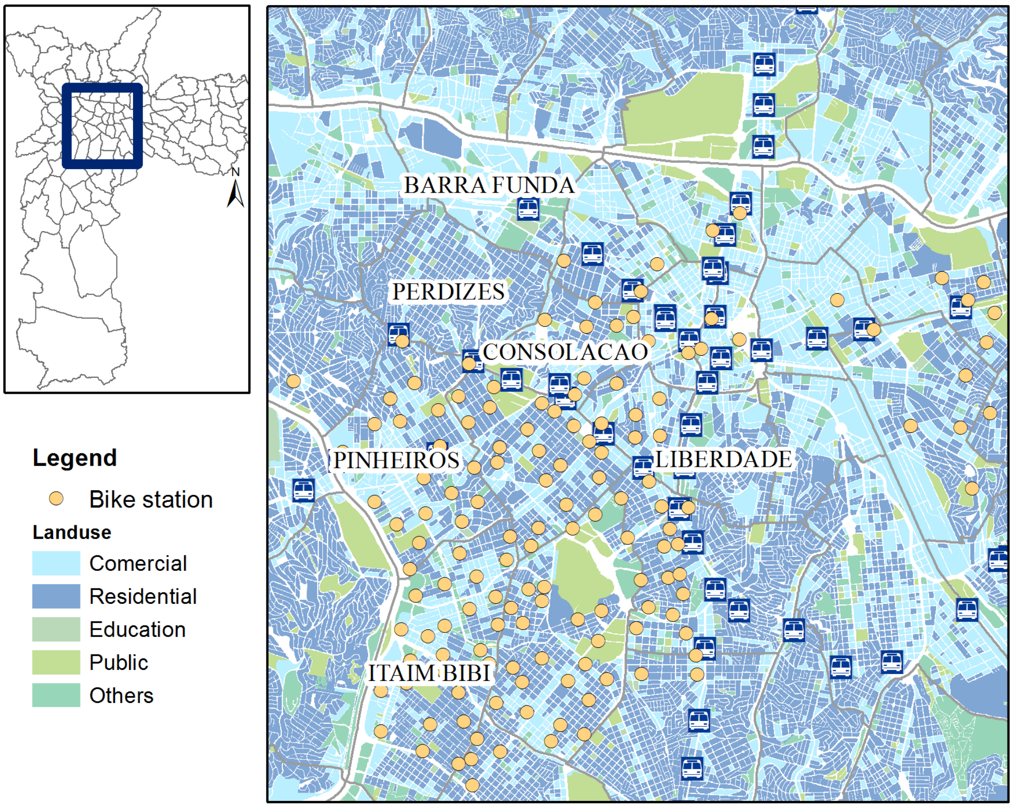

Figure 13: Landuse and bike stations are shown

Reasons for this are mentioned in the interview with bike activist group 'oGangorra': The sponsor and operator focus on rich areas to carry out their brand and avoid violence and theft. The traffic engineering department has made new agreements about the placement of stations after the placement of 60 stations in the neighbourhood of Vila Mariana. A minimum radius has been set up as well as guidelines in the mobility plan for reaching all areas by shared bike before 2030 (Prefeitura de São Paulo, 2014). For the first and last mile the division of stations over the area and inside residential neighbourhoods is crucial.

5.3 Area characteristics

50% of bike sharing trips is made in 5 of the 35 neighborhoods of the city (fig. 14). These regions are in the south-west of the city and are known to have a high income population as well as a high amount of office space. This chapter will compare all regions on the criteria mentioned before (chapter 4.1). Excel is used to determine the linear correlation coefficients from the arcgis data, they are shown in each plot. For this correlation analysis, the values of the containing census area are used.

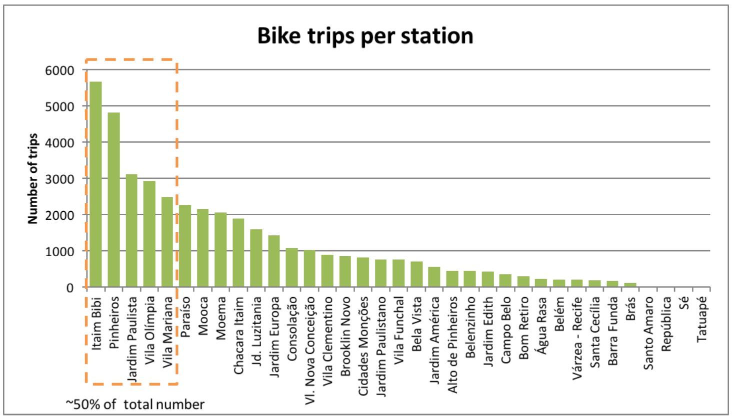

Figure 14: Bike share trips per bike station

Landuse Bike sharing is useful when trips are short and this is more often the case in mixed areas. Well developed areas with this form of transit in mind can stimulate bike use. Looking at the entropy in combination with trip use, small correlation is seen between the entropy and the use of shared bikes when comparing east and west (fig 15, 16). However, the correlation with the density of commercial land use is likely the cause of the higher bike involvement in the south-west regions since it also explains for the lesser involvement in the east (fig 17, 18).

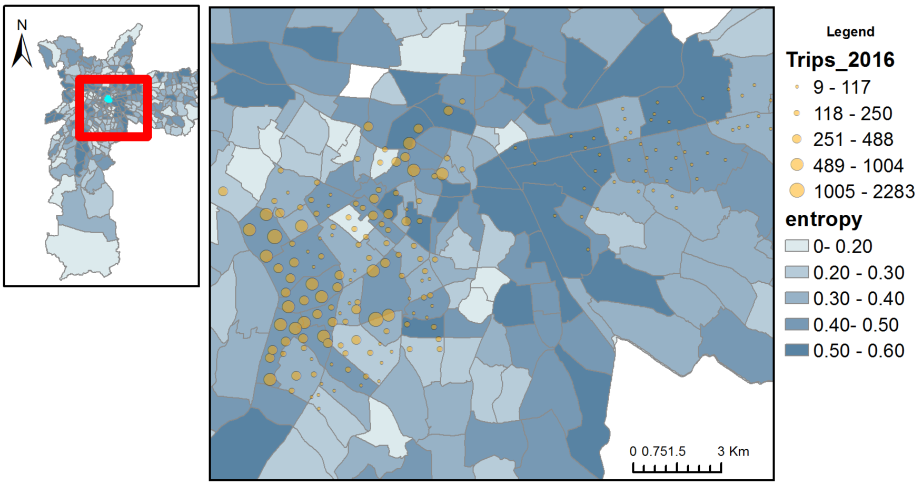

Figure 15: Bike sharing usage with respect to land use entropy

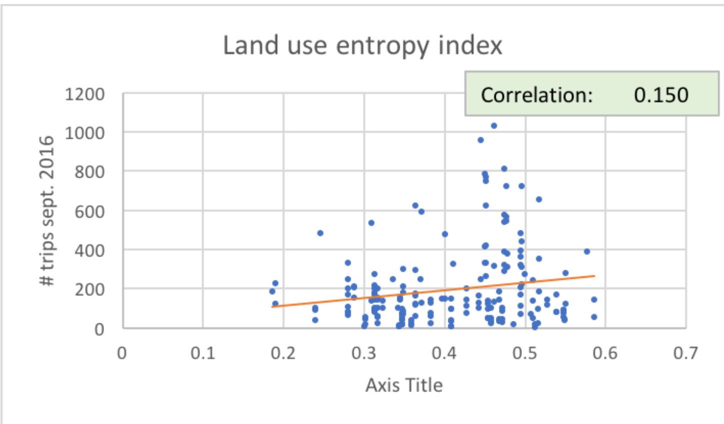

Figure 16: Bike sharing usage with respect to land use entropy

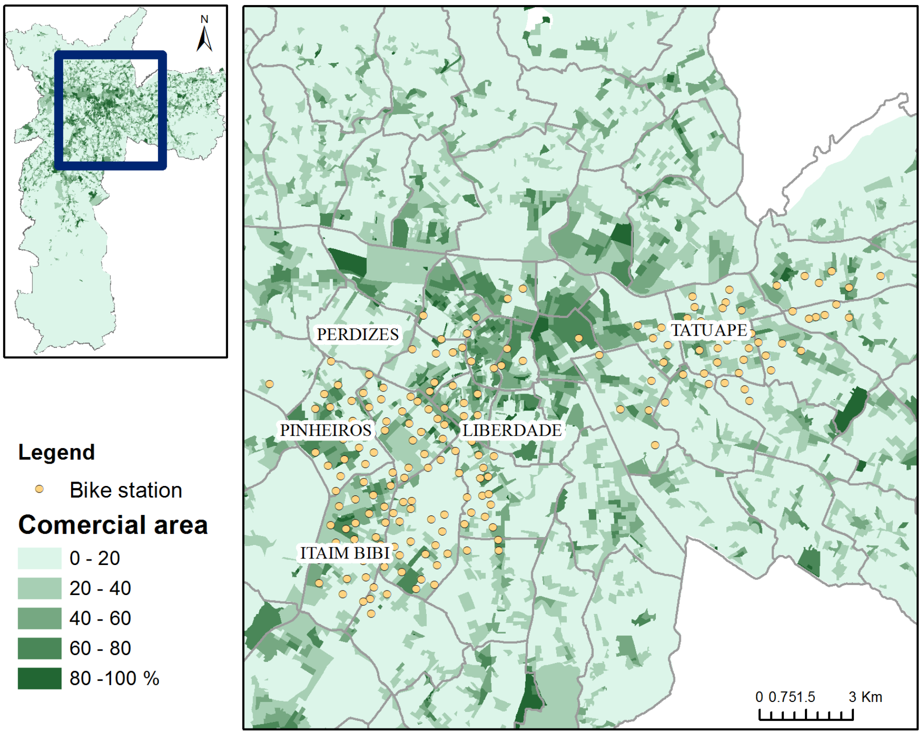

Figure 17: Visualisation of commercial area density in São Paulo

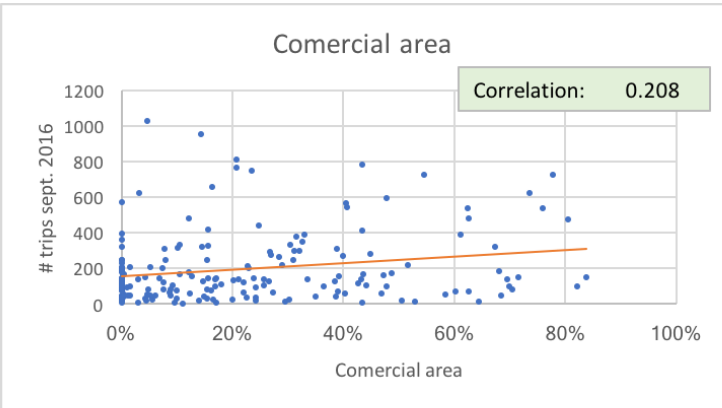

Figure 18: The available amount of commercial in relation to the bike use

Bikeability The bikeability index that was created for São Paulo in this research shows a reason for the lesser popularity in the east. The area has a low concentration of bike lanes and very hilly topography making it unattractive for cycling, if safety was taken into account as a factor the difference would increase even further.

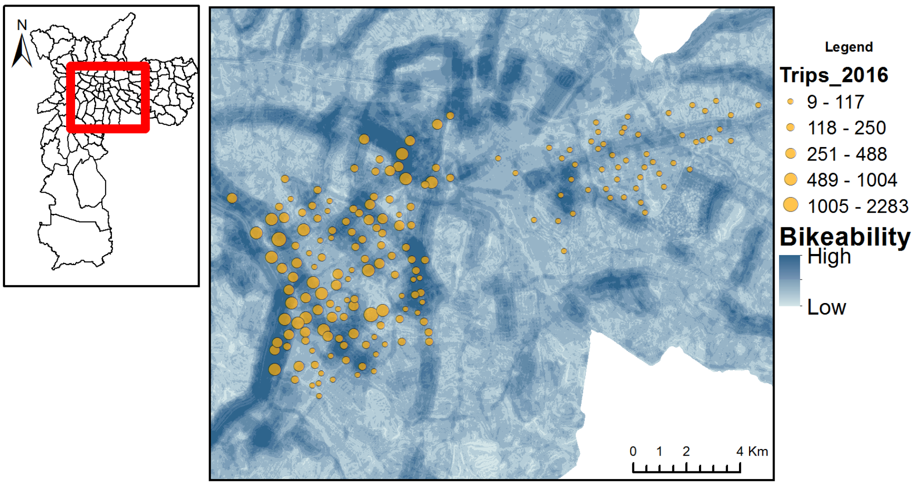

Figure 19: Bike sharing use with respect to bikability

Economic factors Looking at economic factors it is found that there exists a strong correlation between location of successful stations and the higher income per person as well as the job density (figure 20, 21, 22). Stations are available in poorer areas in the east but are way less used. The bike is often used for travelling to work as was discovered in the survey by ativo (2016), the correlation confirms this relation between job density and bike use. Also, people who 'do well' cylce more often can be concluded when looking at the existing correlation. This is one of the conclusions that is also drawn in the most recent thermometer of accessibility report regarding Amsterdam. The 'high class' of Amsterdam tends to see riding a bike as a symbol of status whereas the car is still an important measure of ones success in the lower classes (Stadsregio Amsterdam, 2016). A higher income facilitates a larger array of choices; one can choose to live close to work or to (not) own a car whereas the lower class can only afford to live in the suburbs far away from work and dependent of the car.

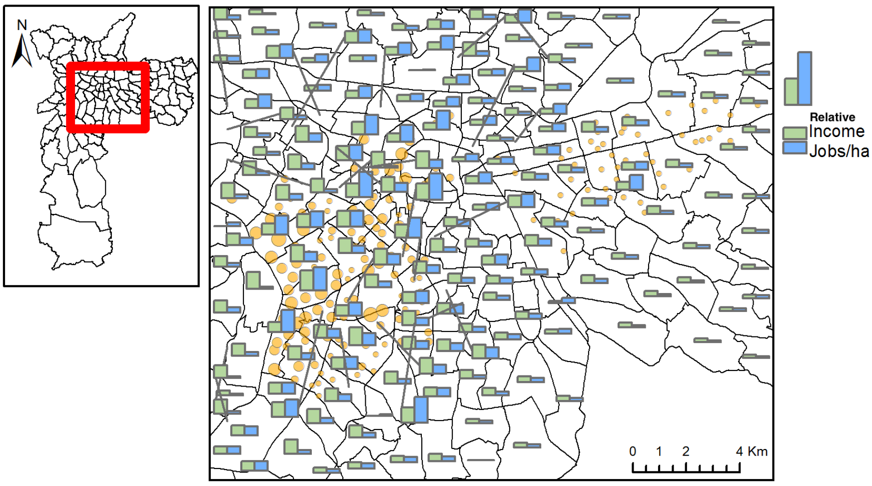

Figure 20: Bike sharing use versus the number of jobs per ha and the income per person

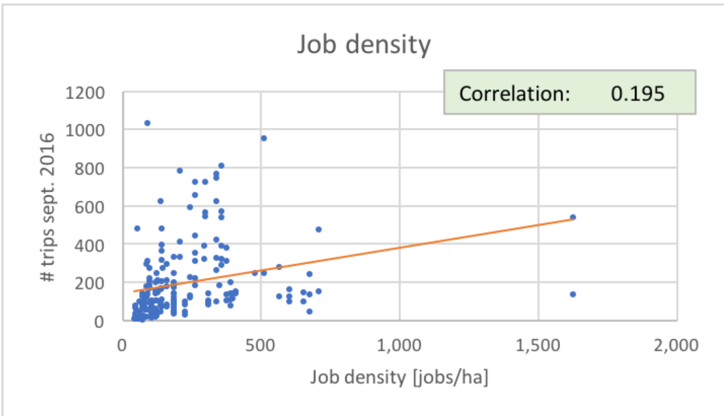

Figure 21: Job density versus the bike use, a moderate correlation exists

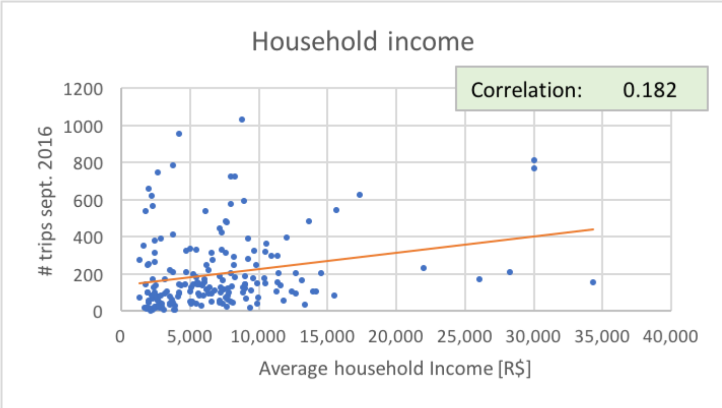

Figure 22: Correlation is shown between bike use and the household income

Statistics An overview of the linear correlation coefficients shown in table 6 connects the variables. The correlations between factors are easy to understand. Job density, population density and the availability of commercial area are dependent of each other since they take away or provide physical space from each other.

Table 6: Correlation coefficients between factors

	Comercial	**PopDens**	**Income**	**JobDens**	**Entropy**
Comercial	-				
PopDens	-0,189	-			
Income	-0,138	0,033	-		
JobDens	0,262	0,155	0,054	-	
Entropy	0,142	0,017	-0,178	0,069	-
Use2016sept	0,208	-0,103	0,182	0,195	0,150

Metro accessibility Compared to other cities as for instance London and Paris, the metro system in São Paulo is very limited. Relatively long distance to metro stations as well as the radial design make it an unattractive option. When considering the bike as a feeder system this makes the metro network available to over 6 times as many inhabitants. The impact of this is seen in figure 23 and table 7. In this analysis the new slope dependent cycling network is used with a trip time of 15 minutes. As a walking distance, 500meter is generally accepted (Advani and Tiwari, 2006), (Cartenì et al., 2014).

Table 7: Inhabitants within service area

Mode	Inhabitants
Walk (500meters)	0.66 million
Cycle (15 minutes)	4.33 million

Besides investing in the metro system it is therefore advisable to create bike facilities like parking near metro stations for peoples personal bike.

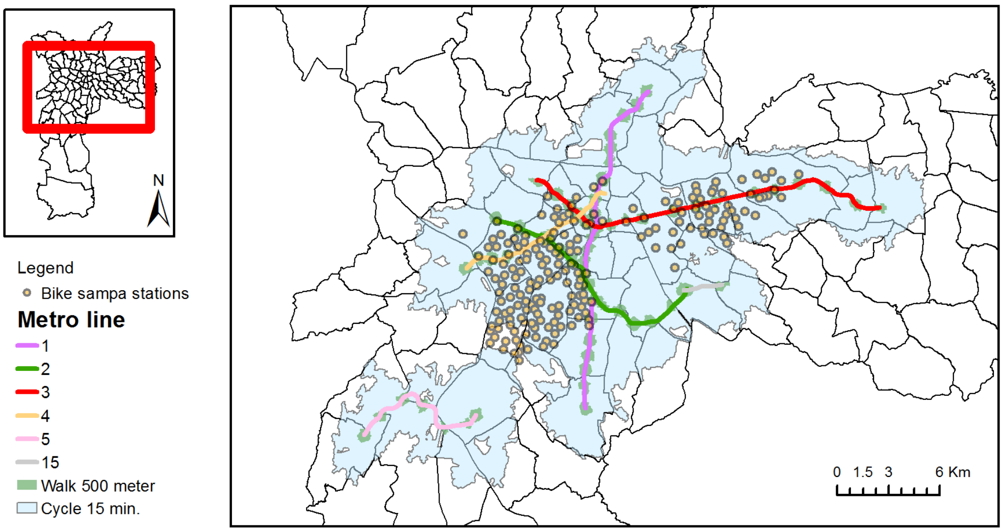

Figure 23: Visualisation of the impact of bike versus walking as a first or last mile modality

6 Conclusion

This chapter discusses the most important conclusions that followed from the research.

The bicycle is very well able and already used to provide transport for first and last mile access in São Paulo . With the added slope depended speed network the catchment areas of the metro system can now be determined more accurately to determine new station locations. The radial metro network in the city leaves large areas uncovered as shown in the results section. Therefore, the coverage area of the metro network would be 6 times larger when including the bike as a feeder system.

Current use of bike sharing in São Paulo is limited and does not reach 1.5 trip per bike per day. Several findings about the behaviour of cyclists in São Paulo that were found:

- Gender inequality: women do not cycle as much as men yet because of the dangerous traffic and conservative gender roles.
- Traffic education: Brazilians are not used to cycling, meaning they are not able to perform the physical act of cycling as well as that they are not used to cyclists riding on the car lanes.
- The topography: 26% of roads has an incline of more than 8% which is seen as a serious barrier for cycling
- The operator: The information in both the app and other communication by the operator are not always correct. This and the lack of maintenance does not stimulate the reliability of the system.
- Users: see this modality as a way of leisure and sports. However, this research has proven that this is changing. The bikes are used in rush hour twice as often in 2016 compared to 2014.

The research has stretched the correlation between the use of bike sharing and the succes factors: 'income', 'job density' and 'commercial area'. When analysing the OD zones it appears commercial areas are the most popular for bike sharing.

The locations of bike sharing are not well chosen when it comes to resolving the traffic problems in São Paulo . The locations have been chosen by a company that wants to advertise their brand and an operator that is not incentivised to perform well. New locations should be build in residential areas so people can pick or drop a bike close to their home. Also, areas that are suitable for cycling and have difficulty accessing a metro station now can be helped by new bike share locations. To make the system available to low as well as high income groups; other forms of payment or deposit should be accepted as cred card penetration in Brazil is low for low income groups.

7 Recommendations to the municipality

To the municipality I would recommend to set up a tender for the new contract. Serttel is not doing a good job as the operator of the system at this moment since there is no incentive for them to do so. Information is false or not available, bikes are lacking maintenance, station are without internet connection often.

- The connection between housing and bike sharing should be improved by gradual expansion of the system throughout the city.
- Lower class neighbourhoods could be included and educated in the combination of cycling and public transport.
- Integration between bus terminals, metro station and the bike in general should be improved. Times for taking the bike on public transport can be expanded and safe bike parking availability is a requirement for every metro station.
- It is necessary that the government has fully accepted that shared bikes are part of the city's mobility system. With the switch to a new municipal government in January 2017 the future of the bike sharing policy is questionable.
- Goals, penalties and data transparency should be part of a new tender contract.
- Maintenance could be carried out in the stations since bikes are now too long out of the system.

8 Discussion

Inside the mind of users houses important information. In further research a survey is crucial to get in touch with this information. It could give a better understanding of the kind of trips that are made by bike and peoples general attitude towards cycling. Whether needing a credit card really is a barrier to using the system for instance, is important to know when wanting to make the system better available to the lower part of society.

A very large increase in the rush hour share of bike use is seen and described in chapter 5.2, figure 11. Data about the trip purpose is not available but it may be said that rush hour trips have a high chance of being commuter trips. This means the trip is a obligatory one and else would have been made by a different modality. When this is proven to be true in further research, bike sharing is contributing to reduce congestion in São Paulo .

Cycle speed network Further improvement of the cycle speed network is possible by implementing more accurate models for up and downhill speeds and taking into account more variables. These for instance could include the type of road, junctions, traffic lights, historical trip data (tracking). Compared to the euclidean distance this already is a great improvement.

Characterizing the area can be done with more variables. Only three have been chosen to create a bikeability map whereas the activism group during my interview mentioned safety as an important factor in São Paulo . Also, the other factors might score different when the focus group was held in São Paulo instead of Vancouver, Canada. Looking at height maps shows this area as rather flat compared to São Paulo . The areas that are well used by cyclist now typically have police or prive security in the streets 24/7. Areas in the east are missing out on this. Also destination density is mentioned by (Winters et al., 2013). When these focus groups were done in São Paulo instead of Vancouver, Canada which is for instance relatively flat, the bikeability index would contain different parameters and weights.

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