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A bikeability index for Curitiba (Brazil)

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ABSTRACT

The city of Curitiba, in the southern region of Brazil is seeking to increase the bicycle network with the construction of new bicycle paths and bicycle lanes, parking locations for bicycles and in the maintenance of the existent cycling infrastructure. Spatial analysis tools, such as the Bikeability Index is a useful approach to incorporate different aspects of bicycle use in a local perspective, giving inputs for decision-makers when deciding to implement new bicycle infrastructure in order to increase the cycling conditions within the city, providing positive cycling experiences and encourage more people to use bicycle for transportation.

Therefore, the purpose of this investigation is to build a Bikeability Index for the city of Curitiba, considering local perspectives about bikeability and bicycle use. The index will be represented in a form of a map, highlighting areas that are more and less propitious to cycle. The map intends to support a potential bicycle network expansion of the city, by identifying areas where cycling conditions needs to be improved. The map was built using Geographic Information System (GIS) data, with the bicycle use aspects being assessed through a quantitative study conducted with the citizens of Curitiba. The index is composed by Residential Density, Mixed Land-use, Topography, Safety and Types of Infrastructure. GIS data was collected thanks to the open data policy from the Municipality of Curitiba and to previous investigations conducted in the city. A Questionnaire was also applied in the city, with the objective of gaining more insights about the aspects that affects bicycle use in Curitiba. 231 individuals participated in the survey. To analyse possible differences between in the survey responses, participants were divided in cyclists versus non-cyclists, and higher income versus lower income.

Results demonstrated that cyclists and non-cyclists perceive differently the aspects related with bikeability and bicycle use. No consistent differences were found between higher and lower income group. Consequently, three bikeability maps were produced. One based on the responses from the whole sample size, one based on the cyclists’ evaluation and one based on non-cyclists’ evaluation. The map indicates areas with good conditions for cycling and areas where the conditions need to be improved. The map is focused on cycling for utilitarian purposes, rather than sports or recreation.

Keywords: Bikeability, Bikeability index, Spatial Analysis.

EXECUTIVE SUMMARY

For being responsible for great part of the pollutant emissions in the atmosphere (23% of the total CO_2 released) (IEA 2009), actions to improve efficiency and reduce energy consumption in the transport sector is considered vital to reduce greenhouse gas emissions and improve environmental standards. Among this sector, land-transport (especially light-duty vehicles) is responsible for 80% of the total energy consumed (Hosking, Mudu, & Dora, 2011), raising the awareness of environmentalists and transport planners about the consequences of the wide use of this method for daily travels in the cities. Developed countries usually experiences higher rates of automobile use, however, developing countries, such as Brazil, together with an increase In the GDP per capita, experienced an expansion of the vehicle fleet in the previous years, mainly in a response to the weakness of the public transport system (Hosking, Mudu, & Dora, 2011). Apart from environmental constraints, the higher use of private vehicle in Brazil brought consequences to the population's health. The country is nowadays the fifth in the number deaths due to traffic-related accidents (Ministério da Saúde, 2015a) and more than half of the population is overweight, with high rates of coronary diseases, high blood pressure, and psychological disturbs caused by stress (Ministério da Saúde, 2015b). A possible measure to mitigate these effects is through active commuting – defined as walking or cycling for transportation purposes – which has the potential to reduce the use of motorized vehicle, increasing the efficiency of the urban transport system and introduce physical activity into people's daily lives (Rabl & Nazelle, 2012).

Aware of the benefits of increasing active commuting and in a response to public opinion, the Municipal administration of Curitiba, in the south of Brazil, is investing in the construction of new bicycle paths and bicycle lanes, parking locations for bicycles and in the maintenance of the existent cycling infrastructure (Gazeta do Povo, 2013). However, in such complex environment with several stakeholders like the city's transport system, and with a scarcity of monetary resources, the expansion of the bicycle network should be done in a theoretically-based manner. The use of spatial analysis tools, such as the Bikeability Index is a useful approach to incorporate different aspects of bicycle use in a local perspective, giving inputs for decision-makers when deciding to implement new bicycle infrastructure that are capable to provide positive cycling experiences and encourage more people to cycle (Greenstein, 2015).

Therefore, the aim of this study is to build a Bikeability Index for the city of Curitiba, taking into account local perspectives about bikeability and bicycle use. The index will be represented in a form of a map, highlighting areas that are more and less propitious for bicycle use. The map intends to support a potential bicycle network expansion of the city, by identifying areas were cycling conditions needs to be improved. The map was built using GIS data, with the bicycle use aspects being assessed through a quantitative study conducted with the citizens of Curitiba. With the use of quantitative data, the researcher sought to present an index closer to the real aspects of bicycle use in the city.

LITERATURE REVIEW

Stimulating the use of active transport for commuting involves a deeper understanding of the factors that influences day-to-day decisions for transport use. To implement effective policies and interventions on walking or cycling, it is important to comprehend that the physical environment, social environment and personal-level attributes are all factors that can be positively or negatively associated with active transport (Titze, Stronegger, Janschitz, & Oja, 2008). Physical environment is commonly addressed in the literature as Built Environment, which can be defined as infrastructures, mainly urban, built by human action. It includes land use patterns, such as the distribution across an area of activities and its corresponding buildings; the transportation system, like the physical infrastructure of roads, sidewalks, bicycle paths, etc.; and the urban design, including the arrangement and appearance of the material elements in a community (Handy, Boarnet, Ewing, & Killingsworth, 2002).

The most common approach found in the literature to describe the influences of the built environment on travel demand is through the "5D's model", based on the characteristics of a specific area. The five dimensions presented in the model are Density, Diversity, Design, Destination accessibility and Distance to transit. Density is measured always by the variable of interest per unit of

area. Diversity is related to the number of different land uses in a certain area, and the degree to which they are represented. The Design dimension includes the street network characteristics within an area, varying from dense urban grids to disperse networks. Destination accessibility measures the easiness of access to trip destinations, represented as distance to the central business district, the number of jobs or other attractions accessible within a given travel time. The Distance to transit dimension is measured as the shortest distance from residences or workplaces to a public transport stop (Ewing & Cervero, 2010). However, studies that correlated the 5 D's and travel behaviour were mainly performed in developed countries. Between citizens from developing nations, walking or cycling might be a matter of necessity rather than influenced by the aspects of the built environment (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009). Many of them cannot afford having a car or even paying the public transport fee. More research is required in cities from developing countries.

Apart from the Physical environment, the Social environment also play an important role in the citizens' travel behaviour. Common factors in this field includes socio-economic status, gender, age, support from family and friends, and others. Different investigation positively correlates higher social status with higher rates of private vehicle and automobile use for daily commuting. Cycling is also more common among males than females. In developing countries, such as Brazil, public insecurity also affects the likelihood of cycling for transportation. In addition, cycling also drops with age and increases when there is support from family and friends. Personal-level attributes are mainly related with individuals' engagement towards active transport. People that that use bicycle for transport normally sees cycling as environmentally friendly, cheap, healthy, physically and mentally relaxing (Camargo, 2012); (Heinen, Maat, & Wee, 2011); (Titze, Stronegger, Janschitz, & Oja, 2008).

The use of spatial analysis tools is a common approach to incorporate some aspects mainly related with physical and social environment, in order to provide a diagnosis of the cycling conditions of a region and present in a user-friendly way. The visualization of the more conducive and less conducive areas for cycling can be used as an important tool for urban planners and city's administrators that seek to rationally invest public resources to promote active commuting, increasing levels of cycling among citizens (Winters M. , Brauer, Setton, & Teschke, 2013).

METHODOLOGY

This investigation took place in Curitiba, the capital city of the State of Parana, in the southern region of Brazil. In order to build the bikeability index, Geographic Information System (GIS) data of the city was used. The data was collected from the municipal organs and by the researcher in situ. The index, which is represented in a form of a map, is composed of five variables: Residential Density, Mixed Land-use, Topography, Safety and Types of Infrastructure. Residential density measures the number of households per square kilometre; Mixed land-use comprises the rate between the number of different types of establishment and its corresponding area; Topography is calculated as the slope of the whole city; Safety is based on the occurrence and severity level of traffic-related accidents involving cyclists between 2013 and 2015; and Types of infrastructure comprises the location and the ranking of each different infrastructures where cycling is possible, including general streets and exclusive bus lanes.

In addition, a Questionnaire was conducted with the citizens of Curitiba, when participants assessed the degree of importance of the common barriers and facilitators/motivators for bicycle use previously identified. Participants also measured their likelihood of cycling in each of the different infrastructures available in the city. Based on their responses, participants were divided by transport behaviour (cyclists versus non-cyclists) and by income level (higher income versus lower income). Independent sample t-test was used to check whether there were significant differences in the assessment between the groups. Binary logistic regression measured the correlation between citizens' travel behaviour and income level with the analysis of the factors that affects bicycle use, their likelihood of cycling in the different infrastructures of the city and with built environment characteristics of their household location. Factor analysis was used to gain insights about the aspects that affects bicycle use in Curitiba, and to perform the weight distribution of the variables from the bikeability index.

RESULTS

The Questionnaire was applied to 231 people (138 males and 90 females). Most of the participants declared to have higher education, and are from higher income class (155 higher income and 76 lower income). Among the sample, 83 people declared to use bicycle as the main transport mode and 148 make use of other modes of transport (car, bus, motorcycle, etc.). A higher importance level was assigned to Traffic unsafety, Public unsafety, Lack of cycling infrastructure, Speed reduction measures and proper signs and Integration between bicycle and public transport. The *independent sample t-test* showed that significant differences were found only in the assessment between cyclists and non-cyclists. The factors that had significant differences between respondents' means were: Topography, Distance, Weather conditions, Integration between bicycle and public transport, with non-cyclists assigning a higher importance degree. Differences were also found in almost all types of infrastructure presented in the survey. People from higher and lower income class assessed similarly the aspects presented in the survey.

The Factor Analysis gathered the aspects into seven factors, named: Attitudes, Safety, Cost-beneficial, Built Environment, Local aspects, Actions of the city's administration and Density. The total variance explained and the factor rotation indicated a higher weight for two of the Bikeability Index variables: Safety and Types of Infrastructure. The Binary Logistic Regression showed that the odds of being a cyclist increases among males, decreases with age and with higher social status. Cyclists are more sensitive to Speed reduction measures, while non-cyclists, to integration between bicycle and public transport. The likelihood of cycling in general roads and exclusive bus lanes is much higher among cyclists. The Results from the Spatial Analysis are represented below. Figure 1 demonstrates the individual maps from each bikeability index variable. In Figure 2, the final bikeability map is presented, with the variables weighted based on the survey responses. The areas in green represents a higher bikeability and the areas in red, a lower bikeability, thus, where bicycle conditions need to improve.

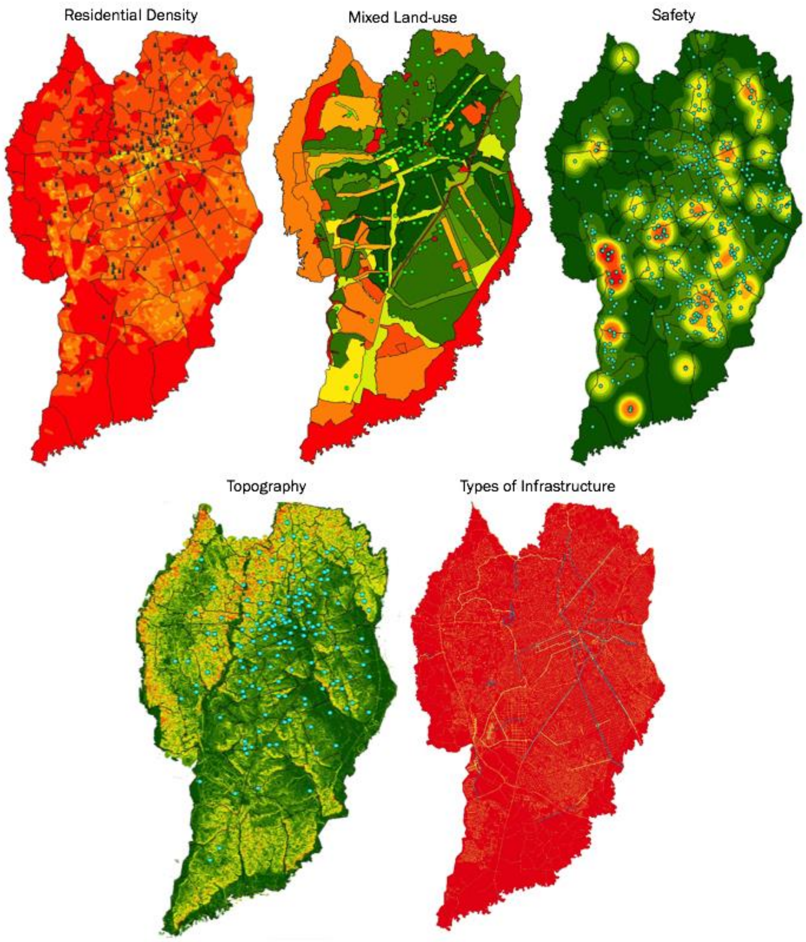

Figure 1: Individual Bikeability Maps

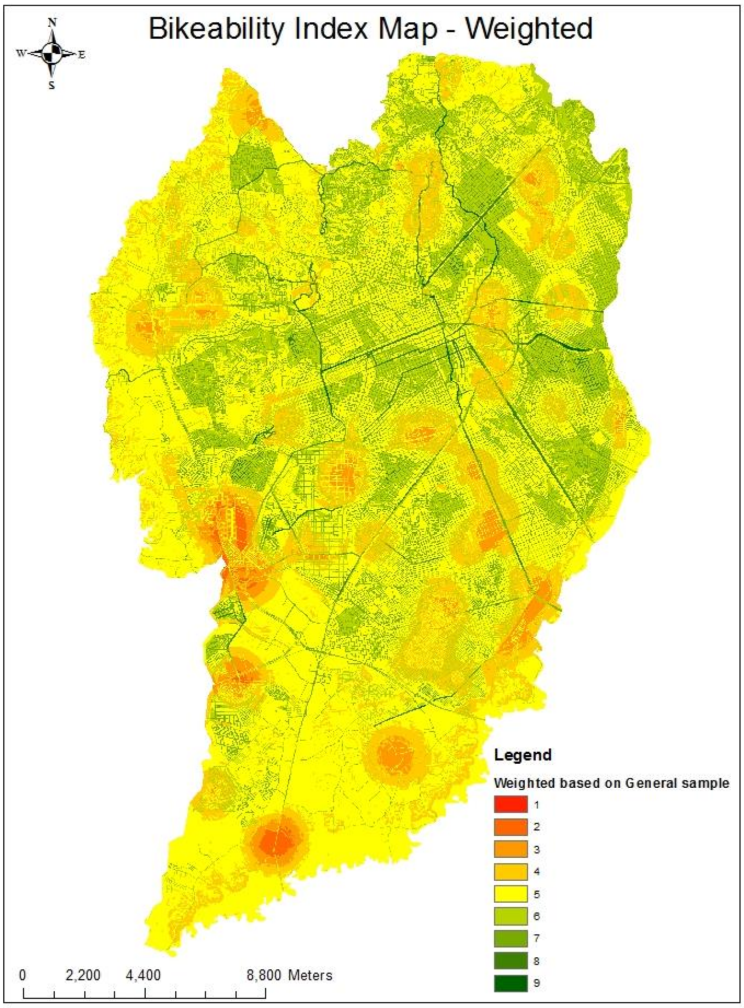

Figure 2: Bikeability Map

CONCLUSIONS AND DISCUSSIONS

Results from the statistical analysis showed consistent differences in the evaluation between cyclists and non-cyclists. This is an indicative that cyclists perceive differently the aspects that affect bicycle use than non-cyclists. While experienced cyclists are more concerned with speed reduction measures and accessibility improvements for bicycle, non-cyclists are more sensitive to distances, weather conditions, public insecurity and integration between bicycle and public transport. Cycling through the different types of infrastructure existent in the city had also some distinctions. Although cyclists give preference to places where a dedicated infrastructure for bicycles exists, they would cycle regardless the conditions. On the other hand, non-cyclists showed a higher rejection for cycling where no dedicated infrastructure is present. Therefore, to increase levels of cycling, implementing cycling infrastructures is essential. In addition, the odds of being a cyclist increase among males, drops with age and with social status.

Results from the spatial analysis demonstrate that areas with a higher occurrence of traffic-related accidents had a strong and negative effect in the final bikeability map. Roads where some dedicated cycling infrastructure is present has also a good bikeability. Residential density showed a negative impact in the index, however, this variable accounted for a small weight which reduced its impact in the final index. Mixed land-use and Topography showed positive impacts in the index, but with moderate effects. The supplementary analysis also demonstrates that dedicated cycling infrastructures are available mostly for higher income people and is still lower in areas with high street density. This research recommends focusing the investments in lower income areas since the bikeability is lower and residents from these locations are more likely to cycle for transportation.

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GLOSSARY OF TERMS

- Bikeability: The term *bikeability* is used to determine the level of interaction between aspects associated with bicycling and the route environment, route distance and other factors that affect the conditions of a specific bicycle trip. Therefore, *bikeability* will measure how these factors and aspects can interact with the perceptions and behaviour of bicycling (Wahlgren & Schantz, 2011).

- Built Environment: Built environment is defined as the spatial context of a specific neighbourhood, city or region. The urban form such as population density, land-use characteristics, roads connectivity and streets' network layout, among others is a common context of the built environment. Another important context is the infrastructure. In terms of cycling, it can be either the type of bicycle infrastructure (bicycle paths, bicycle lanes, on-street bicycle lanes, etc.) or the presence of this infrastructure. Parking facilities and characteristics of the destination (presence of showers, changing facilities and lockers) are also included in the infrastructure context (Heinen E. , 2011).

- Bus Rapid Transit (BRT): BRT is a bus-based system that aims to deliver a cost-effective, fast and comfortable transport service at a metro capacity level. It runs on dedicated bus lanes with the stations typically aligned in the centre of the road, possess off-board fare collection, and fast and frequent operations. A BRT system contain characteristics similar to light rail and metro, which enable to be more convenient, reliable and faster than regular busses (Institute for Transportation and Development Policy [ITDP], 2016).

1 INTRODUCTION

This chapter introduces the main topics of this research, providing a background of the research problem followed by the purpose of the research. After that, the research objective and the questions to be answered by this investigation will be presented.

1.1 Background

The transport segment is one of the main contributors to environmental constraints when compared to other key economic activities such as manufacturing industries, construction, and electricity production. This sector is responsible for 23% of total CO_2 released into the atmosphere and with the highest growth among all the sectors. Near 80% of the total energy consumed with transport activities are related to land transport, mostly by light-duty vehicles such as cars (IEA - International Energy Agency, 2009). Higher rates of private car ownership can be directly associated with a higher Growth Domestic Product (GDP) per capita, with developed countries experiencing a strong use of private vehicle for daily travels. However, developing nations are also facing rapid motorization levels. In those countries, this can be associated with the weakness of the public transport system to respond to mobility needs. In addition, factors such as rapid urbanisation and urban sprawl, socio-economic changes and the common perception that private vehicles are an indication of social status and prosperity contributed to this expansion (Hosking, Mudu, & Dora, 2011). A car-oriented society has negative effects on individuals' health, acting as a facilitator for physical inactivity and injuries regarding traffic incidents (Babisch et al., 2005; Hoek et al., 2002, as cited by Winters (2011). In Brazil, such effects are evident. A research conducted by the Brazilian Health Ministry showed that 52.5% of the population is overweight and 17.9% is obese (Ministério da Saúde, 2015b). In addition, Brazil is the fifth country where most people lost their lives in traffic-related accidents, with 45 thousand causalities every year, when considering urban roads, state and federal highways (Ministério da Saúde, 2015a). In addition, when analysing the percentage of deaths by transport mode presented in the figure below (Figure 3), we can observe that 52% of the casualties occurred with non-automobile users (pedestrians, cyclists and motorcyclists), exposing the vulnerability of these modes within the system (OPAS - Organização Pan-Americana da Saúde, 2015).

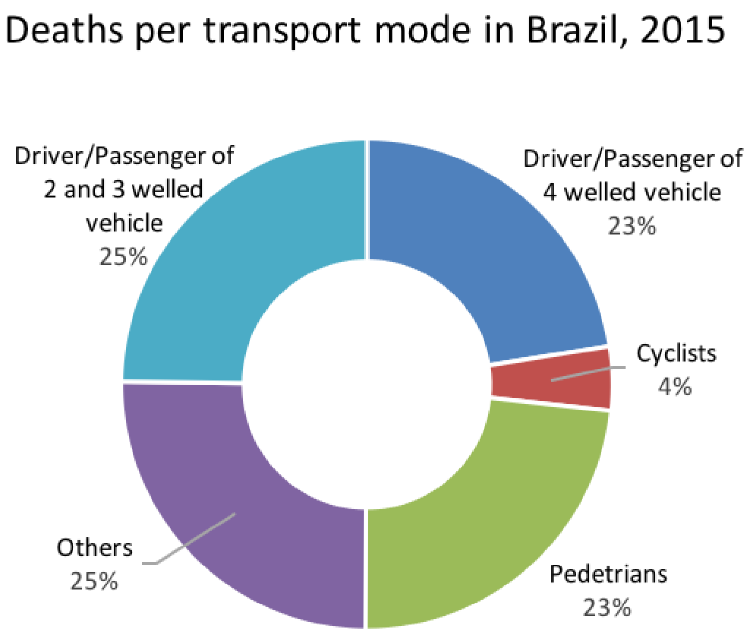

Figure 3: Deaths by transport mode in Brazil (OPAS, 2015)

A possible way to mitigate these effects is through transport & urban planning measures and the use of active transport – defined as walking or cycling for transport purposes. Improving the conditions for walking and cycling, as well as increasing the efficiency of the public transport system is directly associated with higher use of active transport methods and a growth in physical activity levels. The use of these modes also provides more opportunities for social interaction, reduces pollutant emissions and improves accessibility for essential goods and services in a city (Hosking, Mudu, & Dora, 2011). Under this premise, the use of active transport, especially utilitarian cycling is gaining importance in Brazil and in other countries.

The city of Curitiba, in the southern region of Brazil, is known by its successful experience in the field of transport system and land-use regulations. The city's Master Plan, implemented in the late 1960's and considered an innovative approach at the time was commissioned under the premise that transport must work as an integrated system that links housing, land-use, road network, commercial development, and recreational investments such as parks, green areas, and preservation of historic sites. When balancing those aspects, Curitiba could achieve both economic prosperity and sustainable development. Among other things, the plan established a public transport system based on buses at a much lower implementation and maintenance costs when compared to a subway system for instance, with a similar passenger's capacity. This system is called BRT (Bus Rapid Transit) and is viewed as a cost-beneficial solution for mass transportation in cities throughout the world. Curitiba was the first city to implement such system (Rabinovitch, 1995).

The importance of the Master Plan in the development process of the city remains evident since its premises have been guiding land-use regulations and transport initiatives until nowadays. As a matter of fact, the idea of Curitiba as an innovative city was mainly due to the commitment to base its entire growth on this system, rather than in the plan itself (Duarte & Ultramari, 2012). However, recent evaluations of the city's indicators revealed that Curitiba has critical issues regarding its transport system. An index developed by Costa (2008), called Sustainable Urban Mobility Rate (IMUS, in Portuguese) comprise an assessment tool capable of exposing the existing urban mobility conditions and forecasting the impacts of decisions in the field of sustainable transport. Different applications of this index by Costa & Silva (2013) and Miranda & Silva (2012), revealed that Curitiba has a (1) high level or urban fragmentation and urban segregation, (2) little attention for non-motorised modes especially bicycle and pedestrians, (3) a high motorization rate, (4) lower average traffic speed, and (5) a low occupancy rate of the automobiles. According to the authors, these factors have been contributing to the environmental problems regarding air and noise pollution in the city and are an indicative of a large number of physical barriers that hampers the use of alternative transport.

If from one side, the public transport system worked as engines for the city development, on the other side, evidence suggest that the system has reached its maximum capacity. In a survey performed by a local research institute, 419 people were asked about the major problems regarding the public transport system of Curitiba. For 57% of the users, overcrowded buses are the main concern, followed by the price of the ticket (15%) and delays in the schedule (10%). Constant traffic jams in the city (5%) and the travel time (4%) were also pointed as problems faced by public transport users. Other reasons accounted for the remaining 9%. The survey was conducted in April 2015 among residents of Curitiba (Gazeta do Povo, 2015). Another reason that deserves attention is related to the number of private vehicles in the city. Curitiba is the state capital with the highest rate of car ownership of Brazil, with 1.84 habitants per vehicle. A rate similar to developed countries in Europe and North America (Revista EXAME, 2014).

Striving to increase the efficiency of the transport system and to respond the demands from public opinion, the city of Curitiba is investing in bicycle infrastructure and is also experiencing a rise in the number of cyclists. The city is one of the Brazilian state capitals with the largest network of cycling infrastructure. However, most of it was built in the past, viewing this mode as a leisure activity. There is no connectivity between the cycling infrastructures, many of the existent ones are located on the sidewalks and are in poor conditions due to the lack of maintenance (Duarte, Procopiuck, & Fujioka, 2014). The city's administration promised to invest 90 million Reais until 2016 (around 25 million Euros) in new bicycle lanes, bicycle paths, bike parking and maintenance of the existent cycling infrastructure. The goal was to implement 300 kilometres of new bicycle lanes in four with a focus on transportation reasons rather than recreation purposes as in the past (Gazeta do Povo, 2013). Indeed, much has been done to improve cycling conditions in Curitiba recently, and implementing new bicycle infrastructure is an important factor to increase bicycle use. Different investigations in Brazil and worldwide showed that investments in infrastructure (bicycle lanes, bicycle parking, continuity of cycling infrastructure, etc.) have intrinsic connection with the levels of cycling, and are also associated with an increase in cyclists' general safety and safety perception, regardless the lack of clear evidence about the reduction in the number of bicycle-related accidents after the implementation of a cycling infrastructure (Camargo, 2012); (Heinen E. , 2011); (Pucher, Dill, & Handy, 2010). However, as stated by Heinen (2011), many other factors are also associated with bicycle commuting such as the built environment, including infrastructure, natural environment and socio-demographic aspects. As an example, the impact of socio-demographic factors can vary from country to country. In places with lower levels of cycling and less dedicated infrastructure, women are minority among bicycle users. In countries where the cycling culture is more consolidated, this difference is evenly spread between the two genders (Garrard, Rose, & Lo, 2008). When associating income level with the use active transport methods, investigations from Plaut (2005) and Witlox & Tindemans (2004) associates lower likelihood to use non-motorized commuting with higher salary income. Understanding how each of these factors affects the bikeability of specific regions could be the key to design effective interventions that are capable to provide positive cycling experiences, and encourage more people to travel by bicycle (Winters M. , Brauer, Setton, & Teschke, 2013).

Apart from that, other aspects also appeared to influence bicycle use. Findings from an American Housing Survey says that residential density and land-use mixture (number of establishments with non-residential activities within an area) have strong and positive influence on increasing both walking and bicycle commuting. Results also showed that an adequate transit service induces walking and cycling due to the possibilities of modal share (Cervero, 1996). Another investigation performed in Vancouver (Canada) showed that flatness, higher intersection density, fewer highways and arterials roads on cyclist routes, presence of bicycle signage, traffic calming areas and cyclist activated traffic lights, apart from a higher land-use mixture and high density, are associated with more trips made by bicycle (Winters M. , Brauer, Setton, & Teschke, 2013). Other investigation performed in Bogota (Colombia) correlated street design, in this case, route connectivity, with higher levels of utilitarian cycling. In contrast, high fatality levels demonstrated to be deterrent to cycling (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009). In the city of Curitiba, some studies investigated the different factors that influence the use of bicycle such as Camargo (2012), and the association between built environment aspects and levels of walking and cycling such as Hino, Reis, Sarmiento, Parra, & Brownson (2014), but it is not in the knowledge of this author the representation of such effects using spatial analysis techniques.

One of the methods for mapping cycling experiences and assess the potential for cycling considering built environment, natural environment and socio-demographic aspects is through spatial analysis tools. When mapping the aspects that affect bikeability, city planners can have important inputs to guide new transport planning and policies. In cities throughout the world, the bikeability index, which is a spatial analysis tool, is used to support sustainable travel by means of increasing bicycle use, such as showed by Krenn, Oja, & Titze (2015); Winters, Brauer, Setton, & Teschke (2013) and Greenstein (2015). In addition, it supports the allocation of resources by identifying and prioritising areas that are more propitious to implement new cycling interventions. This visualisation is also used to further understand the relationship between built environment and people's travel behaviour, confronting bikeability with actual bicycle use, and engage the population to the city's planning process (Greenstein, 2015).

1.2 Purpose of the study

As mentioned in the previous section, one of the most common approaches for stimulating bicycle use for commuting trips is through the construction of cycling infrastructure (bicycle, lanes, bicycle paths, on-street bicycle routes, etc.). The common understanding says that, is safer to separate cyclists from motorised traffic, especially inexperienced cyclists, women and younger cyclists. However, some authors argue that other aspects such as urban design, land-use objectives, natural environment, socio-demographic aspects, and others can also influence the levels of active transport use by local citizens.

Despite its acknowledged experience in urban planning and public transport, the city of Curitiba is facing constant issues concerning urban mobility, including an overcrowd transit system, higher use of motorised vehicle, environmental problems related to air and noise pollution, constant traffic jams and a higher occurrence of traffic-related accidents. Stimulate commuting trips made by bicycle, and reducing the use of private vehicle can enhance the city's transport system, improve environmental indicators and incorporate some level of physical activity into citizen's routine. The bikeability index tool can support local planners in the decision-making process to increase the use of bicycle through an expansion of the bicycle network, since it highlights areas more conducive and less conducive for cycling, thus, where cycling conditions need to be improved.

Under this premise, this investigation computed a bikeability index for the city of Curitiba (Brazil), considering built environment aspects of the city, such as residential density and land-use mixture; natural environment aspects, such as the city's topography; and safety issues, specifically the location of traffic-related incidents involving cyclists and its respective severity level. The index was built based on Geographic Information System (GIS) data and is represented in a form of a map. With the map, the current conditions for bicycle use in the city of Curitiba are demonstrated. All the GIS data matched with the availability criteria. Figure 4 shows the variables used to compute the bikeability index developed in this research.

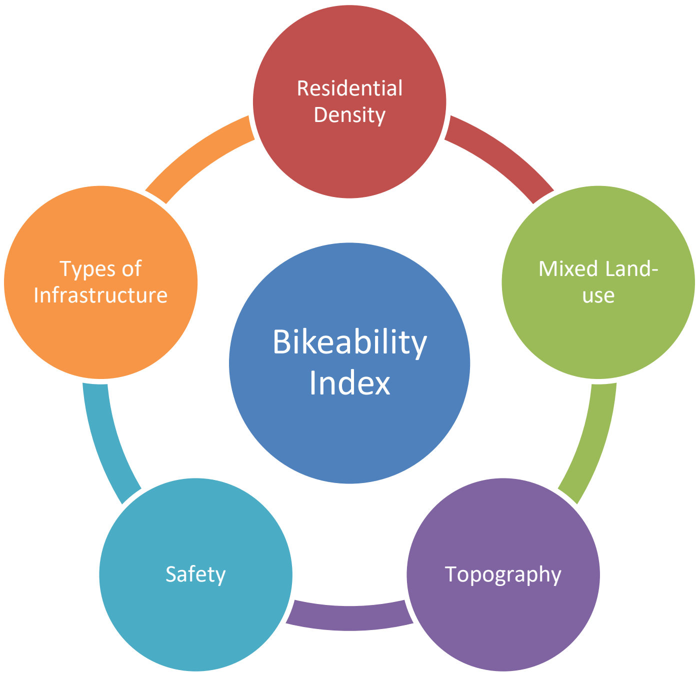

Figure 4: Bikeability Index Variables

In addition, data was also collected through a survey conducted among residents of Curitiba (both online and face-to-face), when respondents had to assess their level of importance concerning the barriers and facilitators for bicycle use, previously identified in the literature. This appraisal will support in the weight distribution between the variables that composes the index, generating a more reliable evaluation and providing more insights about factors that affect bicycle use in Curitiba. As a complement, respondents assessed their likelihood for using bicycle on each of the cycling infrastructures in the city. Socio-economic data was also collected in the questionnaire.

1.3 Research Objectives

The objective of this research is to assess the current cycling conditions of the city of Curitiba (Brazil) by computing a bikeability index based on built environment, natural environment and traffic safety aspects. The index is represented as a map, where areas that are more and less favourable for bicycle use will be highlighted. The focus is the use of bicycle for transportation, rather than recreation or physical activity. In addition, this study aims to investigate whether the aspects that affects bikeability and bicycle use differ depending on the citizens' social status (higher income and lower income) or travel behaviour (bicycle users and non-bicycle users).

1.4 Research Questions

The research questions to be answered by this investigation are presented below:

1. What are the consequences of the built environment, natural environment and safety issues on the overall bikeability of the city of Curitiba?

By analysing built and natural environment factors such as residential density, land-use mixture, presence and type of cycling infrastructure, topography, apart from location and gravity of traffic-related accidents involving cyclists, the bikeability map can be produced. In the map, areas with higher and lower conditions for bicycle use can be exposed. The bikeability map is a user-friendly methodology to present the data to planners and policy-makers (Winters M. , Brauer, Setton, & Teschke, 2013).

2. Are the aspects that affects bikeability and bicycle use in the city of Curitiba differently perceived depending on citizen's social status?

Many correlations can be made between GDP level of countries and motorization rate. Countries with higher GDP possess higher rates of car use and car ownership. In developing countries, together with an increase in the economic indicators, there has been an increase in vehicle ownership. In these countries, having a car is not only a necessity but also a matter of social status and economic prosperity (Hosking, Mudu, & Dora, 2011). This statement is also supported by the concept of "car pride" (Zhao, 2013).

3. How the perceptions about bikeability and bicycle use differ between bicycle and non-bicycle users?

Aspects regarding safety, comfort, convenience and personal beliefs tend to be assessed differently between cyclists and non-cyclists. Each group, based on their own experiences, or in some cases the lack of cycling experience, possess different perceptions on bicycle use (Pezzuto, 2002).

2 LITERATURE REVIEW

The literature review of this document will address the different areas related to bicycle use and bikeability. The chapter was divided in the following manner. In the first section, the objective measures related with transport behaviour will be presented. Evidence existent in the literature correlating built environment aspects with travel behaviour, as well as the concepts and different dimensions of the built environment will be exposed. In the second section, studies that correlate both objective and subjective measures of transport behaviour are mentioned, with the focus on the last. Subjective measures include attitudes towards the environment and active transport, socio-demographic characteristics of individuals, physical activity levels, social support, and others. To conclude, examples of the applicability of spatial analysis tools in different locations will be exposed. The bikeability map is applied considering local aspects of built environment and transport behaviour.

2.1 Objective Measures of Transport Behaviour

Stimulating the use of active transport for commuting involves a deeper understanding of the factors that influences day-to-day decisions for transport use. To implement effective policies and interventions on walking or cycling, it is important to comprehend that the physical environment, social environment and personal-level attributes are all factors that can be positively or negatively associated with active transport (Titze, Stronegger, Janschitz, & Oja, 2008). In this section, it will be explored the concepts related to the physical environment of regions and its relationship with transport use. Physical environment is commonly addressed in the literature as Built Environment, which can be defined as infrastructures, mainly urban, built by human action. It includes land use patterns, such as the distribution across an area of activities and its corresponding buildings; the transportation system, like the physical infrastructure of roads, sidewalks, bicycle paths, etc.; and the urban design, including the arrangement and appearance of the material elements in a community (Handy, Boarnet, Ewing, & Killingsworth, 2002). Aspects of the Built Environment and its influences in transport behaviour is known for being part of what is called objective measures since it can be assessed after confronting the physical aspects of a city or region with the transport demand, routes and/or transport modes of the population. These concepts will be further explained in the next sub-sections.

2.1.1 Built Environment and the 5D model

Urban planners and public health researchers have been arguing that urban design can reduce sedentary levels and improve general people's health, by influencing walking or cycling for transportation reasons (Freeman, et al., 2012). In a simplistic description, daily trips are made and distributed based on the desire to reach places, such as work, study, shopping, recreation, and others. Built environment aspects of these areas, which includes land uses, densities, and design characteristics can affect either the demand for travel, the travel mode, or the travel routes (Cervero & Kockelman, 1997). The most common approach found in the literature to describe the influences of the built environment on travel demand is through the "5D's model", based on the characteristics of a specific area. The five dimensions presented in the model are Density, Diversity, Design, Destination accessibility and Distance to transit. Density is measured always by the variable of interest per unit of area. The variable of interest can be population, residential units, employments, building floor area, and others. Diversity is related to the number of different land uses in a certain area, and the degree to which they are represented. This dimension is normally symbolised as a calculated rate, where low values indicate homogeneous environments and higher values represent a more varied land use. The Design dimension includes the street network characteristics within an area and can vary from dense urban grids with highly interconnected streets to disperse networks with random street patterns ("T" intersections or cul-de-sacs). Measures in this dimension include proportion of four-way intersections, the number of intersections per unit of area, sidewalk coverage, average street widths, specific bicycle infrastructure, and others. Destination accessibility measures the easiness of access to trip destinations, represented as distance to the central business district, the number of jobs or other attractions accessible within a given travel time. The Distance to transit dimension is usually measured as the shortest distance from residences or workplaces to a public transport stop. It can also be represented as transit route density, the distance between transit stops or the number of stations per unit of area. All the five dimensions are characterised as rough boundaries, and the aspects related to one dimension might intersect between two or more dimensions (Ewing & Cervero, 2010). Figure 5 represents the five dimensions of the Built Environment with the overlap possibility between the areas.

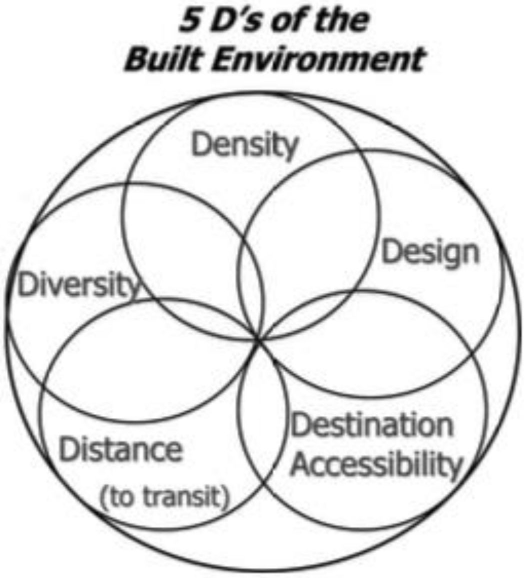

Figure 5: The 5 dimensions of the Built Environment (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009)

2.1.2 Correlations between Built Environment and Transport Behaviour

In this section, studies that correlate the 5 dimension of the built environment with transport behaviour in different cities around the world will be presented. The studies confronted objectively measured aspects with automobile and public transport use, as well as active transport – walking or cycling. Studies from cities in developed countries are the absolute majority in the literature, however, analysis from cities in developing nations also compose this section, including one analysis performed in the case study of this Master Thesis (Curitiba – Brazil).

A Meta-Analysis performed by Ewing & Cervero (2010) combined the results of multiple scientific studies that correlates, quantitatively, characteristics of the built environment to measures of travel, all following in one of the dimensions presented in Figure 5. The analysis included 54 scientific studies available until the end of 2009 and are mainly from different locations in the United States. Studies from Canada, Germany, Denmark and Chile were also included in the analysis. Results indicate that vehicle miles travelled (VMT) drop when destination accessibility improves. Walking was strongly and positive related to land use diversity, intersection density, and the number of destinations within a walking distance. Transit use was strongly associated with proximity to transit stops and street network. This suggests that built environment aspects can be associated with people's travel behaviour, although, the meta-analysis was mainly composed of studies in cities from developed nations. In developing or undeveloped countries, citizens' transport behaviour might be more related to local needs than simply the aspects of the built environment. Another limitation is that the meta-analysis did not include investigations concerning bicycle use, which is gaining importance worldwide as a way to increase efficiency in the transport system and increase physical activity levels among citizens.

With a focus on bicycle modal share, a study was conducted in North American cities and aimed to compare built environment characteristics with levels of cycling across 24 cities in the United States and Canada. To enable the comparison, a Bike Score was developed by computing GIS data of density and quality of cycling infrastructure, topography, desirable amenities and road connectivity. The objective of the study was to assess to what extent a higher Bike Score is associated with higher levels of cycling, both between and within cities. To compute the Bike Score, three variables were generated with different weights among them: Bike Lane Score (50%), a Hill Score (25%), and a Destination and Connectivity Score (25%). The score ranges from 0 to 100, where the highest score correspond to the most bikeable area (more bicycle facilities, flat topography, more destinations and better connectivity). The Linear Regression indicated that, in cities with a higher mean in the Bike Score, more people commute by bicycle. Therefore, the association between the score and cycling modal share was significant and positive. In the analysis between the cities, Bike Score explains 27% of the variation in cycling modal share. When analysing within the cities at a census tract level, for each ten-unit increase in the score, a 0,5% increase in the proportion of cycling was noticed, demonstrating the positive correlation between the score and the levels of cycling, confirming that the built environment components used in this study can be associated with higher levels of bicycle use (Winters, Teschke, Brauer, & Fuller, 2016). However, this study was limited to cities in the United States and Canada, which aspects of built environment and travel behaviour can differ considerably. In addition, the research analysed cities from the United States that already has higher cycling rates, which means that other aspects not related to the components of the Bike Score might be associated with bicycle use. The study also weighted cycling infrastructure separated from the traffic twice as on-street facilities. This might not be ideal since experienced cyclists tend not to make distinctions between on-street or off-street facilities.

A different study focused on the effects of the built environment in non-recreation trips made by car and bicycle in the Vancouver (Canada) region. Participants were asked about the destination, mode, and trip purpose of two common utilitarian trips recently made. Origins and destination points were connected by the shortest route possible using the GIS database from the road network and enhanced by the off-street cycling paths in the region. Since the focus was on the decisions to travel by bicycle instead of car, trips made by public transport, walking and other modes were excluded. In total, 2,257 car trips and 1,023 bicycle trips were analysed from 1,902 individuals. Participants were separated in regular cyclists (cycled at least weekly), frequent cyclists (cycled at least monthly), and rare cyclists (cycled less than 12 times in the past year). Characteristics of the built environment were gathered at the origin and destination point and alongside the route. The main hypothesis was made based on the assumption that the built environment characteristics would affect the decisions to travel by bicycle instead of car. Built environment aspects included green areas, air quality, topography, road hierarchy and street connectivity, bicycle routes, bicycle facilities (traffic calming features, cyclist-activated traffic lights, etc.), population density, and land use mixture. Results indicated that participants were more likely to travel by bicycle when there is less topographical variation, more traffic calming structures and cyclists-activated traffic lights, higher route connectivity (intersection density), local roads instead of highways and arterials, higher population density, and to/from neighbourhoods with more mixed land-use. In addition, higher density in the destination point was also associated with higher likelihood of cycling. In contrast, large commercial land uses were found to be deterrent to cycling. Trip distance was also an important factor. Bicycle trips were 2.5km on average, while car trips had the average of 6km (Winters M. , Brauer, Setton, & Teschke, 2010). The use of actual and modelled trips showed significant differences in terms cycling infrastructure and road networks. Cyclists tend to route away from arterials and highways, and are more likely to use bicycle facilities and local roads, while car users detoured to highways and arterials. This might have underestimated the influences of bicycle facilities on bicycle trips. Other important aspects that can influence cycling was not considered such as traffic accidents.

As previously mentioned, the number of studies that correlates built environment aspects with travel behaviour is quite large in the literature. However, many them was performed in cities or regions from developed countries. Cities from developing nations have different aspects to consider. For many citizens, walking or cycling is matter necessity, regardless the urban environment. Therefore, the statement that built environment aspects affects travel behaviour might not apply to a great portion of the population of developing countries. In order to reduce this gap, a study was conducted in Bogota (Colombia), and it was measured how the five dimensions of the built environment, such as urban densities, land-use mixes, accessibility, and proximity to transit, together with the bikeways, sidewalk facilities and proximity with the Ciclovías Recreativas are associated with walking and cycling. Ciclovías Recreativas are an initiative to promote cycling and leisure activities in urban areas. During Sundays and holidays, some main avenues of the city are closed for vehicles between 7 am and 2 pm and the space is used for cyclists, runners, skaters, and others. To conduct the research, 30 out of 120 neighbourhoods of Bogota were randomly selected after being grouped by socioeconomic status, the average slope of the terrain, proximity to BRT stations, and public park provision. The neighbourhoods were selected using proportionally weighted sampling. Residents from those neighbourhoods were arbitrarily selected and asked to respond a questionnaire. Some participants also made use of an accelerometer. In total, 1500 individuals participated in the survey. When analysing walking for utilitarian purposes, street density and street connectivity were positively associated with the levels of walking for work, shopping and other utilitarian reasons. In addition, other built environment variables like density, diversity, distance to transit, or destination accessibility did not exert influence in the levels of walking among research participants. On the other hand, a steeper topography, cars in the household, and a higher socioeconomic status appeared to discourage utilitarian walking. When increasing the area of analysis, street density was again a significant predictor, together with distance to transit. In terms of cycling for utilitarian purposes, the only built environment variable that significantly affected bicycle use was street density. Results revealed that a Bogotá resident is nearly twice as likely to cycle for utilitarian purposes in high street density areas. Unexpectedly, bike lane density did not significantly influenced levels of cycling for utilitarian purposes. According to the authors, the small sample size might have rendered this variable as statistically insignificant. Regarding the deterrent aspects of cycling, high fatality levels showed to have a strong and negative association, together with steep topography. Utilitarian cycling is also lower for women and drops with age, car ownership and education level. The participants' proximity with the Ciclovías Recreativas, measured within a 1000m distance, showed to have positive influence to use this facility for recreation (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009).

In Curitiba (Brazil), a similar study also analysed the aspects of the built environment of the city with the levels of walking and cycling for transportation. To conduct the analysis, 1206 people were interviewed by phone in the year of 2008, and their answers were confronted with 4 "D's" from the model presented in Figure 5. Are they: Density, Design, Distance to transit, and Diversity. In addition, topography and safety aspects, measured as the number of traffic lights within the examined area, were included in the analysis. All the variables were analysed by performing a 500 meters' buffer around the residence location of the participants. Socio-demographic data and health indicators were also collected. Results showed that walking for any reason was lower among males, older adults (above 55 years old), classified as overweight or obese, higher educated people, and who possess a car in the household. On the other hand, the number of BRT tube stations, and the proportion of residences and commercial activity within the area positively influenced the levels of walking for transportation. Participants from higher income areas are 44% less likely to any walking when compared to lower income areas. Furthermore, cycling for transportation was higher among males, young adults (18-34 years old), lower education levels, living alone, normal weight status, and not owning a car. Bicycle use was also associated with higher income areas, higher number of traffic lights, with mixed land-use, and higher residential densities (Hino, Reis, Sarmiento, Parra, & Brownson, 2014). This study, however, is from a period before the recent expansion of the cycling infrastructure experienced in Curitiba. Although the expansion was timid, the effects of it might have changed the levels of cycling.

2.2 Subjective Measures of Transport Behaviour

This section is composed by a literature review in the articles that correlates not only aspects of the built environment (objective measures) with transport behaviour but also the subjective aspects that are related to day-to-day decisions for travel. Subjective aspects include attitudes towards the environment and active transport use, household characteristics, socio-demographic information, physical activity levels, social support, and others.

Commuting can be defined as the act of travel some distance between the traveller's residence and the workplace on a regular basis. In urban environments, commuting is one of the main travel purposes among citizens. When considering the benefits of bicycle for transportation, described earlier in this master thesis, governments and urban planners are seeking to increase the cycling rates, and many studies were performed to measure the attitudes and perceptions for bicycle use (Heinen E. , 2011). The Theory of Planned Behaviour (TPB) is constantly applied for this purpose. TPB is a model that aims to understand how human actions is guided, being capable of predicting some specific behaviour and whether this behaviour is intentional or not (Francis, et al., 2004). Attitudes towards bicycle use and factors that influence the decision for cycling can differ from country to country. Unlike in cities where bicycle use is much more spread and the traffic structure understands the bicycle as a travel mode, countries where bicycle use is still incipient and this modal is mainly viewed as a leisure activity, thus, traffic engineering does not consider cycling in usual commuting routes, the analysis of behaviour and attitudes can differ significantly. The application of such appraisals like TPB is essential in many different contexts as possible.

A research conducted by Heinen, Maat, & Wee (2011) analysed the influence of attitudes towards the benefits of using bicycle for commuting trips in the Netherlands. The attitudes were measured between different groups of people: cyclists, both part-time and full-time, and non-cyclists. In addition, the attitudinal factors on bicycle commuting over different distances was also analysed, supposing that the attitudes become more positive as the frequency and cycling distances increase. To perform the investigation, the data was collected through a survey and the participants were approached by two ways: internet and regular mail. The target groups were employees from several large companies in the Netherlands and residents from the cities of Zwolle, Delft and two adjacent cities called Midden-Delfland and Pijnacker-Nootdorp. To analyse the attitudinal components, a 5-point Likert Scale was used to measure the following beliefs: environmental benefits, mentally relaxing, physically relaxing, comfortable, time-saving, flexible, cheap, pleasant, offers privacy, provides status, healthy, traffic safety, socially safe and suits lifestyle. The Theory of Planned Behaviour assessed the subject norm. Data were analysed by doing a descriptive analysis and a factor analysis. The descriptive analysis showed that cyclists, in general, consider important that their commuting mode is environmentally friendly, cheap, healthy, physically and mentally relaxing, but they don't concern about comfort, time-saving and flexibility of their transport mode. By increasing the travel distance, it was noticed a decrease in the average value of attitudes in respect to comfort, time-saving, flexible, cheap, pleasant and suits lifestyle. The study results showed that, from those who selected bicycle as a preferred transport mode for many purposes, they also showed a greater likelihood for cycling to work over all distances (up to 5km, between 5 and 10km and more than 10km). Among all distance classes, the likelihood for cycling is higher if they perceive that the activity is possible. However, the "perceived social pressure" only influences in case of short distances. For longer distances, respondents were not affected by the opinion of the society, indicating in those cases that cycling is a decision based on their own considerations. In terms of distances, a higher score was achieved for the "awareness" group. This represents an awareness of the effects of their travel behaviour over the environment and in their own health. By analysing the results, we can state that attitudes do influence in the decisions regarding commuter cycling. This indicates that individuals base their modal choice decisions on the benefits in terms of time, comfort and flexibility.

In another study conducted in Curitiba (Brazil) using Focus Groups, cyclists were asked to identify the main barriers and facilitators to bicycle use according to their own perceptions. It was evaluated bicycle use for commuting, as a recreation activity and among cycle-activists. Bicycle commuters and people that use the bicycle for recreation were approached after an analysis in a census track level. Activists were approached through one of the bicycle activist organisations of the city. The group of bicycle commuters and recreational cyclists was composed of 12 participants each, and cycle-activists was composed by 24 individuals. Within each group, participants were divided by gender, with the same proportion of men and women. Among the barriers to bicycle use, some similarities were found between the three groups. In terms of objective measures (Built Environment), the lack of cycling infrastructure in general (bicycle lanes, specific traffic lights, traffic calming structures, etc.) was the most important one. The insecurity in traffic was also identified as an important barrier, which can be related to the lack of specific infrastructure for cyclists. Regarding the subjective measures for bicycle use, recreational cyclists and bicycle commuters had some similarities. Both groups identified the lack of attitude and the weather conditions as important barriers for bicycle use. Furthermore, people that commute by bicycle identified socio-economic status as a negative aspect, in the sense that, people that can afford a vehicle or the public transport fee are less likely to commute by bicycle. Cycle-activists pointed as the lack of support from the government as the main barrier. Public unsafety was also pointed as an important barrier among all groups. Concerning the facilitators for bicycle use, the most important built environment aspect in all groups was the presence of specific infrastructure for cyclists. Among the subjective measures, the sense of well-being was the common factor between the groups. The social support was stronger between cycle-activists and bicycle commuters, and having a company for cycling was stronger among women (Camargo, 2012).

To obtain a deeper knowledge about active transport, an investigation conducted by Titze, Stronegger, Janschitz, & Oja (2008) aimed to correlate built-environment, social-environment, and personal-level factors with bicycle use for transportation in Graz, a mid-sized city in Austria. The participants were randomly selected and a questionnaire was made by telephone. Near 1,000 people answered the survey out of 2,951 attempts. Based on previous studies on bicycling and behavioural change model, together with Focus Groups discussions, a list of relevant built-environment, social-environment and personal items were generated. The questionnaire involved enquiries about transport behaviour, perceived physical environment along the route, parking facilities at origin and destination, the general perception of the neighbourhood, perceived social environment, and barriers & benefits of bicycle use. Information about trip distance and physical activity levels was also collected. Principal Component Analysis was performed to interpret the data. Additionally, the effect modification was made between gender (male versus female), age (15-20 years versus more than 20 to 60 years old), education level (intermediate vocational degree or lower versus high-school diploma or higher), body mass index (25 or lower versus more than 25), and physical activity level (inactive versus moderately active or highly active). The regression model showed all significant associations between built-environment, social-environment, and personal-level factors. Bike lane connectivity, the presence of steep elevation, social/support modelling, and the perceived benefit of “rapidity” were all positively associated with cycling for transportation. Physical discomfort and impracticality were negatively associated with cycling. The likelihoods of cycling increase among respondents who perceived bicycle as a rapid transport mode and were physically active. In contrast, the likelihood decreases between female respondents who perceived cycling as an impractical transport mode. After Factor Analysis, the items were gathered in four different factors: Functional feature (bike lane connectivity, presence of elevations, presence of street lights, presence of sidewalks), Safety feature (safety from traffic), Aesthetic feature (attractiveness of cycling conditions), and Destination feature (land-use mix diversity of uses). Results also showed that the support from friends and family members were also positive factors for cycling.

2.3 Spatial Analysis Models

Application examples of spatial analysis tools compose this section. Bikeability map is a useful spatial analysis tool used to represent the bikeability of a specific region. By providing a visualisation of the current conditions for bicycle use, decision-makers can have more inputs for increasing levels of cycling through investments in the built environment characteristics of the city, especially in cycling infrastructure. To produce the maps, a large amount of GIS data was processed as well as subjective measures of bicycle use within the case studies. One example presented also the potential bikeability of the region (Austin – United States) based on the Bicycle Master Plan.

2.3.1 Vancouver - Canada

By analysing characteristics of the built environment, a study conducted by Winters, Brauer, Setton, & Teschke (2013) developed a bikeability index as a planning tool that identified areas more conducive and less conducive to cycling using spatial analysis data. Since the focus was reducing car travel, it was considered cycling for transportations purposes rather than recreation or fitness. The authors intended to build a flexible tool from commonly available data in order to facilitate the application in other regions and taking locals aspects into consideration. The area selected was the Metro Vancouver, a metropolitan region in western Canada that comprises 22 municipalities and 2.1 million people. To identify the components of the bikeability index, three previous studies were employed as qualitative data sources: an opinion survey, a travel behaviour study, and a series of Focus Groups. The opinion survey was conducted in the region to identify built environment factors that influence cycling. A total of 1402 people participated in the survey, and seventy-three potential motivators and deterrent for bicycle use were identified, which from those, one-third were related to built environment. The most relevant factors were: bicycle facilities, aesthetics, topography, traffic and trip distance. In addition, the survey asked about their preferred type of cycling infrastructure. Off-street or separated route was the best evaluated by the respondents. The travel behaviour analysis was based on the journey characteristics made by the participants. 3,280 car and bicycle trips were examined to identify which built environment aspects were associated with a higher likelihood of cycling versus driving. The second analysis was made by comparing the actual route taken and the shortest route between origin and destination. The objective was to understand how the built environment influenced on the route selection. Results showed that bicycle facilities, connectivity, topography and land-use were determinant factors when choosing for a specific itinerary. The third data source was the Focus Groups. A total of four groups were formed by cycling activists, regular cyclists (who had cycled at least once a week), occasional cyclists (who had cycled less than once a week), and prospective cyclists (who had not cycled in the last year but are willing to cycle). Bicycle facilities were by far the most important factor derived from the Focus Groups.

After analysing the results of the three qualitative data sources, Winters, Brauer, Setton, & Teschke (2013) identified four main domains for the bikeability index calculation: bicycle facilities, street connectivity, topography, and neighbourhood land-use. All the variables met the criteria of data availability. In the following, the connectivity factor became “connectivity of bicycle-friendly streets” and neighbourhood land-use became “destination density”. A preliminary index with four components was developed. After an appraisal from local planners and a re-assessment of the qualitative data sources, a fifth factor was included: bicycle route separation. Each component was scored from 1 to 10 and combined to generate the bikeability map from Metro Vancouver region. When analysing the results from the map presented in Figure 6, it can be identified bicycle-friendly areas (in green) and areas where cycling conditions need to be improved (in red). This index is highly correlated with cycle-to-work modal share and is a useful planning tool to support sustainable travel, guiding local actions and stimulating active transport.

One limitation of the study of Winters, Brauer, Setton, & Teschke (2013) is that since the tool considers local aspects regarding density, topography, available infrastructure, and others, the so-called most propitious areas to cycle might not be the ones that are preferred by local cyclists. A deeper analysis of bicycle use and an evaluation about the cycling experiences in both higher and lower bikeable areas are required. In addition, important aspects that affect bicycle use was not considered in this study such as population or residential density, traffic safety and others. Furthermore, the inclusion of another variable in the bikeability index (bicycle route separation), doubling the weight of cycling infrastructure variables without some pre-defined criteria, since "bicycle facilities" was already part of the index, might have overestimated the importance of off-street facilities when compared to on-street facilities. Cyclists with some level of experience tend not to distinguish between these types of infrastructure.

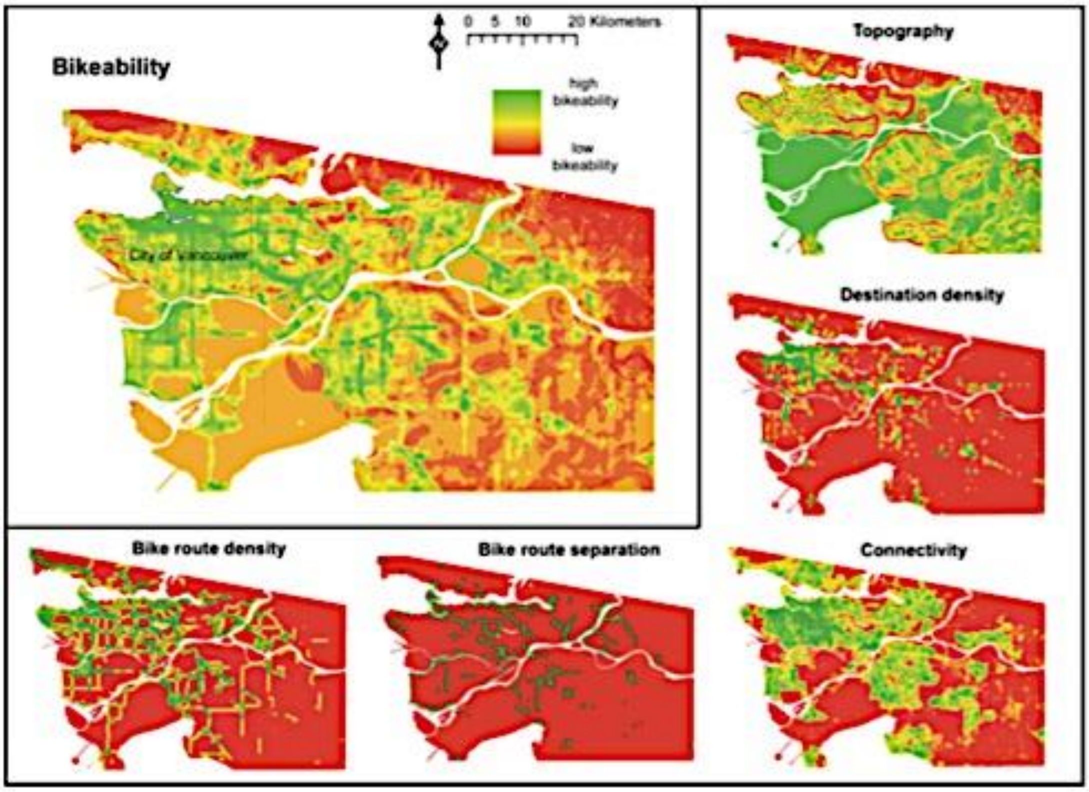

Figure 6: Bikeability and component maps for Metro Vancouver (Winters M. , Brauer, Setton, & Teschke, 2013).

2.3.2 Graz - Austria

In a similar study, a bikeability index was proposed to the city of Graz (Austria) based on built environment characteristics and using GIS data. In order to examine the predictive validity of the index and provide a visualisation of the bikeability in the city, a bikeability map was also created. The index was developed based on 278 different bicycle trips made by 113 individuals. A comparison between the shortest route possible between the origin and destination point of the participants and the actual route taken was used to identify the difference in distance and built environment aspects. The most significant differences between the two routes were used as components to form the bikeability index. Are they: cycling infrastructure, presence of separated bicycle pathways, main roads without parallel bicycle lanes, green and aquatic areas, topography and land-use mix. After the first calculation of the index, land-use mix was suppressed since it did not change the final results. The predictive validity of the bikeability index was confronted with a cycling behaviour survey of the city by performing a logistic regression. The analysis showed a positive relationship between the bikeability index and the citizens' cycling behaviour, controlled by sex, age and education. If the bikeability index increase by one unit, the odds for cyclists in this area increase by 8%. The correlation between sex, age and education did not show statistical significance. The index varies from 1 to 10, where 1 is bicycle-unfriendly and 10, bicycle-friendly. Figure 7 shows the bikeability map of the city and each of the components used. To give a higher importance to dedicated infrastructure for cyclists, the variable "separated bicycle pathways" was also included in the "cycling infrastructure" map, therefore, accounting twice. The map summarises the urban environment conditions for cycling in the city of Graz, with a focus on transportation reasons (Krenn, Oja, & Titze, 2015). One limitation of the index is the use of "Green and Aquatic areas" as one of the variables. People that commute by bicycle tend to prefer areas with higher connectivity, which is not the case of the most bicycle friendly areas according with this specific variable. As noticed in the individual map, most part of the green and aquatic areas are located in the city boundaries, while the cycling infrastructure is concentrated in the city centre.

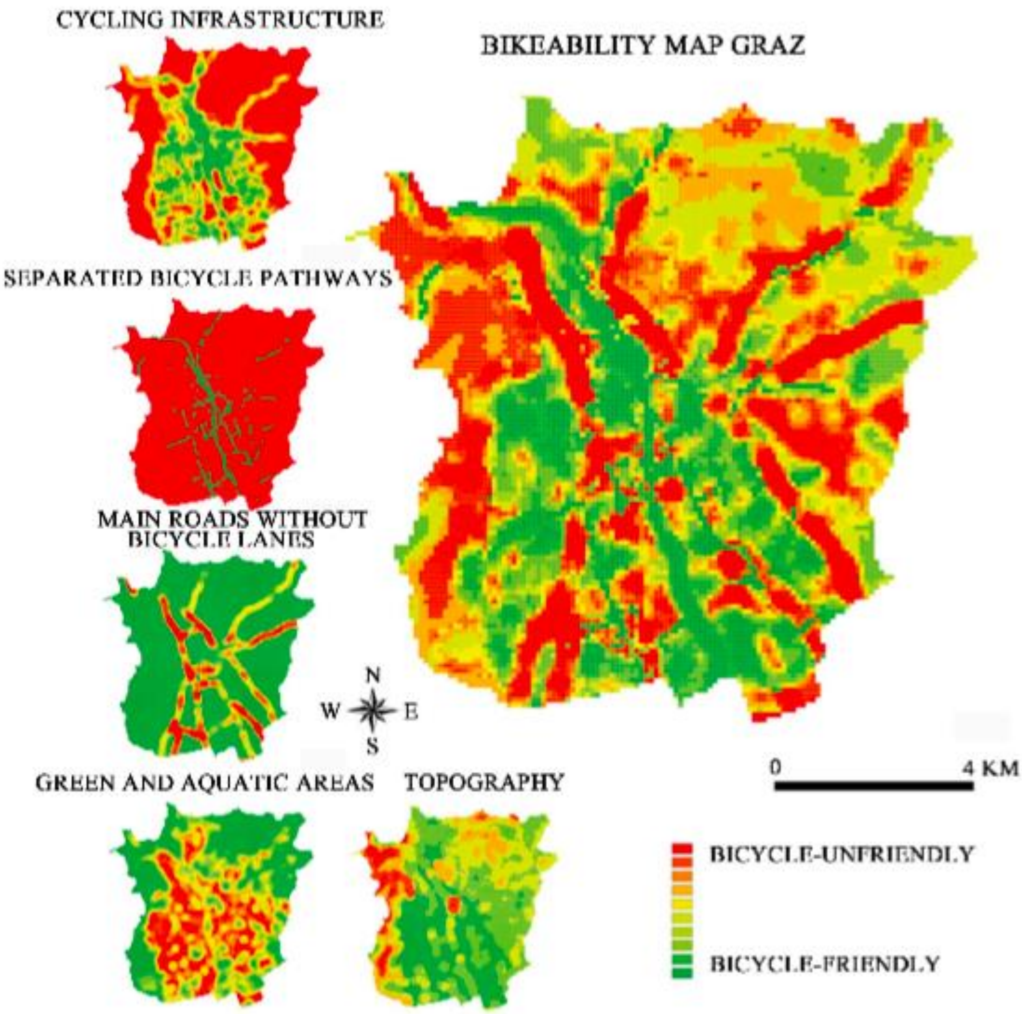

Figure 7: Mapped components of the bikeability index and the final bikeability map for the city of Graz

2.3.3 Austin – United States

For the city of Austin – Texas (United States), a bikeability map was also generated to represent the reality of how cyclists perceive bikeability through many areas of the city. The index is based on built environment factors that affect bicycle use, which was mapped and scored in order to represent the current and potential bikeability of the city. The index was developed based on bicycle facilities, network connectivity, land-use, slope, and barriers. Bicycle facilities include multi-use path, cycle tracks, bike boulevard, and others. The score is based on quality and density of the infrastructure. The network connectivity is based on intersection density of grid networks, excluding highway networks. The land-use data was scored based on the destination and originating quantity of trips of each land-use zone. Commercial, industrial and retail land uses are considered destination points, while residential land use is considered origin points. The slope was calculated based on the elevation surface map of the city and Barriers refer to highways and waterways that cross the city. Highways represent barriers due to the flow and vehicle speed, and Waterways represents crossing barriers for cyclists. Factors of bikeability were weighted based on their degree of influence on the overall bikeability index. Therefore, Bicycle facilities account for nearly one-third of the final index. Figure 8 represents the current bikeability in the city of Austin. The index varies from 0 to 100 (Greenstein, 2015). This index also did not consider any measure of safety in the evaluation of the city's bikeability.

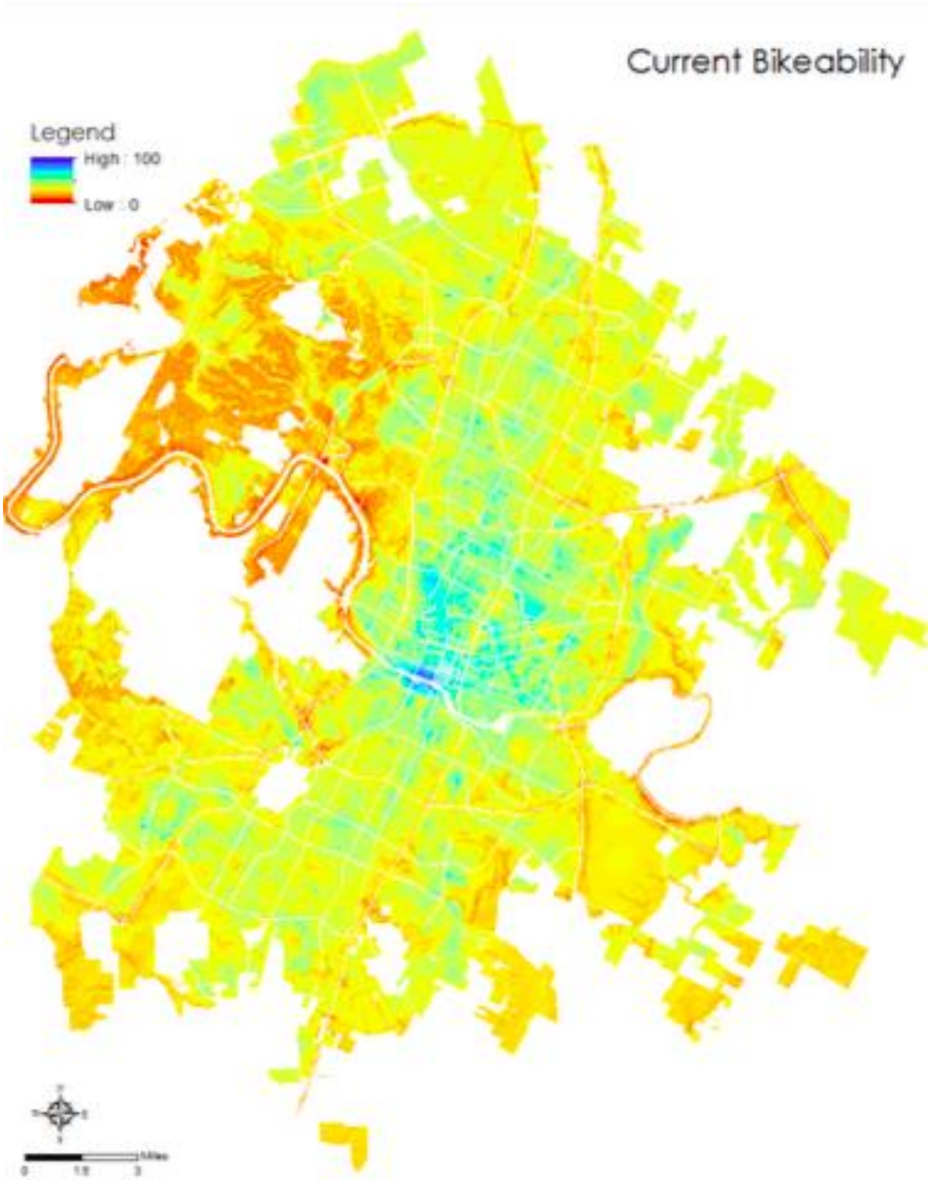

Figure 8: Current Bikeability in the city of Austin - Texas (United States) (Greenstein, 2015).

In addition, a potential bikeability map was also produced, by imputing the long terms recommendations of the 2014 Bicycle Master Plan of Austin, which is focused on increase the bicycle network and implement specific infrastructure components to increase the safety of cyclists.

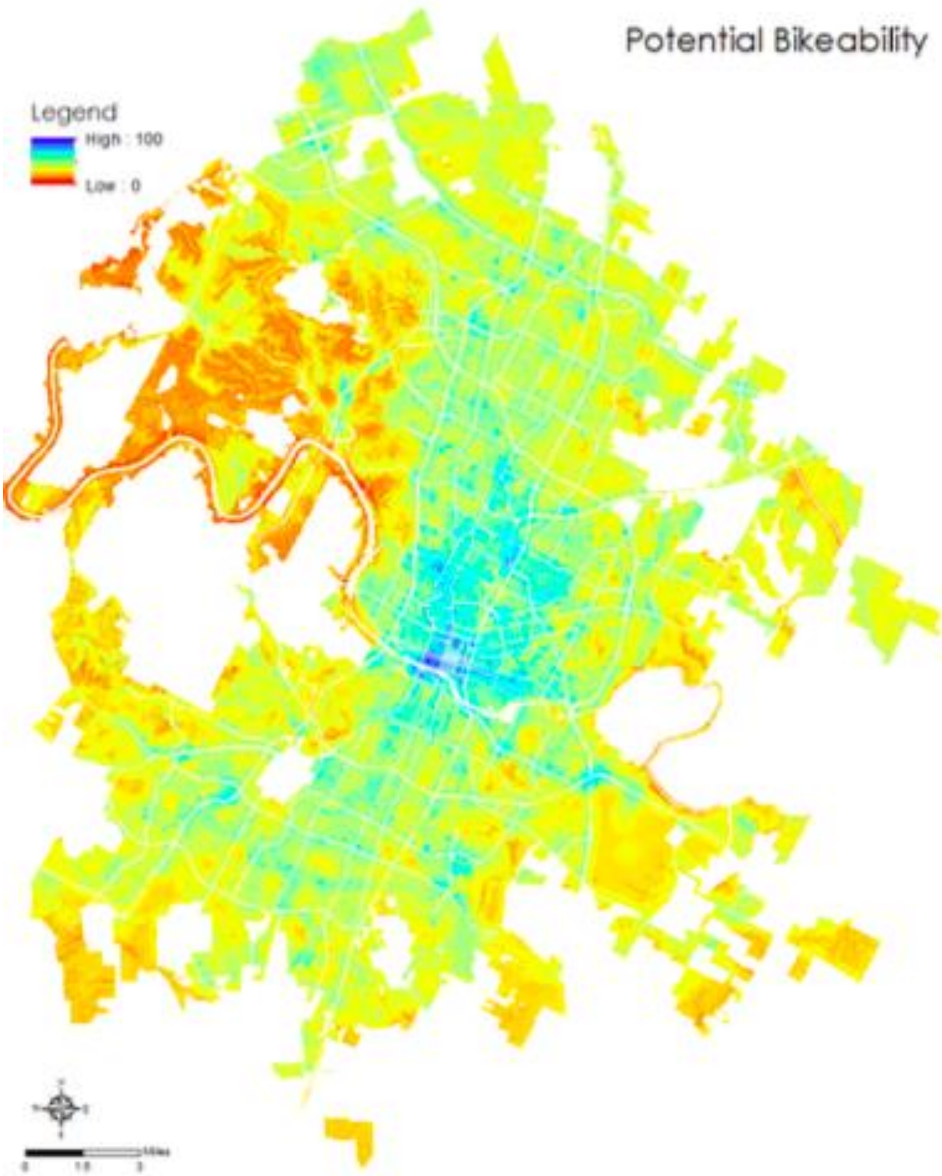

Figure 9: Potential Bikeability for the city of Austin - Texas (United States) (Greenstein, 2015).

2.4 Summary

Urban planning and neighbourhood characteristics can have a major impact on the travel behaviour of citizens. Higher residential densities, certain land-use mixture in the area, street connectivity, block size and other factors can be determinant to influence levels of cycling, walking and public transport use. Apart from the objective measures of travel behaviour, the subjective aspects are also important in the travel behaviour of citizens. Social status, physical activity levels, age, gender, attitudes towards active transport use, household characteristics are some examples of subjective aspects that are able to influence the levels of automobile, transit or active transport use. Common findings suggest that bicycle infrastructure (especially off-streets), bike lane connectivity, shorter trip distances, and social support are all positive aspects associated with cycling. On the other hand, physical discomfort, safety perception, and impracticality were pointed as barriers for bicycle use. In fact, in car-dominant cities the unsafety perception of cycling is even stronger, demonstrating the need for specific bicycle infrastructures. Examples of bikeability map application in different cities and with different methodologies were also exposed. The three examples exposed in the section 2.3 gave inputs for the computation of the bikeability index of Curitiba. Limitations identified in the variables selection and in the weight distribution was avoided in the index developed during this Master Thesis. Specifically, the inclusion of the Safety variable (number of accidents involving cyclists) and the weight distribution through Factor Analysis intended to overcome the limitations presented. Little research correlating built environment aspects with travel behaviour is available from cities in the developing word. In addition, it is not from the knowledge of this author the computation of the bikeability index neither the production of the bikeability map in a Brazilian scenario. This Master Thesis intends to fill this gap.

3 METHODOLOGY AND DATA DESCRIPTION

Similar to many other medium and large-size Brazilian cities, Curitiba experienced in the previous years a substantial increase in the motorised vehicle fleet. In the city, the use of private vehicle for commuting trips is quite significant, despite the lack of an accurate modal share and transport behaviour survey. The fact that Curitiba has the highest rate of car ownership of Brazil, reinforce this statement. In addition, typical characteristics of car-dominant cities can be found in Curitiba: high level of urban fragmentation and urban segregation, little attention for pedestrians and non-motorized vehicles, lower average traffic speed, and a low vehicle occupancy rate. Furthermore, the city's public transport system, once viewed as an effective and innovative solution is now operating near its maximum capacity. In an attempt to improve the efficiency of the transportation network and to answer the needs of public opinion, mainly represented by groups of cycling activists, the city's administration is investing in the expansion of the bicycle network and in the maintenance of the existent infrastructure in order to increase the levels of cycling in the city. With an increase in the commuting trips made by bicycle with a possible reduction of automobile use, many benefits can be achieved, such as a decrease in CO_2 emissions, noise, traffic congestions, traffic accidents, apart from introducing physical activity into citizen's routine. Aspects such as neighbourhood's design, urban planning, natural environment and the attitudes towards active transport can be determinant for increasing levels of walking and cycling for commuting. Understanding those aspects in a local perspective is essential to propose and implement effective solutions capable of changing people's travel behaviour into a more sustainable way. Among others, the implementation of cycling infrastructure is an important initiative to increase bicycle use. In a city with 1.88 million inhabitants, with several stakeholders and scarce monetary resources, the implementation of new infrastructure should be done in a theoretically-based manner, prioritising specific locations, implementing the appropriate type of infrastructure and planning the required secondary interventions (crossings, public safety measures, etc.). The bikeability index tool is a useful methodology that gives inputs for local decision-makers when taking actions to increase bikeability and bicycle use in an urban perspective, mainly by identifying areas that should be prioritised when receiving cycling infrastructure investments. Bikeability Index is a spatial analysis tool that uses GIS data to, among other things, provide a diagnosis of the cycling conditions of a specific location, considering aspects of the built environment, natural environment and others.

The GIS information required to build the bikeability map was gathered thanks to the open database policy from the Municipality of Curitiba. Another relevant set of GIS data was kindly provided by the Institute of Research and Urban Planning of Curitiba (IPPUC, in Portuguese) and the Information & Technology Office (SIT, in Portuguese), both organs from the Municipality. In addition, data also was collected at the location by the researcher.

In addition, a questionnaire was applied with the citizens of Curitiba. The survey was performed online and through face-to-face interviews. Inferences about the survey sample was drawn using Principal Component Analysis (PCA), *Independent sample t-test,* and Binary logit-model. PCA was used to support the weight distribution of the bikeability index variables, and the *t-test* was used to compare the mean scores from distinct population groups (cyclists and non-cyclists, higher and lower income) and to measure whether there are significant differences between them. Binary logit model was used to correlate built environment aspects with the travel behaviour of the participants of the survey.

3.1 Setting

This investigation took place in the city of Curitiba, the capital of the State of Parana, in the southern region of Brazil. The city is located on the first plateau of the State of Paraná, 934 meters above sea level. Founded in 1693, the economic activities of the city were focused mainly on agriculture until the 20th century, when Curitiba faced a huge exodus of rural population. After this period, the industrial activities of city accelerated and formed together with commerce and services, the base of the economy nowadays (Rabinovitch, 1996). Curitiba is the fourth city of Brazil that most contribute to the national Growth Domestic Product (GDP), with 58 billion Reais every year, representing 1.4% of all finished goods and services produced in the country (Revista EXAME, 2013). To better understand the geopolitical arrangements, some terms will be explained. The City of Curitiba is the capital of the State of Paraná, which is inserted in the Metropolitan Region of Curitiba, a cluster of 29 Municipalities with a population of 3.17 million inhabitants. The city has an estimated population of 1.88 million, around 59% of the RMC (Agência Curitiba de Desenvolvimento S/A , 2015). The key economic activities of the city are service, manufacturing, and commerce (Rabinovitch, 1996).

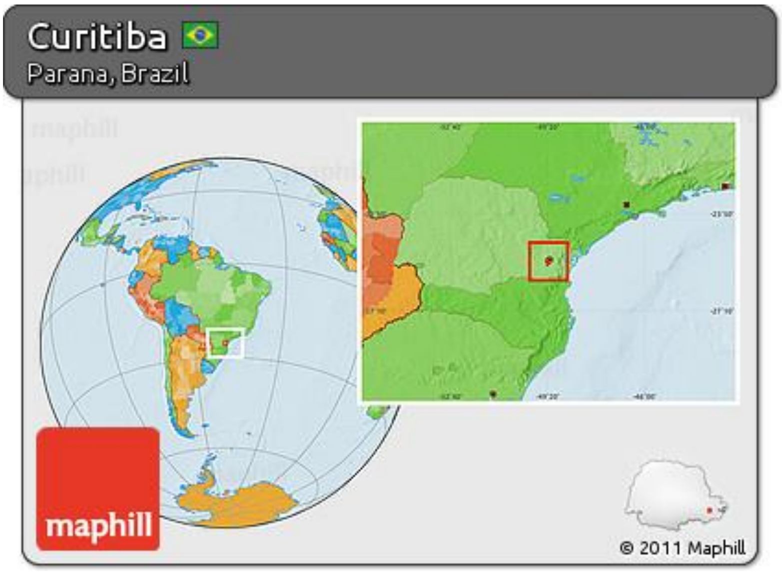

Figure 10: Curitiba - Location (Map Graphics Revolution, 2011)

Curitiba is worldwide recognised by its capacity to implement efficient and ad hoc solutions in the field of transport and urban planning. The land-use regulations, the city's BRT, which is considered a cost-effective approach for mass transportation, together with the adjacent transit structure forming the structural axis (North, South, West, East, Boqueirão and Green Line), guided the city expansion for many years and influenced the development process of some cities around. Figure 11 demonstrates the location of the structural axis of Curitiba, where the BRT is situated. The city was also one of the first in the country to implement a dedicated infrastructure for cyclists and has also one of the largest networks of bicycle lanes of Brazil (Duarte & Ultramari, 2012). Until December 2016, Curitiba has nearly 200 km of cycling infrastructure, including separated and integrated bicycle lanes, bicycle routes and pedestrian shared bicycle lanes. An exemplification of each type of cycling infrastructure and the location within the city can be seen in APPENDIX I.

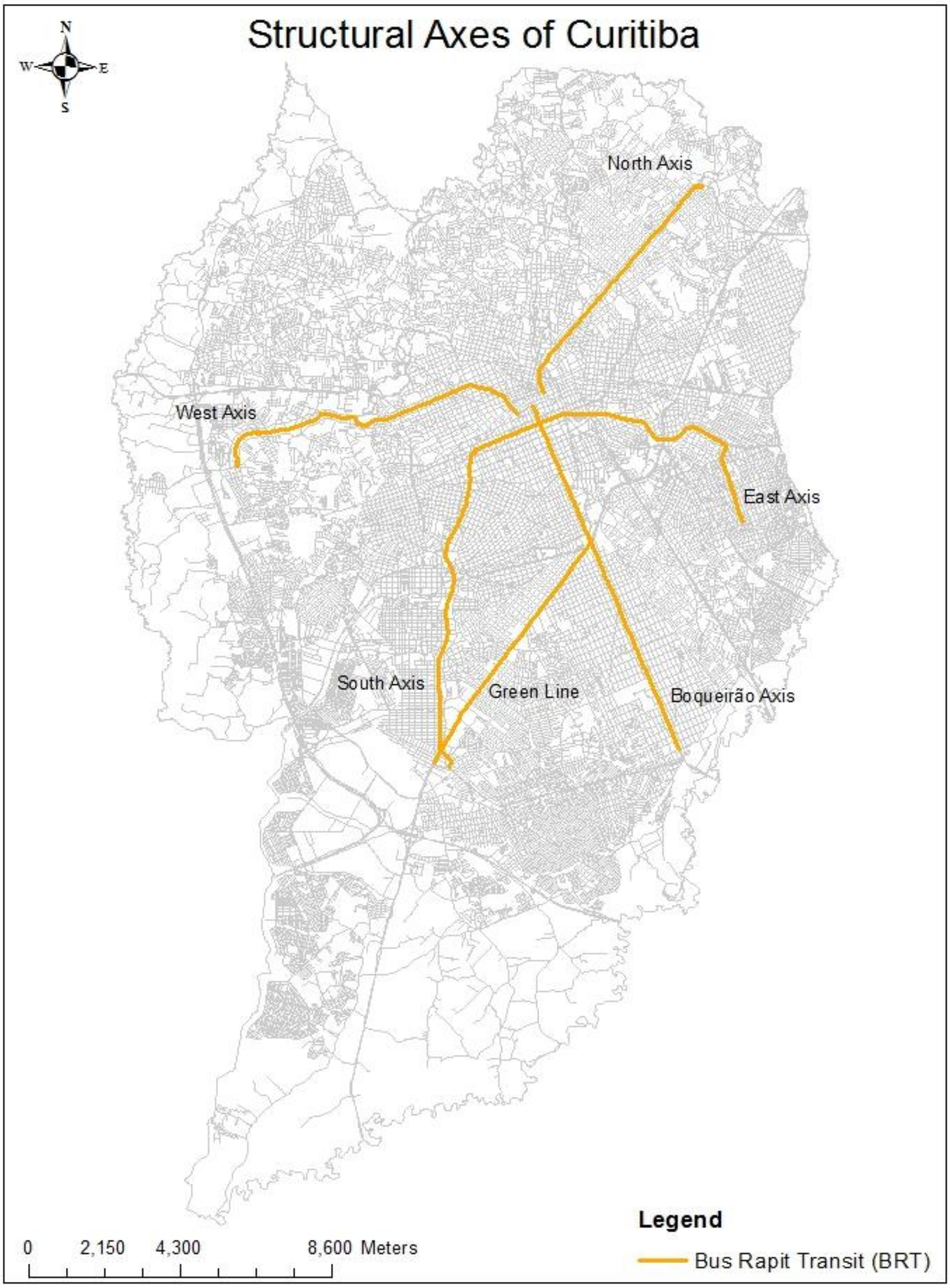

Figure 11: The structural axis of Curitiba

This research, amongst others, was developed as a result of an international cooperation agreement, also called Memorandum of Understanding (MoU), signed in 18th September of 2015 between the Municipality of Curitiba/PR (Brazil), Universities in Brazil and in The Netherlands, the Federation of Industries of Paraná (FIEP, in Portuguese) and a cycling activist society from Curitiba (Cicloiguaçu). The main motivation of the agreement is to integrate the bicycle into the city's transportation network, in order to increase efficiency and promote sustainability in the city's transport system. The partnership with Dutch institutions will be important to increase collaboration, by performing research and suggest actions in the field of Transport Policy and Planning, Urban Planning & Design, Governance, Collaboration, and Sustainability. The Dutch example of modal diversion is considered by the city of Curitiba as a model to be followed (IGS, 2015).

3.2 Sampling strategy

The sampling procedure used by the researcher to collect quantitative data (Questionnaire) was part random and part purposive sampling. As part of the random sampling, the researcher made use of the Social Media Facebook© to share the research link of the online questionnaire. The link was shared in the personal profiles of one stakeholder from the city's transport system, the official communication portal of the University of Twente in Brazil, and through one of the ambassadors of the Holland Alumni Network (HAN), an association created by the official representative of the Dutch higher education system. The figure bellow (Figure 12) is a screenshot of the Facebook© posts with the link to the research.

Figure 12: Facebook© posts of the survey link.

As part of the purposive sampling approach, the research was sent to an email list provided by *Cicloiguaçu* – a non-governmental organisation based in Curitiba that promotes discussions, seminaries and bicycle rides in the city. The list provided by Cicloiguaçu was not necessarily composed by cyclists, but also by citizens that are somehow interested in bicycle mobility and active transport. The objective of selecting this purposive sampling was to achieve a good number of respondents that use the bicycle as the main transport mode. In addition, the research link was sent by email to key stakeholders from the MoU. Those stakeholders are composed by professors, coordinators, and managers from local universities and industries. Finally, in order to achieve a higher number of respondents from lower income classes, the same questionnaire was applied through face-to-face interviews with employees from the administrative building of the Municipality of Curitiba, with the kindly help from the International Relations Office of the city's administration. In total, thirteen employees responsible for the support activities, such as cleaning, receptionist, waitress, security office and others were interviewed.

The inclusion criteria of the respondents were defined as follows: participants must be residents of Curitiba and have their travel destination point within the city boundaries. In addition, participants should be more than 18 years-old. The participants of the study were from diverse ethnic backgrounds. From the online interview, the majority were between 25 and 34 years-old, followed by groups between 35 and 44 years-old, and 18 to 24 years old. The online survey had 218 participants: 135 men and 83 women. Most the online survey respondents had post graduate degree, followed by people with a bachelor degree and respondents that are attending bachelor programmes (students). A few respondents declared to have lower education. The majority of the participants declared to have monthly family income between 4 and 10 Brazilian minimum wages (R$ 3,520 – R$ 8,800), configured as a "C" class as defined by the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese). The second largest group was from the social class "B", with monthly family income between 10 and 20 Brazilian minimum wages (R$ 8,800 – R$ 17,600). The smallest groups were the extremes: class "A" (with family income more than R$ 17,600 per month) and class "E" (up to R$ 1,760 of monthly family income). The respondent's travel behaviour showed that bicycle and car were the main transport mode used by the participants, followed by bus.

In the face-to-face interviews, from the thirteen employees, 10 women and 3 men were interrogated, with age varying from 38 to 66 years-old. The majority do not have higher education and are mainly bus users. They are positioned in the income classes "C", with family income between 4 and 10 Brazilian minimum wages per month (R$ 3,520 – R$ 8,800), "D" with a family income between 2 and 4 minimum wages per month (R$ 1,760 and R$ 3,520), and "E" with an income up to 2 minimum wages per month (less than R$ 1,760).

3.3 Measurement Instruments

In this Master Thesis, two different measurement instruments were used. Firstly, to process the spatial data of the city and compute the bikeability index, the researcher made use of spatial analysis tools. Those tools enabled the assessment of the cycling conditions of the city and its representation in a form of a map, highlighting areas that are more propitious and less propitious for bicycle use. With this method, the overall cycling conditions of the city could be known in detail. Secondly, to gain insights about bicycle use in Curitiba and to support the weight distribution of BI variables, a survey was conducted. The questionnaire was a research made instrument developed by the own researcher. Both spatial analysis and questionnaire will be explained separately in the following sub-sections.

3.3.1 Questionnaire

A questionnaire was conducted among the citizens of Curitiba, both on-line and through face-to-face interviews. This measurement instrument can be considered a research made one since the questionnaire was developed by the own researcher exclusively for the investigation in question. To support the weight distribution among the BI variables, as well as to gain insights about bicycle use for transportation reasons in the city of Curitiba, the questions were divided into four different groups: Personal information, Travel information, Assessment of the common barriers and facilitators/motivators for bicycle use, and Assessment of the likelihood of the respondents to use bicycle in the different infrastructures of the city, regardless if they are cyclists or not.

The common list of barriers and facilitators/motivators for bicycle use presented in the questionnaire was based on previous researchers conducted in Brazil and worldwide, such as Camargo (2012), Heinen E. (2011), and Silveira & Maia (2015). The questions were all formulated in Portuguese and separated into four different groups, which will be explained separately. In APPENDIX II and APPENDIX III, both versions of the questionnaire can be found (original and an English version). The questionnaire was built using the software LimeSurvey 2.0.

3.3.1.1 Personal information

This group consist of personal information type of questions, such as the neighbourhood of residence, postal code, age, gender, education level, occupation, family income and whether the respondent possesses a driver license or not. The exact address of the participants was not asked to ensure that respondents will have their privacy aspects protected under any circumstances. In the question regarding the family income, respondents were given five different answer options based on their family income per month, taking as a reference the Brazilian minimum wage in 2016, which is R$ 880.00. The question was based on the simplest criteria used by IBGE for income classes separation in Brazil:

Table 1: Social class separation by family income (IBGE, 2010)

Income Class	Family Income per month (in Brazilian minimum wage)	Family Income per month (in Brazilian Real)
Class A	More than 20 minimum wages	More than R$17,600
Class B	Between 10 and 20 minimum wages	Between R$ 8,800 and R$ 17,600
Class C	Between 4 and 10 minimum wages	Between R$ 3,520 and R$ 8,800
Class D	Between 2 and 4 minimum wages	Between R$ 1,760 and R$ 3,520
Class E	Up to 2 minimum wages	Up to R$ 1,760

To enable the analysis of responses from people with distinct income levels as purposed in the research questions, respondents were separated into two groups. Classes “A”, “B” and “C”, with family income higher than 4 Brazilian minimum wages per month were gathered in the “Higher Income” group, and those with family income lower than 4 Brazilian minimum wages (Classes “D” and “E”) were gathered in the “Lower Income” group.

3.3.1.2 Travel information

In this question group, details from the respondent’s daily travel were asked, such as the location (neighbourhood) and the frequency that they access their work or study place, which transport mode is mostly used, how many times per week they access their work or study location and the respective travel time, and their working or studying period. Respondents that selected “Bicycle” as the main transport mode were gathered in the “Cyclists” group, while the others were gathered in the “Non-cyclists” group. This separation enabled the analysis of people’s transport behaviour as proposed in the research questions.

Only for the Cyclists, it was asked whether they use any of the existent cycling infrastructures of the city, and which one. To support the respondents in this specific question, a map of the cycling infrastructure available in the city was presented. The figure can be seen in APPENDIX I.

3.3.1.3 Barriers and Facilitators/Motivators for bicycle use

The assessment of the common factors (barriers and facilitators/motivators) that affects bicycle use is part of this question group. As described in the Section 3.3.1, the factors were selected based on previous investigations performed in Brazil and worldwide. Respondents were asked to assess their importance level for each of the barriers and facilitators/motivators presented. A 1-5 Likert Scale was used and the answer options were: 1-Not important; 2-Little important; 3-Moderately important; 4-Important; and 5-Very important. This question group was developed for two reasons: firstly, to gain insights about the opinion of the citizens of Curitiba regarding bicycle use, and secondly to support the weight distribution of the variables of the Bikeability Index.

The barriers and facilitators/motivators presented in the questionnaire can be found in the table below (Table 2).

Table 2: Barriers and Facilitators/Motivators for bicycle use (Camargo, 2012); (Heinen E. , 2011); (Silveira & Maia, 2015).

Barriers for bicycle use	Facilitators/Motivators for bicycle use
Insecurity in traffic	Short distances
Lack of street lighting;	Insufficient public transport in the neighbourhood
Lack of cycling infrastructure;	Security in traffic
Lack of bicycle parking and/or changing room at the destination point;	Accessibility and cycling infrastructure
Lack of signs at the crossings;	Land-use mix
Behaviour of car users and cyclists in the traffic;	Shorter travel time
Poor surface quality;	Speed reduction measures and proper signs
Topography;	Integration between bicycle and public transport
Public insecurity;	Higher fuel prices
Distance;	Expensive car parking
Need to carry luggage or bags during the travel;	High cost to have a car
Weather conditions;	

3.3.1.4 Types of Infrastructure

In the city of Curitiba, five different types of cycling infrastructure can be found. Are they: Bicycle path, Bicycle lane, Calm lane, Shared sidewalk, and Bicycle route. Respondents were asked to assess their likelihood of cycling in each of the existent cycling infrastructures of the city in a 1-5 Likert scale. The answer options were: 1-Unlikely; 2-Somewhat likely; 3-Neutral; 4-Very Likely; and 5-Certainly. Each type of cycling infrastructure was presented together with a picture and a short definition. In addition, it was also asked if respondents would cycle in the general roads and in the exclusive bus lanes, which means with any sort of specific signs or separation for cyclists. Results from this question group supported the ranking criteria of the Bikeability Index. The different types of infrastructure presented in the questionnaire is demonstrated in the APPENDIX I.

3.3.2 Spatial Analysis

The spatial analysis performed in this Master Thesis was done by computing Geographic Information System (GIS) data with the use of the software Esri ArcGIS Desktop 10.3. Part of the data was available thanks to the open data policy from the Municipality, part was kindly provided by the municipality as a result of the MoU agreement, and part was collected by the own researcher in the city of Curitiba. Another set of data was available due to previous collaboration between the ambulance service providers of the city (SAMU and SIATE), the Military Police of the State of Parana and the Federal Technological University of Parana (UTFPR, in Portuguese). Each variable from the bikeability index was computed separately and it will be explained bellow.

3.3.2.1 Residential Density

The Residential Density variable was calculated based on the data from the Census 2010, the most recent occurred in Brazil and performed by the Brazilian Institute of Geography and Statistics (IBGE, in Portuguese). The dataset was separated and treated by IPPUC and kindly provided thanks to the MoU. The dataset consists in a shapefile, with geographic location and information about the number of people distinguished by gender, the number of residences, and average income of the residents. To perform the Census, IBGE divided the city into small areas called *Setor Censitário* Census Track). Those areas represent a territorial unit established by means of registration control, with a number of households feasible enough to be investigated by a single census taker (IBGE, 2010). Therefore, Curitiba was divided into 2,395 small areas. In order to calculate the Residential Density of each area (*Setor Censitário*), it was used the equation bellow (Equation 1). This methodology was adapted from Frank, Schmid, Sallis, Chapman, & Saelens (2005).

$$Residential\ Density = \frac{Number\ of\ residences\ in\ the\ "Setor\ Censitário"}{Area\ (in\ km^2) of\ the\ respective\ "Setor\ Censitário"}$$

Equation 1: Residential Density (Frank, Schmid, Sallis, Chapman, & Saelens, 2005).

With the results of the Equation 1, a Raster Map was created using the software ArcMap (ESRI) in a 10 x 10 meters' grid. After that, results were grouped into 10 different classes following the Natural Breaks classification method. "Natural breaks classes are based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximise the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values" (Environmental Systems Research Institute, Inc, 2016). After that, the "Reclass tool" from ArcMap was used to obtain a raster map in a 1 to 10 scale, compatible with the Bikeability Index. Lower density areas were assigned with and a score of 1 (low bikeability) and higher density areas with a score of 10 (high bikeability). Therefore, high density has a positive impact in the final BI.

3.3.2.2 Mixed Land-use

The Mixed Land-use rate was calculated with the information kindly provided by IPPUC and SIT, thanks to the MoU and due to previous collaboration with UTFPR. The dataset was combined and treated by the own researcher. The calculation of the Mixed Land-use rate was based on the most recent land-use zones and land-use objectives approved by the City Council and sanctioned by the Mayor of Curitiba (Prefeitura Municipal de Curitiba, 2015). There are forty-nine different zones in Curitiba (e.g. Residential Zone, Commercial Zone, Industrial Zone, etc.) and twenty-eight different land-use objectives (e.g. residential activity, commercial activity, industrial activity, service activity, etc.). The Mixed Land-use rate is a comparison between the number of different activities performed in the same land-use zone and its respective areas. The methodology was based on the work of Frank, Schmid, Sallis, Chapman, & Saelens (2005) and was calculated with equation bellow.

$$\begin{aligned} &Mixed\ Land\text{–}use\ Rate \\ &= \left[\left(\frac{m^2 of\ land\text{–}use\ activity\ type\ 1}{total\ m^2 of\ respective\ land\text{–}use\ zone}\right) x\ ln\left(\frac{m^2 of\ land\text{–}use\ activity\ type\ 1}{total\ m^2 of\ respective\ land\text{–}use\ zone}\right)\right] \\ &+ \left[\left(\frac{m^2 of\ land\text{–}use\ activity\ type\ 2}{total\ m^2 of\ respective\ land\text{–}use\ zone}\right) x\ ln\left(\frac{m^2 of\ land\text{–}use\ activity\ type\ 2}{total\ m^2 of\ respective\ land\text{–}use\ zone}\right)\right] + \cdots \\ &+ \left[\left(\frac{m^2 of\ land\text{–}use\ activity\ type\ n}{total\ m^2 of\ respective\ land\text{–}use\ zone}\right) x\ ln\left(\frac{m^2 of\ land\text{–}use\ activity\ type\ n}{total\ m^2 of\ respective\ land\text{–}use\ zone}\right)\right] \end{aligned}$$

Equation 2: Mixed Land-use Rate (Frank, Schmid, Sallis, Chapman, & Saelens, 2005).

Where land-use objective type 1, land-use objective type 2 and land-use objective type *n* represents the different types of activities existent in the city (residential activity, commercial activity, industrial activity, etc.), totalizing twenty-eight. The Mixed Land-use Rate is an absolute value of the Equation 2. With the results, a Raster Map was created with the software ArcMap (ESRI) in a 10 x 10 meters' grid. Results were grouped in ten different classes by following the Natural Breaks classification method, the same used in the section above. To obtain a 1 to 10 scale compatible with the Bikeability Index and the other variables, the "Reclass tool" from ArcMap was used. A higher value in the equation above means a higher mix of activities of that specific area, and therefore, with a positive impact in the bikeability (10: High bikeability). On the other hand, lower values in the equation represent areas with more homogeneous activities and less diversity in the land-use objectives (1: Low bikeability).

3.3.2.3 Topography

The Topography map was based on the geographic data from the city of Curitiba, available in the IPPUC database due to the open data policy. The dataset was compiled in March 2015 by IPPUC and contains the contour lines, with the elevation in numerous points of the city (Institute of Urban Research and Planning [IPPUC], 2015). In order to calculate the slope of all areas of Curitiba, two procedures were used. Firstly, the “Topo to Raster” tool from ArcMap (ESRI) in the original contour lines map made the interpolation from the different elevation values of the shapefile. It was generated a Raster map with 10 x 10 meters’ grid. After that, the “Slope tool” calculated the gradient between the different areas of the city, with percentage rise as the output measurement unit. Natural Breaks was also used as the classification method, and the “Reclass tool” to transform the output values of the slope calculation into a 1-10 scale. Areas with higher slope differences were assigned an index of 1 (Low bikeability), meaning a negative impact in the final BI. Areas with lower slope differences (flat) were assigned an index of 10 (High bikeability). The assumption is that flat areas are more propitious for bicycle use.

3.3.2.4 Safety

The Safety map was generated based on the records of traffic-related accidents involving cyclists in the city of Curitiba during the years of 2013, 2014 and 2015. The data was available due to previous collaboration research between the ambulance service providers of the city (SAMU and SIATE), the Military Police of the State of Parana, and researchers from UTFPR. The dataset comprises a list of accidents occurred in the city in the previous years, with the date of the occurrence, type of vehicle involved, the gender of the victim, address of the incident and its respective severity level. All the accidents were imputed manually in the ArcGIS by the researcher using “X” and “Y” coordinates obtained with the support of Google Earth (Google Inc.) software.

According to the methodology used by the ambulance service providers of the city, the severity level of the incidents was separated into four categories. Are they:

- Code 1: Uninjured or light injury.
- Code 2: Non-incapacitating existent injury.
- Code 3: Incapacitating injury - severe.
- Code 4: Fatal (within 30 days).

Following the same methodology of the World Health Organization (WHO), it is considered a fatal accident when the victim dies within 30 days immediately after the occurrence of the accident (WHO, 2015). In order to obtain an index for each of the gravity levels and to enable the comparison among the different incidents, the direct and indirect costs of a traffic-related accident were used. Those costs refer to (a) costs of temporary or definite replacement of a workforce, (b) damage cost of vehicles, (c) cost of medical assistance both for rescue and hospital treatment, (d) cost of judicial proceedings, (e) cost of congestion, (f) cost of removing the vehicles, (g) damage costs, (h) cost of police and traffic agents support, and (i) costs regarding the family impact of an accident. The methodology was based on a study from the national Institute of Applied Economic Research (IPEA, in Portuguese) (IPEA, 2003). These costs served as a basis to calculate the impact of each accident level and the step-by-step of the computation can be found in the APPENDIX IV.

Results from Table 7 (APPENDIX IV) indicates that, an accident Code 2 (Non-incapacitating existent injury) has an impact twice higher than an accident Code 1 (Uninjured or light injury), while an accident Code 3 (Incapacitating injury - severe) has an impact nine times higher than a Code 1. Consequently, an accident Code 4 (Fatal) has an impact forty-four times higher than a Code 1. The impact was calculated in terms of direct and indirect costs of the accidents as described previously. This served as input to generate the accidents density map. The “Kernel Density tool” from ArcMap (ESRI) was used with a precision of 10 x 10 meters and the “population” field was assigned with the values calculated in the Table 7 (APPENDIX IV). The Code 1 (Uninjured or light injury) accidents were excluded from the analysis based on the assumption that, the aspects that lead to an accident with no injury or light injury might not represent a dangerous area for cycling. Some accidents were also excluded due to the lack of information about either the precise location or the severity level. Therefore, from 1,743 accidents involving cyclists between 2013 and 2015 in Curitiba, 1,063 were imputed in the map, representing 61% of the total. Results were classified into ten levels using the Natural Breaks methodology and the “Reclass tool” was used to generate a 1-10 scale. Areas with higher density of accidents were assigned with a bikeability of 1 (Low bikeability), while areas with less density of accidents were assigned with a bikeability of 10 (High bikeability).

Table 3: Number of accidents analysed.

Severity Level	Years			Total
	2013	2014	2015	
Code 2: Non-incapacitating existent injury	297	303	356	
Code 3: Incapacitating injury - severe	24	18	21	
Code 4: Fatal (within 30 days)	16	11	17	
Total	337	332	394	1063

3.3.2.5 Types of Infrastructure

The infrastructure map was generated based on the data from IPPUC (2015). This information is available due to the open data policy from the Municipality of Curitiba. However, the dataset does not contain all the distinctions between the different types of cycling infrastructure of the city, explained in the section 3.3.1.4. This separation was done by the researcher. To generate the raster map, a buffer of 25 meters to each side of the respective cycling infrastructure were applied. In the general roads and exclusive bus lanes, a buffer of 10 meters to each side was applied. This difference in the buffer size was done to assure that the positive impact in the index generated by the presence of a cycling infrastructure would prevail over the general road and the possible bus lane in the area. The assumption is that, where a cycling infrastructure is present, cyclists would make use of it, instead of cycling through cars or buses. The raster map was generated with a 10 x 10 meters’ grid. Figure 13 demonstrates the location of the different types of cycling infrastructure existent in the city. The definition of each one can be found in the APPENDIX I.

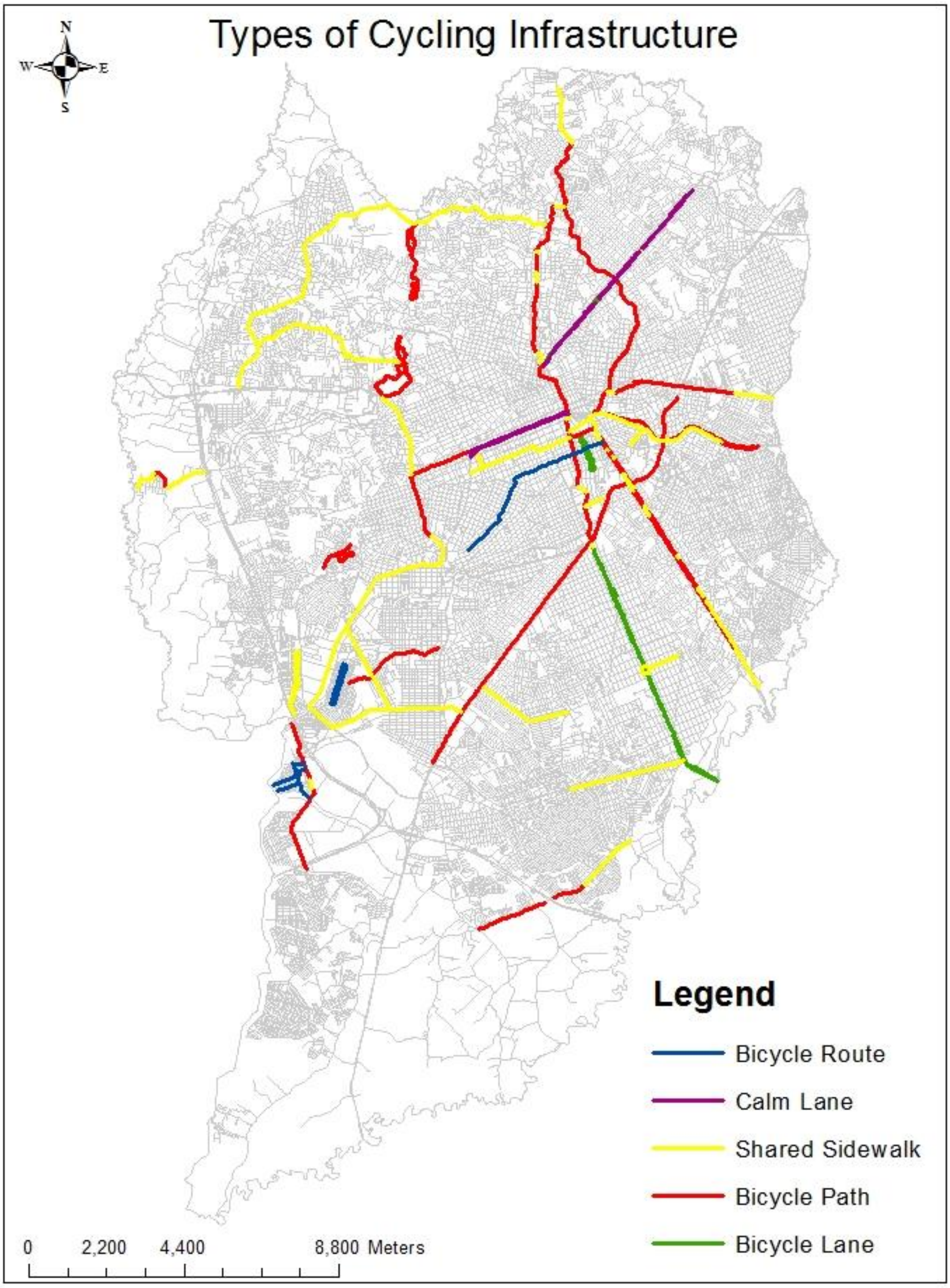

Figure 13: Types of cycling infrastructure – Location

Classifying the different types of infrastructure

To classify the different types of infrastructure and compute an index to be used in the GIS analysis, results from the survey (explained in the section 3.3.1 above) was considered. Among the questions presented, respondents were asked to assess their likelihood of cycling in each of the types of infrastructures existent in the city (presented in the section 3.3.1.4) on a 1-5 Likert scale. The answer options were: 1-Unlikely; 2-Somewhat likely; 3-Neutral; 4-Very Likely; 5-Certainly. In order to transform the respondents' answers from a 1-5 Likert scale to a 1-10 scale compatible with the Bikeability Index, the following equation was used:

$$Y = \frac{(B - A)\,(x - a)}{(b - a)} + A$$

Equation 3: Transforming different Likert scales to a common scale (IBM, 2010).

Where:
Y = Final index to be calculated;
x = Mean of the survey respondents;
A = 1;
B = 10;
a = 1;
b = 5;

Results from Equation 3 was used to classify the different types of infrastructure.

3.4 Data Collection

The GIS data used in this research was collected between 30th April 2016 and 25th June 2016, which was the period that the researcher lived in the city of Curitiba. During this time, information about the city's population aspects, land-use objectives and characteristics, as well as information regarding traffic-related accidents was sent directly by the respective data providers to the researcher in different moments. The other part of the data containing the city's topographic information and the existent cycling infrastructure was downloaded in the IPPUC's website.

The quantitative data was collected through interviews, both online and face-to-face. The online questionnaire was developed using the software LimeSurvey 2.0 and remained active for the period of two and a half weeks (between 27th May 2016 and 14th June 2016). As described in the section 3.3.1 the participants were approached by email and by social media. The emails were sent on the 27th May 2016 and on the 30th May 2016 using the MailChimp® platform. The estimated response rate was 10%. The social media approach was done on the 31st May 2016 and 3rd June 2016 by tree posts on Facebook©. The face-to-face interviews were done on the 9th June and 10th June 2016 in the administrative building of the Municipality of Curitiba during the morning period. Each interview lasted between 10-15 minutes and it was conducted by the researcher.

3.5 Data Analysis

As described in section 3.3, the GIS data was analysed using the software ArcGIS 10.3 (ESRI). The procedures were described above and the results will be exposed in the following chapter (Chapter 4). The data derived from the survey conducted among residents of Curitiba was analysed using the software IBM SPSS Statistics 23. Firstly, results from the online questionnaire were exported from the LimeSurvey portal in a compatible format. After that, the answers from face-to-face interviews were inputted manually in the SPSS data file following the same format. To enable the analysis of the different groups proposed in the Research Questions, two dummy variables were created to separate the sample by transport behaviour and income class. The "Cyclists" and "Non-cyclists" groups were created, as well as the "Higher Income" and "Lower Income". The independent sample t-test was conducted to compare the mean scores and to identify whether significant differences between the mean scores of the sample groups exist. The analysis was done separately, first by transport behaviour and then, by income class. In addition, exploratory factor analysis was used to understand the structure of the selected variables and to identify a cluster of variables within the dataset. As extraction method, Principal Component Analysis was used based on Eigenvalues greater than 1. The rotation method was Varimax and the regression method of Factor Scores was selected. Principal Component Analysis also supported in the weight distribution of the BI variables. Binary logistic regression was used to analyse the association between the transport behaviour of participants of the survey (cyclists and non-cyclists) and their socio-demographic aspects with the bikeability index variables, their evaluation regarding the barriers and facilitators/motivators for bicycle use and the likelihood for cycling in the different infrastructures of the city.

4 RESULTS

In this chapter, it will be exposed the results of the Survey and the outcomes of the Spatial Analysis. In addition, with the statistical analysis conducted on the survey data, the research questions regarding possible differences between distinct population groups, such as “cyclists”, “non-cyclists”, “higher income” and “lower income” were answered. The results of Factor Analysis, the Independent sample t-test and the Binary Logistic Regression will also be presented in this chapter.

Furthermore, it will be exposed the computation and the results of each variable from the bikeability index, as well as the final bikeability map, answering the main research question of this investigation. Different bikeability maps, based on the analysis of distinct population groups might also be demonstrated.

4.1 Questionnaire

To present the results of the survey, this section will be separated into two subsections named Descriptive Statistics and Inferential Statistics. The first subsection will describe the dataset collected from the sample, such as the total number of participants and the composition of each of the subgroups. The Inferential Statistics will demonstrate the Factor Analysis performed in the dataset and the procedures for the weight distribution among the BI variables. This subsection will also present the Significance test, which measured the differences in the evaluation between the sample groups, and the Binary Logistic Regression.

4.1.1 Descriptive Statistics

The total number of participants from the survey, considering online and face-to-face interviews were 231. Results from the questionnaire will be presented by groups of questions.

4.1.1.1 Personal Information and Travel Characteristics

This sub-section will present the characteristics of the sample, based on the most relevant enquiries from the personal and travel information groups of questions. In Figure 14, respondents are separated by gender. As noticed, most of the participants were man, representing 60% of the total sample.

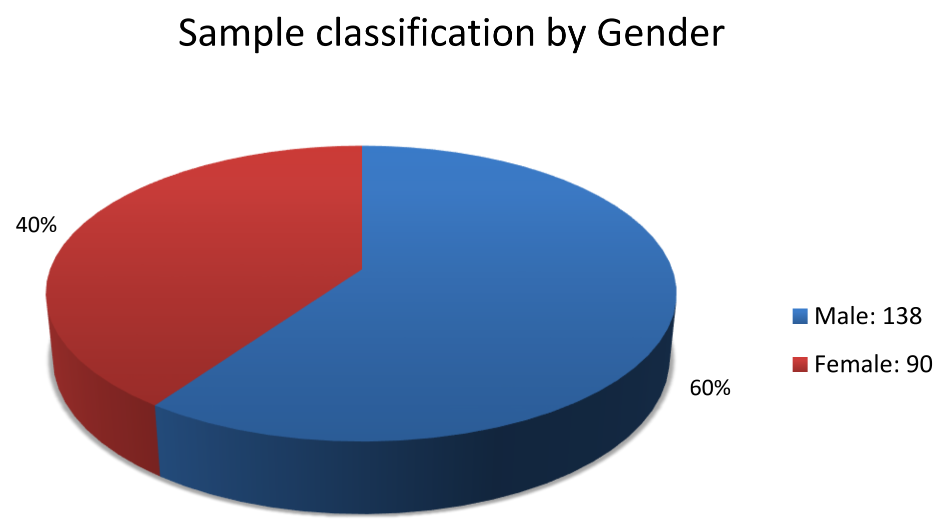

Figure 14: Sample classification by gender

In the figure below (Figure 15), participants were divided by educational level. Most of the participants declared to have higher education degree. The second largest group are those who are attending a bachelor programme (students) or those who did not complete the Bachelor.

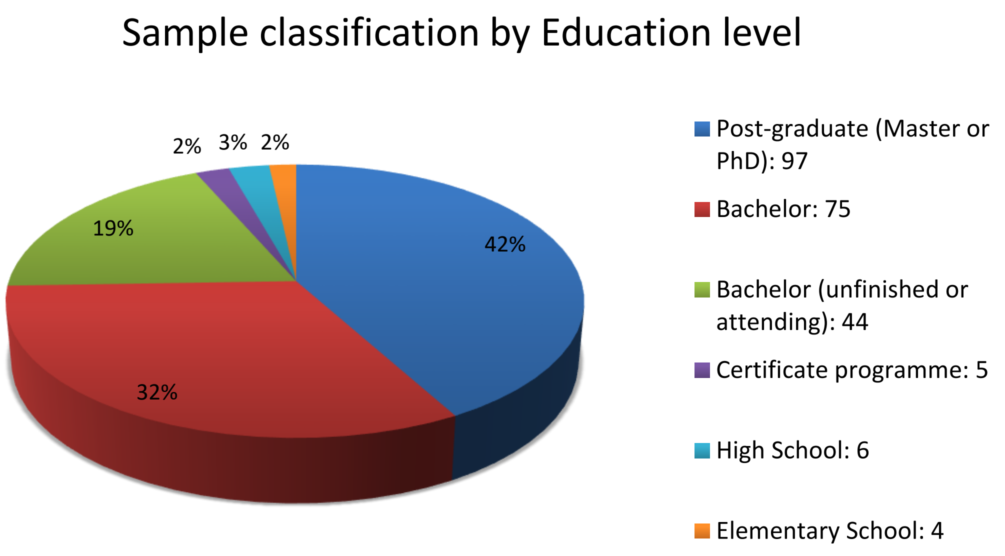

Figure 15: Sample classification by Education level

The Table below (Table 4) shows a comparison with the total population of the city of Curitiba measured in the Census 2010 (IBGE, 2010). The categorization is presented according to the methodology of IBGE. The institute does not distinguish Graduation (Bachelor degree) from Post-graduation (Master or PhD degree), neither Certificate programmes or people that are attending a bachelor programme, such as in the Questionnaire. Therefore, it was considered Graduated people, those who has a Bachelor, Master or PhD degree. People that are attending a Bachelor programme and those who attended a Certificate programme were gathered at the High School level. To present the education level of citizens, the institute (IBGE) only considers individuals with more than 10 years old. The table below is only a demonstration about the characteristics of the population and the survey participants. This research did not intend to investigate the differences based on education level. Therefore, any adjustment in the weighting to compensate the lack of participants from specific education levels was required.

Table 4: Population of Curitiba versus Survey sample - Education Level

Education level	Population older than 10 years - Census 2010 (IBGE)		Survey	
	Frequency	Percentage	Frequency	Percentage
Graduated	307,175	20%	172	74.5%
High School	457,452	29.9%	55	23.8%
Elementary School	271,175	17.7%	4	1.7%
No Education	485,443	31.7%	0	0%
Not determined	10,592	0.7%	0	0%
Total	1,531,837	100%	231	100%

Figure 16 shows the social status of the survey participants, with most of them located in the social classes “C” and “B”, respectively. As demonstrated in the section 3.3.1.1, this investigation considered Higher income people those from the social classes A, B and C, while Lower income those from the social classes D and E.

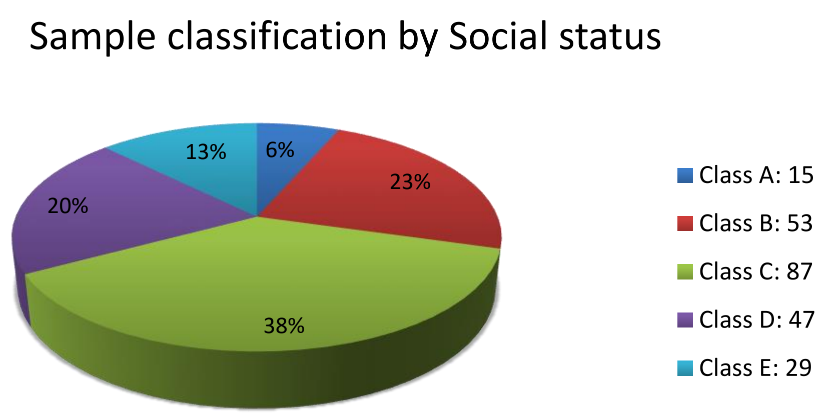

Figure 16: Sample classification by Social status

The tables below show a comparison between the social class of the total population from Curitiba, measured in the Census 2010 (IBGE, 2010), and the participants of the Survey. As noticed, most of the city’s population are from the social classes C and D. When analysing the two main groups (Higher Income and Lower Income) from Tables 5 and 6, the total population of the city and the sample had similar percentages in the frequency. 66% of the citizens are from the Higher Income class, while 68% of the participants of the survey are also from Higher Income class (Table 5). In the Lower Income class group, similar percentages were also achieved. 34% of the entire population of Curitiba against 33% of the survey participants are from Social Classes D and E (Table 6). However, when analysing the percentages of each income class separately (A, B, C, D and E), some distinctions can be found, especially in the number of participants from Social Classes D and E. For this reason, the “weighted by cases” tool from SPSS was used, with the cases being weighted by Income Class in the statistical analysis[1].

Table 5: Population of Curitiba versus Survey sample (Higher Income)

Income Class		Total population - Census 2010 (IBGE)		Survey	
		Frequency	Percentage	Frequency	Percentage
Higher Income	Class A	52,993	3%	15	7%
	Class B	291,108	17%	53	23%
	Class C	803,744	46%	87	38%
	Sub-Total	1,147,845	66%	155	68%

[1] The only statistical test that analysed differences in the five Income Classes was the Binary Logit Model, precisely when predicting the odds of being a cyclist or not, using the five classes as a predictor variable. In all the other analysis, the “weighted by cases” was not applied, since significant differences were not found in the two main groups (Higher Income and Lower Income).

Table 6: Population of Curitiba versus Survey (Lower Income)

Income Class		Total population - Census 2010 (IBGE)		Survey	
		Frequency	Percentage	Frequency	Percentage
Lower Income	Class D	579,403	33%	47	20%
	Class E	24,659	1%	29	13%
	Sub-Total	604,062	34%	76	33%

In Figure 17, the modal distribution of the participants is showed. The graph demonstrates a good number of respondents that declared to use the bicycle as the main transport mode, being the largest sample group. The second largest is the car users, followed by bus users. Since this investigation intends, among other things, to look at the differences between cyclists and non-cyclists, respondents that did not assign “bicycle” as the main transport mode (car users, bus users, etc.) were gathered in the non-cyclists group. Consequently, the cyclist's group is formed by those who declared to use the bicycle as the main transport mode.

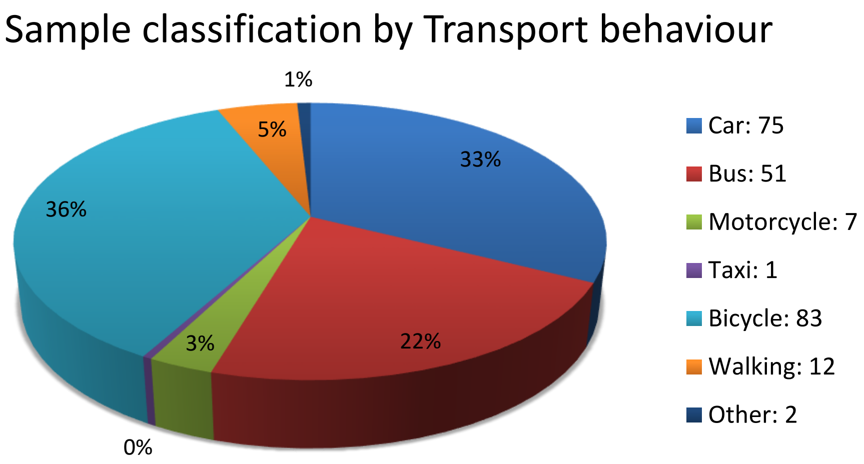

Figure 17: Sample classification by Transport behaviour

Among the 83 cyclists that answered the questionnaire, there was 20 women and 63 men, 34 from lower income class and 49 from higher income class, and 61 higher educated and 22 with lower education.

Figure below (Figure 18) represents how many times per week participants’ make use of the selected transport mode presented above. As noticed, most of the car, bus and bicycle users travel 5 times per week with the selected mode.

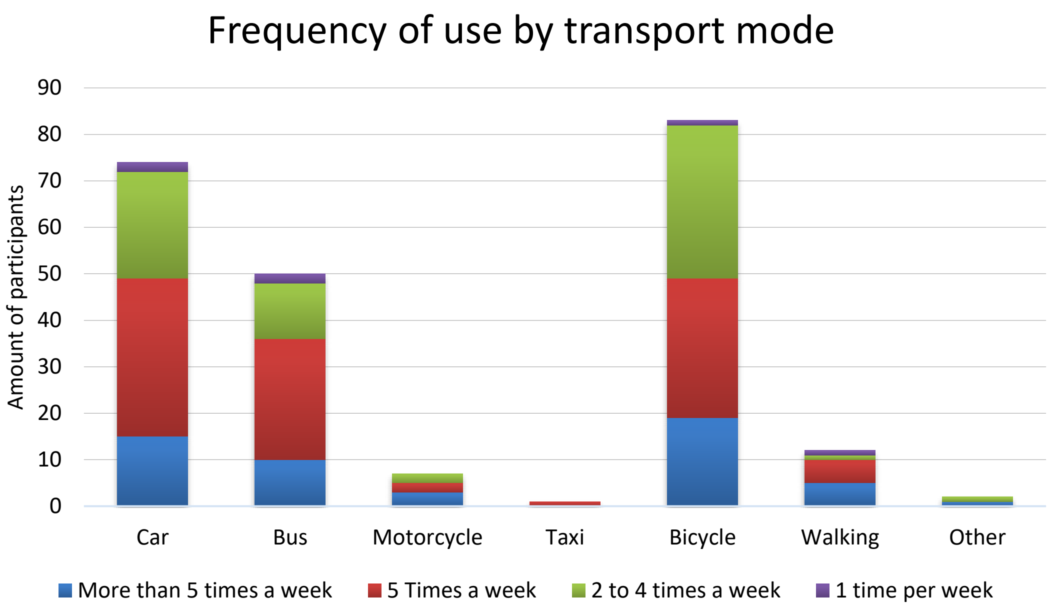

Figure 18: Frequency of use by transport mode

4.1.1.2 Barriers and Facilitators/Motivators for bicycle use

This group of questions contains the assessment of the barriers and facilitators/motivators for bicycle use on a scale of importance. The complete list of factors can be found in the section 3.3.1.3. The factors were presented separately, first the barriers and later the facilitators/motivators for cycling in the city of Curitiba. In this section, it will only be presented the most relevant factors according to the survey participants. The complete evaluation will be presented in APPENDIX V, together with the measures of central tendency and variability.

Figure below (Figure 19) shows the main Barriers for the use of bicycle for transportation purposes in the city of Curitiba, according to the survey participants. Specific cycling infrastructure and the safety aspects for bicycle use constitute as the most important barriers to the use of bicycle.

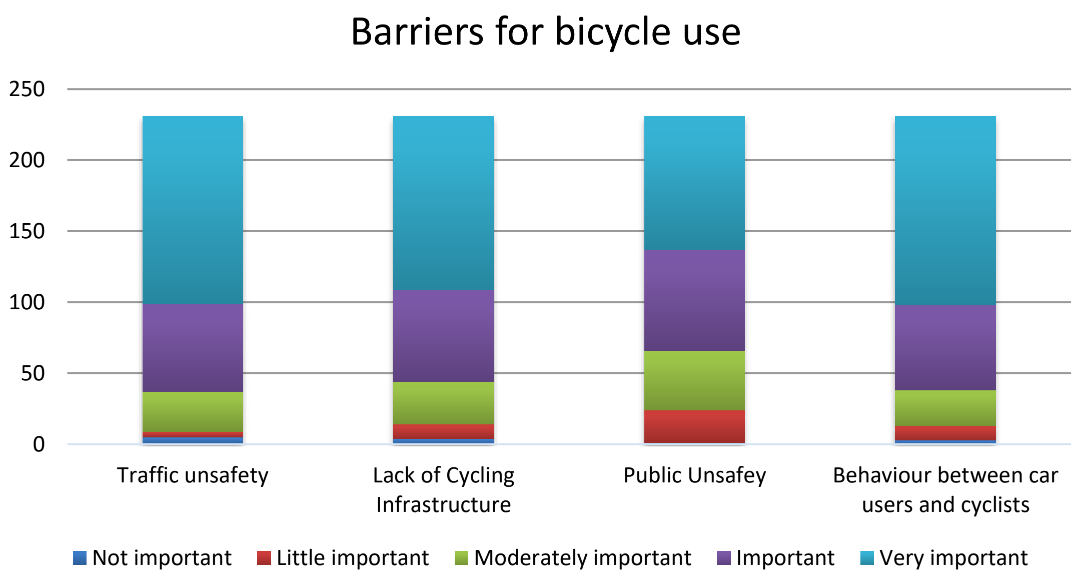

Figure 19: Barriers for bicycle use

Figure 20 demonstrates the most relevant Facilitators and/or Motivators for bicycle use in the city of Curitiba. Again, safety and cycling infrastructure aspects were the most important factors evaluated by the survey participants, together with the possibility for integration between bicycle and public transport.

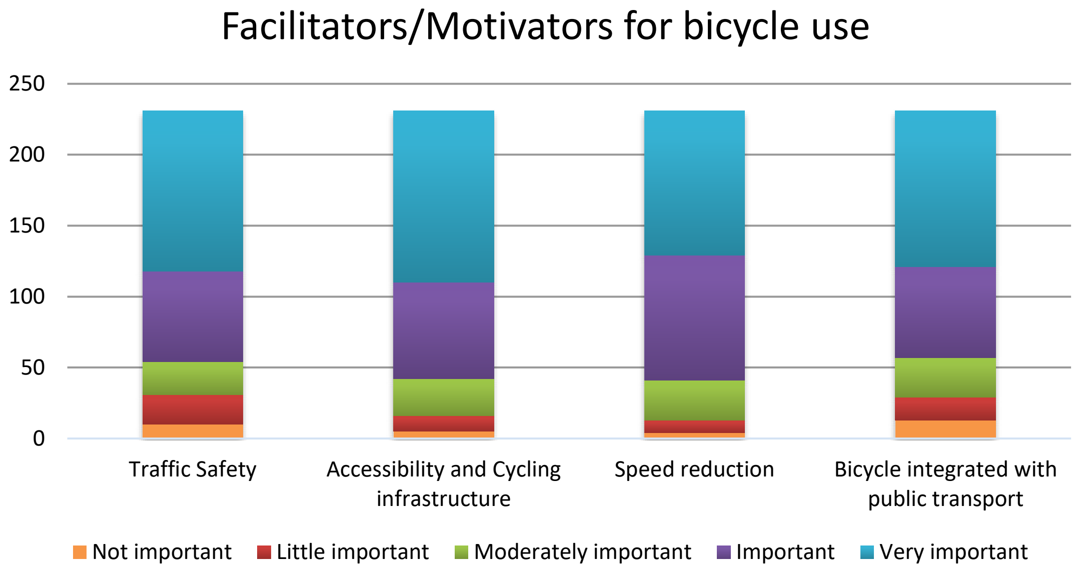

Figure 20: Facilitators/Motivators for bicycle use

4.1.1.3 Types of Infrastructure

In the last group of questions, participants assessed their degree of likelihood for using the bicycle in the different types of infrastructure of Curitiba. In order to measure how the presence or absence of a cycling infrastructure would affect the participants' probability for cycling, the question included whether they would cycle in the general roads and exclusive bus lanes. In those locations, any cycling infrastructure exists. In addition, cycling in the bus lanes was prohibited in the city by the Act Nº 695/95 and Act Nº 759/95. Figure 21 presents the likelihood for cycling in each of the types of infrastructure existent in the city. Like demonstrated by the graph, the likelihood for cycling from all participants is higher when a dedicated cycling infrastructure exists, and substantially decreases when any cycling infrastructure is present (general roads and exclusive bus lanes). The detailed results together with the measures of central tendency and variability can be found in APPENDIX VI.

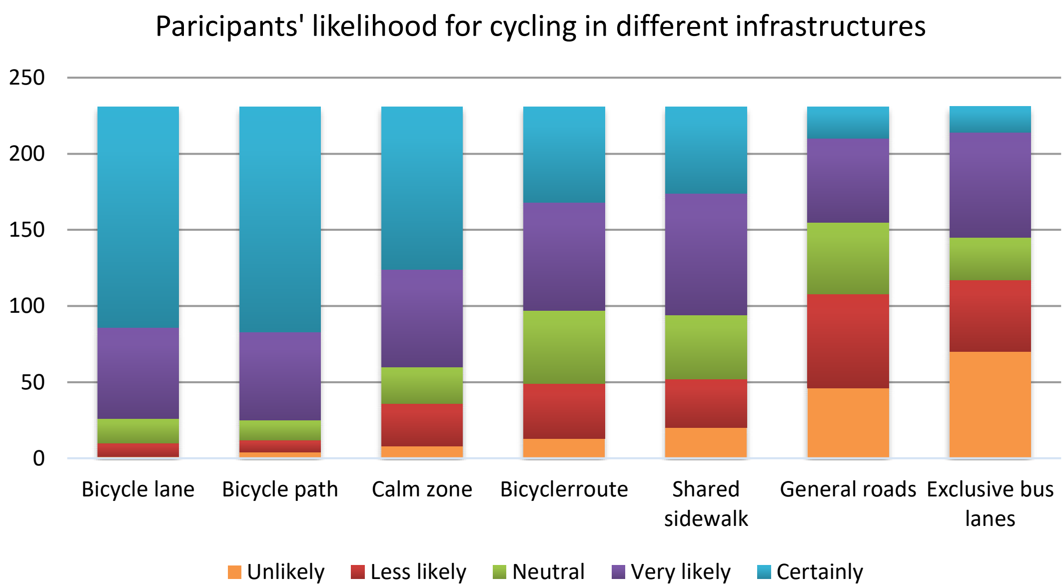

Figure 21: Likelihood for cycling in the different types of infrastructure

4.1.2 Inferential Statistics

This section comprises the statistical analysis performed to drawn inferences about the aspects regarding bicycle use in Curitiba, based on the results of the survey. In the first sub-section, the independent sample t-test will be exposed. The test measured how the mean differences between the sample groups represented a real difference, or if they are due to chance. This analysis intended to answer the questions regarding the differences between the sample groups and possibly produce individual bikeability maps for each of the groups. The second sub-section will expose the results of the Factor Analysis. In this Master Thesis, Factor analysis was used to gain insights about the aspects that affects bicycle use in Curitiba and to distribute the weight between the BI variables. According to Field (2009), factor analysis is a technique for identifying groups or cluster of variables and is capable, among other things, to reduce a data set to a more manageable size while preserves most of the information as possible. Results from the Binary Logistic Regression will be presented in the third sub-section. This analysis intends to predict, based on several predictor variables, an outcome variable. In this study, socio-demographic characteristics, the evaluation regarding barriers and facilitators/motivators for bicycle use, the likelihood for cycling in the different infrastructures of the city collected by the Questionnaire, as well as the spatial analysis was used as predictor variables. Different analysis was made for each outcome variable. The outcome variables that the model intended to predict are: the citizens' travel behaviour (cyclist or non-cyclist) and income class (higher income or lower income).

4.1.2.1 Significance test

The independent sample t-test is a basic experiment study conducted to analyse whether one independent variable has some effect on a dependent variable. The test will look at differences between a pair of scores (Field, 2009). In this research, the independent sample t-test was used to measure the mean differences between the groups separated by income level and transport behaviour. By following the classification described in the sections 3.3.1.1 and 3.3.1.2, respondents were separated into "Higher income" and "Lower income", "Cyclists" and "Non-cyclists". According to Field (2009), if the value of the independent sample t-test is equal or below 0.05, this is an indicative that the groups are significantly different. When Sig. (2-tailed) value is higher than 0.05, the equal variance is assumed, therefore, no significant differences between the sample groups were detected. The following sub-sections will present only the variables that had significant differences between the two groups. The complete results of the independent sample t-test can be found in APPENDIX VII. The test was performed with the software IBM© SPSS© Statistics 23.

Cyclists versus Non-cyclists

The *independent sample t-test* of the Barriers for bicycle use performed between "Cyclists" and "Non-Cyclists" demonstrates that, significant differences (Sig. < 0,05) between the mean of two groups were found in the following variables

- Topography (Non-cyclists: 3.22; Cyclists: 2.65);
- Public insecurity (Non-cyclists: 4.22; Cyclists: 3.64);
- Distance (Non-cyclists: 3.26; Cyclists: 2.47);
- Need to carry luggage or bags during the travel (Non-cyclists: 3.14; Cyclists: 2.40);
- Weather Conditions (Non-cyclists: 3.73; Cyclists: 3.14).

As noticed, in all of them, non-cyclists gave more importance to those factors than the cyclist's group. The sample is composed by 148 non-cyclists and 83 cyclists.

The *independent sample t-test* performed with the Facilitators/Motivators for bicycle use showed significant differences (Sig. < 0,05) between the mean of two groups in the following factors:

- Short distances (Non-cyclist: 4.01; Cyclists: 3.61);
- Insufficient public transport in the neighbourhood (Non-cyclist: 3.44; Cyclists: 2.92);
- Integration between bicycle and public transport (Non-cyclist: 4.16; Cyclists: 3.84);
- Expensive car parking (Non-cyclist: 3.48; Cyclists: 3.04).

In all them, Non-cyclists assigned more importance than Cyclists.

When analysing the different types of infrastructure, those that had significant differences (Sig. < 0.05) between respondents' means were:

- Bicycle Lane (Non-cyclists: 4.29; Cyclists: 4.78);
- Calm Lane (Non-cyclists: 3.69; Cyclists: 4.59);
- Bicycle Route (Non-cyclists: 3.36; Cyclists: 3.98);
- General Roads (Non-cyclists: 2.24; Cyclists: 3.67);
- Exclusive Bus Lanes (Non-cyclists: 2.18; Cyclists: 3.46).

Bicycle Path and Shared Sidewalk did not show significant differences between the means.

Results from the *independent sample t test* showed that, among Cyclists and Non-cyclists, the factors that are related to attitudes towards bicycle use such as topography, distance, weather conditions, and need to carry bags or luggage during the trip had significant differences in the evaluation. People that are engaged in active transport tend to feel less the effects of these factors when commuting by bicycle. Not surprisingly, when analysing the t-test results from the types of infrastructure, we notice that cyclists are more likely to cycle in almost all types of infrastructures existent. The only exception was on Shared sidewalks, where non-cyclists had a higher mean but with no significant differences between the groups. A similar evaluation between the groups was also found on Bicycle path. This infrastructure is the only one where the cyclist is fully separated from both pedestrians and other vehicles. The high rejection from the non-cyclists group regarding general roads and exclusive bus lanes highlights the importance that this group gives for the presence of cycling infrastructure.

The fact that Topography, which can be directly related with one of the Bikeability Index variables, and most of the types of infrastructure had significant differences between the respondents' means, justifies the computation of specific indices to each group. Therefore, one bikeability map will be produced based on the Cyclists responses, and another bikeability map based on the Non-cyclists' responses.

Higher Income versus Lower Income

In order to analyse possible differences in the assessment of the determinant factors for bicycle use, the independent sample t-test was performed by separating the sample between Higher income and Lower income individuals. Among the Barriers and Facilitators/Motivators for bicycle use, significant differences (Sig. < 0.05) between respondents' means were found on:

- Lack of Signs at Crossings (Classes A, B and C: 3.50; Classes D and E: 3.96);
- Accessibility and Cycling Infrastructure (Classes A, B and C: 4.34; Classes D and E: 4.07).

In the evaluation of the different types of infrastructure, any significant differences between the two groups were found. This is an indicative that both higher and lower income respondents assessed similarly their likelihood for cycling in the different types of infrastructure. The lack of significant differences found between the groups did not justify the elaboration of exclusive bikeability maps for the higher and lower income population.

4.1.2.2 Factor Analysis

In this Master thesis, Factor Analysis was used to gain insights about the aspects that affects bicycle use in Curitiba, and to perform the weight distribution of the variables from the bikeability index. Therefore, two Factor Analysis was done. The first was performed with all the Barriers and Facilitators/Motivators for bicycle use presented in the Questionnaire. With this analysis, it was possible to understand how the research participants evaluated all the aspects presented in the survey. The second Factor Analysis was done in order to distribute the weight among the BI variables according to the survey respondents. The objective was to generate an index more in line with the real cycling conditions of the city. Therefore, factors that are not related to the BI variables were excluded from this second analysis.

From the barriers and facilitators/motivators for bicycle use, which served as a basis for the weight distribution among the BI variables, none of them could be directly related to the Residential Density variable. In order to assign a score to this variable and enable the weight distribution through factor analysis, an index was calculated to each respondent, based on the Residential Density map and the participant's place of residence. The index was computed in the following manner: Firstly, using the participant's postal code answered in the questionnaire, each respondent was positioned on the map with the support of BatchGeo platform (BATCHGEO LLC) and Google Earth (Google Inc.). Although the exact residence position was not known, the postal code gives an approximate location of the respondent's residence. Each participant was inputted in the ArcMap (ESRI) as a "Point Feature". Secondly, with the "Extract values to points" tool, each participant was assigned a score according to their residence approximate location, varying from 1 to 10. As an example, if the respondent's residence is in the highest dense area calculated as described in the section 3.3.2.1 (Residential Density), a score of 10 was assigned to this participant. On the other hand, if the respondent's residence is in the lowest dense area, a score of 1 was assigned to this participant, and so on. From 231 respondents of the Survey, 217 had the necessary postal code information that enabled their location in the map. Therefore, the sample size was reduced to 217 participants. This factor was included in the SPSS and named as "Density".

The first sub-section will present the Factor Analysis performed with all the Barriers and Facilitators/Motivators for bicycle use, and the second sub-section will show the Factor Analysis performed only with the factors related to the BI variables.

Exploratory Factor Analysis

The results of the Factor Analysis performed with all the Barriers and Facilitators/Motivators for bicycle use were: With 217 participants, a principal component analysis (PCA) was conducted on the 24 items with orthogonal rotation (Varimax). The Kaiser–Meyer–Olkin measure verified the sampling adequacy for the analysis, KMO = .764 ('good' according to Field, 2009), and all KMO values for individual items were > 0.593, which is above the acceptable limit of 0.5 (Field, 2009). Bartlett's test of sphericity 2 (276) = 1710.260, $p < .001$, indicated that correlations between items were sufficiently large for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Seven components had eigenvalues over Kaiser's criterion of 1 and in combination explained 62.63% of the variance.

Figure 22 demonstrates how the Barriers and Facilitators/Motivators for bicycle use loaded into each factor. The factors were named as: Attitudes, Safety, Cost-beneficial factors, Built environment, Local aspects, Actions of city's administration and Density.

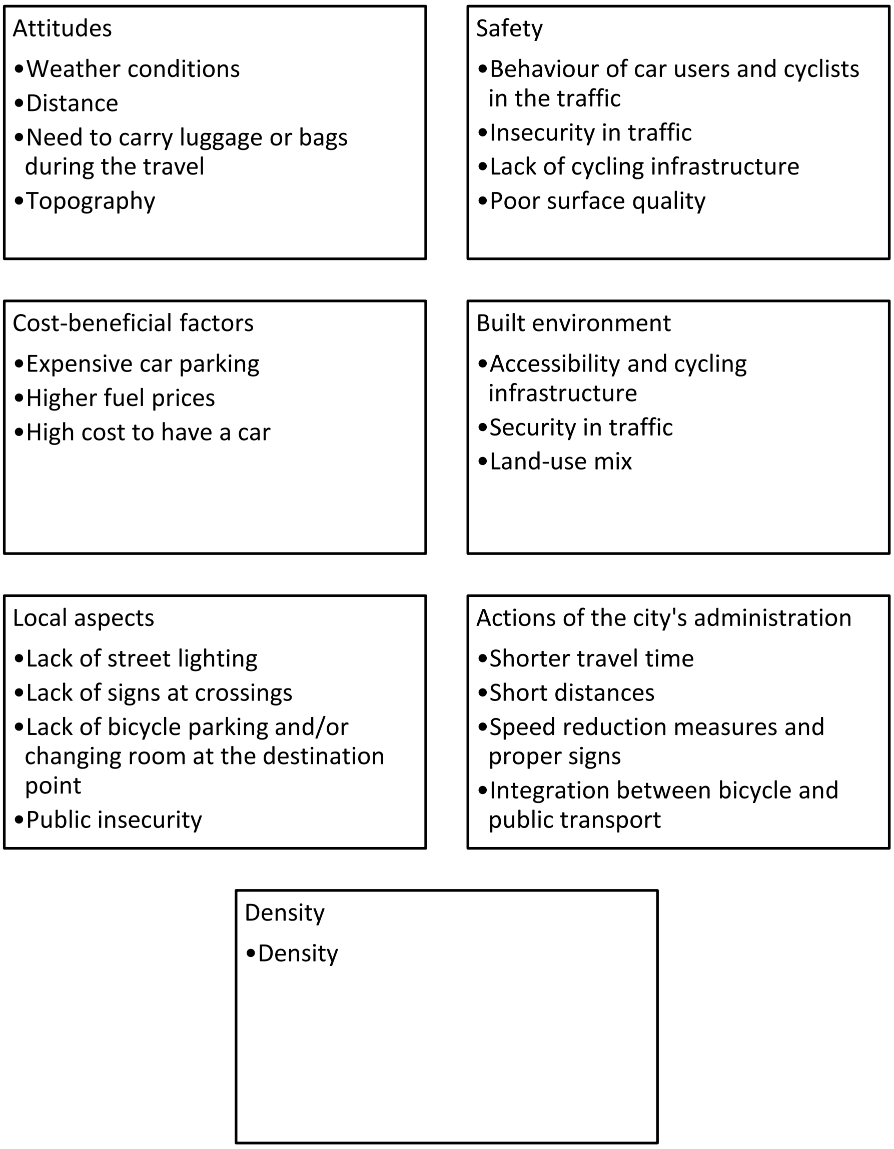

Figure 22: Factor Analysis - Group factors and variables

Performing the weight distribution between the Bikeability Index variables

As described previously, some Barriers and Facilitators/Motivators for bicycle use presented in the Survey was not directly related with any of the Bikeability Index variables. Consequently, those factors were excluded from this analysis. The factor “Security in traffic” was also excluded for being a contradicting one. The reason is that the Questionnaire also presented “Insecurity in traffic” as one of the barriers for bicycle use, which is the antonym of this factor. Since “Security in traffic” received a lower evaluation from the survey participants, this factor was excluded.

For each BI variable (Residential Density, Mixed Land-Use, Topography, Safety and Cycling Infrastructure), it was selected one or a group of factors that are directly related to them. Figure 23 demonstrates the factors that were assigned to each BI variable. Results from the factor analysis performed with the entire sample (General sample) and with Cyclists and Non-cyclists’ groups will be presented separately. Factor Analysis for Higher and Lower Income group was not performed since the independent sample t-test did not justify the computation of exclusive bikeability maps for those groups.

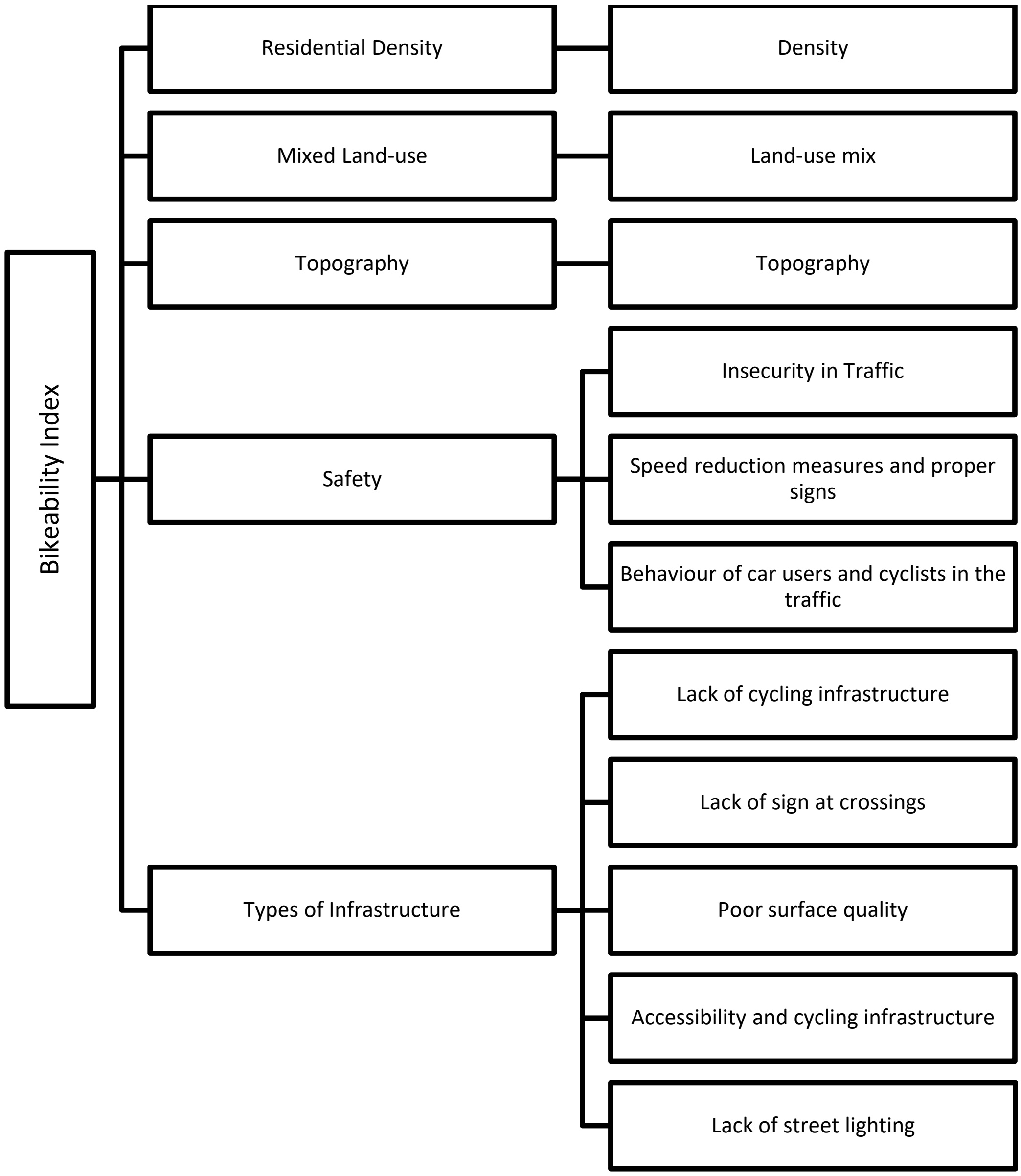

Figure 23: Bikeability Index variables and related factors

General Sample

With 217 participants, a principal component analysis (PCA) was conducted on the 11 items with orthogonal rotation (Varimax). The Kaiser–Meyer–Olkin measure verified the sampling adequacy for the analysis, KMO = .759 ('good' according to Field, 2009), and all KMO values for individual items were > 0.656, which is above the acceptable limit of 0.5 (Field, 2009). Bartlett's test of sphericity 2 (55) = 529.151, p < .001, indicated that correlations between items were sufficiently large for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Four components had eigenvalues over Kaiser's criterion of 1 and in combination explained 62.76% of the variance.

Figure 24 demonstrates how 62.76% of the variance was distributed between all the items used in the Factor Analysis. The second column shows the variances from each item and the first column, the sum of the variances of each corresponding item that composes the BI variable.

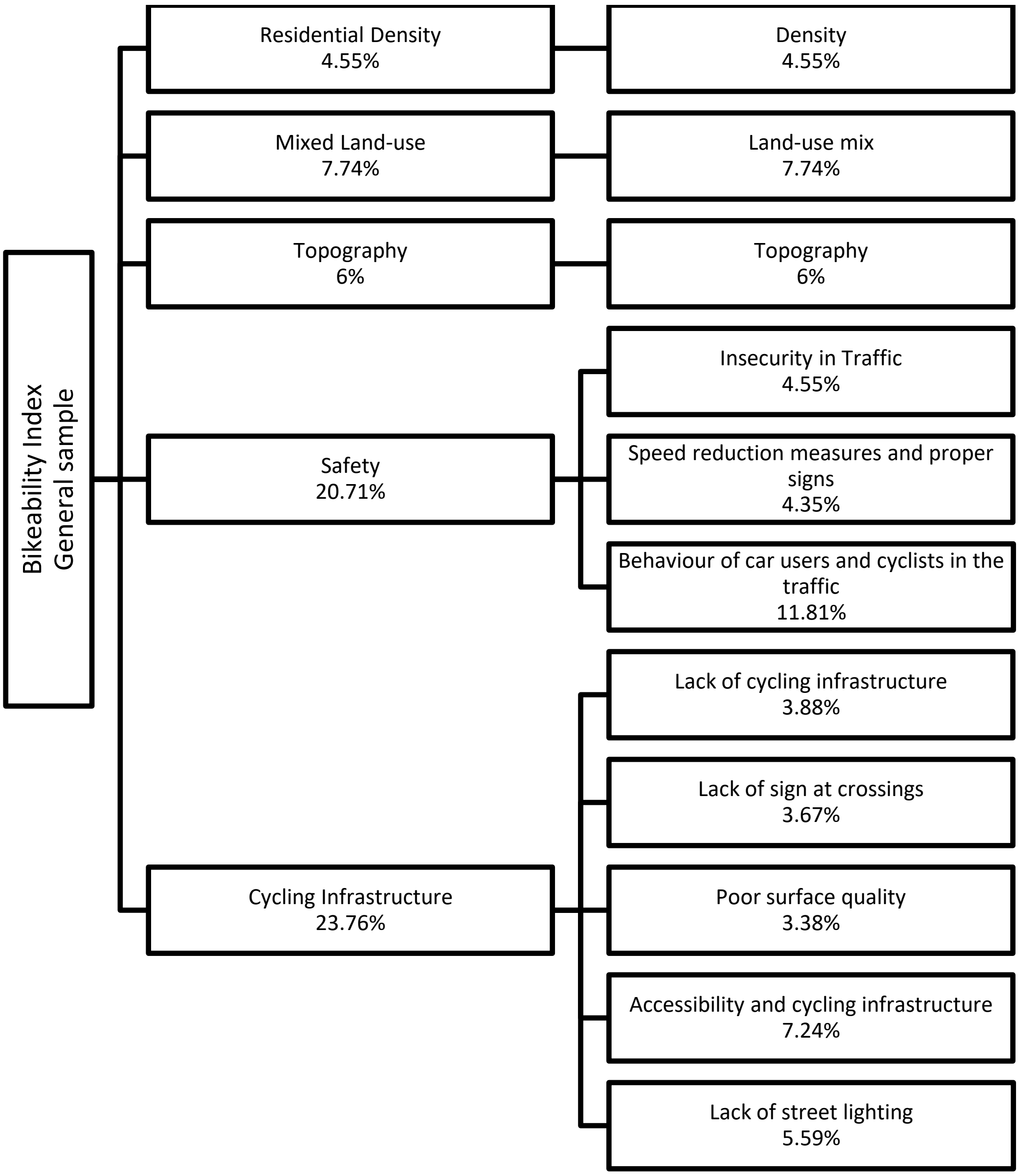

Figure 24: Factors loading into each BI variable - General sample

Cyclists versus Non-cyclists

This group is divided between the respondents that affirmed to use the bicycle as the main transport method and the participants that assigned any other transport mode (car, bus, motorcycle, etc.). Firstly, the Factor analysis from the Cyclists group will be presented.

With 77 participants that assigned bicycle as their main transport mode, a principal component analysis (PCA) was conducted on the 11 items with orthogonal rotation (Varimax). The Kaiser–Meyer–Olkin measure verified the sampling adequacy for the analysis, KMO = .704 ('good' according to Field, 2009), and all KMO values for individual items were > 0.546, which is above the acceptable limit of 0.5 (Field, 2009). Bartlett's test of sphericity 2 (55) = 226.684, p < .001, indicated that correlations between items were sufficiently large for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Four components had eigenvalues over Kaiser's criterion of 1 and in combination explained 66.72% of the variance.

Figure 25 demonstrates how 66.72% of the variance was distributed between all the items used in the Factor Analysis. The second column shows the variances from each item and the first column, the sum of the variances of each corresponding item that composes the BI variable.

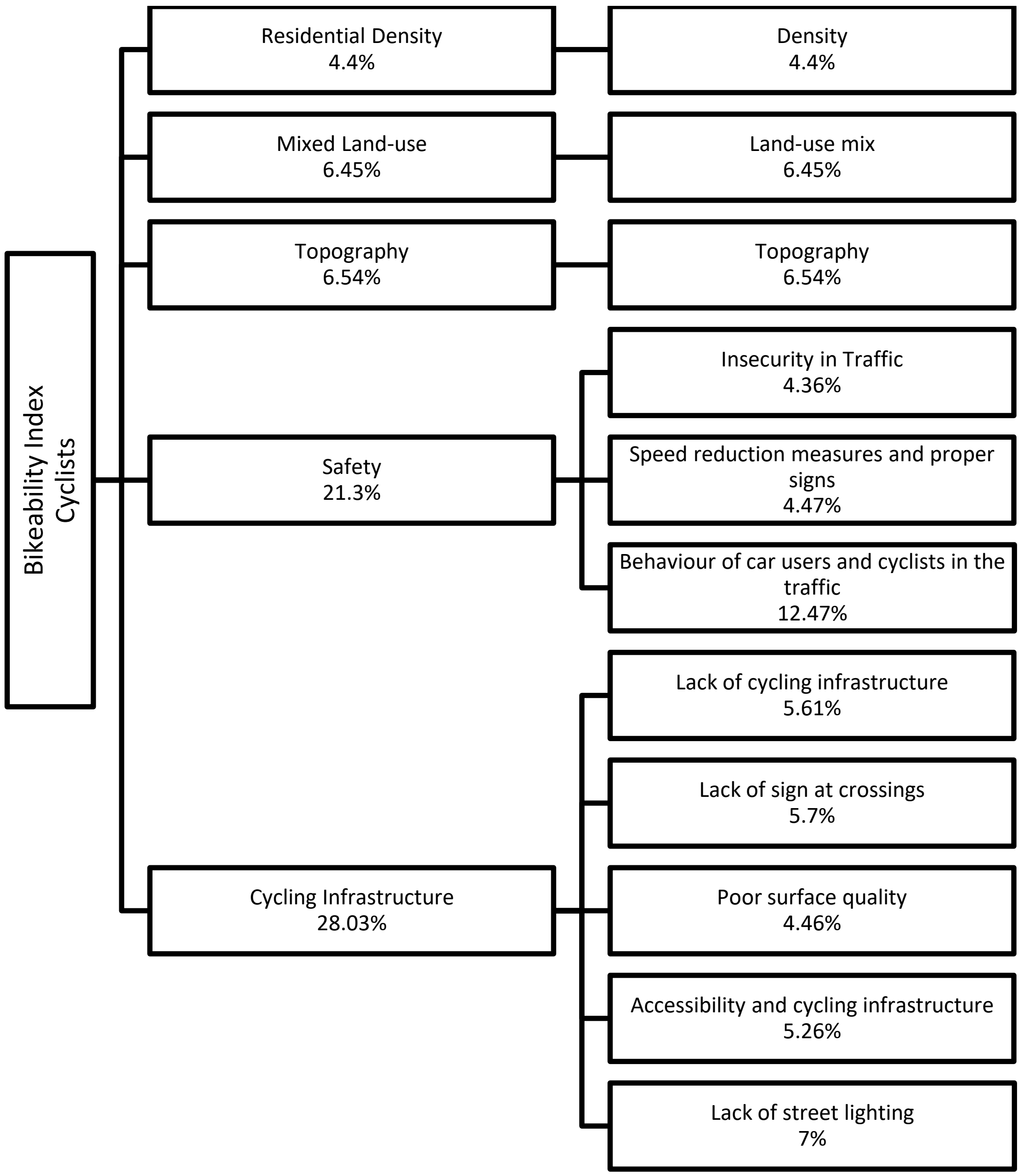

Figure 25: Factors loading into each BI variable – Cyclists

By conducting Factor Analysis with the Non-cyclists' participants, the results are: With 140 participants, a principal component analysis (PCA) was conducted on the 11 items with orthogonal rotation (Varimax). The Kaiser–Meyer–Olkin measure verified the sampling adequacy for the analysis, KMO = .755 ('good' according to Field, 2009), and all KMO values for individual items were > 0.604, which is above the acceptable limit of 0.5 (Field, 2009). Bartlett's test of sphericity 2 (55) = 335.925, p < .001, indicated that correlations between items were sufficiently large for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Four components had eigenvalues over Kaiser's criterion of 1 and in combination explained 62.43% of the variance.

Figure 26 demonstrates how 62.43% of the variance was distributed between all the items used in the Factor Analysis. The second column shows the variances from each item and the first column, the sum of the variances of each corresponding item that composes the BI variable.

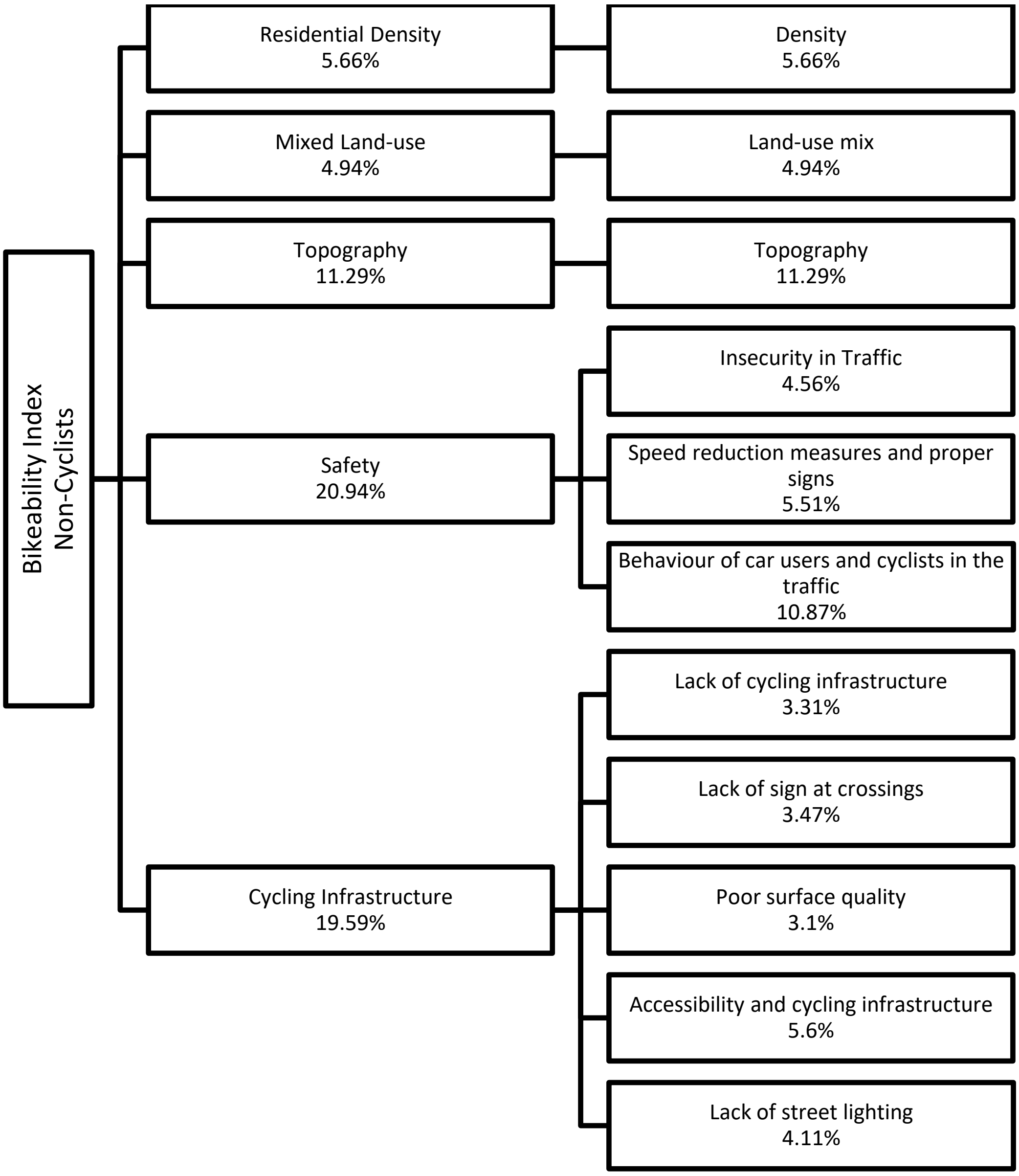

Figure 26: Factors loading into each BI variable – Non-Cyclists

4.1.2.3 Binary Logistic Regression

Logistic regression has the purpose of assessing the likelihood of a set of predictors to falling into one of the outcome categories (Field, 2009). In this Master Thesis, the first outcome category to be tested will be based on citizens' transport behaviour, in this case, the odds of being a cyclist or not. The second outcome category is based on income level and will test the odds of citizens' to be from a higher income class or from a lower income class. The predictor variables that will test these probabilities are the final bikeability score based on the general sample and the individual bikeability scores from the five variables (Residential Density, Mixed Land-use, Topography, Safety and Types of Infrastructure). To test this, the survey participants were inputted in the map and, depending on their household location, the scores of the corresponding predicted variable was assigned to these participants. The "Extract Multi Values to Points" tool from ArcMap (ESRI) was used. In addition, socio-demographic characteristics such as age, gender, education level and social status, and the assessment of the survey respondents' concerning the barriers and facilitators/motivators for bicycle use and the likelihood to cycle on each type of infrastructure of the city were also used as predictor variables.

The results of the Binary Logistic Regression will be presented separately. The first sub-section will demonstrate the regression results based on transport behaviour, measuring the odds of individuals of being a cyclist or not. The second sub-section will demonstrate the odds of individuals of being from a higher or lower income class. The complete results can be found in the APPENDIX IX and APPENDIX X. The regression was performed with the software IBM SPSS Statistics 23.

Transport Behaviour

This section will present the results of the logistic regression performed to assess the likelihood of the individuals to use bicycle as the main transport mode (cyclists) or not (non-cyclists), based on the final bikeability index, the individual bikeability index variables, socio-demographic characteristics, the assessment concerning the barriers and facilitators/motivators for bicycle use and the likelihood of using bicycle in the different types of infrastructure existent in Curitiba.

Results demonstrate that, in the importance evaluation scale from the Questionnaire (1-Not important to 5-Very important), for every point increased in “Public insecurity” and “Integration between bicycle and public transport” assessment, the odds of being a cyclist decreases 45% and 26.5% respectively. On the other hand, for every point increased on the importance scale of “Speed reduction measures and proper signs”, the odds of being a cyclist increases 68.9%.

When performing the regression using the likelihood of cycling (1-Unlikely to 5-Certainly) in the different types of infrastructures as predictor variables, results indicate that, for every point increased in the “General roads” and “Exclusive bus lanes” evaluation, the odds of being a cyclist increases 104% and 80.5% respectively. By analysing the socio-demographic characteristics, the regression indicates that women are 74.4% less likely of being a cyclist than men, and for every extra year-old, individuals are 5.7% less likely of being a cyclist. The regression between transport behaviour and social class indicates that, for every ascension in the five income class levels presented in the Table 1 Section 3.3.1.1, the odds of being a cyclist decreases 27.4%, indicating that higher income people are less likely of use the bicycle for transportation.

Income Class

This section will expose the Binary Logistic Regression performed between the participants’ income class (Higher income and Lower income) and the final bikeability index, the individual bikeability index variables, the assessment concerning the barriers and facilitators/motivators for bicycle use and the likelihood of using the bicycle in Curitiba. The predictor variable (income class) is a categorical variable, therefore, only two levels are possible: higher income and lower income. The complete results can be seen in APPENDIX X.

“Safety” was the only variable that achieved statistical significance ($\rho < 0.05$). The regression suggests that for every unit increased in the Safety index, which means a safer area for cycling, the likelihood of individuals being from a higher income class increases 20.2%. This indicates that higher income areas are safer for cycling, in this case with a lower occurrence of traffic accidents.

4.2 Spatial Analysis

This section will expose the results of the Spatial Analysis performed with the support of the software ArcGIS 10.3 (ESRI). The BI index variables were computed as explained in the section 3.3.2 and will be presented separately.

4.2.1 Residential Density

The Residential Density index was calculated based on the number of households in a census track level and its respective areas. The density values were categorized into ten different classes following the Natural Breaks method and an index of 1 was assigned to the lowest dense areas (Low bikeability) and an index of 10 to the highest dense areas (High bikeability). The original Residential density map can be found in APPENDIX XI. The map presented in the figure bellow (Figure 27) was made by performing a deciles distribution. This method divides the values into ten groups with similar frequencies. This representation was made to improve the visualization of the map in this document.

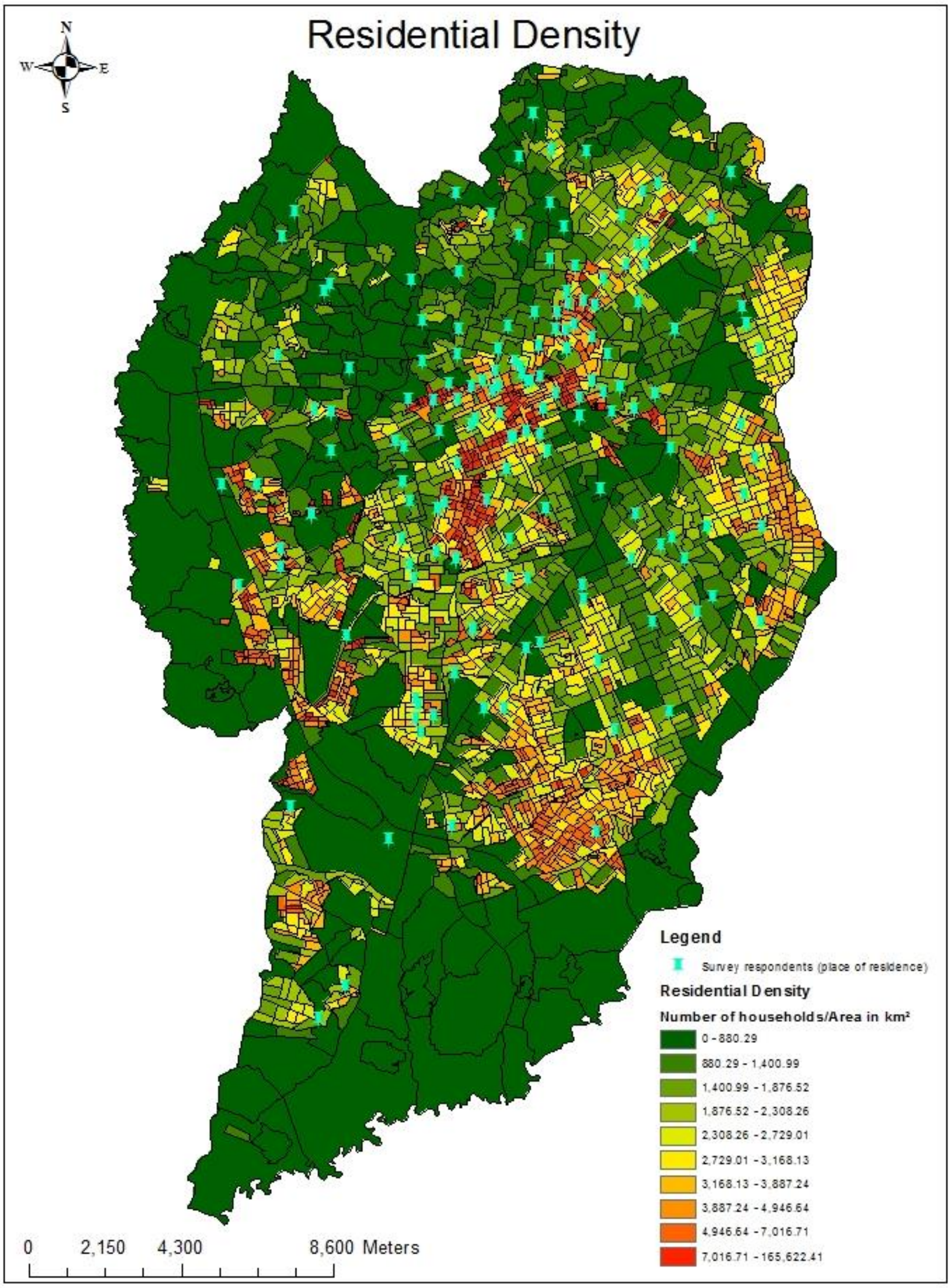

Figure 27: Residential Density map

4.2.2 Mixed Land-use

The map bellow (Figure 28) presents the mixed land-use rate of each area of Curitiba. The areas with the higher rates, which means a higher number of different activities (residential, commercial, industrial, etc.) performed in the same region were assigned with a higher score. Areas with lower scores represent regions that are more homogeneous. The map division consists of the different land-use zones of the city. The place of residence of the survey participants are located on the map.

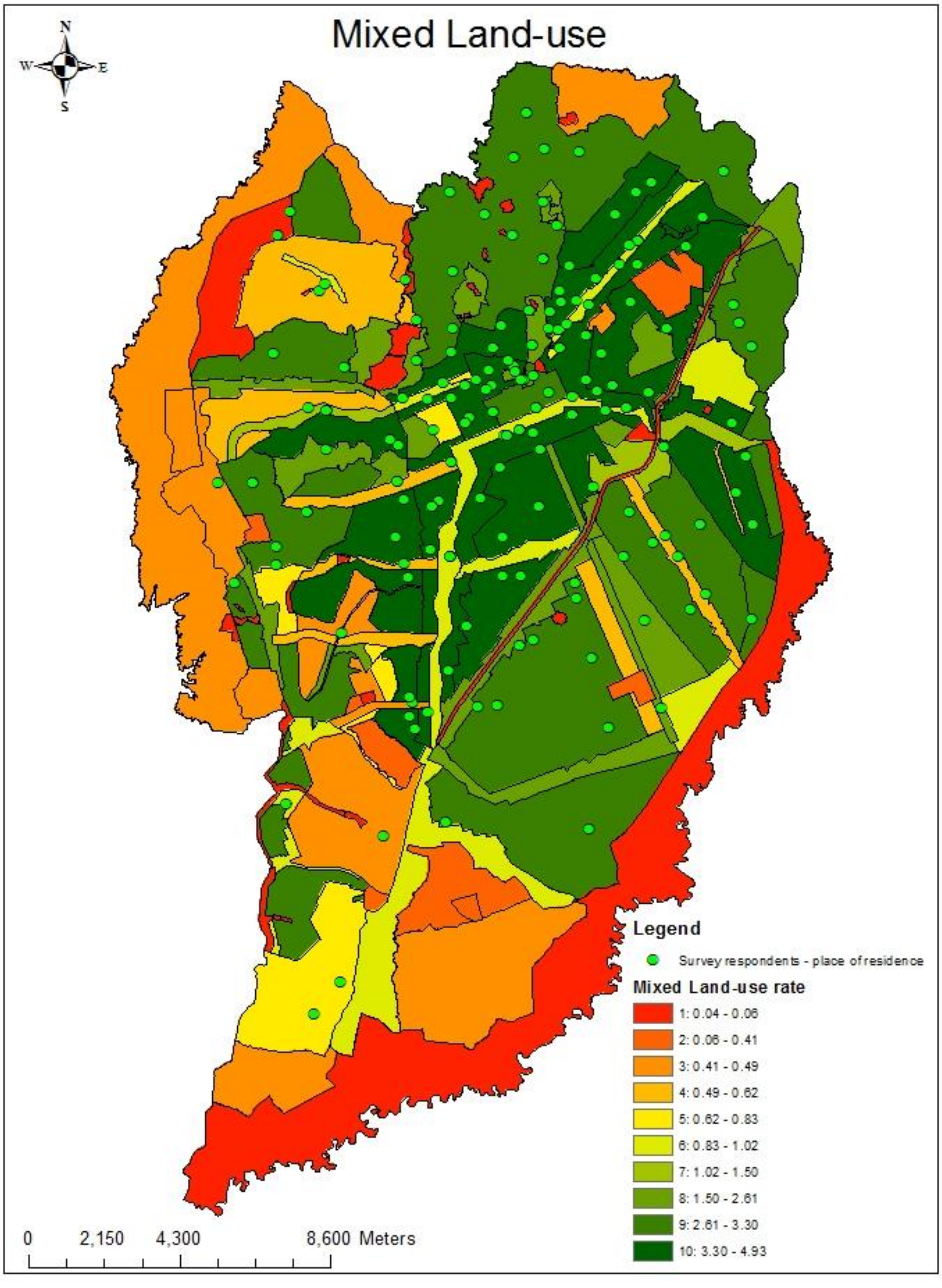

Figure 28: Mixed Land-use map

4.2.3 Topography

The topography map (Figure 29) was calculated based on the contour lines with the elevation of the different points of the city. The areas in red are those with a higher slope, therefore, less propitious to use the bicycle for transportation. For this reason, hilly areas were assigned a lower score, while flatter areas were assigned a higher score. Survey respondents are also placed on the map.

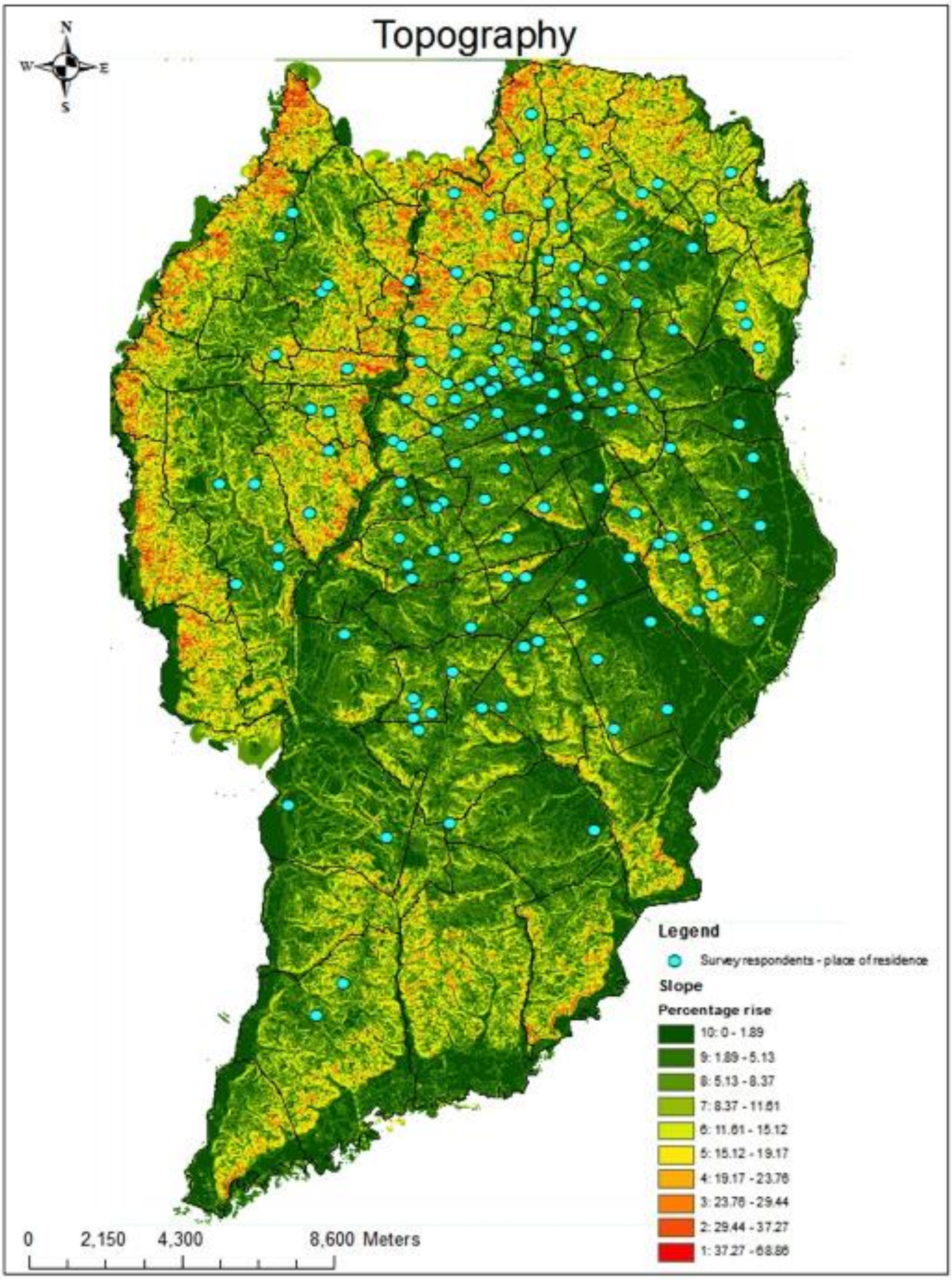

Figure 29: Topography map

4.2.4 *Safety*

The safety map (Figure 30) was generated based on the location of the accidents involving cyclists between 2013 and 2015 in Curitiba. Apart from the location, the severity level of the accident was considered. The areas in red represent a high number and/or more severe accidents occurred. Therefore, those areas were assigned a low score. The areas with any or a few accidents with a lower severity level were assigned with a higher score.

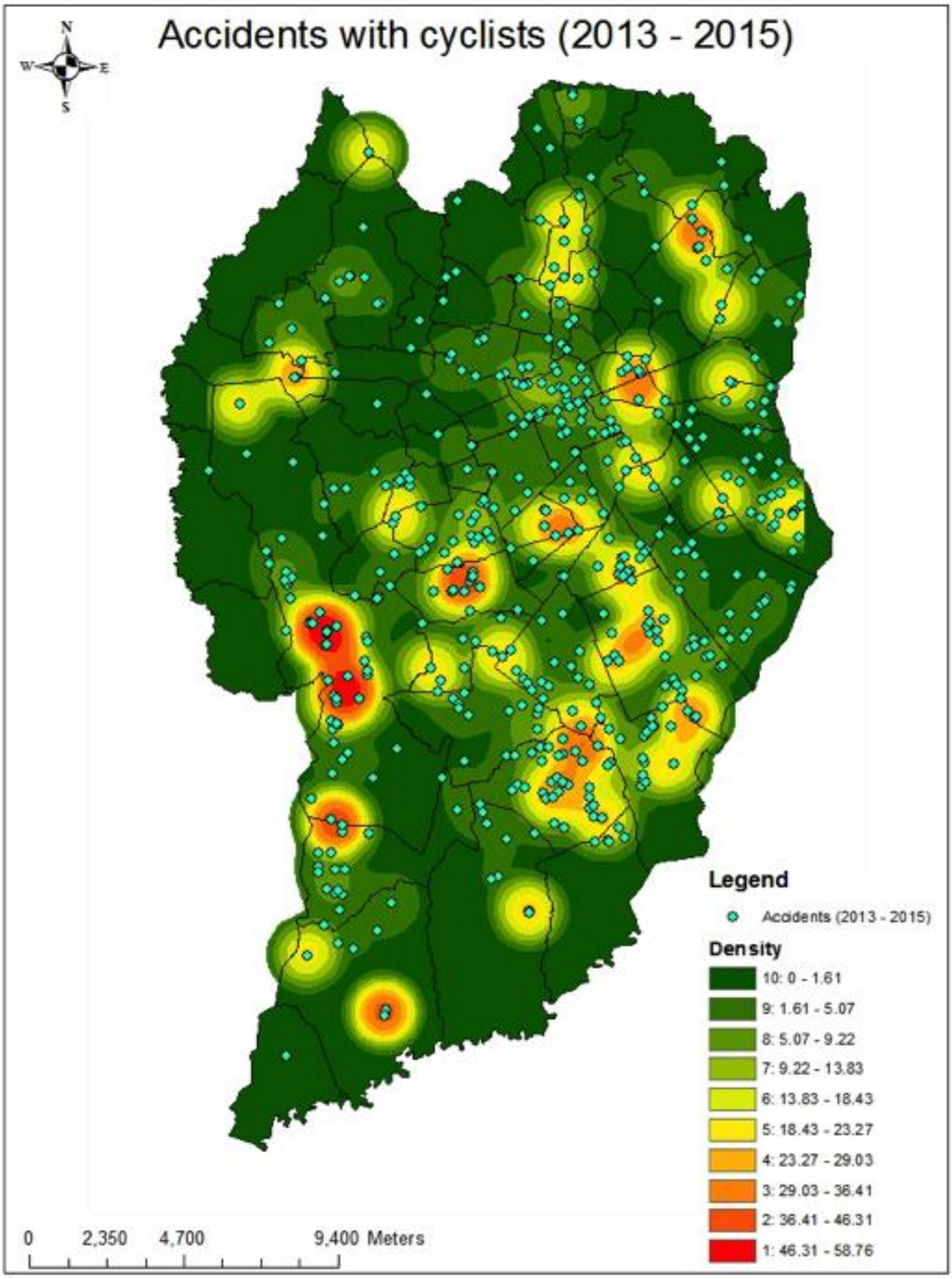

Figure 30: Accidents involving cyclists (2013 - 2015)

4.2.5 Types of Infrastructure

As described in the section 3.3.2.5, the infrastructure raster map was generated by doing different buffer sizes on the cycling infrastructures and general roads/bus lanes. The maps presented in the following sub-sections shows the location of each one after the application of the buffer tool and the computation of the individual scores. The first version of the Types of Infrastructure map was done considering the evaluation of the whole sample. Afterwards, supported by the findings of the *independent sample t-test* described in the section 4.1.2.1, two more versions were made: one based on the cyclists' evaluation and other based on the non-cyclists' evaluation.

4.2.5.1 General Sample

Figure 31 shows the types of infrastructure raster map with the ranking criteria performed considering the responses of the entire sample. Table 7 presents the scores of each type of infrastructure calculated as described in the section 3.3.2.5.

Table 7: Types of infrastructure ranking - General sample

Types of cycling infrastructure	Score based on the entire sample Mean
Bicycle Path	9
Bicycle Lane	9
Calm Lane	8
Shared Sidewalk	7
Bicycle Route	7
General Roads	5
Exclusive Bus Lanes	5

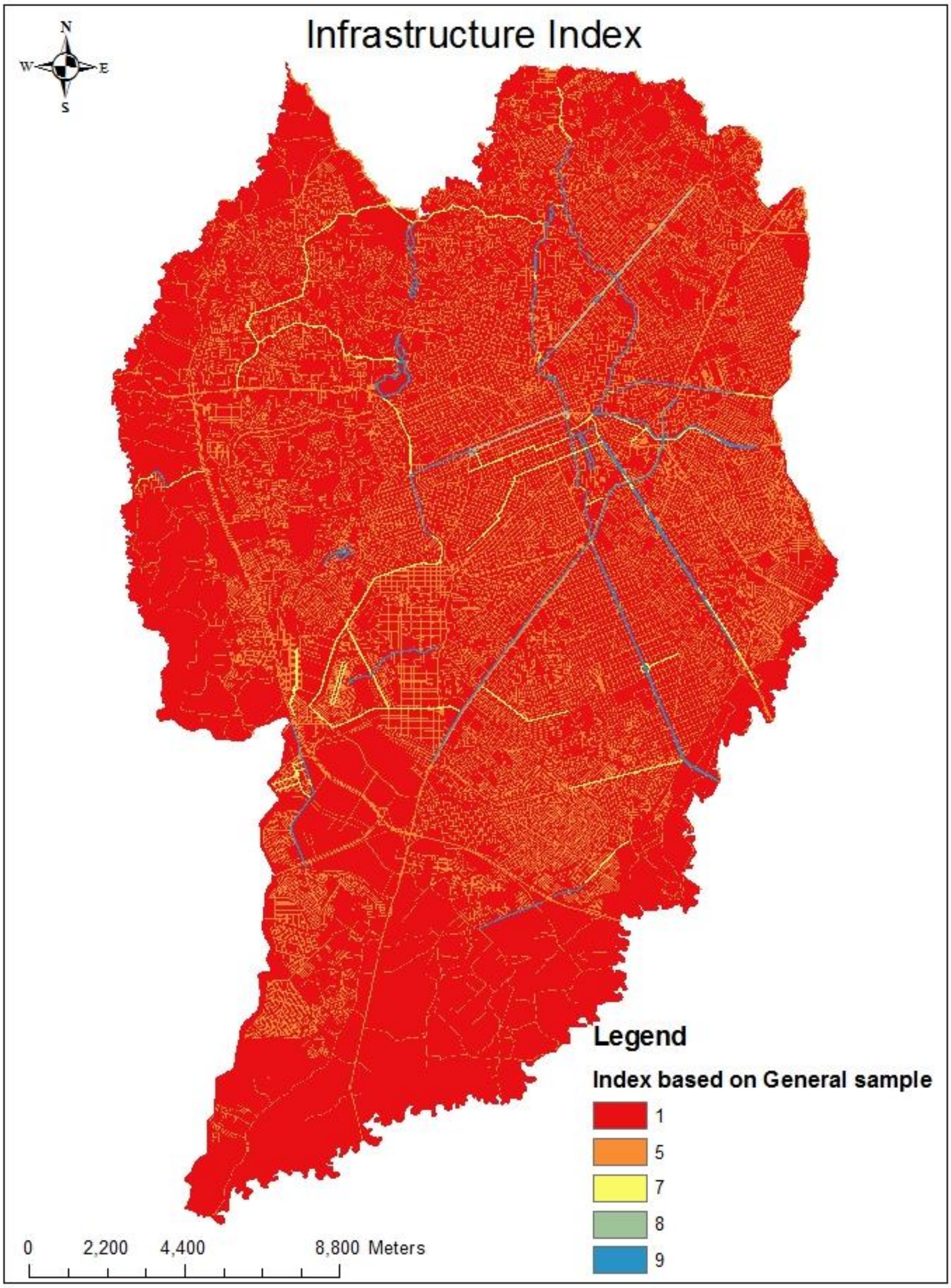

Figure 31: Types of infrastructure - Ranking based on the entire sample

4.2.5.2 Cyclists

The Cycling Infrastructure map showed in Figure 32 was done based on the cyclists' evaluation measured through the Questionnaire and described in the section 3.3.2.5. The scores are presented in Table 8.

Table 8: Cycling infrastructure ranking - Cyclists

Types of cycling infrastructure	Score based on the cyclists' Mean
Bicycle Path	9
Bicycle Lane	10
Calm Lane	9
Shared Sidewalk	7
Bicycle Route	8
General Roads	7
Exclusive Bus Lanes	7

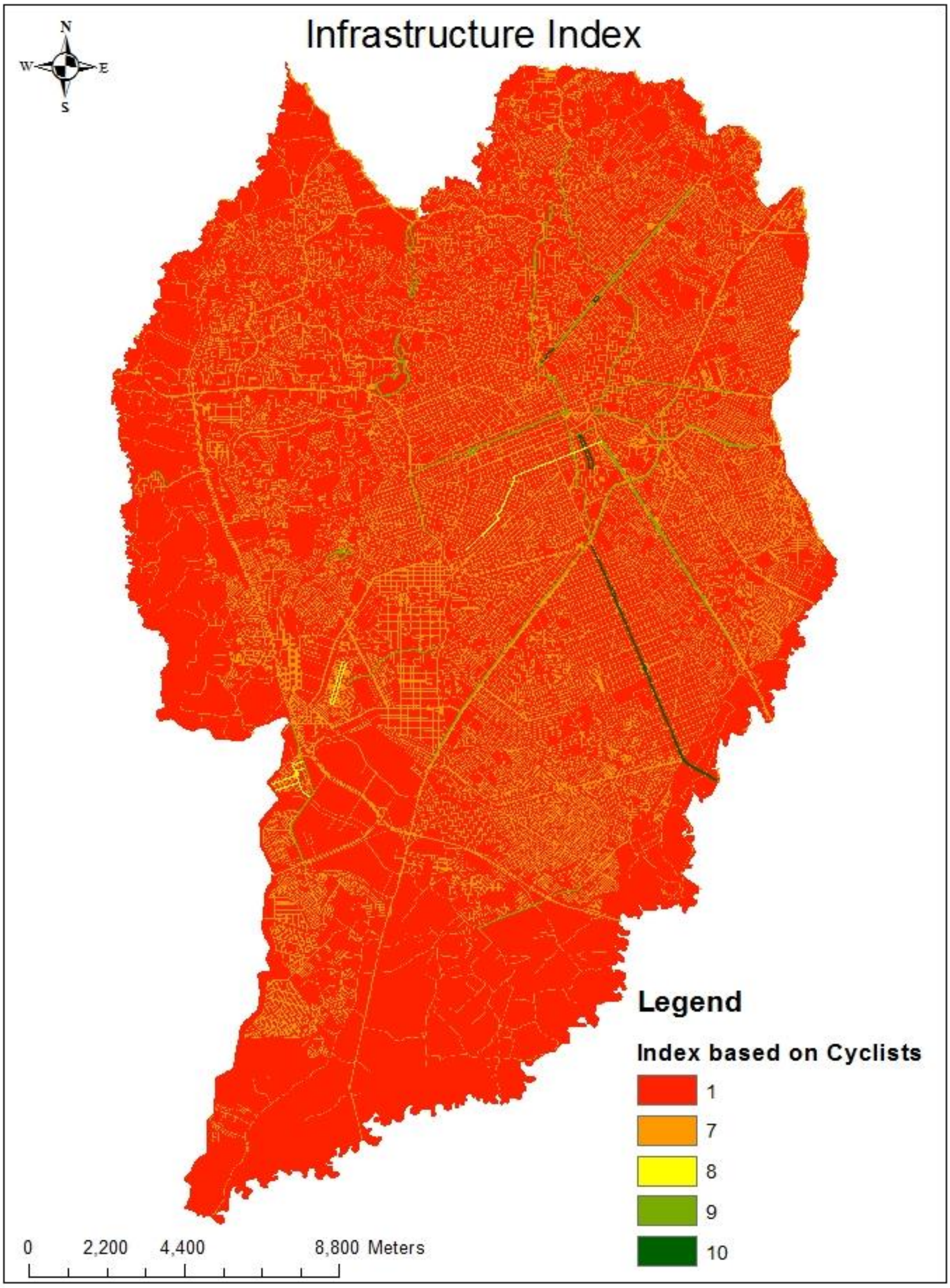

Figure 32: Types of cycling infrastructure - Ranking based on the cyclists' evaluation.

4.2.5.3 Non-Cyclists

The Non-cyclists' version of the infrastructure map was generated based on the responses of the Questionnaire. The scores are presented in Table 9 and the map in Figure 33.

Table 9: Cycling infrastructure ranking - Non-cyclists

Types of cycling infrastructure	Score based on the cyclists' Mean
Bicycle Path	9
Bicycle Lane	8
Calm Lane	7
Shared Sidewalk	7
Bicycle Route	6
General Roads	4
Exclusive Bus Lanes	4

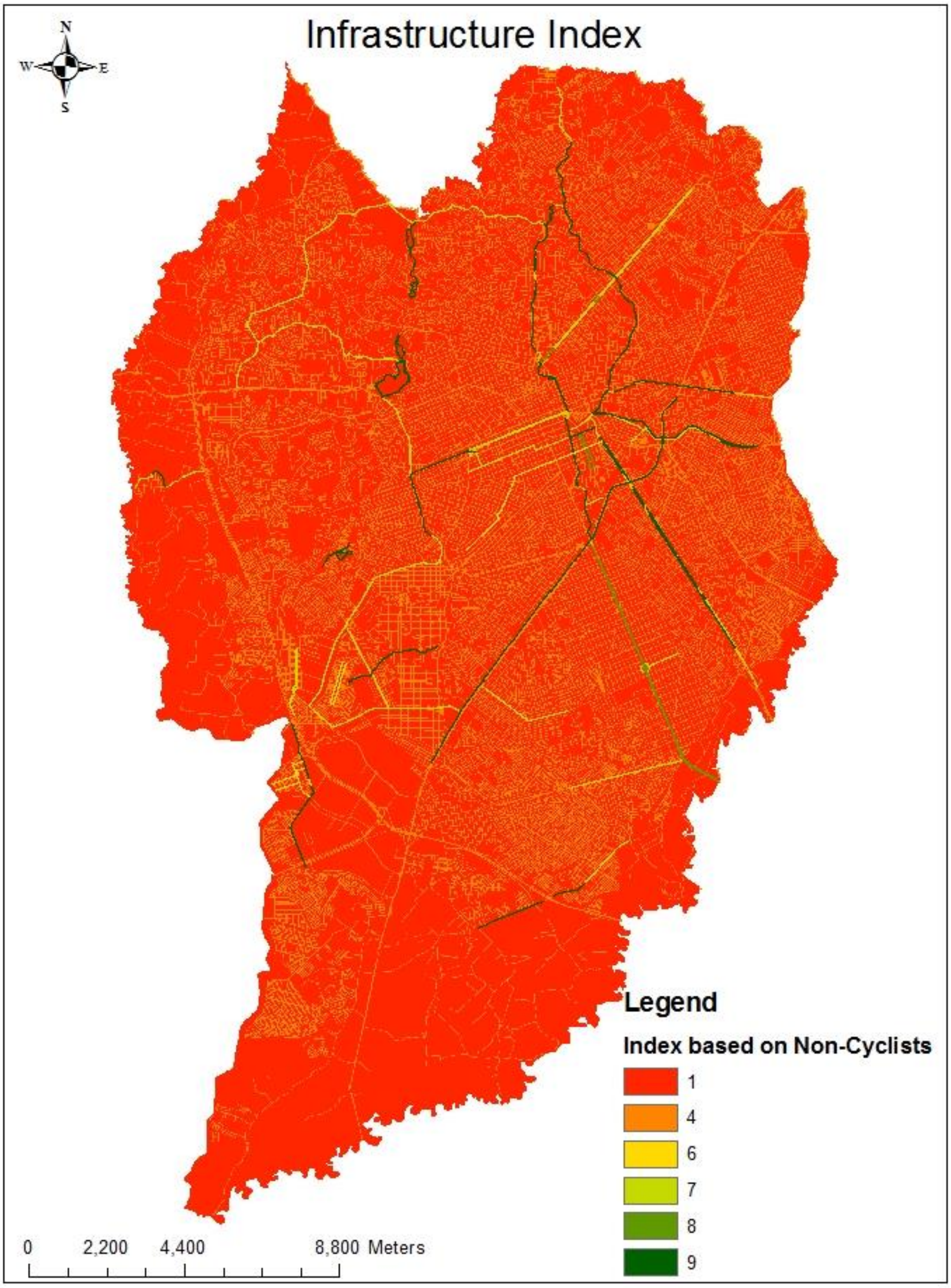

Figure 33: Types of cycling infrastructure - Ranking based on non-cyclists' evaluation.

4.2.6 Bikeability Index

The final bikeability index of Curitiba was calculated based on the variables presented in the previous sections (Residential Density, Mixed Land-use, Topography, Safety and Cycling Infrastructure). For each variable, a raster map was created with a 10 x 10 meters' grid. The final bikeability map was generated by combining each map using the "Weighted Overlay" tool from ArcMap (ESRI). Firstly, the weights were equally distributed among the variables and the results are showed in the next sub-section. Secondly, different weights were assigned to the variables, according to the Factor Analysis and presented in the section 4.1.2.2. The maps generated by sample group will also be exhibited in the following sub-sections. The table below (Table 10) shows the computation of the Bikeability Index for each variable.

Table 10: Computation of the Bikeability Index

Bikeability score	Bikeability Index variables				
	Residential Density	Mixed Land-use	Topography	Safety	Cycling Infrastructure (e.g. General sample)
1	0 – 649.5	0.04 – 0.06	37.27 – 68.86	46.31 – 58.76	No cycling infrastructure
2	649.5 – 2,598.0	0.06 – 0.41	24.44 - 37.27	36.41 – 46.31	-
3	2,598.0 – 5,196.0	0.41 – 0.49	23.76 – 29.44	29.03 – 36.41	-
4	5,196.0 – 9,742.5	0.49 – 0.62	19.17 – 23.76	23.27 – 29.03	-
5	9,742.5 – 15,588.0	0.62 – 0.83	15.12 – 19.17	18.43 – 23.27	General Roads/Exclusive Bus Lanes
6	15,588.0 – 21,433.0	0.83 – 1.02	11.61 – 15.12	13.83 – 18.43	-
7	21,433.5 – 30,526.5	1.02 – 1.50	8.37 – 11.61	9.22 – 13.83	Shared Sidewalk / Bicycle Route
8	30,526.5 – 50,011.5	1.50 – 2.61	5.13 – 8.13	5.07 – 9.22	Calm Lane
9	50,011.5 – 75,991.5	2.61 – 3.30	1.89 – 5.13	1.61 – 5.07	Bicycle Path / Bicycle Lane
10	75,991.5 – 165,622.4	3.30 – 4.93	0 – 1.89	0 – 1.61	-

4.2.6.1 Equal weight distribution

The first version of the bikeability map was generated by equally distributing the weight among the variables. In this version, to produce the cycling infrastructure map, the evaluation of the cycling infrastructure performed by the entire sample was used. Table 11 shows the weight distribution and Figure 34, the bikeability map.

Table 11: Weight distribution – Variables equally weighted

Bikeability Index variables	Weight distribution
Residential Density	20%
Mixed Land-use	20%
Topography	20%
Safety	20%
Types of Infrastructure	20%

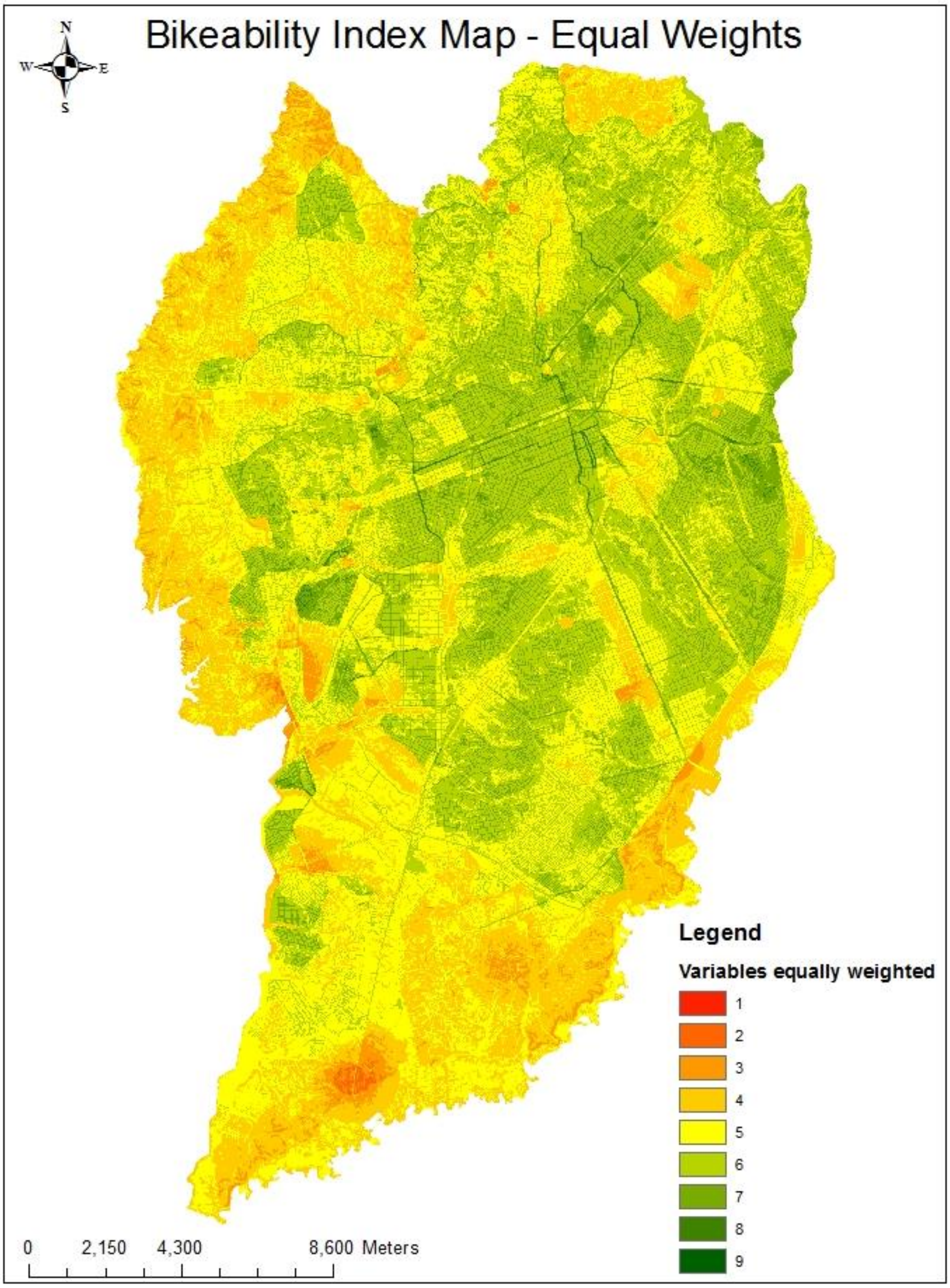

Figure 34: Bikeability Index - variables equally weighted

4.2.6.2 Weighted based on General sample

The Bikeability Map with different weights between the variables was done by taking into consideration the evidence encountered in the Literature Review and in the Questionnaire conducted in this research. Previous researchers showed that the presence of dedicated infrastructure, the type of infrastructure and safety issues are more determinant for the use of bicycle and can influence more people to cycle. In this case, Factor Analysis was used to measure how respondents evaluated the aspects presented in the survey and to distribute the weight among the variables, as demonstrated in the section 4.1.2.2. Principal Component Analysis showed a 62.76% of variance, with the higher ones achieved in the factors related to cycling infrastructure and safety. The distribution of the variance between the BI variables can be seen in Figure 24 (Section 4.1.2.2). To perform the weight distribution in the ArcMap (ESRI), it was necessary a normalisation of this percentage to a 1-100% scale. The normalisation was done dividing the individual variances by the total variance (62.76%). Table 12 demonstrates the variance calculated in the Factor Analysis and the weight distribution. The Bikeability Map can be seen in Figure 35. In addition, Figure 36 presents the average index per neighbourhood of the city.

Table 12: Weight distribution based on the entire sample

Bikeability Index variables	Variance	Weight distribution
Residential Density	4.55%	7%
Mixed Land-use	7.74%	12%
Topography	6%	10%
Safety	20.71%	33%
Types of Infrastructure	23.76%	38%
Total	62.76%	100%

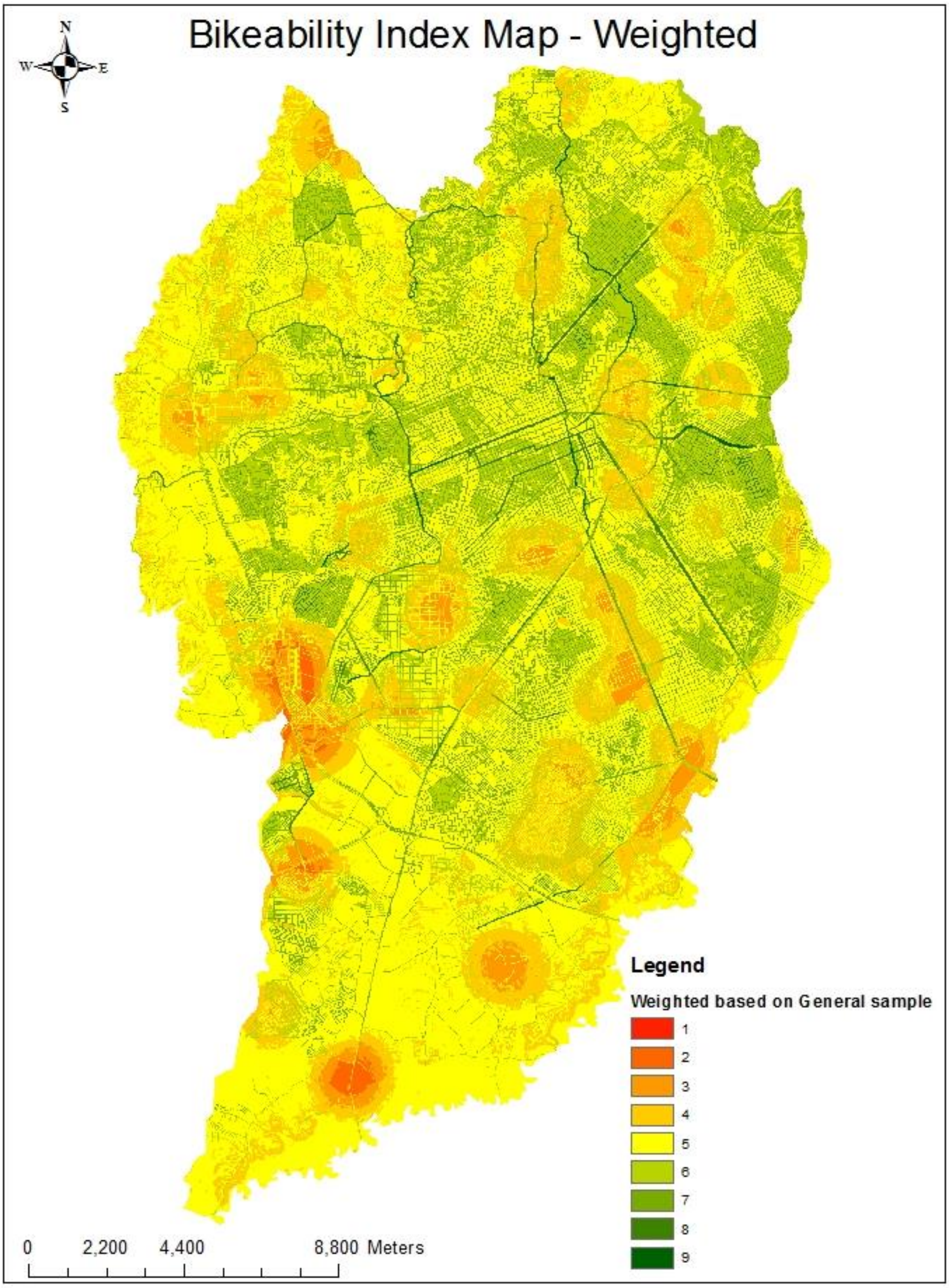

Figure 35: Bikeability Index - weighted based on the entire sample

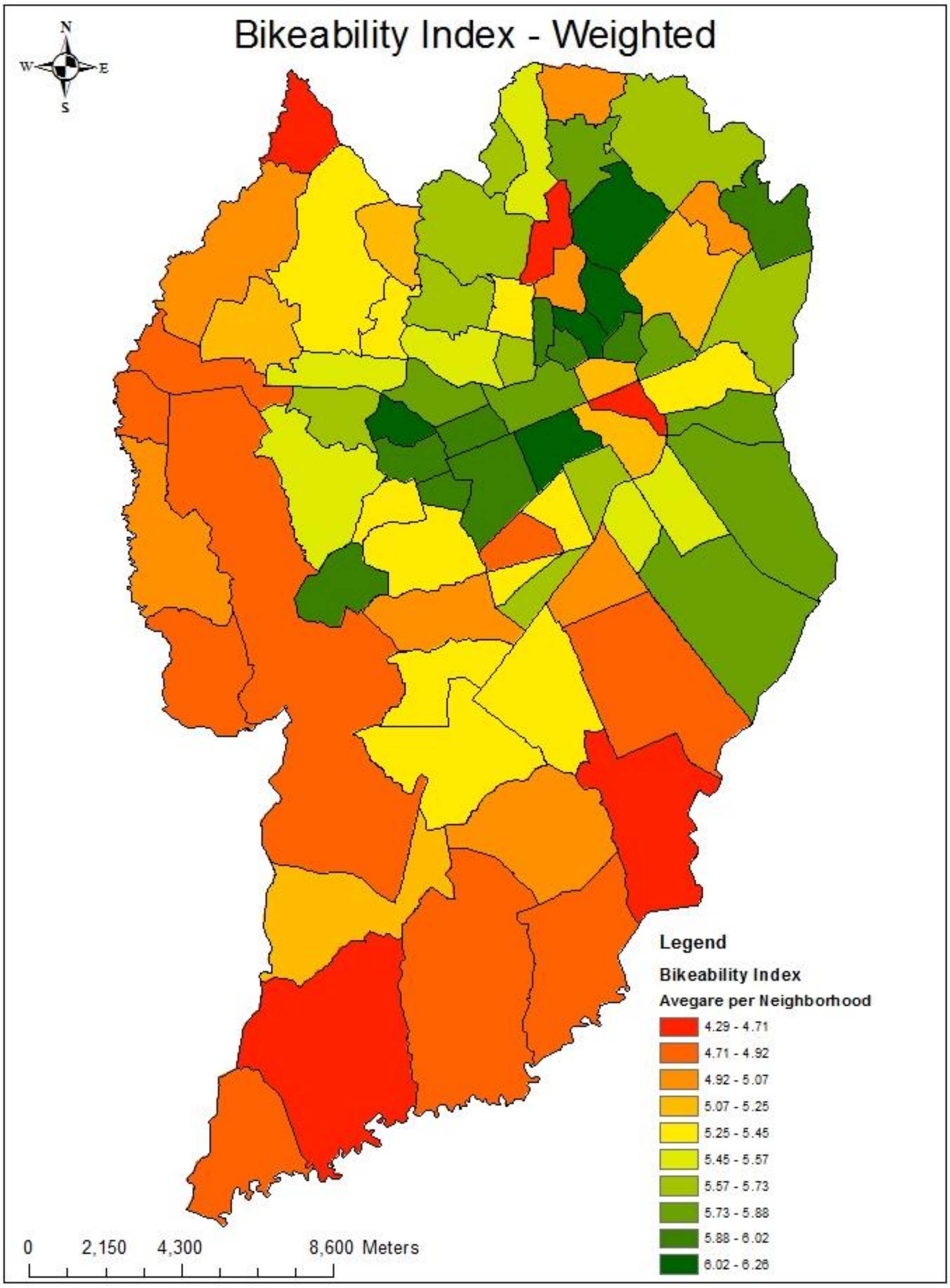

Figure 36: Bikeability Index - weighted based on general sample (Average per neighbourhood)

4.2.6.3 Weighted based on Cyclists group

This version was generated by performing the Factor Analysis in the cyclists' responses from the Survey. The same procedure from the section above was used and the individual weights of the BI variables were achieved after a normalisation of the variances, dividing the individual variance by the total variance, to compute a 1-100% scale, compatible with ArcMap (ESRI). Table 13 demonstrates the variances of each factor calculated in the Factor Analysis (represented in Figure 25 Section 4.1.2.2) and the final weight of the BI variables. In Figure 37, the bikeability map produced based on cyclists' evaluations can be seen. Figure 38 presents the average index per neighbourhood of the city.

Table 13: Weight distribution based on cyclists group

Bikeability Index variables	Variance	Weight distribution
Residential Density	4.4%	7%
Mixed Land-use	6.45%	10%
Topography	6.54%	10%
Safety	21.3%	32%
Types of Infrastructure	28.03%	41%
Total	66.72%	100%

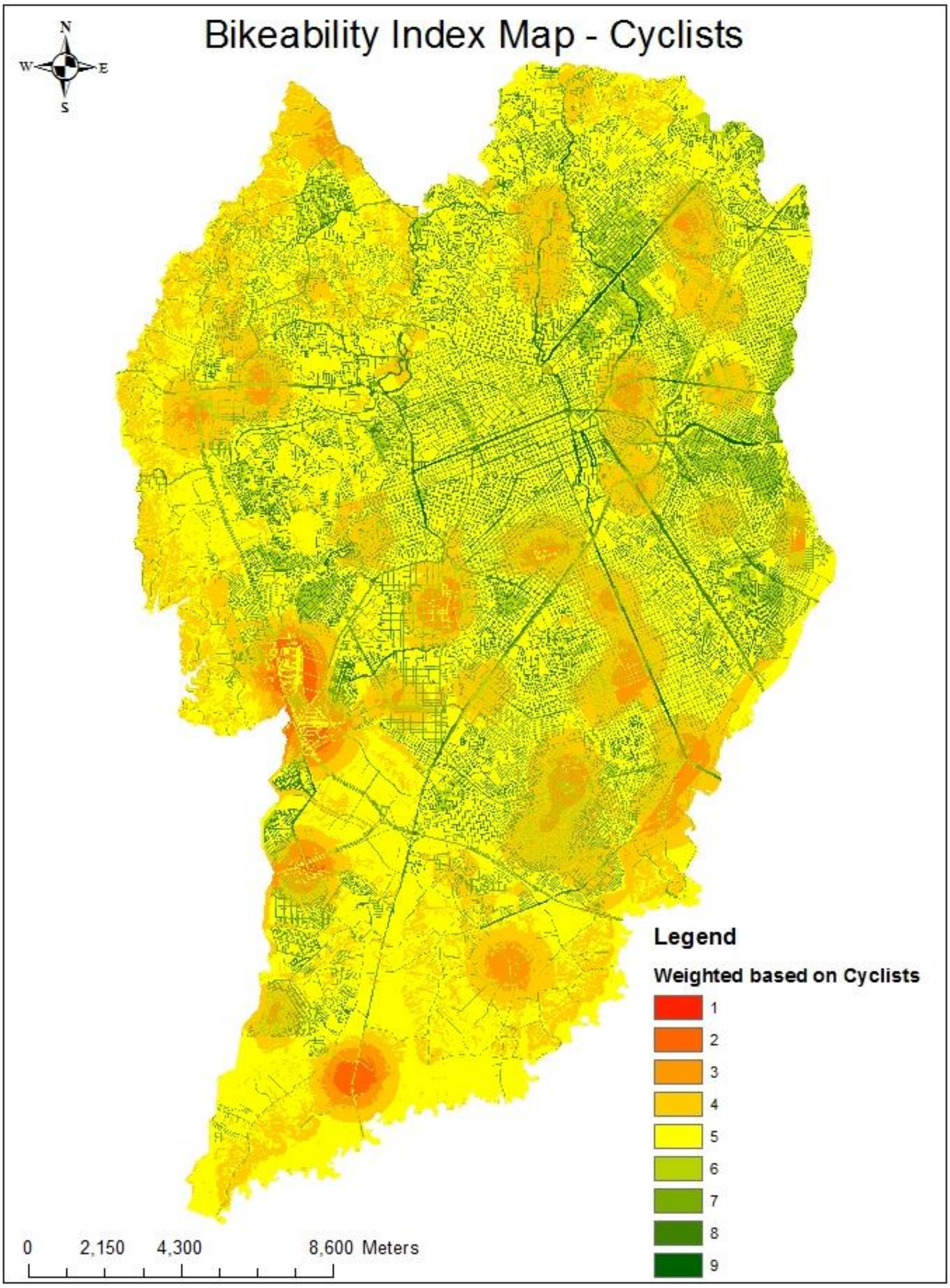

Figure 37: Bikeability Index - Weighted based on cyclists' evaluation.

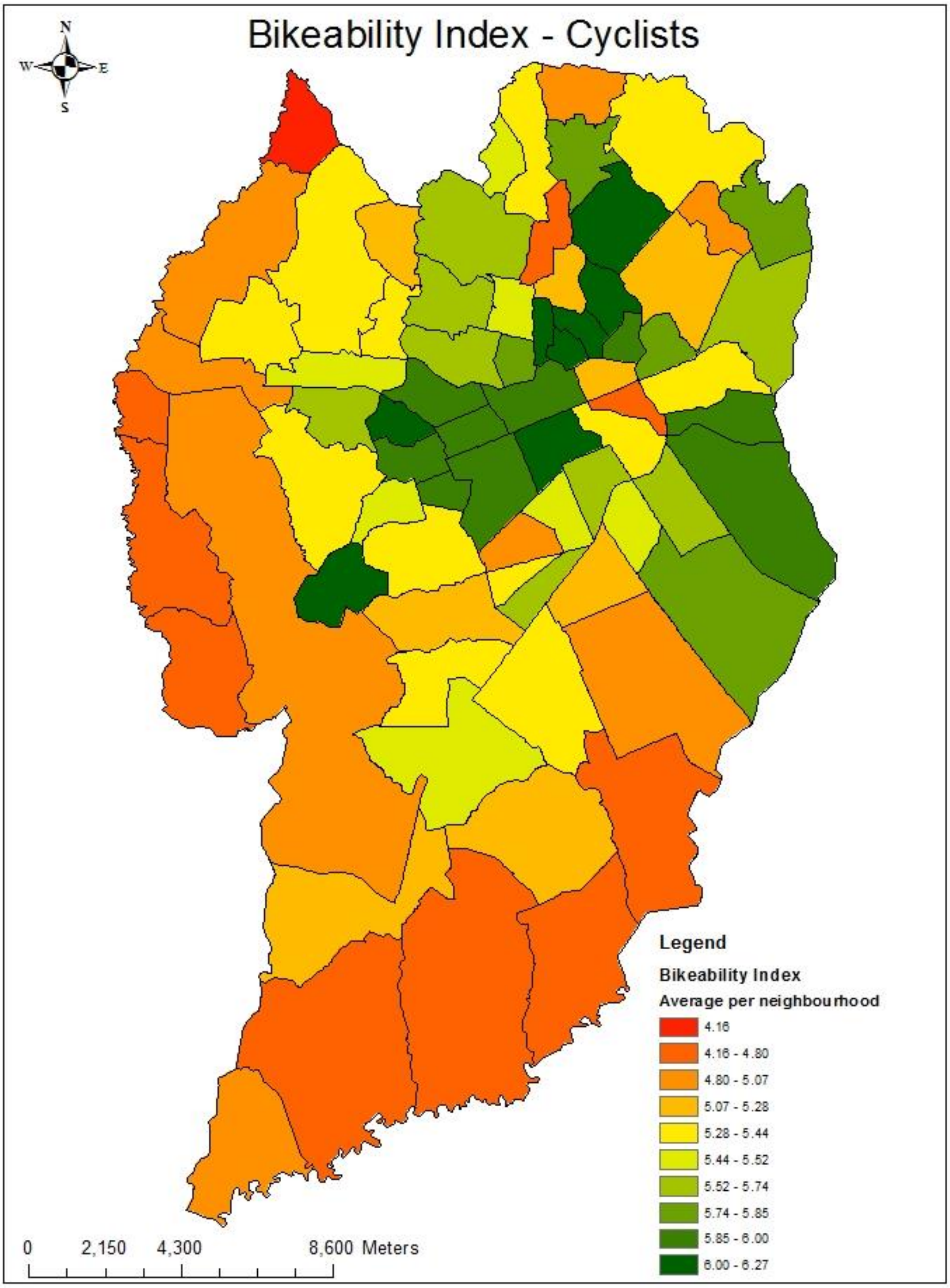

Figure 38: Bikeability Index – Weighted based on cyclists' evaluation (Average per Neighbourhood)

4.2.6.4 *Weighted based on Non-cyclists group*

This version of the bikeability map was done in the same manner as the section above, but using the Non-cyclists' responses from the Survey in the Factor Analysis. Table 14 shows both the variance achieved in the Factor Analysis (presented in Figure 26) and weight distribution after the normalisation procedure, transforming the variance in a 1-100% scale. Figure 39 exposes the bikeability index for the city of Curitiba according to non-cyclists' evaluation. Figure 40 presents the average index per neighbourhood of the city.

Table 14: Weight distribution based on non-cyclists group

Bikeability Index variables	Variances	Weight distribution
Residential Density	5.66%	9%
Mixed Land-use	4.94%	8%
Topography	11.29%	18%
Safety	20.94%	34%
Types of Infrastructure	19.59%	31%
Total	62.42%	100%

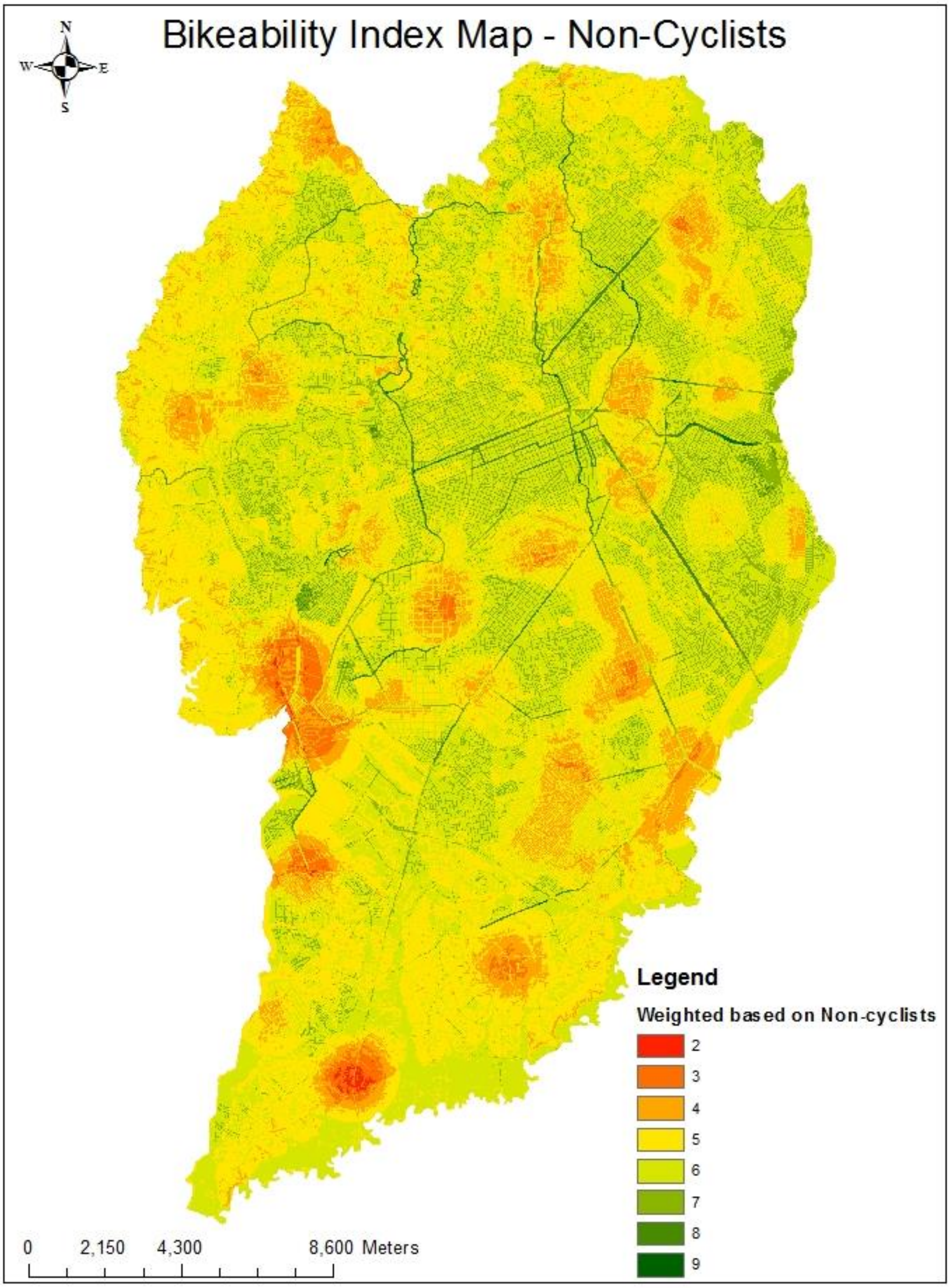

Figure 39: Bikeability Index - Weighted based on non-cyclists' evaluation.

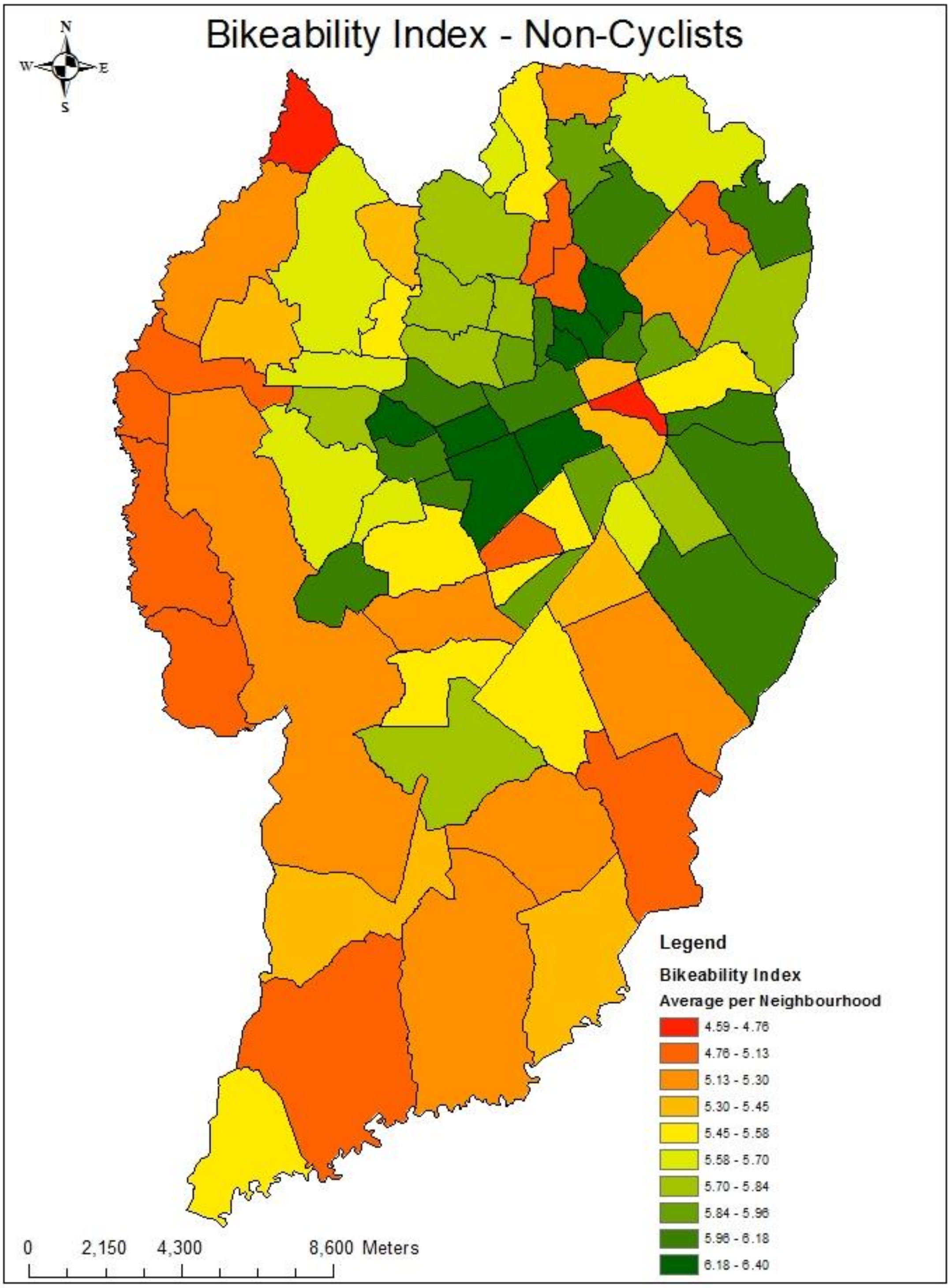

Figure 40: Bikeability Index - Weighted based on non-cyclists' evaluation (Average per Neighbourhood)

4.2.7 *Sensitivity Analysis*

This section will expose a sensitivity analysis performed to identify how different values in the Safety and Types of Infrastructure variables would affect the bikeability index in certain areas of Curitiba. Among the five variables of the index (Figure 4), those two were selected since the improvements proposed are possible to be implemented by the city's administration in a feasible time. Three scenarios will be presented in the following sub-sections.

4.2.7.1 *Scenario 1: Decrease in the number of accidents*

The first scenario was built after analysing the most critical neighbourhood in terms of traffic safety. The Industrial Neighbourhood (Cidade Industrial, in Portuguese), highlighted in Figure 41, is the area with the highest occurrence of traffic-related accidents in Curitiba, 138 in total. By focusing the accidents reduction in one area, the improvements in the bikeability index can be demonstrated in more detail. Therefore, a reduction of 50% is proposed in all three types of accidents considered in the analysis (described in the section 3.3.2.4). In the map below, after a comparison with the bikeability map from the Figure 35 (Section 4.2.6.2), it is possible to see that the bikeability in the area increased considerably.

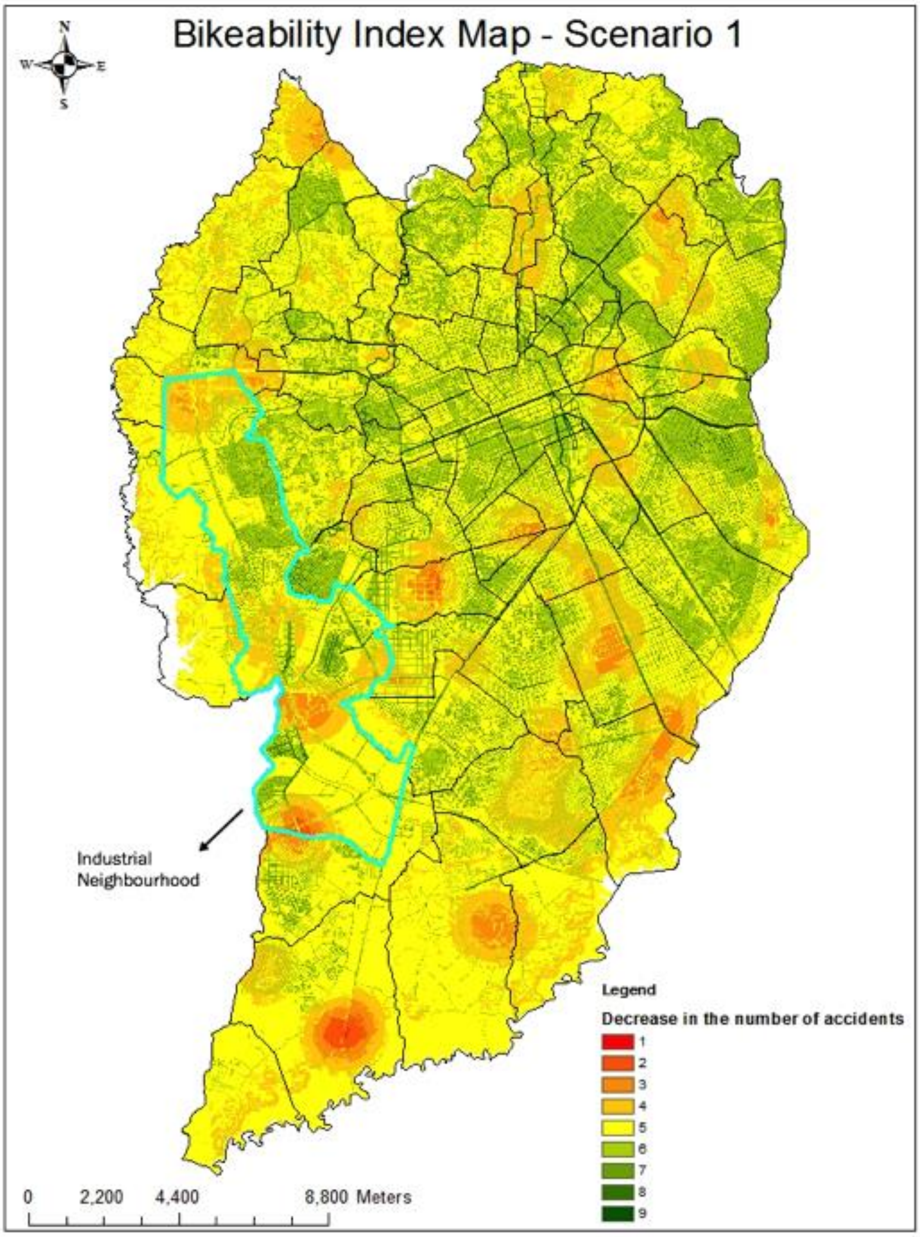

Figure 41: Scenario 1 - Accidents reduction in the Industrial Neighbourhood

4.2.7.2 Scenario 2: Increasing the Cycling Infrastructure network

The second scenario was built by increasing the dedicated cycling infrastructure network of the city in different locations, mainly in the highlighted areas from the Figure 42. Those locations had the lowest bikeability index of the city, exposed in the Figure 35 (Section 4.2.6.2). In total, 114 km of dedicated cycling infrastructure is proposed in those areas, which increased the bikeability of the regions. The type of infrastructure suggested for this scenario can be either Bicycle Path or Bicycle lane, the two better evaluated infrastructures according to the participants of the survey (Section 4.1.1.3).

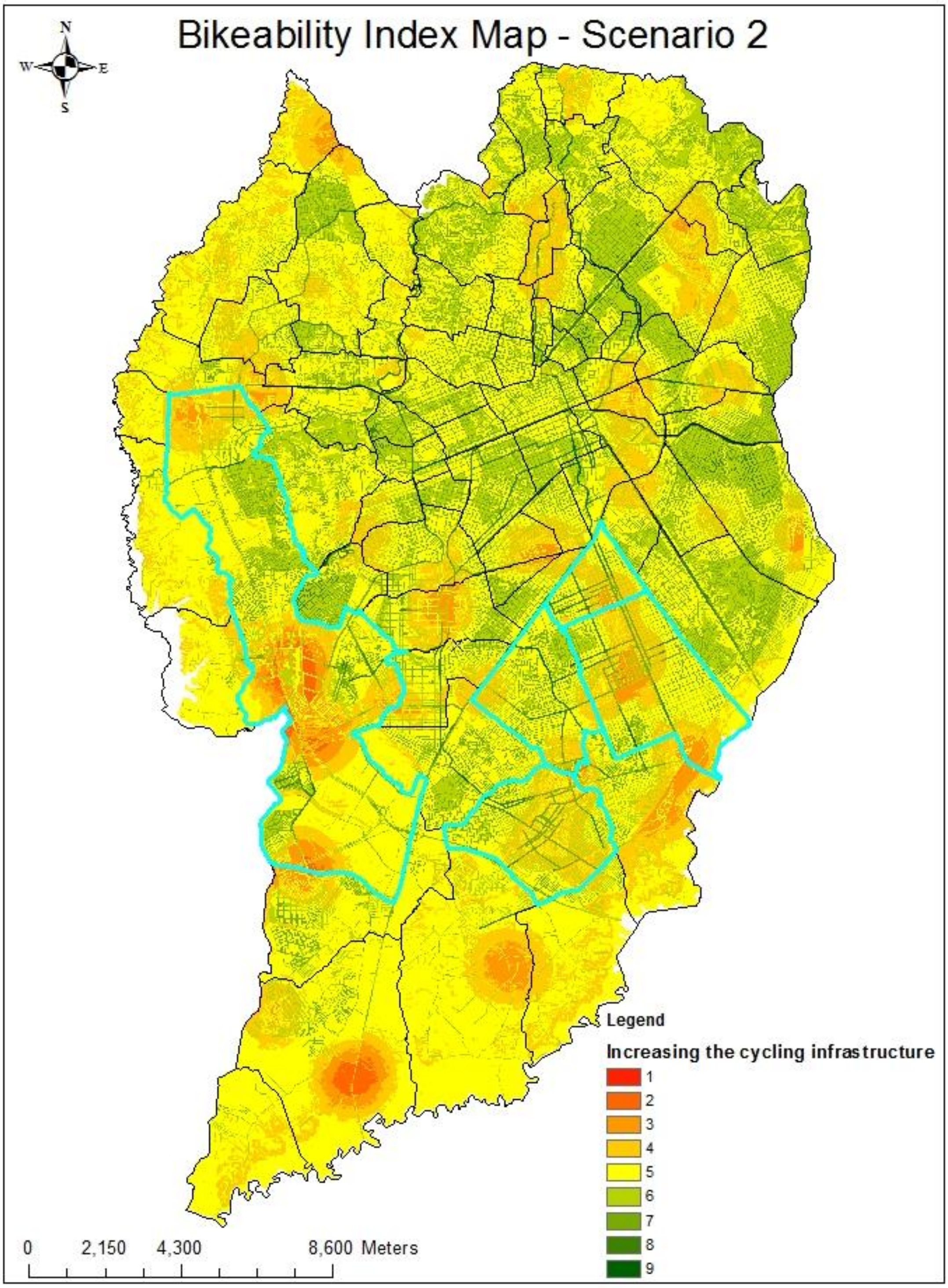

Figure 42: Scenario 2 - Increasing cycling infrastructure network

4.2.7.3 Scenario 3: Combination of Scenarios 1 and 2

The third and last scenario was built after combining the results from the first and second scenarios. Together with a reduction in the number of accidents, the implementation of dedicated cycling infrastructure increased considerably the bikeability index of the areas highlighted in the figure below. Although increasing the bicycle infrastructure itself might lead to a reduction in the number of accidents, another set of interventions are also required in order to accomplish a significant reduction of the accidents. Those interventions include improvements in vertical and horizontal road signs, better conditions for crossings, implementing speed limit in certain areas, etc.

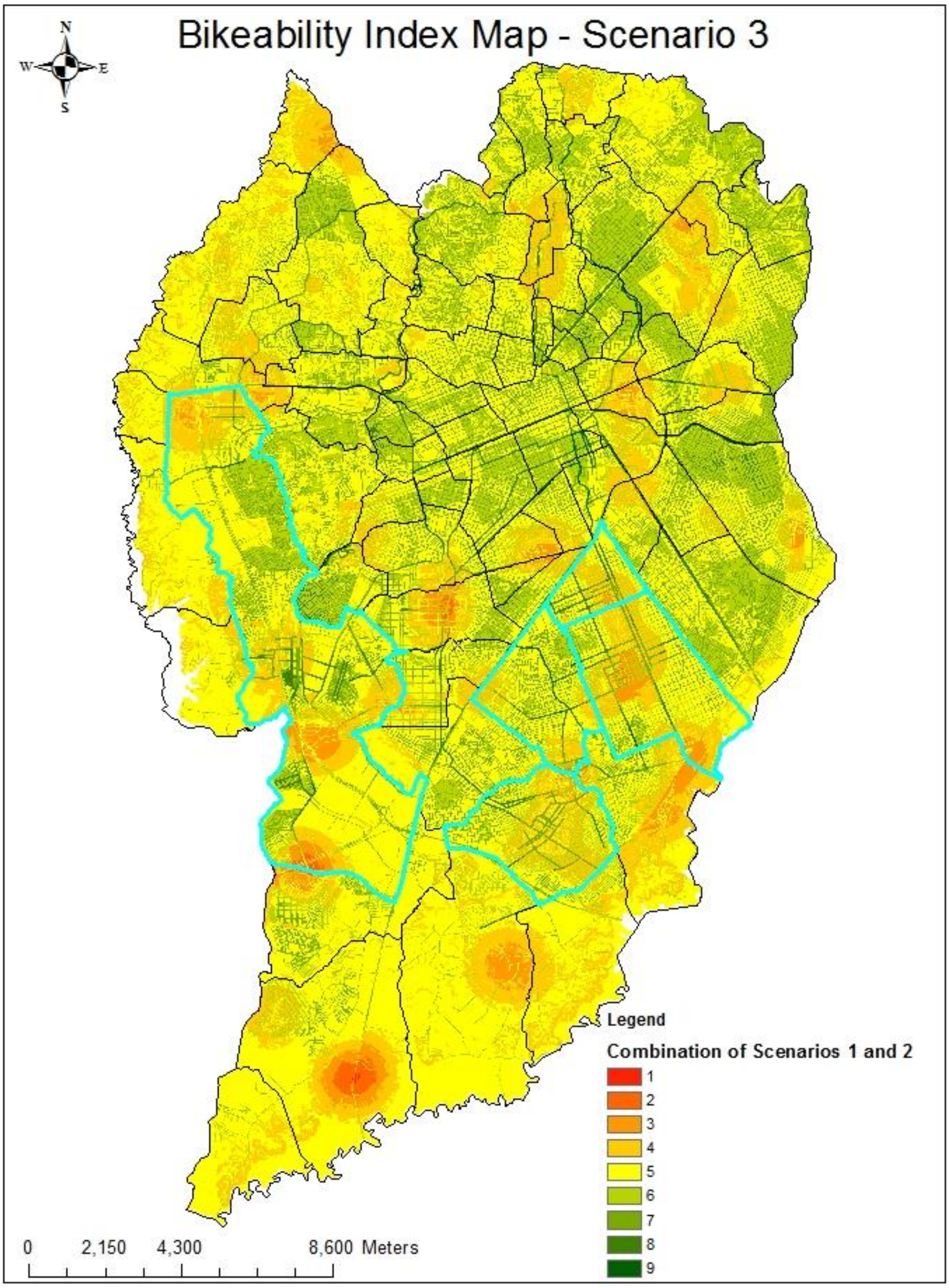

Figure 43: Combination of Scenarios 1 and 2

4.2.8 *Supplementary Analysis*

This section will explore the information obtained in the spatial data collected and produced for this Master Thesis, regarding the location of the cycling infrastructures and the socio-demographic characteristics of the city. Firstly, the amount of people affected by the cycling infrastructures existent in the city is presented. Secondly, the socioeconomic characteristics of this population will be analysed. Thirdly, a comparison will be made between the road density of the city and the influence area of the cycling infrastructures. The influence area was defined after applying a 200 meters' buffer to each side of the existent cycling infrastructures.

4.2.8.1 *Population affected by a Cycling Infrastructure*

This sub-section will expose the amount of people in the city that are affected by the influence area of a cycling infrastructure. Figure 44 demonstrates the different density classes by Census Track area and the area of influence of the cycling infrastructures.

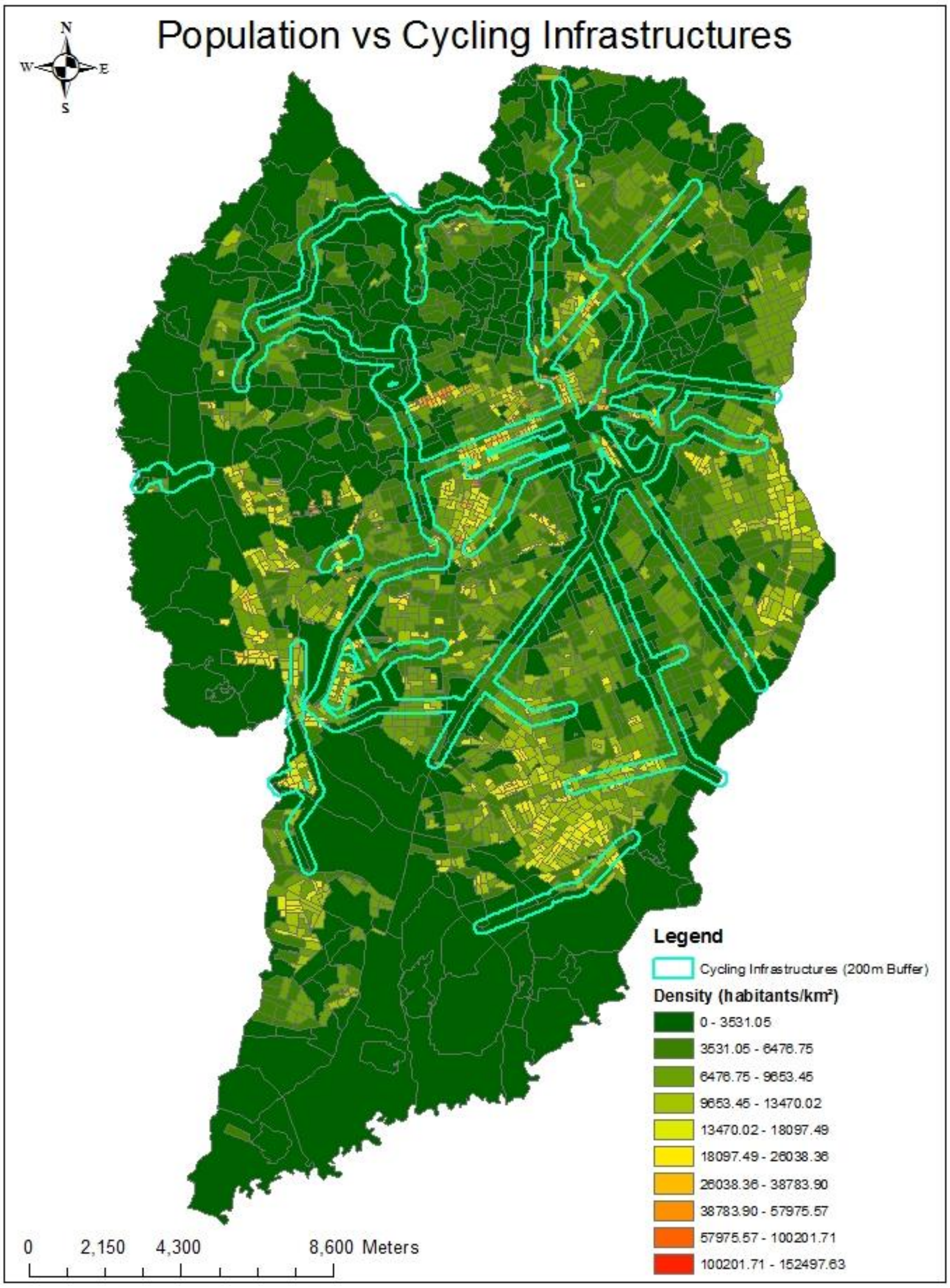

Figure 44: Population affected by Cycling Infrastructures

The table below (Table 15) shows the amount of people and households within the 200 meters' buffer, the total area of the buffer and the density (people/km^2) inside the buffer area. A comparison is made with the entire city of Curitiba.

Table 15: Population affected versus Population of Curitiba

	Within the 200m buffer	Curitiba
Population	603,659	1,751,907
Households	229,147	635,631
Area (km^2)	62.39	435,01
Density (people/km^2)	9,675.57	4,027.28

With the results presented in the table above, we noticed that 34% of the population of Curitiba is affected, that is, lives within a 200 meters' distance from a dedicated cycling infrastructure, which contemplates 36% of the households of the city. It is also demonstrated that the total area of influence of the cycling infrastructures represents 14% of the entire city's area. The population density within the area of influence is much higher than the density of the city as a whole.

Socio-Economic Characteristics

The socio-economic characteristics of the population inserted in the area of influence of the cycling infrastructures will be presented in this sub-section, and a comparison will be made with the entire population of Curitiba. In the table below (Table 16), the income details of the population within the 200 meters' buffer and the total population of the city is presented.

Table 16: Income details - comparison

	Within the 200m buffer	Curitiba
Average Income (R$/month)	2,747.57	2,258.20
Maximum Income	13,807.53	13,807.53
Standard Deviation	1,960.63	1,707.05

After performing a One Sample t-test to check whether there are significant differences between the income of the population within the 200 meters' buffer and the income of the population of Curitiba, it is possible to notice that the income of the population within the 200 meters' buffer is higher ($M=2,757.47$, $SE=67.49$), $t(844) = 7.398$, $\rho<0.001$, $r=0.25$ then the income of the city of Curitiba. Citizens affected by the 200m buffer has an income R$ 500 higher than the city's mean. Figure 45 demonstrates the income classes of the population in a Census Track level and the area of influence of the cycling infrastructures. As noticed, most of the population within a 200 meters' buffer from the cycling infrastructures are from higher income classes (Classes A, B and C).

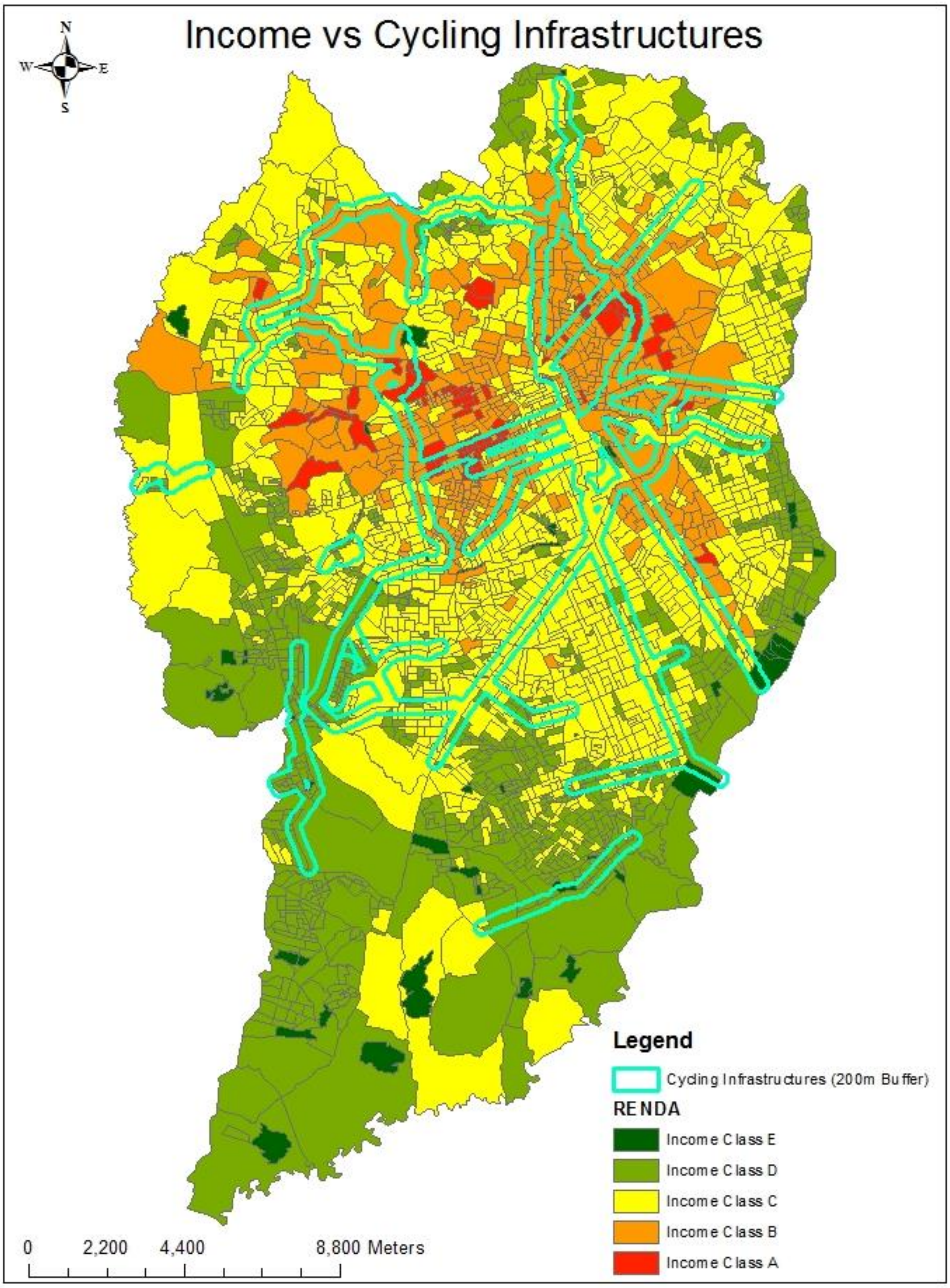

Figure 45: Income class of population affected by Cycling Infrastructures

4.2.8.2 Road Density versus Cycling Infrastructures

In order to compare the influence area of the cycling infrastructures with the road network of Curitiba, it was calculated the road density of the city, using the software ArcMap (ESRI) and demonstrated in the Figure 46. Areas in green represent a lower street density while areas in red, a higher street density. The "Zonal Histogram" tool from ArcMap was used to calculate how much of the influence area of cycling infrastructures falls into each of the ten categories of the road density map, presented in the legend of the figure below. The analysis demonstrates that 64% of the cycling infrastructures' influence area is situated in places with a lower street density (below 15.89 km/km^2). This fact is related with the previous investments in cycling infrastructure, which mainly connected parks and green areas of the city in a way to increase cycling for recreation. As presented in the Literature Review of this Master Thesis, precisely in section 2.1, aspects such as road density, road connectivity and intersection density were all positively related with higher levels of walking and cycling for transportation purposes. Therefore, increasing bicycle network in higher dense street areas can affect in a positive way the levels of utilitarian cycling in in the city.

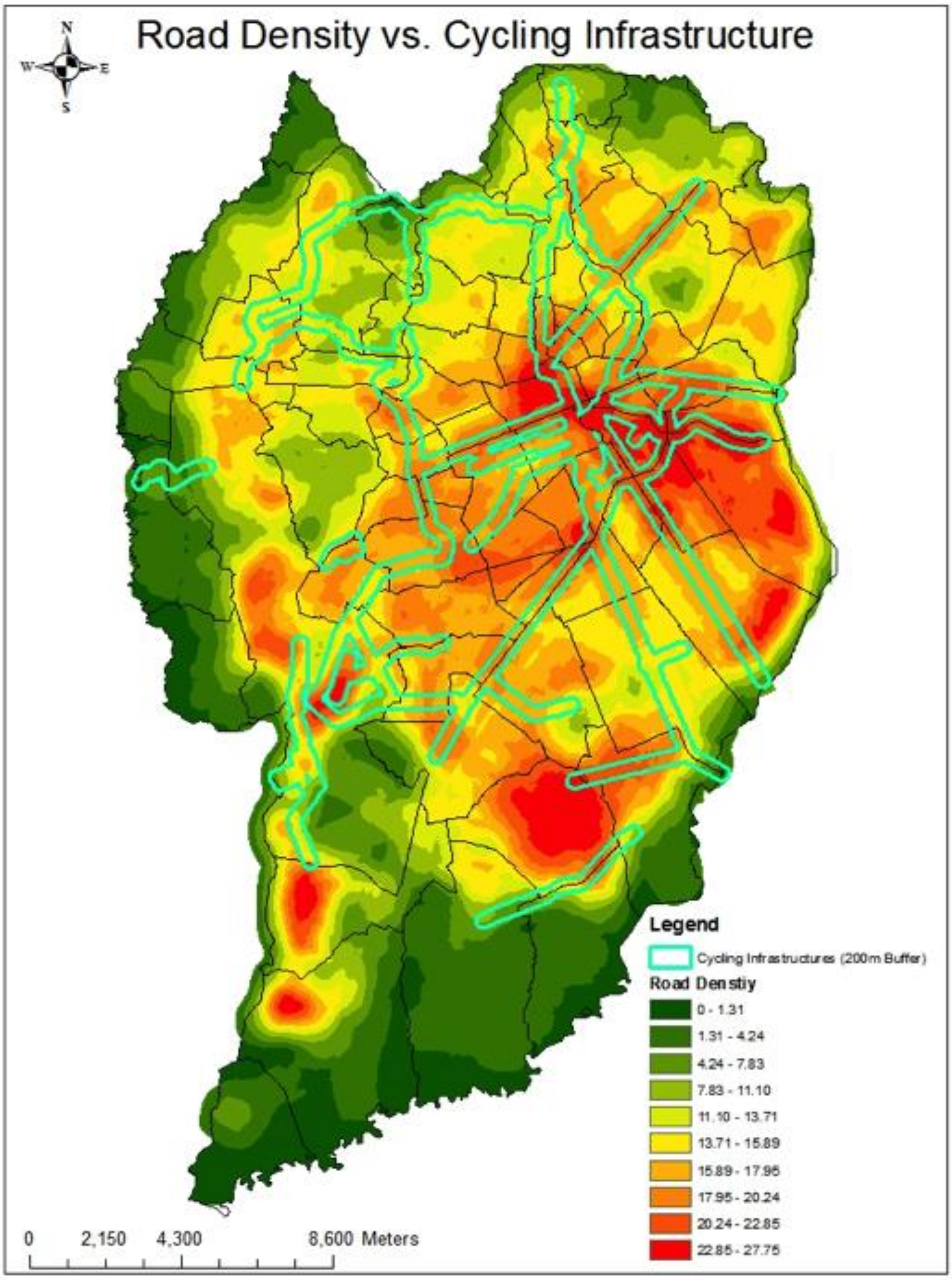

Figure 46: Road density versus Cycling Infrastructure

5 DISCUSSION

In the following sub-sections, the results presented in the Chapter 4 will be discussed one by one. Firstly, the quantitative data collected through the survey and the inferences drew about the entire sample and about the sample groups will be explored. Secondly, the different versions of the Bikeability map will be examined, as well as the applications of this tool for a possible expansion of the bicycle network in Curitiba.

5.1 Questionnaire

In this sub-section, it will be discussed the results from the statistical analysis performed in the survey answers. Firstly, the significance test analysed whether the sample group assessed differently the variables that affects bicycle use in Curitiba. Results from this analysis provided the rationale for building indexes for specific sample groups – Cyclists versus Non-cyclists. Secondly, after the analysis of the sample groups, Factor Analysis was used to gain insights about the aspects of bicycle use in Curitiba and to perform the weight distribution of the BI variables, based on the Total Variance Explained and in the factor rotation. Thirdly, Binary Logistic Regression intended to predict the citizens travel behaviour (cyclists or non-cyclist) and income level (higher income or lower income) based on aspects of the built environment of Curitiba, and on the answers of the Questionnaire.

5.1.1 Significance test

The significance test performed in this investigation was the *independent sample t-test*. The discussion will be done separately by sample group.

5.1.1.1 Cyclists versus Non-cyclists

The analysis performed in the Cyclists versus Non-cyclists' groups showed that among the possible barriers for bicycle use, Topography, Public Insecurity, Distance, Need to carry luggage or bags during the travel and Weather conditions were evaluated differently between those groups. In all cases, Non-cyclists assigned a higher importance level to those factors than Cyclists, which means that, for those who don't use bicycle for transportation, those aspects are perceived as more significant obstacles for bicycle commuting. Other investigations also pointed the presence of slopes in the route (Rietveld and Daniel (2004); Rodríguez and Joo (2004); Timperio et al. (2006); Parkin et al. (2008), as cited by Heinen (2011)), longer distances (Heinen, Maat, & Wee, 2011) and the climate conditions (Stinson and Bhat (2004), Dill and Carr (2003), Nankervis,1999; Brandenburg et al., (2004), as cited by Heinen (2011)) as obstacles for bicycle use. Although in the study of Camargo (2012), the survey participants did not assess importance levels, public insecurity and need of carrying luggage or bags during the trip were also identified as discouraging factors for bicycle use. In terms of topography and distance, the finding was comprehensible, since experienced cyclists are more used to cycle and are performing some level of physical activity, which makes them more resistant to cycle on roads with higher slope and through longer distances. In addition, people that are engaged in cycling normally do not consider the season aspects.

After comparing the respondents' means from the common facilitators/motivators for bicycle use, significant differences were found in the factors Short distances, Insufficient public transport in the neighbourhood, Integration between bicycle and public transport and Expensive car parking. Once more, non-cyclists assigned a higher importance level for all those factors than cyclists. Coherently, non-cyclists assigned greater value to short distances, reinforcing that inexperienced cyclists are more sensitive to cycling distances. This also reflects in the higher importance level assigned to integration between bicycle and public transport. Combining bicycle and transit in commuting trips is a way to mitigate the effects of long cycling distances.

When analysing the likelihood for cycling in the different types of infrastructure existent in Curitiba, significant differences were found in all the types of infrastructure except "Bicycle paths" and "Shared sidewalk". Not surprisingly, Cyclists are more likely to use the bicycle in most of the different types of infrastructure than Non-cyclists. People that commute by bicycle are more experienced cyclists and more aware of the possible risks. Another assumption can be made after examining the types of infrastructure that did not show significant differences between the groups (Bicycle path and Shared sidewalk), which means that non-cyclists are likely to cycle in those locations as much as the cyclists.

Those types of infrastructure are the only ones where cyclists are fully separated from the traffic of vehicles. This can be an indicative that inexperienced cyclists are more likely to cycle where a full separation occurs.

5.1.1.2 Higher Income versus Lower Income

When separating the groups by income level, the independent sample t-test did not show many differences between the groups. Among the possible barriers for bicycle use, only Lack of sign at crossings had significant difference between them. In this case, lower income people assigned a higher importance level. In lower income areas, the infrastructure either for vehicles, pedestrians and cyclists is quite poor, with insufficient traffic signs and little respect to traffic legislation. For this reason, lower income people tend to perceive the lack of signs at crossings differently than higher income people.

Accessibility and cycling infrastructure was the only among facilitators/motivators for bicycle use with different evaluation, but, with higher income people giving more importance to this factor. This can be explained by analysing the characteristics of the survey respondents. Many participants live in the central area of the city, are from a higher income class and have more access to a dedicated cycling infrastructure, as demonstrated in the section 4.2.7. In general, lower income people has poor accessibility to dedicated infrastructure and benefit less from it, which makes them less capable of assessing this factor as a facilitator/motivator for bicycle use.

5.1.2 Factor Analysis

In this sub-section, it will be discussed the results of the Factor Analysis performed to distribute the weight among the BI variables, based on the proportion of variance explained and in the factor rotation. Factor Analysis was done firstly with all the barriers and facilitators/motivators for bicycle use presented in the Questionnaire. Secondly, another analysis was done with the factors that are related to the BI variables to perform the weight distribution. The analysis used the whole sample size and separated the participants by transport behaviour (Cyclists vs. Non-cyclists).

5.1.2.1 Exploratory Factor Analysis

As noticed in Figure 22 (Section 4.1.1.2), the barriers and facilitators/motivators for bicycle use were gathered into seven different factors. Are they: Attitudes, Safety, Cost-beneficial factors, Built environment, Local aspects, Actions of the city's administration, and Density. The Attitudes factor includes aspects that are dependent on the cyclists' engagement towards active commuting. Safety and Built environment factors gathered aspects that are similar and represents concerns regarding traffic safety and dedicated cycling infrastructure, as well as the built environment characteristics of the city. Cost-beneficial factors include aspects that the use of bicycle for commuting would have an impact on the car users' expenditures since fewer resources would be spent on fuel, parking and general maintenance of the vehicle. Local aspects and Actions of the city's administration can also be related. Despite having gathered different aspects, most of them can be improved by the programmes and initiatives of the city's administration.

5.1.2.2 Weight distribution

The Factor Analysis performed to assign different weights to the BI variables will be discussed in the following sections. The analysis was done using the eleven factors that were directly related to the variables. Firstly, the analysis made with the general sample will be discussed and secondly, the analysis performed with each sample group.

General sample

When analysing the results from the Factor Analysis conducted with the entire sample, based on the proportion of variance explained and in the factor rotation, "Safety" and "Cycling Infrastructure" received higher weights. Assigning more importance to those aspects intends to produce a bikeability map more similar to the real cycling conditions of the city since the Questionnaire showed that aspects related to safety and cycling infrastructure are more determinant than density and land-use for example. This is also in line with the findings of Winters, Brauer, Setton, & Teschke (2013) and Greenstein (2015).

Cyclists versus Non-cyclists

The Factor Analysis performed using the Cyclists group as a selection variable showed Types of Infrastructure with a higher weight in the final index, nearly half of the total (41%). A possible reason was that cyclists in Curitiba are most of the times actively engaged to increase the bicycle network and improve the conditions for cycling. Therefore, aspects presented in the Questionnaire related with cycling infrastructure had a stronger evaluation, resulting in a higher weight for this aspect. This fact contradicts the initial assumption of the author, which was that the weight distribution according to cyclists' evaluation would be more homogeneous, since most of the bicycle users from Curitiba are used to cycle in any situation, minimising the effects of infrastructure and safety.

After restricting the survey answers to Non-cyclists, the Factor Analysis showed a higher weight for Safety (34%) and Types of Infrastructure (31%), in line with the assumption that inexperienced cyclists tend to cycle only when a dedicated infrastructure is present, which provides them with an extra safety perception. Topography (18%) also received a higher weight in this group when compared with Cyclists, in accordance with the findings and with the literature review, which states that higher slopes are a deterrent for non-cyclists.

5.1.3 Binary Logistic Regression

This section will discuss the results from Binary Logistics Regression. Firstly, the results based on transport behaviour (cyclist versus non-cyclist) will be presented, followed by income class (higher versus lower income).

5.1.3.1 Transport Behaviour

When analysing the evaluation of the barriers and facilitators/motivators for bicycle use, it was observed that people more reactive to reduce speed limits in urban areas and improve traffic signalling are more propitious to be a cyclist in 68.9%. For people that commute by bicycle in Curitiba, cycling through cars is a common practice due to the lack of dedicated cycling infrastructure in many areas of the city. With the largest vehicle fleet in the country, the streets of Curitiba can be risky for cyclists, especially during rush hours which makes cyclists more sensitive to those aspects. In addition, the city recently implemented a speed reduction policy in some areas of the city centre (Via Calma and Área Calma), where bike users could feel the positive effects of cycling through traffic calming streets.

On the other hand, the odds of being a cyclist diminishes when public insecurity issues increase, and when the demand for integration between bicycle and public transport growths. The last can be explained by the fact that, with the combined use of bicycle and public transport, the cycling distances can be diminished, which might be able to attract non-bicycle users that are reactive to trip distances.

After evaluating the possibility of cycling through different types of infrastructure, the odds of being a cyclist substantially increases when individuals would cycle in general roads and exclusive bus lanes. For many years, the exclusive bus lanes (BRT lanes) was the most used cycling routes in the city, and cycling through cars and buses is a common reality. Non-cyclists also showed a rejection in cycling through those areas due to safety concerns. In addition, the odds of being a cyclist increase between males, drops with age and social status, in line with the results from the investigation of Hino, Reis, Sarmiento, Parra, & Brownson (2014).

5.1.3.2 Income Class

After performing the Binary Logistic Regression by income class (higher income versus lower income), Safety was the only aspect that achieved statistical significance. When safety aspects increase, individuals within that area are more likely to be from higher income class. In Curitiba, like many other cities from developing countries, higher income areas are those with more investments in infrastructure in general, either for vehicles, pedestrians or cyclists. Consequently, those areas have lower occurrences of traffic-related accidents.

5.2 Spatial Analysis

The spatial analysis was performed using the software ArcGIS (ESRI). GIS data was computed and different bikeability maps for the city of Curitiba was generated with a 10 x 10 meters' grid. The versions of the Bikeability map will be discussed separately.

5.2.1 Bikeability Index – Equal weight distribution

The first Bikeability map was produced assigning equal weights to the five BI variables. By assigning the same importance to all variables, it is assumed that different aspects such as residential density, topography, land-use and cycling infrastructure exert the same influence in the citizens' travel behaviour. The results can be seen in Figure 34 (Section 4.2.6.1). In this version, most of the city has a good bikeability, with an index between 7 and 8. However, empirical evidence shows the opposite of what is presented on the map. Many areas are considered problematic for bicycle use, either due to absence of specific infrastructure for cyclists, dangerous crossing for both cyclists and pedestrians, a high number of accidents, roads with high vehicle flow and no respect to speed limits, apart from aspects not addressed in this research, such as public safety. Furthermore, different investigations (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009); (Ewing & Cervero, 2010) demonstrated that built environment aspects can have different effects in the levels of vehicle, transit, walking and bicycle use. In terms of cycling, the presence of dedicated infrastructure in the commuter's route can exert a positive influence towards bicycle use, either by increasing the safety conditions, improving accessibility, and others (Winters M. , Brauer, Setton, & Teschke, 2013) (Winters, Teschke, Brauer, & Fuller, 2016); (Camargo, 2012); (Krenn, Oja, & Titze, 2015); (Heinen E. , 2011).

Under this premise, results of the Questionnaire supported the weight distribution among the bikeability index variables, in order to considerer the effects of local aspects and produce a bikeability map closer to the real cycling conditions of the city.

5.2.2 Bikeability Index – Weighted

The Bikeability map generated based on the weight distribution performed using the whole sample size is presented in Figure 35. The areas contemplated with some sort of cycling infrastructure has a good bikeability index (between 7 and 9). Most of the areas with no infrastructure has a lower index (5 or less). Since Types of Infrastructure variable was assigned a higher weight (38%), followed by Safety (33%), these two variables have a strong influence in the final index. Therefore, areas with a low index are mainly those with a higher occurrence of traffic-related accidents.

In the Cyclists' version of the Bikeability map, the total variance explained were higher in the Cycling Infrastructure factors, this variable accounted for nearly half of the total weight distributed (41%). This group also evaluated all the types of infrastructure, including general roads and bus lanes, with a good index (above 7). This explains the fact that all the types of infrastructure achieved a good index in this map version.

The Non-cyclists' version of the bikeability map, Safety was the variable that received a higher importance (34%). Therefore, risky areas for cyclists has a very low bikeability index. On the other hand, areas with less occurrence of traffic-related accidents has a good index, also influenced by the Topography variable. It can also be seen that, locations with some dedicated cycling infrastructure has a good bikeability, in contrast with general roads and bus lanes.

5.3 Policy Recommendations

This section will suggest, based on the spatial analysis and in the results from the Questionnaire, the policy recommendations and the future steps to be taken by the Municipality of Curitiba in order to increase the levels of cycling in the city. In addition, the researcher will expose his personal view about how to improve the cycling conditions of Curitiba, based on his own experience. In the data collection phase of this investigation, the researcher lived in the city for a period of 2 months, using the bicycle as the main transport mode.

Firstly, from the spatial analysis performed with the whole sample size, three critical areas for bicycle use were identified as demonstrated in Figure 47 (below). In Area 1, the high occurrence of traffic accidents had a strong and negative impact in the bikeability of the region. The area is located in the Industrial Neighbourhood, where industries and manufacturing activities of the city are concentrated.

The neighbourhood is destination point of many lower skilled people that lives in the vicinity, and access their jobs mainly by bus, bicycle or walking. A federal highway (BR 376) intersect the region, which aggravates the safety problem. There is no physical barrier between the highway and the surrounding roads and only a few safe crossing places for both pedestrians and cyclists. Therefore, citizens risk themselves between the trucks and automobiles. In addition, the cycling infrastructure existent in the area (Bicycle path – St. Vinte e Cinco and St. Bernardo Meier) did not improve safety conditions for cyclists, since this infrastructure was built far from the main origin and destination points. Although interventions in the federal highway can only be made by the national government, the municipal administration could improve the existent crossing points by implementing a dedicated cycling infrastructure and improving the traffic signs not only at those places, but also in the main roads and avenues of the neighbourhood, since the local traffic is also heavy. Such interventions would improve the conditions for cyclists and increase safety. The Area 2 from the Figure 47 was highlighted because of two main reasons. Firstly, the region has also a high occurrence of traffic accidents, poor conditions for pedestrians and no dedicated infrastructure for cyclists. Secondly, the region has a good potential for bicycle use because of the high residential density, a high mixed land-use and a favourable topography for cycling (fewer slopes). With the implementation of a dedicated cycling infrastructure and a better connectivity with the structural axes, the bikeability of the region could be increased substantially. Area 3 have similar issues. The high occurrence of traffic accidents had a negative impact in the bikeability of the region. However, the cycling infrastructure present in the area is in good condition and was well placed (Av. Mal Floriano Peixoto). The problematic aspects are found in the adjacent roads. Cyclists are exposed to risk situations due to the lack of infrastructure and dangerous crossing points on the streets that gives access to the avenue. In addition, investments in cycling infrastructure in the region could enhance the integration between bicycle and public transport since one of the busiest bus terminals in the city (Terminal Boqueirão) is located there. The good connectivity with the city centre is also a positive aspect although, improvements in traffic signs and safety crossings for cyclists are still needed. The avenue is one of the structural axes of Curitiba.

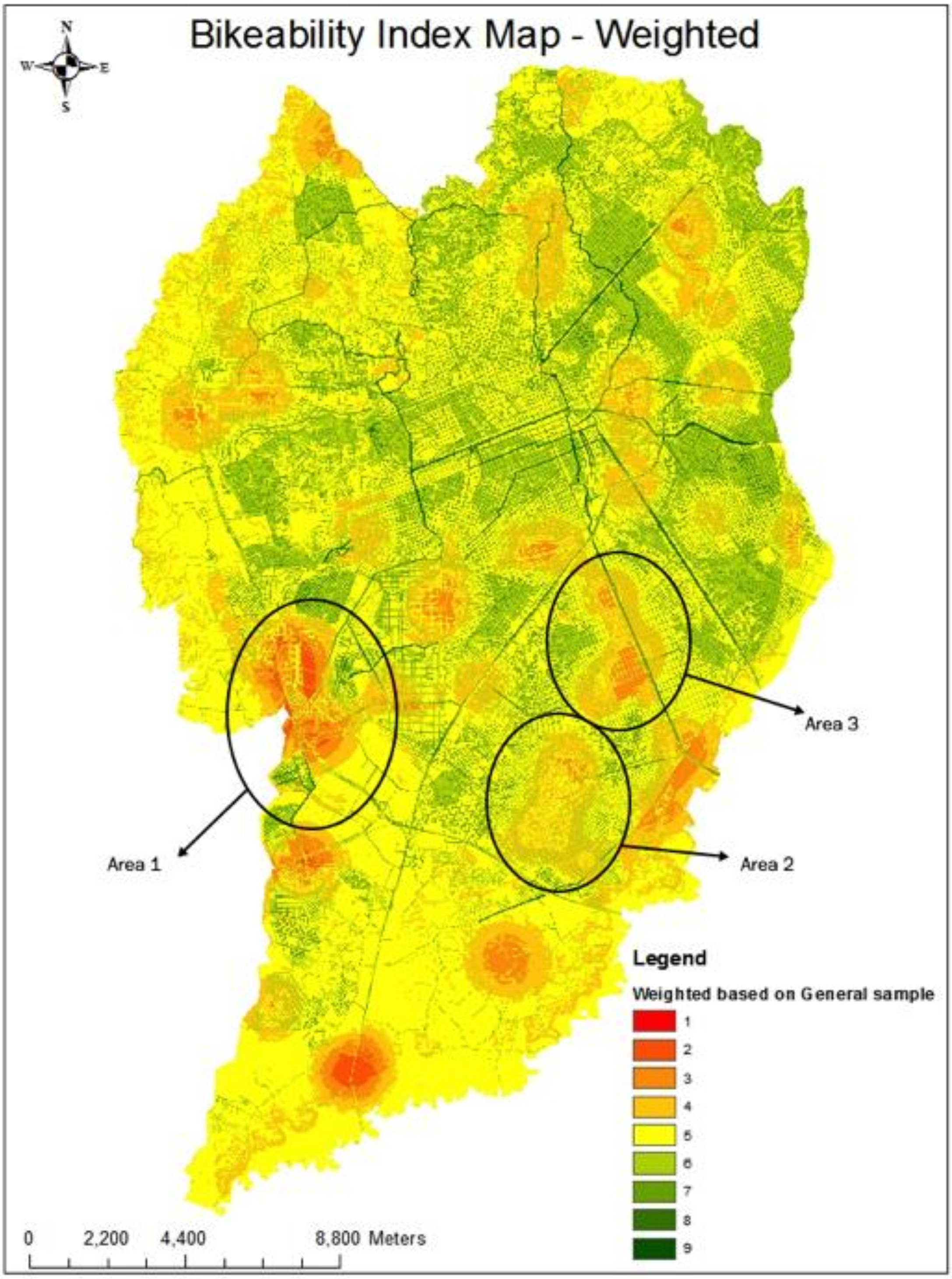

Figure 47: Bikeability Index - Policy Recommendations

In addition to the lack of cycling infrastructure and a high occurrence of traffic accidents, these three areas have also another aspect in common: residents from those locations are mainly from lower social classes (poorer), as exposed in Figure 45 (section 4.2.8.1). This section also shows that most of the cycling infrastructures of Curitiba are placed in higher income areas. In contrast, the Binary Logistic Regression presented in the section 4.1.2.3, indicated that the odds of using the bicycle for transportation are lower among people from higher income classes. Which means that cycling infrastructure is being placed where people is less favourable to commute by bicycle. Lower income neighbourhoods should be prioritised in the allocation of resources for new infrastructures to attract more people to cycle. Firstly, those areas have a lower bikeability index in the average, like demonstrated in the figure below (Figure 48), mainly due to the lack of infrastructure and the high occurrence of traffic accidents involving cyclists. Secondly, people from lower income classes are more likely to use bicycle for transportation than citizens from higher income classes.

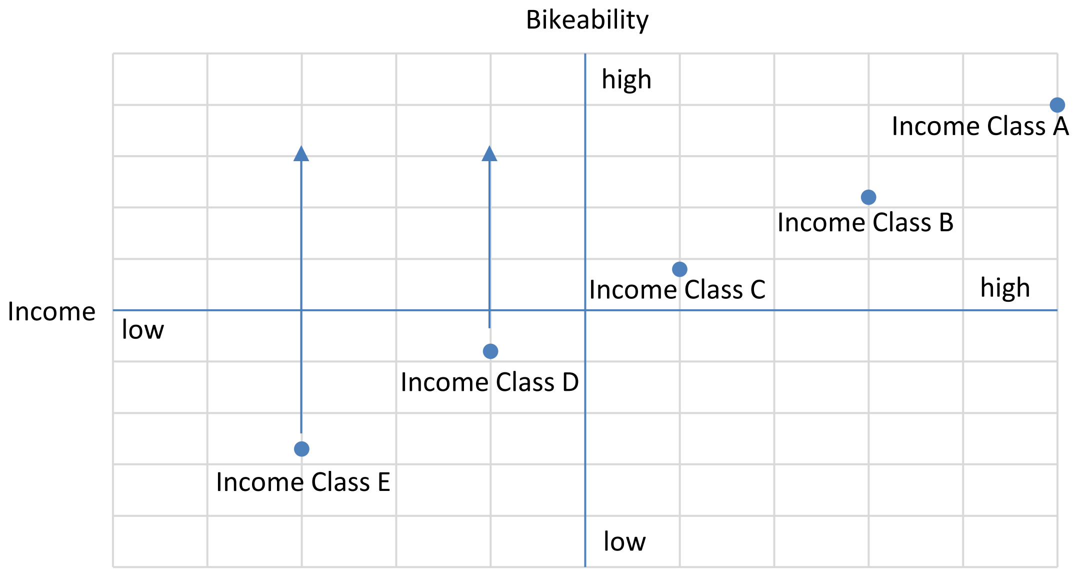

Figure 48: Bikeability versus Income

Secondly, the recommendations derived from the Questionnaire are related with the presence of cycling infrastructure. Analysing the survey responses, especially the non-cyclists group, participants are more favourable to use the bicycle when a full separation from the general traffic occurs (Bicycle paths), the crossings are well signalised and traffic safety measures were taken. In addition, non-cyclists have a high restriction to cycle on roads with no cycling infrastructure. Consequently, to influence more people to cycle, the implementation of more dedicated infrastructure is essential. However, placing bicycle paths in every location of the city is not feasible due to space and budget restrictions. Areas must be prioritised and decisions regarding the type of infrastructure to be implemented should vary according to the road characteristics of the area. As an example, in locations where the flow of vehicles is intense, a full separation between bicycle and car is preferred (Bicycle path). For areas with moderated traffic of vehicles, infrastructures that promote the integration between bicycles and vehicles can be an alternative (Bicycle lanes, Calm lanes and Bicycle routes). In areas with low or very low traffic of vehicles, dedicated cycling infrastructure might not be needed. Traffic signs and educational campaigns must inform that bicycle and motorised vehicles should co-exist. Furthermore, speed reduction measures showed to be very important to increase safety perception and actions to restrict vehicle speed should be explored. Another interpretation derived from the Questionnaire was that both Cyclists and Non-cyclists poorly evaluated the mixing between pedestrians and bicycle. As a reminder, the construction of this type of cycling infrastructure was widely done in the past and a great part of the cycling network of Curitiba is still composed by Shared Sidewalks. Pedestrians are the most vulnerable part of the traffic system and their space must be preserved. This type of infrastructure should not be built any longer. Actions to improve the integration between bicycle and public transport was also importantly evaluated. Those actions include the possibility of carrying the bicycle inside the bus or providing a safe bike parking in the bus terminals. This aspect should also be more explored. In addition, respondents clarified that public safety is also a matter of concern when using the bicycle for transportation reasons. Specific actions could mitigate the effects of public safety such as improvements in the public light system, expansion of the video surveillance system in critical areas, creation of specific bike patrols by the municipal police, and others.

The third and last set of recommendations came from the experiences gathered by the researcher during his period in Curitiba. Empirical evidence showed that street crossings for cyclists are still an issue in the city, even in places where a bicycle infrastructure was recently implemented. Secondary interventions such as cyclists' signs, exclusive traffic lights for cyclists and improvements in the sidewalks are also important. In some locations where a new cycling infrastructure was built, pedestrians make use of this infrastructure since the sidewalks are in very poor conditions. The pavement quality is also another point of concern. Many of the shared sidewalks and bicycle paths built in the past did not receive the proper maintenance over the years. Thus, many of these infrastructures have obstacles that make cycling dangerous and less attractive. To conclude, despite the investments in dedicated cycling infrastructure and educational campaigns, Curitiba is still below of what can be considered a bicycle-friendly city. In order to actually influence people's travel behaviour towards a more sustainable transport method, the city administration needs to take actions to increase the cycling conditions, either with the implementation of new cycling infrastructure, stimulate the integration between bicycle and public transport, incorporate technologies of mobile applications, implement innovative designs for new cycling infrastructures and act in the field of public safety. Furthermore, as an alternative to the lack of financial resources, partnerships with the private sector for implementing new infrastructure and maintenance of the existent ones should be considered.

5.4 Strengths and Limitations

This research aims to contribute to the existent literature regarding the correlation between built environment and people's travel characteristics. Several studies investigate how the aspects of the built environment affect levels of vehicle, transit, walking and/or bicycle use. However, the great majority was performed in cities from developed countries. Researchers in a developing country context is scarce in the literature. In those places, other aspects rather than the 5 D's of the built environment (presented in the Figure 5 – Section 2.1.1) might affect peoples' travel behaviour and travel demand. In addition, it is not from the knowledge of this author the application of the bikeability index in Brazil. Therefore, this investigation is the first to develop a bikeability map to a Brazilian city. Another strength of this study is related to the index. The bikeability index proposed by this investigation considered local aspects that were not addressed by other applications of this tool, such as the accident analysis. Inputting the location and severity level of traffic accidents involving cyclists called attention to the authorities, demanding actions from the city's administration and increasing the accuracy of the map. Furthermore, this investigation presented in a high level of detail, the current cycling conditions of the city, highlighting where infrastructure investments should be prioritised to effectively increase the levels of cycling. In this manner, the municipal administration can make use of monetary resources in a more rational way.

Although the Bikeability map presented a detailed evaluation of the cycling conditions of Curitiba, this study has several limitations. The first was related to the sample and sample size. The sample size of 231 participants, which was reduced to 217 after the computation of the "Density" variable, might not have been ideal for performing Factor Analysis. According to MacCallum, Widaman, & Zhang (1999), for low communalities and few indicators for each factor, a sample size of at least 300 participants is required. Due to lack of time and resources, together with some bureaucratic hurdles, the researcher was not able to achieve this number, although a total of 500 responses were purchased from the LimeSurvey platform. Another limitation relies on the application of the questionnaire. Since the focus of the Questionnaire was on the online approach, participants that do not have easy access to the internet might not have been reached, possibly influencing the few differences encountered between Higher and Lower income groups. When considering the face-to-face interviews, specific limitations can be pointed. Since the questionnaire was performed in the administrative building of the Municipality of Curitiba, with employees from lower hierarchical positions, respondents might have felt inhibited by the application of it. Another limitation can be pointed in the sample characteristics. To reach more bicycle users, the questionnaire was sent to a list provided by Cicloiguaçu, a Non-Governmental Organization (NGO) formed by cycling activists. Respondents might have had a bias for factors related to "cycling Infrastructure" since Cicloiguaçu is one of the most active associations that fights for more dedicated infrastructure for bicycles.

Additional limitations are related to the bikeability index and the assumptions that were taken for Curitiba. The use of Spatial Analysis tools itself is extremely dependent on Geographic Information System data and/or digital data map. Locations where this information does not exist or is not available for research, the application of this method is practically unfeasible. The Bikeability Index of Curitiba has also other limitations. Firstly, the selection of the variables that composes the index was made based on the existent literature, rather than insights collected in the city. Therefore, other factors that might affect bicycle use could have been neglected. Secondly, the computation of the scores of each BI variable had some constraints. The Land-use information provided by the Municipality of Curitiba contains information about the total areas per type of establishment, instead of the individual establishment area. In addition, with the information provided, it was not possible to calculate the land-use rate based on the precise location. Thus, the same rate was calculated to zones with the same classification, even if they are in different areas of the city. The Safety map has also some limitations. The most relevant is that the map was generated based on a simplistic evaluation of the accidents (occurrence and gravity). The circumstances that lead to the incident was not considered, which could have hidden important aspects of a traffic-related accident and risky areas for cycling. Finally, the limitations regarding the Types of Infrastructure map relies on the fact that, in the Bikeability map, every location with some sort of cycling infrastructure was assigned with a high score. However, some infrastructures are in very poor conditions or have a lot of obstacles. Those locations do not represent good areas for use the bicycle and might be neglected by cyclists and potential cyclists. This Master Thesis considered the presence and types of cycling infrastructure, not the conditions of each one.

5.5 Recommendations for Future Research

Based on the results of the study, there are several recommendations for future research. Firstly, some of the limitations outlined in the previous section can be minimised. The Bikeability map resulted from this investigation can be confronted with the travel behaviour survey that is currently under performance in the whole Metropolitan Region, with the results expected to be published in 2017. The Binary Logistic Regression can be done with a much bigger sample, and new correlations can be made between areas with a good bikeability index and people's travel behaviour from the same region. Using a much bigger sample, variables could also be tested independently to check whether the bicycle use is higher in areas where the score was high. Information from the travel behaviour research can also be confronted with socio-demographic characteristics of the city, and new conclusions might emerge.

To gain more insights about cycling conditions in the city, and aspects that affect bicycle use, the sample size could be increased, and new approaches for data collection implemented, such as qualitative methods. So, that, more factors can be assigned to each Bikeability Index variable. Secondly, an analysis of cyclists' journey with Global Positioning System (GPS) could be made and compared with the bikeability map to check whether areas assigned with a good index are actually those where cyclists normally use. Day-to-day decisions about the travel route can reveal important aspects of bikeability and bicycle use. Collecting information about cyclists' and potential cyclists' experiences can also expose hidden factors of cycling. Finally, this methodology could be applied in the near future to check whether the conditions for bicycle use is improving or not, over the time.

6 CONCLUSION

This chapter provides the answers for the research questions done by this investigation. The first question is concerning the consequences of the built environment, natural environment and safety issues on the overall bikeability of Curitiba. To answer this question, a bikeability index was produced based on Residential Density, Mixed Land-use and Types of Infrastructure (Built environment), Topography (Natural environment) and Safety, developed based on the occurrence and severity level of traffic-related accidents involving cyclists. Binary logistic regression was used to test the effects of each individual variable in the likelihood of cycling for transportation. However, the test did not show statistical significance to any of the aspects. In addition, a questionnaire was conducted in the city, and the results were used to perform the weight distribution between the variables and compute the final index. The index demonstrates that Residential Density had little consequences in the overall bikeability of the city. The city's residential density is low, on average (1,468.05 houses/km2) when compared to a large city from developing countries, resulting in a lower impact in the index. On the other hand, Mixed Land-use exerted a positive impact in the index, since most parts of the city have a higher proportion of different types of establishments in the same area. This land-use mixture was influenced by the city's Master Plan. Topography was another factor that had a positive impact on the bikeability index. The reason relies on the fact that, 70% of the city's territory is in a flat area. In terms of Safety, different consequences were observed. The areas with a high number of accidents had a strong and negative impact on the final index since this variable also received a higher weight. On the other hand, areas with no occurrence of accidents had a strong and positive influence in the final index. Types of Infrastructure was also an important factor. In areas where a dedicated infrastructure for cyclists is present, a positive influence in the final index was achieved. The impact is different, depending on the type of infrastructure available. Areas with any cycling infrastructure had a lower index. The bikeability index is represented in a form of a map (Figure 35).

The second question to be answered in this investigation is concerning the possible differences in the aspects that affect bikeability and bicycle use, between higher and lower income population. To answer this specific question, an independent sample t-test was conducted in the results from the Questionnaire. The test did not show consistent differences between the two groups in any of the factors analysed. Therefore, no significant differences were found in the evaluation of the aspects that affects bikeability and bicycle use between the two groups, suggesting that higher income and lower income people have similar assessments regarding those aspects.

The third and last research question intend to answer whether cyclists and non-cyclists differently perceive aspects related with bikeability and bicycle use. The independent sample t-test revealed consistent differences between the two groups in most of the aspects that influence bicycle use presented in the Questionnaire. Furthermore, differences were also found in the evaluation of the different types of cycling infrastructure. Results indicated that cyclists perceive differently the aspects related to bicycle use than non-cyclists, and are more propitious to cycle in all situations. These findings gave grounds to develop specific bikeability map to each group. The bikeability map according to the cyclists' point of view can be seen in Figure 37, while the bikeability map based on non-cyclists point of view can be seen in Figure 39.

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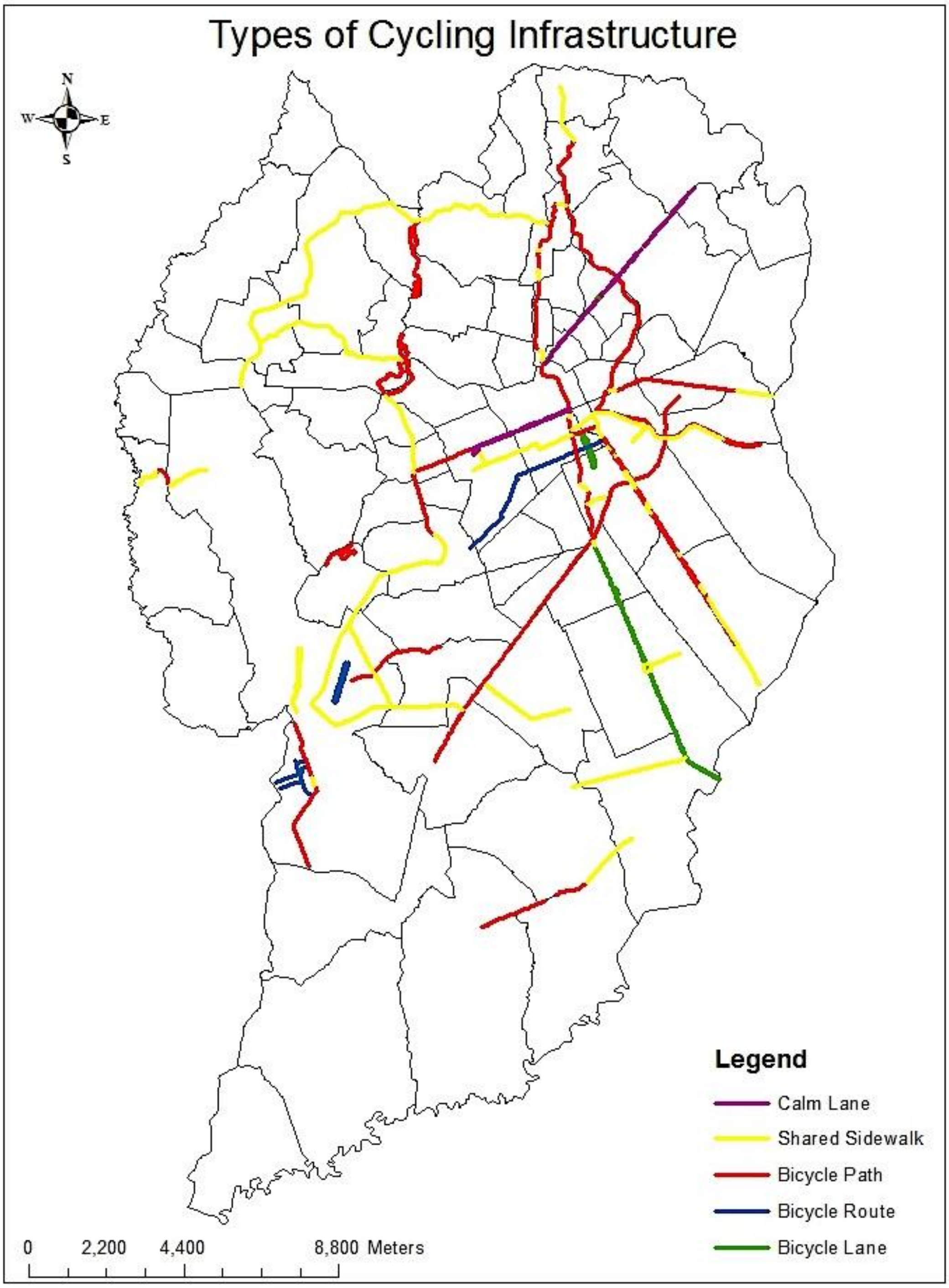
APPENDIX I



Types of Cycling Infrastructure
N
W
E
S
Legend
Calm Lane
Shared Sidewalk
Bicycle Path
Bicycle Route
Bicycle Lane
0
2,200
4,400
8,800 Meters

Bicycle Path

Bicycle path (Figure 49) consist in an exclusive space for the cyclists, separated from the general traffic, pedestrians or any other vehicle. Unlike in the Netherlands, scooters are not allowed to use the bicycle paths.

Figure 49: Bicycle path.

Bicycle Lane

Bicycle lanes (Figure 50) are normally located at the edge of general roads, with a specific signalling for the transit of cyclists. In Curitiba, a small physical barrier prevents cars and motorcycles of using this infrastructure.

Figure 50: Bicycle Lane.

Calm Lane

Calm lane, or *Via Calma* in Portuguese it is a type of cycling infrastructure developed in Curitiba and is located alongside some structural axis. The space for cyclists is delimitated, but the integration between car/motorcycle and cyclists is more likely to occur. The speed limit in those locations is 30 kilometres per hour. Figure 51 shows an example of a Calm Lane in Curitiba.

Figure 51: Calm Lane.

Shared Sidewalk

Another type of cycling infrastructure that can be found in Curitiba is where cyclists and pedestrians shares the same space. This method is viewed as an alternative to the lack of space for implementing a cycling infrastructure in certain areas of the city, and it was widely used in the past. Figure 52 represents one of the Shared sidewalks in Curitiba.

Figure 52: Shared sidewalk.

Bicycle Route

Bicycle route (Figure 53) consists in the implementation of specific signs in streets with less traffic of vehicles, forming a route where cyclists can detour from streets and avenues with a more intense traffic flow. There is no physical separation between cyclists and other vehicles and the signs are mainly to call attention that there are cyclists in the region. Some crossings also received signs interventions.

Figure 53: Bicycle Route (Prefeitura Municipal de Curitiba, 2015).

General Roads

In the general roads, it was explained that no dedicated infrastructure is present. Therefore, cyclists must share the space with the vehicles. The Brazilian traffic legislation specifies conduct rules for cyclists in locations with no specific cycling infrastructure.

Figure 54 : General roads (Va de Bike, 2016).

Exclusive Bus Lanes

Despite the bicycle use in the exclusive bus lanes from the BRT is prohibited by a municipal law (Act N° 695/95 and Act N° 759/95), cyclists still make use of these lanes. Experienced cyclists say that a good pavement quality and a good connectivity with different areas of the city are among the reasons for it.

Figure 55: Exclusive Bus Lanes.

APPENDIX II

Pesquisa de Mobilidade - Curitiba/PR

Esse questionário compõe a dissertação de Mestrado do aluno Bruno Guasti Motta, da Universidade de Twente (Holanda), em cooperação com a Universidade Tecnológica Federal do Paraná (UTFPR). Todos os dados serão mantidos sob sigilo, não possibilitando a identificação dos respondentes, sendo usados unicamente para fins de produção de conhecimento científico.

Informações Pessoais

1. **Em que bairro de Curitiba você reside?**

   ....

2. **Qual CEP da sua rua?**

   ....

3. **Qual sua idade?**

   ....

4. **Gênero**

   Mark only one oval.

   - ( ) Masculino
   - ( ) Feminino

5. **Grau de escolaridade**

   Mark only one oval.

   - ( ) Pós-graduação
   - ( ) Superior completo
   - ( ) Superior incompleto
   - ( ) Profissionalizante (Técnico, etc.)
   - ( ) Ensino médio
   - ( ) Ensino fundamental
   - ( ) Não possui

6. **Qual a sua ocupação?**

   ....

7. **Qua sua renda familiar mensal?**
Mark only one oval.

- Acima de 20 salários mínimos (Mais de R$17.600)
- Entre 10 e 20 salários mínimos (R$8.800 à R$17.600)
- Entre 04 e 10 salários mínimos (R$3.520 à R$8.800)
- Entre 02 e 04 salários mínimos (R$1.760 à R$3.520)
- Até 02 salários mínimos (Até R$1.760)

8. **Possui Carteira Nacional de Habilitação (CNH)?**
Mark only one oval.

- Categoria A (Motocicleta)
- Categoria B (Automóvel)
- Categoria A/B (Motocicleta/Automóvel)
- Categoria C (Caminhão)
- Categoria D (Ônibus)
- Categoria E (Carreta)
- Categoria ACC (Ciclomotor)
- Não Possui

Informações sobre o trajeto

9. **Em que bairro de Curitiba está situado seu local de trabalho ou estudo?**

10. **Com que frequência você acessa seu local de trabalho ou estudo?**
Indique quantas vezes por semana voce faz o trajeto de casa para o trabalho/estudo
Mark only one oval.

- Mais de cinco vezes por semana
- Cinco vezes por semana
- De duas a quatro vezes por semana
- Uma vez por semana

11. **Qual meio de transporte que você mais utiliza para chegar ao seu local de trabalho ou estudo?**
Mark only one oval.

- Automóvel
- Ônibus
- Motocicleta
- Taxi
- Bicicleta
- A pé
- Other: ______________________

12. **Com que frequência você utiliza o meio de transporte selecionado para chegar ao seu local de trabalho ou estudo?**
Mark only one oval.

- Mais de cinco vezes por semana
- Cinco vezes por semana
- De duas a quatro vezes por semana
- Uma vez por semana

13. **Quanto tempo voce gasta para chegar ao seu local de trabalho ou estudo?**
Mark only one oval.

- De 0 a 15 minutos
- De 15 a 30 minutos
- De 30 a 45 minutos
- De 45 minutos a 1 hora
- Mais de 1 hora

14. **Quanto tempo voce gasta para retornar à sua residência?**
Mark only one oval.

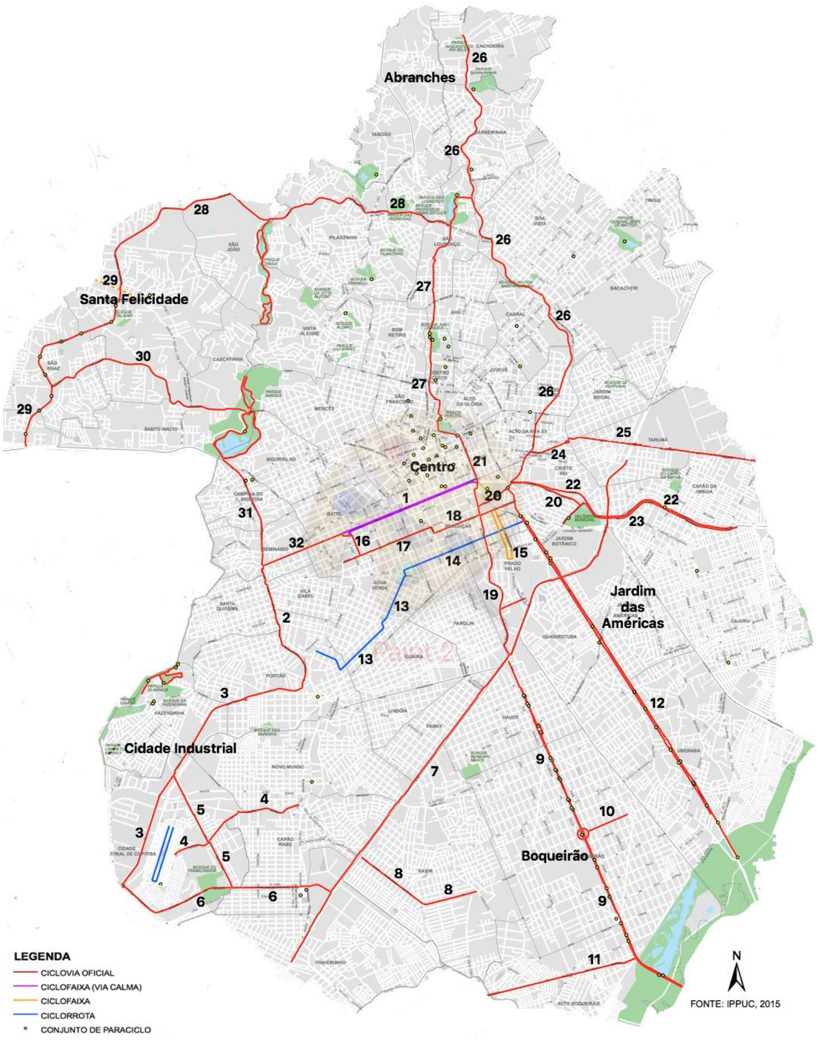
- De 0 a 15 minutos
- De 15 a 30 minutos
- De 30 a 45 minutos
- De 45 minutos a 1 hora
- Mais de 1 hora

15. **Qual é o seu turno de trabalho ou estudo?**
Check all that apply.

- [ ] Manhã
- [ ] Tarde
- [ ] Manhã e Tarde
- [ ] Noite
- [ ] Madrugada

Estrutura Cicloviária

Você utiliza alguma estrutura cicloviária para chegar ao seu destino? Se sim, qual (quais)?



16. **Região Central**
Check all that apply.

- [ ] 1: Av. Sete de Setembro
- [ ] 2: Av. Presidente Arthur da Silva Bernardes
- [ ] 13: Rua Otávio Francisco Dias + Rua Pará
- [ ] 14: Rua Baltasar Carrasco dos Reis
- [ ] 15: Rua Iapó + Rua Imac. Conceição
- [ ] 16: Rua Dr. Alexandre Gutierrrez
- [ ] 17: Av. Presidente Getúlio Vargas
- [ ] 18: Rua Engenheiro Rebouças
- [ ] 19: Rua Conselheiro Laurindo
- [ ] 20: Av. Dr. Dario Lopes dos Santos
- [ ] 21: Rua Mariano Torres
- [ ] 22: Av. Presidente Affonso Camargo
- [ ] 23: Av. Prefeito Maurício Fruet
- [ ] 24: Av. Sete de Setembro (parte oriental)
- [ ] 25: Av. Victor Ferreira do Amaral
- [ ] 31: Rua General Mário Tourinho
- [ ] 32: Av Sete de Setembro - Trecho Praça do Japão à Av. Pres. Arthur da São Bernardes
- [x] Other: ____________

17. **Região Sul**
Check all that apply.

- [ ] 3: Rua João Bettega
- [ ] 4: Rua Pedro Gusso
- [ ] 5: Av. das Industrias
- [ ] 6: Rua João Rodrigues Pinheiro
- [ ] 7: Marginal Linha Verde até UFPR
- [ ] 8: Rua Omar Raymundo Picheth + Rua Waldemar Lodeiro Campos
- [ ] 9: Av. Marechal Floriano Peixoto
- [ ] 10: Rua Napoleão Laureano
- [ ] 11: Rua WIlson Daecheux Pereira
- [ ] 12: Av. Comendador Franco
- [ ] Other: ____________

18. **Região Norte**
Check all that apply.

- [ ] 26: Rua Flavio Dallegrave - Trajeto ao Longo da ferrovia
- [ ] 27: Passeio Público <---> São Lourenço
- [ ] 28: Av. Fredolin Wolf
- [ ] 29: Av. Vereador Toaldo Tulio
- [ ] 30: Rua Antônio Escorsin
- [ ] Other: ....

Qual a sua avaliação sobre os fatores que DIFICULTAM o uso da bicicleta como meio de transporte?

19. *Mark only one oval per row.*

	Sem importância	Pouco importante	Moderadamente importante	Importante	Muito importante
Imperfeição do pavimento	◯	◯	◯	◯	◯
Falta de bicicletário ou e/ou vestiário no destino	◯	◯	◯	◯	◯
Insegurança no trânsito	◯	◯	◯	◯	◯
Insegurança pública	◯	◯	◯	◯	◯
Necessidade de carregar bagagem/bolsas durante o trajeto	◯	◯	◯	◯	◯
Comportamento no trânsito entre motoristas e ciclistas	◯	◯	◯	◯	◯
Condições Meteorológicas	◯	◯	◯	◯	◯
Falta de vias cicláveis	◯	◯	◯	◯	◯
Topografia da cidade	◯	◯	◯	◯	◯
Falta de sinalização nos cruzamentos	◯	◯	◯	◯	◯
Falta de iluminação no deslocamento	◯	◯	◯	◯	◯
Distância dos deslocamentos	◯	◯	◯	◯	◯

20. **Outro:**

....

....

....

....

....

Qual a sua avaliação sobre os fatores que FACILITAM o uso da bicicleta como meio de transporte?

21. *Mark only one oval per row.*

	Sem importância	Pouco importante	Moderadamente importante	Importante	Muito importante
Estacionamento para automóveis com preços elevados	◯	◯	◯	◯	◯
Segurança no trânsito	◯	◯	◯	◯	◯
Transporte público insuficiente no bairro	◯	◯	◯	◯	◯
Alto custo para ter automóvel	◯	◯	◯	◯	◯
Medidas de redução de velocidade para motoristas e sinalização apropriada	◯	◯	◯	◯	◯
Ocupação e uso misto do solo (número de estabelecimentos comerciais, residenciais, de serviços, etc. em uma mesma região)	◯	◯	◯	◯	◯
Acessibilidade e infraestrutura cicloviária	◯	◯	◯	◯	◯
Redução do tempo de deslocamento	◯	◯	◯	◯	◯
Pequenas distâncias entre origem e destino	◯	◯	◯	◯	◯
Bicicleta integrada com transporte público	◯	◯	◯	◯	◯
Alta de preços dos combustíveis	◯	◯	◯	◯	◯

22. **Outro:**

Tipos de Estrutura Cicloviária

Baseado na SUA percepção ou experiência, qual o grau de probabilidade de você utilizar a bicicleta como meio de transporte nas estruturas indicadas abaixo?

23. **Ciclovia**

Mark only one oval per row.

	Improvável	Pouco Provável	Neutro	Muito Provável	Certamente
Ciclovia: Espaço exclusivo para o ciclista, com separação física dos carros e pedestres	◯	◯	◯	◯	◯

24. **Ciclofaixa**

Mark only one oval per row.

	Improvável	Pouco Provável	Neutro	Muito Provável	Certamente
Ciclofaixa: No bordo da pista, sem compartilhar com outros veículos e com sinalização apropriada	⬭	⬭	⬭	⬭	⬭

25. **Via Calma**

Mark only one oval per row.

	Improvável	Pouco Provável	Neutro	Muito Provável	Certamente
Via Calma: No bordo da pista, eventualmente compartilhando com outros veículos mas com demarcação de espaço	⬭	⬭	⬭	⬭	⬭

26. **Passeio Compartilhado**
Mark only one oval per row.

	Improvável	Pouco Provável	Neutro	Muito Provável	Certamente
Passeio Compartilhado: Na calçada, compartilhando o espaço com pedestres	⬭	⬭	⬭	⬭	⬭

27. **Ciclorrota**

Mark only one oval per row.

	Improvável	Pouco Provável	Neutro	Muito Provável	Certamente
Ciclorrota: Em vias de tráfego leve, com sinalização indicando a presença de ciclistas na região	⬭	⬭	⬭	⬭	⬭

28. **Vias de tráfego geral**

Mark only one oval per row.

	Improvável	Pouco Provável	Neutro	Muito Provável	Certamente
Vias de tráfego geral: Em vias de tráfego geral, sem sinalização específica	⬭	⬭	⬭	⬭	⬭

29. **Via exclusiva de ônibus**

Mark only one oval per row.

	Improvável	Pouco Provável	Neutro	Muito Provável	Certamente
Via exclusiva de ônibus: Nas pistas exclusivas dos coletivos (canaletas), sem sinalização específica	◯	◯	◯	◯	◯

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APPENDIX III

Mobility Questionnaire - Curitiba/PR

This questionnaire is part of the Master Thesis of the student Bruno Guasti Motta, from the University of Twente (The Netherlands), in cooperation with the Technological Federal University of Paraná (UTFPR). All your data will be kept in secret, being used exclusively for academic purposes. The identification of the respondents is impossible.

Personal Details

1. **In which neighborhood of Curitiba do you live?**

   ....

2. **What is your post code?**

   ....

3. **What is your age?**

   ....

4. **Gender**

   Mark only one oval.

   - ◯ Male
   - ◯ Female

5. **Education Level**

   Mark only one oval.

   - ◯ Post-Graduate
   - ◯ Bachelor
   - ◯ Bachelor (Unfinished or attending)
   - ◯ Technical studies
   - ◯ High School
   - ◯ Elementary School
   - ◯ Do not have

6. **What is you occupation?**

   ....

7. **What is your family income?**
Mark only one oval.

- ( ) More than 20 minimum wages (more than R$17.600)
- ( ) Between 10 and 20 minimum wages (R$8.800 à R$17.600)
- ( ) Between 04 and 10 minimum wages (R$3.520 à R$8.800)
- ( ) Between 02 and 04 minimum wages (R$1.760 à R$3.520)
- ( ) Up to 02 minimum wages (Até R$1.760)

8. **Do you have a drive license?**
Mark only one oval.

- ( ) Type A (Motocycle)
- ( ) Type B (Automobile)
- ( ) Type A/B (Motorcycle/Automobile)
- ( ) Type C (Truck)
- ( ) Type D (Bus)
- ( ) Type E (Heavy trucks)
- ( ) Type ACC (Moped)
- ( ) Do not have

Information about the trip

9. **In which neighborhood of Curitiba is located your work or study place?**

____

10. **How many times per week do you access you work or study place?**
Mark how many times do you go from home to you working or studying place
Mark only one oval.

- ( ) More than five times a week
- ( ) Five times a week
- ( ) Between two and four times a week
- ( ) Once a week

11. **Which type of transport do you mainly use to reach your study or work place?**
Mark only one oval.

- ( ) Automobile
- ( ) Bus
- ( ) Motorcycle
- ( ) Taxi
- ( ) Bicycle
- ( ) On foot
- ( ) Other: ____________________

12. **How many times per week do you use the selected transport mode?**
Mark only one oval.

- More than five times a week
- Five times a week
- Between two and four times a week
- Once a week

13. **How much time do you take to access your working or studying place?**
Mark only one oval.

- From 0 to 15 minutes
- From 15 to 30 minutes
- From 30 to 45 minutes
- From 45 minutes to 1 hour
- More than 1 hour

14. **How much time do you spend to return to your residence?**
Mark only one oval.

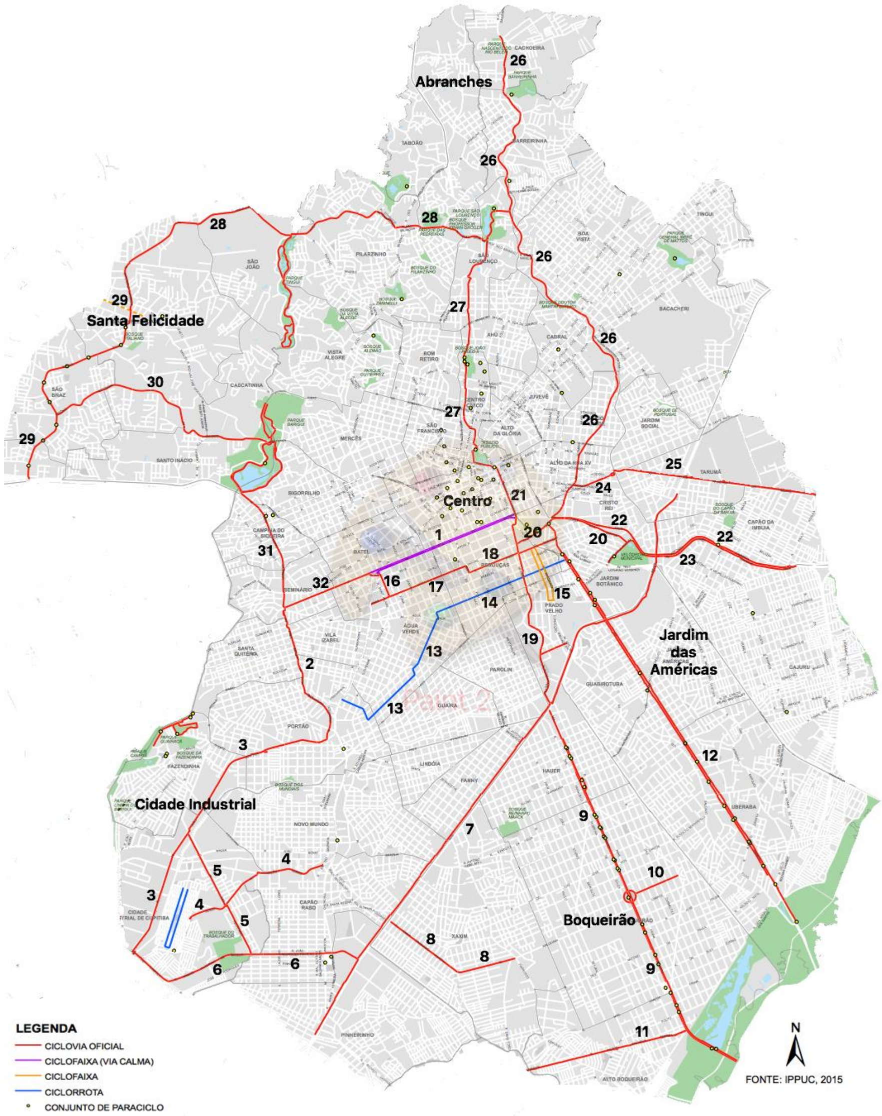
- From 0 to 15 minutes
- From 15 to 30 minutes
- From 30 to 45 minutes
- From 45 minutes to 1 hour
- More than 1 hour

15. **What is your working or studying shift?**
Check all that apply.

- [ ] Morning
- [ ] Afternoon
- [ ] Morning and Afternoon
- [ ] Evening
- [ ] Night

Cycling Infrastructure

Do you make use of any cycling infrastructure to access your destination point? If yes, which one?


Abranches
Santa Felicidade
Centro
Jardim das Américas
Cidade Industrial
Boqueirão
LEGENDA
CICLOVIA OFICIAL
CICLOFAIXA (VIA CALMA)
CICLOFAIXA
CICLORROTA
CONJUNTO DE PARACICLO
FONTE: IPPUC, 2015

16. **Central part**

Check all that apply.

- [ ] 1: Av. Sete de Setembro
- [ ] 2: Av. Presidente Arthur da Silva Bernardes
- [ ] 13: Rua Otávio Francisco Dias + Rua Pará
- [ ] 14: Rua Baltasar Carrasco dos Reis
- [ ] 15: Rua Iapó + Rua Imac. Conceição
- [ ] 16: Rua Dr. Alexandre Gutierrrez
- [ ] 17: Av. Presidente Getúlio Vargas
- [ ] 18: Rua Engenheiro Rebouças
- [ ] 19: Rua Conselheiro Laurindo
- [ ] 20: Av. Dr. Dario Lopes dos Santos
- [ ] 21: Rua Mariano Torres
- [ ] 22: Av. Presidente Affonso Camargo
- [ ] 23: Av. Prefeito Maurício Fruet
- [ ] 24: Av. Sete de Setembro (parte oriental)
- [ ] 25: Av. Victor Ferreira do Amaral
- [ ] 31: Rua General Mário Tourinho
- [ ] 32: Av Sete de Setembro - Trecho Praça do Japão à Av. Pres. Arthur da São Bernardes
- [ ] Other: ....

17. **South**

Check all that apply.

- [ ] 3: Rua João Bettega
- [ ] 4: Rua Pedro Gusso
- [ ] 5: Av. das Industrias
- [ ] 6: Rua João Rodrigues Pinheiro
- [ ] 7: Marginal Linha Verde até UFPR
- [ ] 8: Rua Omar Raymundo Picheth + Rua Waldemar Lodeiro Campos
- [ ] 9: Av. Marechal Floriano Peixoto
- [ ] 10: Rua Napoleão Laureano
- [ ] 11: Rua WIlson Daecheux Pereira
- [ ] 12: Av. Comendador Franco
- [ ] Other: ....

18. **North**

Check all that apply.

- [ ] 26: Rua Flavio Dallegrave - Trajeto ao Longo da ferrovia
- [ ] 27: Passeio Público <---> São Lourenço
- [ ] 28: Av. Fredolin Wolf
- [ ] 29: Av. Vereador Toaldo Tulio
- [ ] 30: Rua Antônio Escorsin
- [ ] Other: ______________________

How do you evaluate the BARRIERS for bicycle use?

19. *Mark only one oval per row.*

	Not important	Little important	Moderately important	Important	Very important
Poor surface quality	○	○	○	○	○
Lack of bicycle parking and/or changing room at the destination point	○	○	○	○	○
Insecurity in traffic	○	○	○	○	○
Public insecurity	○	○	○	○	○
Need to carry luggage or bags during the travel	○	○	○	○	○
Behaviour of car users and cyclists in the traffic	○	○	○	○	○
Weather conditions	○	○	○	○	○
Lack of cycling infrastructure	○	○	○	○	○
Topography	○	○	○	○	○
Lack of signs at crossings	○	○	○	○	○
Lack of street lighting	○	○	○	○	○
Distance	○	○	○	○	○

20. **Other:**

____

____

____

____

____

How do you evaluate the FACILITATORS for bicycle use?

21. *Mark only one oval per row.*

	Not important	Little important	Moderately important	Important	Very important
Expensive car parking	⬭	⬭	⬭	⬭	⬭
Security in traffic	⬭	⬭	⬭	⬭	⬭
Insufficient public transport in the neighbourhood	⬭	⬭	⬭	⬭	⬭
High cost to have a car	⬭	⬭	⬭	⬭	⬭
Speed reduction measures and proper signs	⬭	⬭	⬭	⬭	⬭
Land-use mix	⬭	⬭	⬭	⬭	⬭
Accessibility and cycling infrastructure	⬭	⬭	⬭	⬭	⬭
Shorter travel time	⬭	⬭	⬭	⬭	⬭
Short distances	⬭	⬭	⬭	⬭	⬭
Integration between bicycle and public transport	⬭	⬭	⬭	⬭	⬭
Higher fuel prices	⬭	⬭	⬭	⬭	⬭

22. **Other:**

....

....

....

....

....

Types of Cycling Infrastructure

According to YOUR perception or experience level, what is the probability to use bicycle for transportation in the infrastructures below?

23. **Bicycle path**
Mark only one oval per row.

	Unlikely	Somewhat likely	Neutral	Very likely	Certainly
Bicycle path: Exclusive space for cyclists normally with a physical separation from cars and pedestrians	⬭	⬭	⬭	⬭	⬭

24. **Bicycle lane**

Mark only one oval per row.

	Unlikely	Somewhat likely	Neutral	Very likely	Certainly
Bicycle lane: In the side of the road, without sharing with other vehicles and with specific signs	⬭	⬭	⬭	⬭	⬭

25. **Calm lane**

Mark only one oval per row.

	Unlikely	Somewhat likely	Neutral	Very likely	Certainly
Calm lane: In the side of the road, eventually sharing with other vehicle, but with signs	⬭	⬭	⬭	⬭	⬭

26. **Shared sidewalk**

Mark only one oval per row.

	Unlikely	Somewhat likely	Neutral	Very likely	Certainly
Shared sidewalk: At the sidewalk, sharing the space with pedestrians	⬭	⬭	⬭	⬭	⬭

27. **Bicycle Route**
Mark only one oval per row.

	Unlikely	Somewhat likely	Neutral	Very likely	Certainly
Bicycle Route: In roads with low traffic flow, with signs indicating the presence of cyclists	⬭	⬭	⬭	⬭	⬭

28. **General roads**
Mark only one oval per row.

	Unlikely	Somewhat likely	Neutral	Very likely	Certainly
General roads: In general roads, with specific signs	⬭	⬭	⬭	⬭	⬭

29. **Exclusive bus lanes**

Mark only one oval per row.

	Unlikely	Somewhat likely	Neutral	Very likely	Certainly
Exclusive bus lanes: In the BRT roads	◯	◯	◯	◯	◯

APPENDIX IV

Impact of accidents by severity level. The impact was calculated using the following steps.

Firstly, the average price of traffic-related accidents was analysed:

Table 17: Average cost of traffic-related accident (in Brazilian Real) (IPEA, 2003).

Severity Level	Cost of Accident
Uninjured	R$ 3,262
Evident injury	R$ 17,460
Fatal	R$ 144,143

By computing the proportion of “Uninjured” severity level in comparison with “Evident injury” and “Fatal”, we achieve the following ratio:

Table 18: Ratio of accident per severity level

Severity Level	Ratio
Uninjured	$\frac{R\$ 3,262}{R\$ 3,262} = 1$
Evident injury	$\frac{R\$ 17,460}{R\$ 3,262} = 5.35$
Fatal	$\frac{R\$ 144,143}{R\$ 3,262} = 44.19$

The table above demonstrates that, in terms of costs, a “Fatal” accident and an accident with “Evident injury” have an impact 44.19 and 5.35 times higher that an “Uninjured” accident, respectively.

Since the classification of accidents adopted by IPEA has three levels and the methodology adopted by the ambulance service providers of the city has four levels, the costs of hospital treatment per patient admitted in the hospital will also be considered. According with this classification, an “Evident injury: Moderate” and an “Evident injury: Severe” accidents have the following costs:

Table 19: Average cost of hospital treatment per patient admitted in the hospital [IPEA] (2003)

Severity level	Costs of hospital treatment
Evident injury: Moderate	R$ 14,938
Evident injury: Severe	R$ 92,314
Average	R$ 53,626

By calculating the proportion of “Evident injury: Moderate” and “Evident injury: Severe” accident by the average, we achieved the following ratio:

Table 20: Ratio of the average cost of hospital treatment per patient admitted in the hospital

Severity level	Ratio
Evident injury: Moderate	$\frac{R\$ 14,938}{R\$ 53,626} = 0.28$

Evident injury: Severe	$\frac{R\$\ 92,314}{R\$\ 53,626} = 1.72$

When multiplying the results of "Evident injury" from Table 18 by the results of Table 20, the impact of each accident according to their severity level can be known. Note that the impact of accidents "Code 1: Uninjured or light injury" and "Code 4: Fatal" were calculated in Table 18.

Table 21: Impact of accidents by severity level

Severity Level	Weight distribution
Code 1: Uninjured or light injury	1
Code 2: Non-incapacitating existent injury	$5.35\ x\ 0.28 \cong 2$
Code 3: Incapacitating injury - severe	$5.35\ x\ 1.72\ \cong 9$
Code 4: Fatal (within 30 days)	44

APPENDIX V

Table 22: Sample classification by transport behaviour.

Modal distribution	Frequency	Percentage
Car	75	32.5
Bus	51	22.1
Motorcycle	7	3
Taxi	1	0.4
Bicycle	83	35.9
Walking	12	5.2
Other	2	0.9
Total	231	100

Table 23: Barriers for bicycle use - Frequency table

Barriers for bicycle use	Frequency					Total
	Not important	Little important	Moderately important	Important	Very important	
Insecurity in traffic	5	4	28	62	132	231
Lack of street lighting	4	34	62	82	49	231
Lack of cycling infrastructure	4	10	30	65	122	231
Lack of bicycle parking and/or changing room at the destination point	13	34	64	64	56	231
Lack of signs at the crossings	9	25	58	85	54	231
Behaviour of car users and cyclists in the traffic	3	10	25	60	133	231
Poor surface quality	4	29	77	61	60	231
Topography	28	48	74	54	27	231
Public insecurity	1	23	42	71	94	231
Distance	32	56	63	45	35	231

Need to carry luggage or bags during the travel	35	60	63	45	28	231
Weather conditions	15	36	57	60	63	231

Table 24: Barriers for bicycle use - Central tendency and Variability

Barriers for bicycle use	Mean	Median	Mode	Standard Deviation	Variance
Insecurity in traffic	4.35	5	5	0.915	0.837
Lack of street lighting	3.60	4	4	1.033	1.068
Lack of cycling infrastructure	4.26	5	5	0.961	0.924
Lack of bicycle parking and/or changing room at the destination point	3.50	4	3	1.172	1.373
Lack of signs at the crossings	3.65	4	4	1.073	1.150
Behaviour of car users and cyclists in the traffic	4.34	5	5	0.928	0.861
Poor surface quality	3.62	4	3	1.055	1.114
Topography	3.02	3	3	1.183	1.400
Public insecurity	4.01	4	5	1.015	1.030
Distance	2.98	3	3	1.266	1.604
Need to carry luggage or bags during the travel	2.87	3	3	1.239	1.536
Weather conditions	3.52	4	5	1.226	1.503

Table 25: Facilitators/Motivators for bicycle use - Frequency table

Facilitators/Motivators for bicycle use	Frequency					Total
	Not important	Little important	Moderately important	Important	Very important	
Short distances	14	15	45	71	86	231
Insufficient public transport in the neighbourhood	26	45	49	67	44	231
Security in traffic	10	21	23	64	113	231
Accessibility and cycling infrastructure	5	11	26	68	121	231
Land-use mix	24	35	74	60	38	231
Shorter travel time	2	16	32	96	85	231
Speed reduction measures and proper signs	4	9	28	88	102	231
Integration between bicycle and public transport	13	16	28	64	110	231
Higher fuel prices	22	44	47	55	63	231
Expensive car parking	31	42	39	60	59	231
High cost to have a car	22	31	51	64	63	231

Table 26: Facilitators/Motivators for bicycle use - Central tendency and Variability

Facilitators/Motivators for bicycle use	Mean	Median	Mode	Standard Deviation	Variance
Short distances	3.87	4	5	1.166	1.360
Insufficient public transport in the neighbourhood	3.25	3	4	1.281	1.641
Security in traffic	4.08	4	5	1.158	1.342
Accessibility and cycling infrastructure	4.25	5	5	0.981	0.963
Land-use mix	3.23	3	3	1.199	1.438
Shorter travel time	4.06	4	4	0.928	0.861
Speed reduction measures and proper signs	4.19	4	5	0.918	0.842
Integration between bicycle	4.05	4	5	1.177	1.385

and public transport					
Higher fuel prices	3.40	4	5	1.321	1.746
Expensive car parking	3.32	4	4	1.380	1.906
High cost to have a car	3.50	4	4	1.282	1.642

APPENDIX VI

Table 27: Types of Infrastructure - Frequency table

Types of Infrastructure	Frequency					Total
	Unlikely	Somewhat likely	Neutral	Very Likely	Certainly	
Bicycle Path	4	8	13	58	148	231
Bicycle Lane	1	9	16	60	145	231
Calm Lane	8	28	24	64	107	231
Shared Sidewalk	20	32	42	80	57	231
Bicycle Route	13	36	48	71	63	231
General Roads	46	62	47	55	21	231
Exclusive Bus Lanes	70	47	28	69	17	231

Table 28: Types of Infrastructure - Central tendency and Variability

Type of Infrastructure	Mean	Median	Mode	Standard Deviation	Variance
Bicycle Path	4.46	5	5	0.883	0.780
Bicycle Lane	4.47	5	5	0.822	0.676
Calm Lane	4.01	4	5	1.170	1.369
Shared Sidewalk	3.53	4	4	1.243	1.546
Bicycle Route	3.58	4	4	1.202	1.444
General Roads	2.75	3	2	1.270	1.613
Exclusive Bus Lanes	2.64	2	1	1.373	1.885

APPENDIX VII

Descriptive statistics by transport mode (Cyclists versus Non-cyclists)

Barriers for bicycle use	Transp. Behaviour	N	Mean	Std. deviation	*Independent sample t test*
					Sig. (2-tailed)
Insecurity in traffic	Non-cyclist	148	4.36	0.896	0.869
	Cyclist	83	4.34	0.954	
Lack of street lighting	Non-cyclist	148	3.67	0.972	0.179
	Cyclist	83	3.47	1.130	
Lack of cycling infrastructure	Non-cyclist	148	4.32	0.933	0.223
	Cyclist	83	4.16	1.006	
Lack of bicycle parking and/or changing room at the destination point	Non-cyclist	3.59	1.166	0.096	0.138
	Cyclist	3.35	1.173	0.129	
Lack of signs at crossings	Non-cyclist	148	3.69	1.093	0.452
	Cyclist	83	3.58	1.037	
Behaviour of car users and cyclists in the traffic	Non-cyclist	148	4.35	0.910	0.838
	Cyclist	83	4.33	0.964	
Poor surface quality	Non-cyclist	148	3.64	1.018	0.822
	Cyclist	83	3.60	1.126	
Topography	Non-cyclist	148	3.22	1.093	0.001
	Cyclist	83	2.65	1.254	
Public insecurity	Non-cyclist	148	4.22	0.910	0.000
	Cyclist	83	3.64	1.089	
Distance	Non-cyclist	148	3.26	1.253	0.000
	Cyclist	83	2.47	1.130	
Need to carry luggage or bags during the travel	Non-cyclist	148	3.14	1.256	0.000
	Cyclist	83	2.40	1.059	
Weather conditions	Non-cyclist	148	3.73	1.193	0.000
	Cyclist	83	3.14	1.201	

Facilitators/Motivators for bicycle use	Transp. Behaviour	N	Mean	Std. deviation	*Independent sample t test*
					Sig. (2-tailed)
Short distances	Non-cyclist	148	4.01	1.072	0.020
	Cyclist	83	3.61	1.286	
Insufficient public transport in the neighbourhood	Non-cyclist	148	3.44	1.258	0.030
	Cyclist	83	2.92	1.261	
Security in traffic	Non-cyclist	148	4.15	1.071	0.241
	Cyclist	83	3.95	1.296	
Accessibility and cycling infrastructure	Non-cyclist	148	4.30	0.916	0.274
	Cyclist	83	4.16	1.087	
Land-use mix	Non-cyclist	148	3.31	1.124	0.169
	Cyclist	83	3.08	1.318	
Shorter travel time	Non-cyclist	148	4.07	0.862	0.954
	Cyclist	83	4.06	1.040	
Speed reduction measures and proper signs	Non-cyclist	148	4.12	0.954	0.128
	Cyclist	83	4.31	0.840	
Integration between bicycle and public transport	Non-cyclist	148	4.16	1.107	0.048
	Cyclist	83	3.84	1.273	
Higher fuel prices	Non-cyclist	148	3.51	1.275	0.110
	Cyclist	83	3.22	1.389	
Expensive car parking	Non-cyclist	148	3.48	1.312	0.019
	Cyclist	83	3.04	1.460	
High cost to have a car	Non-cyclist	148	3.61	1.227	0.081
	Cyclist	83	3.30	1.359	
Density	Non-cyclist	140	2.46	0.884	0.771
	Cyclist	77	2.49	0.868	

Types of cycling infrastructure	Transp. Behaviour	N	Mean	Std. Deviation	*Independent sample t test*
					Sig. (2-tailed)
Bicycle Path	Non-cyclist	140	4.43	0.858	0.481
	Cyclist	77	4.52	0.929	
Bicycle Lane	Non-cyclist	148	4.29	0.883	0.000
	Cyclist	83	4.78	0.585	
Calm Lane	Non-cyclist	148	3.69	1.223	0.000
	Cyclist	83	4.59	0.797	
Shared Sidewalk	Non-cyclist	148	3.56	1.191	0.595
	Cyclist	83	3.47	1.337	
Bicycle Route	Non-cyclist	148	3.36	1.179	0.000
	Cyclist	83	3.98	1.147	
General roads	Non-cyclist	148	2.24	1.096	0.000
	Cyclist	83	3.67	1.013	
Exclusive bus lanes	Non-cyclist	148	2.18	1.255	0.000
	Cyclist	83	3.46	1.182	

APPENDIX VIII

Descriptive statistics by income class (Higher income versus Lower income)

Barriers for bicycle use	Income Class	N	Mean	Std. deviation	*Independent sample t test* *Sig. (2-tailed)*
Insecurity in traffic	Classes A, B and C	155	4.35	0.978	0.957
	Classes D and E	76	4.36	0.778	
Lack of street lighting	Classes A, B and C	155	3.57	1.075	0.534
	Classes D and E	76	3.66	0.946	
Lack of cycling infrastructure	Classes A, B and C	155	4.25	1.004	0.855
	Classes D and E	76	4.28	0.873	
Lack of bicycle parking and/or changing room at the destination point	Classes A, B and C	155	3.43	1.206	0.196
	Classes D and E	76	3.64	1.092	
Lack of signs at crossings	Classes A, B and C	155	3.50	1.095	0.001
	Classes D and E	76	3.96	0.958	
Behaviour of car users and cyclists in the traffic	Classes A, B and C	155	4.27	1.002	0.097
	Classes D and E	76	4.49	0.739	
Poor surface quality	Classes A, B and C	155	3.61	1.059	0.830
	Classes D and E	76	3.64	1.055	
Topography	Classes A, B and C	155	3.01	1.192	0.843
	Classes D and E	76	3.04	1.171	
Public insecurity	Classes A, B and C	155	4.04	1.025	0.583
	Classes D and E	76	3.96	0.999	
Distance	Classes A, B and C	155	3.01	1.259	0.555
	Classes D and E	76	2.91	1.288	
Need to carry luggage or bags during the travel	Classes A, B and C	155	2.92	1.222	0.467
	Classes D and E	76	2.79	1.279	
Weather conditions	Classes A, B and C	155	3.56	1.223	0.460
	Classes D and E	76	3.43	1.237	

Facilitators/Motivators for bicycle use	Income Class	N	Mean	Std. deviation	*Independent sample t test*
					Sig. (2-tailed)
Short distances	Classes A, B and C	155	3.90	1.152	0.565
	Classes D and E	76	3.80	1.200	
Insufficient public transport in the neighbourhood	Classes A, B and C	155	3.30	1.295	0.440
	Classes D and E	76	3.16	1.255	
Security in traffic	Classes A, B and C	155	4.17	1.068	0.092
	Classes D and E	76	3.89	1.312	
Accessibility and cycling infrastructure	Classes A, B and C	155	4.34	0.950	0.044
	Classes D and E	76	4.07	1.024	
Land-use mix	Classes A, B and C	155	3.22	1.135	0.863
	Classes D and E	76	3.25	1.328	
Shorter travel time	Classes A, B and C	155	4.04	0.911	0.541
	Classes D and E	76	4.12	0.966	
Speed reduction measures and proper signs	Classes A, B and C	155	4.16	0.964	0.491
	Classes D and E	76	4.25	0.819	
Integration between bicycle and public transport	Classes A, B and C	155	4.13	1.103	0.133
	Classes D and E	76	3.88	1.306	
Higher fuel prices	Classes A, B and C	155	3.38	1.306	0.719
	Classes D and E	76	3.45	1.360	
Expensive car parking	Classes A, B and C	155	3.32	1.377	0.972
	Classes D and E	76	3.32	1.397	
High cost to have a car	Classes A, B and C	155	3.49	1.250	0.899
	Classes D and E	76	3.51	1.351	
Density	Classes A, B and C	147	2.40	0.865	0.095
	Classes D and E	70	2.61	0.889	

Types of cycling infrastructure	Income Class	N	Mean	Std. Deviation	*Independent sample t test*
					Sig. (2-tailed)
Bicycle Path	Classes A, B and C	155	4.46	0.892	0.900
	Classes D and E	76	4.47	0.871	
Bicycle Lane	Classes A, B and C	155	4.47	0.848	0.928
	Classes D and E	76	4.46	0.774	
Calm Lane	Classes A, B and C	155	4.05	1.136	0.552
	Classes D and E	76	3.95	1.243	
Shared Sidewalk	Classes A, B and C	155	3.58	1.216	0.360
	Classes D and E	76	3.42	1.299	
Bicycle Route	Classes A, B and C	155	3.51	1.197	0.178
	Classes D and E	76	3.74	1.204	
General roads	Classes A, B and C	155	2.68	1.222	0.196
	Classes D and E	76	2.91	1.358	
Exclusive bus lanes	Classes A, B and C	155	2.59	1.381	0.437
	Classes D and E	76	2.74	1.360	

APPENDIX IX

Binary Logistic regression by Transport behaviour

Variables	B	Sig.	OR	95% C.I for EXP(B)	
				Lower	Upper
Bikeability Index – General sample	.051	.138	1.053	.803	1.379
Bikeability Index Variables:					
Density	-.024	.889	.977	.703	1.357
Safety	-.081	.352	.922	.778	1.094
Types of Infrastructure	.033	.761	1.034	.835	1.280
Mixed Land-use	.006	.947	1.006	.855	1.182
Topography	.103	.269	1.108	.924	1.329
Barriers for Bicycle use:					
Insecurity in traffic	.096	.689	1.100	.689	1.757
Lack of street lighting	-.025	.888	.976	.692	1.375
Lack of cycling infrastructure	-.184	.388	.832	.548	1.264
Lack of bicycle parking and/or changing room at the destination point	-.026	.855	.974	.733	1.293
Lack of signs at crossings	.066	.724	1.069	.740	1.543
Behaviour of car users and cyclists in the traffic	.184	.460	1.201	.738	1.955
Poor surface quality	.230	.203	1.258	.883	1.792
Topography	-.069	.681	.934	.673	1.296
Public insecurity	-.602	.001	.548	.379	.793
Distance	-.298	.077	.742	.534	1.032
Need to carry luggage or bags during the travel	-.236	.185	.789	.557	1.120
Weather conditions	-.044	.794	.957	.687	1.332

Variables	B	Sig.	OR	95% C.I for EXP(B)	
				Lower	Upper
Facilitators/Motivators for bicycle use:					
Short distances	-.156	.264	.856	.651	1.125
Insufficient public transport in the neighbourhood	-.242	.060	.785	.610	1.010
Security in traffic	-.073	.668	.930	.666	1.298
Accessibility and cycling infrastructure	-.054	.798	.948	.627	1.432
Land-use mix	-.017	.900	.983	.748	1.291
Shorter travel time	.023	.900	1.023	.717	1.461
Speed reduction measures and proper signs	.524	.012	1.689	1.124	2.537
Integration between bicycle and public transport	-.308	.047	.735	.542	.996
Higher fuel prices	.001	.996	1.001	.715	1.401
Expensive car parking	-.156	.418	.855	.586	1.248
High cost to have a car	.021	.905	1.021	.728	1.432
Types of Infrastructure:					
Bicycle Path	-.075	.774	.928	.556	1.549
Bicycle Lane	.374	.356	1.453	.657	3.216
Calm Lane	.461	.135	1.585	.867	2.898
Shared Sidewalk	-.242	.149	.785	.565	1.091
Bicycle Route	-.007	.973	.993	.660	1.494
General Roads	.713	< .001	2.040	1.379	3.019
Exclusive Bus Lanes	.590	< .001	1.805	1.328	2.453
Socio-demographic characteristics					
Education Level	-.054	.741	.947	.686	1.307
Gender	-1.435	< .001	.238	.120	.473
Income Class	-.443	.005	.642	.470	.877
Age	-.054	.002	.948	.915	.981

APPENDIX X

Binary Logistic Regression by Income class

Variables	β	Sig.	OR	95% C.I for OR	
				Lower	Upper
Bikeability Index – General sample	.108	.455	1.114	.840	1.478
Bikeability Index variables:					
Density	-.254	.139	.776	.554	1.086
Safety	.184	.044	1.202	1.005	1.437
Types of Infrastructure	.187	.117	1.206	.954	1.524
Mixed Land-use	.038	.660	1.039	.877	1.231
Topography	-.125	.212	.882	.725	1.074
Barriers for bicycle use:					
Insecurity in traffic	.253	.258	1.288	.831	1.998
Lack of street lighting	.073	.671	1.076	.767	1.510
Lack of cycling infrastructure	.029	.889	1.030	.684	1.550
Lack of bicycle parking and/or changing room at the destination point	-.116	.405	.891	.679	1.169
Lack of signs at crossings	-.536	.008	.585	.394	.868
Behaviour of car users and cyclists in the traffic	-.179	.457	.836	.521	1.340
Poor surface quality	.128	.466	1.136	.806	1.602
Topography	-.098	.555	.906	.654	1.257
Public insecurity	.174	.331	1.190	.838	1.690
Distance	.056	.738	1.058	.762	1.468
Need to carry luggage or bags during the travel	.070	.689	1.072	.762	1.509
Weather conditions	.088	.593	1.092	.790	1.510
Facilitators/Motivators for bicycle use:					
Insufficient public transport in the neighbourhood	.040	.756	1.041	.809	1.340
Security in traffic	.167	.319	1.182	.851	1.642
Accessibility and cycling infrastructure	.207	.322	1.231	.816	1.855
Land-use mix	-.138	.336	.871	.657	1.154

Shorter travel time	-.012	.946	.988	.689	1.415

Variables	β	Sig.	OR	95% C.I for OR	
				Lower	Upper
Facilitators/Motivators for bicycle use:					
Speed reduction measures and proper signs	-.316	.115	.729	.492	1.080
Integration between bicycle and public transport	.229	.131	1.257	.934	1.692
Higher fuel prices	-.029	.867	.972	.694	1.360
Expensive car parking	.039	.840	1.040	.710	1.523
High cost to have a car	.048	.782	1.049	.748	1.471
Types of Infrastructure:					
Bicycle Path	-.113	.595	.894	.590	1.353
Bicycle Lane	.125	.674	1.133	.634	2.024
Calm Lane	.216	.335	1.241	.800	1.927
Shared Sidewalk	.145	.276	1.157	.890	1.503
Bicycle Route	-.308	.075	.735	.523	1.031
General Roads	-.093	.586	.911	.652	1.273
Exclusive bus lanes	-.089	.494	.915	.710	1.180

APPENDIX XI

Residential Density map: