Universidade de Aveiro Departamento de Engenharia Civil

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Catarina Brown de Matos

Relação entre uso do solo e mobilidade urbana. Desafios associados à mobilidade em bicicleta

The relationship between urban mobility and land use. Challenges related with cycling

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do Grau de Mestre em Engenharia Civil, realizada sob a orientação científica do Doutor Joaquim Miguel Gonçalves Macedo, Professor Auxiliar do Departamento de Engenharia Civil da Universidade de Aveiro e coorientação do Doutor Frederico Armando de Moura e Sá, Professor Auxiliar Convidado do Departamento de Ciências Sociais, Políticas e do Território da Universidade de Aveiro.

Don't Sell Cycling, Sell Mobility Solutions

Hans Michael Kloth
Head of Communications International Transport Forum, OECD

O júri / The jury

Presidente / President

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Palavras chave

Uso do Solo, Mobilidade, Acessibilidade, Bicicletas, Estratégias, Promoção

Resumo

A mobilidade suave surge devido aos desafios que as sociedades vêm sentindo ao longo dos últimos anos. Devido à dispersão urbana e às inúmeras deslocações diárias que são feitas maioritariamente por transportes motorizados, a mobilidade urbana está na origem de 40% das emissões de CO_2 e de 70% das emissões de outros poluentes. Este aumento do tráfego nas cidades tem conduzido a um fenómeno de congestionamento crónico, com inúmeras consequências negativas no meio urbano e na qualidade de vida daqueles que partilham esse mesmo espaço.

Esta dissertação de mestrado pretende contribuir para inverter a tendência e aponta um conjunto de medidas e estratégias que contribuem para promover o aumento da mobilidade ciclável nas cidades portuguesas. Surge assim a necessidade de estabelecer uma relação clara entre uso do solo e mobilidade urbana, de modo a aproveitar ao máximo essa relação para promover o uso da bicicleta.

Portugal tem evoluído a um ritmo muito lento, com pouca promoção e incentivo da utilização da bicicleta nas cidades, sobretudo nas vertentes do uso do solo e da mobilidade. Neste sentido, nesta dissertação analisar-se-á a relação entre uso do solo e mobilidade urbana tanto numa perspetiva histórica, evolutiva, bem como no que respeita às variáveis que a influenciam. Posteriormente serão também analisados os fatores que influenciam o uso da bicicleta, de forma a obter-se uma melhor compreensão das medidas políticas de promoção (medidas "hard" ligadas às infraestruturas e uso do solo e medidas "soft" mais relacionadas com a promoção do uso, que reforçam a eficácia das anteriores).

Um dos objetivos principais é contribuir para a iniciativa IMPACT do Compromisso pela Bicicleta, um projeto colaborativo da iniciativa da Universidade de Aveiro, no sentido de fornecer dicas úteis para a promoção da bicicleta. Neste sentido foram analisados vários planos de promoção da bicicleta de modo a avaliar o custo-benefício das várias medidas estratégicas para poder informar à administração política e a todos subscritores do Compromisso pela Bicicleta acerca do custo-benefício das diferentes soluções para promover o uso da bicicleta.

Conclui-se que não existe uma única forma de promover o uso da bicicleta, sendo que o sucesso das estratégias de incentivo ao uso da bicicleta variam de acordo com a extensão e implementação. Neste sentido as estratégias de promoção devem ser implementadas de acordo com a repartição modal observada e com o nível de desenvolvimento de uma dada região, pois a eficácia das medidas diferem. Por exemplo, para a maioria das cidades Portuguesas (com uma utilização da bicicleta menor que 1%) é recomendado que se implementem primeiro medidas "hard" e numa segunda fase as medidas "soft". Apostar na promoção da bicicleta como modo complementar de mobilidade terá benefícios a médio e longo prazo, não só para os ciclistas, mas também para todos os que partilham o espaço urbano.

Keywords Land use, Mobility, Accessibility, Bicycle, Strategies, Promoting

Abstract

Soft mobility arises from the challenges that societies have been facing over the past few years. Due to urban sprawl and numerous daily trips that are mostly made by motorized transport. Urban mobility is the source of 40% of CO_2 emissions and 70% of emissions of other pollutants. This increase of traffic in cities has led to a chronic congestion, with numerous negative consequences on the urban environment and in quality of life of those who share this space.

This dissertation aims to contribute to reverse this trend and define strategical measures that can help increase cycling in Portuguese cities. This raises the need to establish a clear relationship between land use and urban mobility in order to make the most of this relationship to promote bicycle use.

Portugal has been evolving at a very slow pace, with little promotion and encouragement of cycling in cities, especially on land use and mobility. Therefore, this dissertation studies the relationship between land use and urban mobility, both in a historical, evolutionary perspective and the factors that influence them. Posteriorly, cycling influencing factors were also analysed in order to have a better understanding of bicycle promotion measures (Infrastructure and land use measures, to "soft" measures that reinforce the effectiveness of the previous ones).

One of the main objectives is to contribute to the IMPACT initiative of the “Compromisso pela Bicicleta”, a collaborative project of the University of Aveiro, by providing useful tips to promote cycling. In this sense, several bicycle promotion plans are analysed to evaluate the cost-effectiveness of various strategical measures in order to inform the political administration and the subscribers of the bicycle commitment of the cost-effectiveness of the different cycling measures.

There is not only one way to promote bicycle use, therefore, the success of the strategies to encourage cycling vary according to extension and implementation. This is why promotion strategies should be implemented according to modal share and the level of development of a region, because the effectiveness of the measures differ. For example, for most Portuguese cities (with a bicycle share less than 1%) it is recommended firstly to implement "hard" measures and in a second phase "soft" measures. Encouraging the promotion of cycling as a complementary mode of mobility will have medium and long term benefits, not only for cyclists, but for all who share the urban space.

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Acronyms

APA	Portuguese Environment Agency - “Agência Portuguesa do Ambiente”
DGOTDU	Directorate General of Spatial Planning and Urban Development - “Direção Geral do Ordenamento do Território e Desenvolvimento Urbano”
EC	European Commission
ECF	European Cycling Federation
EEA	European Economic Area
EU	European Union
FHWA	Federal Highway Administration
HOV	High occupancy vehicle
IMTT	Institute for Mobility and Land Transport - “Instituto de Mobilidade e Transportes Terrestres”
MUBI	Association for the Urban Mobility on Bicycle - “Associação pela Mobilidade Urbana em Bicicleta”
NMT	Non-motorized transport
OECD	Organization for Economic Cooperation and Development
PMT	Mobility and Transport Plans - “Planos de Mobilidade e Transportes”
TDM	Transportation demand management
TIB	Theory of Planned Behaviour
TPB	Theory of Interpersonal Behaviour
VMT	Vehicle miles travelled

Glossary

It is considered necessary to classify the context of the following terms related to the mobility, due to the ambiguity that sometimes exists between them and their uses.

Mobility	Form as provided accessibility are used in each time and for each movement by citizens, individually and collectively (DGOTDU, 2011). It corresponds to the characteristic of being mobile, moving from one place to other (Alves, 2009). Establishes the links between the various stages of the production chain, allowing the customer service and also a source of employment. (European Commission, 2008).
Accessibility	Relative to a given point, is measured by the provision of infrastructure and various modes of transport services from several sources (DGOTDU, 2011). Sets - qualifies and quantifies - the nearest facility (Alves, 2009).
Sustainable Mobility	Ability to meet the needs of populations traveling costs / acceptable time, safely and comfort, maximizing energy efficiency and minimizing the environmental impact (DGOTDU, 2011). Concept that involves disconnecting mobility from its harmful effects. (European Commission, 2008).
Active modes (Or soft modes)	Are all forms of transport in which the power is supplied by human being: walking trips, bike, wheelchair, rollerblading or even skating (Agence de la santé publique du Canada, 2009). These assets or soft modes are especially competitive in short distances, in urban areas and environments with low speeds, providing an important link between various modes of travel (GART, 2012).

Chapter 1

Introduction

1. INTRODUCTION

This section is an introduction to the subject under study followed by the aims and the structure of this document.

1.1. Motivation

"(...) By 2050, the world has to reduce emissions of greenhouse gas effect in the less than 15%" (European Commission, 2006).

The ever-growing traffic in cities has led to chronic congestion, with numerous negative consequences on the environment and quality of life of those who share this space. It is estimated that in Europe these factors lead to annual losses of 100 billion, or 1% of EU GDP (Gross domestic product), which offset by the unsustainability scrolling options (European Commission, 2007b).

Energy consumption and emissions of many pollutants transport fell in 2009, but this reduction may only be a temporary effect of the economic downturn. Nevertheless, transport still accounts for around a third of all final energy consumption in the EEA member countries, and for more than a fifth of greenhouse gas emissions. It is also responsible for a large share of urban air pollution as well as noise nuisance (European Comisison, 2016).

According to European Commission (2000) more than 30% of trips made by cars in Europe cover distances of less than 3 km and 50% are less than 5 km. For such journeys alone, bicycles could easily replace cars, thus satisfying a large proportion of the demand and contributing directly to cutting down traffic jams. Therefore, it is precisely for these journeys that cycling can compete with the automobile and become a credible alternative to meet the needs of commuting in the city.

Some European countries have realized that the bicycle is a vehicle capable to compete with the car in urban journeys, resulting in more and more cities creating policies and strategies to encourage cycling even in countries with a more hostile climate. For example, in Sweden, considered a cold country, 33% of daily travel in the city of Vasteras is allocated to the bicycle; Switzerland, which is not a plan country, bicycle is used on 23% of all trips in the city of Basel; and even in the relatively rainy English city of Cambridge, 27% of all journeys are made by bicycle (Martens, 2002).

Unlike the previous examples, Portugal has evolved at a very slow pace, with little promoting and encouragement of cycling, especially in the areas of mobility and transportation. For instance, in Lisbon, the Portuguese capital, bicycle use does not reach 1% of the number of daily commuting. Moreover, Portugal has currently one of the highest motorization rates in the world, with 778 vehicles per 1000 inhabitants, and is the third EU country with more cars per inhabitant (European Environment Agency, 2008). In Portugal, the use of soft modes, such as walking or cycling (that was really high a few decades ago), is at the moment commonly related to the stigma of people with low socio-economic situations, whereas, on the other hand, the possession and use of motorized vehicles is associated with the higher economic classes (IMTT, 2012).

1.2. Compromisso pela Bicicleta

As result of international conjuncture due to the political and economic situation in the European Union, Portugal was faced with the need to respond to major challenges, among which, the evolution of the transport sector, towards a competitive and efficient transport system by promoting soft modes. Therefore, many municipalities and organizations have been implementing bicycle plans in the recent years to put bicycle mobility on the public agenda. One of the most recent projects "Compromisso pela Bicicleta" launched on the 26th of April 2016 in Murtosa, a project created by the "Plataforma Tecnológica da Bicicleta e mobilidade suave" of the University of Aveiro that involves the national bicycle manufacturing industry, municipalities, universities, public and private sector, and cyclists'. This initiative has currently about 150 subscriptions and still growing (see Figure 1). "More bicycles, better cities, healthier society and economy!" is the motto of the newly-launched Portuguese Bicycle Commitment that aims to be the pivoting point between different stakeholders (CPB, 2016b).

The main aim of this project is to create collaborative dynamics between participants, bicycle advocacy groups, public administration and institutions related to mobility, road safety, cities, environment, health and sports, university and research centres, as well as local and national media. In sum, a bicycle capital bound on a multinational bicycle network.

Figure 1. Logo and the official launch of "Compromisso pela Bicicleta". Source: CPB (2016b) and Pedais (2016)

One of the ongoing projects of the "Compromisso pela Bicicleta" is IMPACT (IMportant Practices, ACtions and Tips), a collaborative initiative that aims to strengthen the cooperation between all the organizations involved and to increase the possibility of achieving the project goals. This dissertation pretends to contribute to the IMPACT initiative by suggesting some guidelines of low and high impact bicycle strategies (Table 1).

Table 1. The guidelines to the IMPACT collaborative initiative. Source: CPB (2016a)

IMPORTANT PRACTICES	Directed primarily to researchers and umbrella organizations. Intends to compile inspiring examples of initiatives, movements and exemplary practices, national or international, to promote the use of bicycles.
ACTIONS	Directed to all citizens, is the suggestion of transforming actions of low cost and high impact to develop the territories or the physical spaces of the participating organizations to develop new actions.
TIPS	Aims in collecting tips were more experienced bicycle users can share their experience to new bicycle users. They can be generic tips or referenced to particular sites and situations.

1.3. Dissertation Outline

The document is divided into 6 chapters. The structure of this thesis and aims of this research are described in the present chapter. Land use characteristics are examined in chapter 2. A historical approach of the transformation of land use and the current trends as well as the land use variables considered in this study. Mobility patterns and mobility factors are examined in chapter 3, as well as the evolution of urban mobility and transport until the present day.

Chapter 4 reviews recent literature concerning the relationships and impacts between land use and travel patterns. Evidence for interlinkage between land use characteristics and travel patterns is also reviewed as well as a critique of the evidence. Chapter 5 explores the challenges and opportunities of the bicycle as a sustainable and alternative transport mode. It also discusses the evolution of the bicycle, bicycle commuting and factors that affect the level of cycling. Chapter 6 discusses the challenges and promotion of cycling, strategies measures concerning “hard” and “soft” cycling measures and finally an impact analyses of the cycling measures considered. The final remarks of the study and future developments are introduced in chapter 7. The structure of the study is summarised in Figure 2.

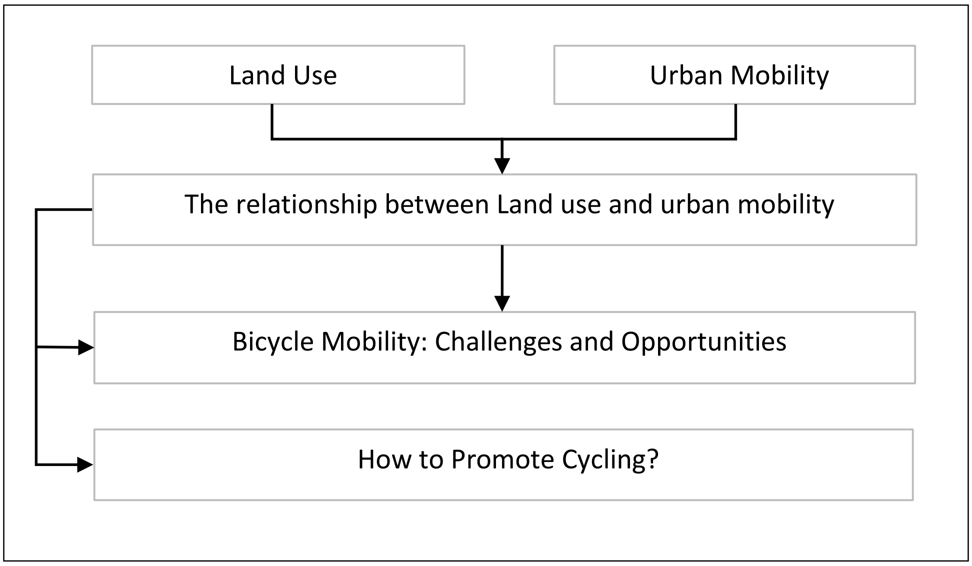


Figure 2. The structure of the study. Source: Developed by the author

Chapter 2

Land-use: actual patterns

2. LAND-USE: ACTUAL PATTERNS

Land Use development patterns also known and related with *Land Development*, *Spatial Development*, *Community Design*, *Urban Design*, *Cityscape*, *Built Environment* or *urban geography*, refers to the human use of the earth's surface, including the location, type and design of infrastructure such as roads and buildings. Land use patterns can have diverse economic, social and environmental impacts. Therefore, land use can be referred by various factors, such as density, mix, connectivity and the quality of the pedestrian environment among others. Moreover, land use science can be defined as an inclusive, interdisciplinary subject that focuses on material related to the nature of land use and their changes over space and time, and the social, economic, cultural, political, decision-making and environmental (Hill and Aspinal, 2008).

2.1. The evolution of land use

Humans have actively managed and transformed the world's landscapes for millenniums. There are many examples of rapid or extensive modifications of the environment by ancient cultures (Redman, 1999). The formation of cities is an ancient process; however, the phenomenon of massive urbanization began with the Revolution Industrial. Moreover, the main changes can be observed over the last past 40 years, especially in the beginning of the century, cities have been subjected to great effects of market forces that have been transforming the city into a more complex entity (Antrop, 2004). Therefore, a notable change in land use can be observed by the growth of residentially oriented suburban neighbourhoods, located further away from employment and service centres, which lead as consequence the decentralisation both of people and facilities to suburban areas. Linked with this growth are the increasing levels of traffic congestion, pollution, and general disenchantment with suburban life (Marshal and Banister, 2007).

Consequences of urban growth may have both positive and negative impacts; however, negative impacts are generally more highlighted since this growth is often uncontrolled or uncoordinated. While the positive implications of urban growth include higher economic production, opportunities for the underemployed and unemployed, better life due to better opportunities, better services, and better lifestyles. Urban growth can extend better basic services (such as transportation, sewer, and water) as well as other specialist services (such as better educational and health care facilities) to more people. However, in many instances, urban growth is uncontrolled and uncoordinated resulting in sprawl (EEA, 2006).

Urban sprawl, an undesirable type of urban growth, is one of the major concerns to the city planners and administrators. In the recent decades, analysis of urban growth from various perspectives has become an essentially performed operation for many reasons. One of the major effects of rapid urban growth is sprawl that increases traffic, gradually weakens or destroys local resources and open space. Urban sprawl is responsible for changes in the physical environment, and in the form and spatial structure of cities. Part of this growing transformation of cities (deeply referenced to the emergence of automobile cities), results from the inconsistency of city boundaries, which reflects the demographic "boom" and the strong influence that change in activities (patterns and lifestyles) has on urban territory (McCormack et al., 2001).

Alternative the land use-transportation planning may be the connection that links environmental consequence of urban form, by increasing density or intensity of land use that supports cycling contrasting to auto-dependent sprawl. Therefore, planning for cycling can reduce carbon emissions, attain air quality standards, reduce sprawl, and meet other objectives.

2.2. Land use variables

An important component of this research is the identification of transportation related land use variables that affect and could potentially affect travel behaviour, therefore, resulting in an increase of bicycle use. The literature review was conducted to assist in the identification of land use variables and on their influence on travel patterns.

To gain an understanding of the impact of land use variables on travel behaviour it becomes necessary firstly to understand land use categories, which can be divided into built-environment and open space (see Table 2). The land use variables studied are based on a various range of factors namely: size, density, diversity, urban structure, accessibility and other aspects related to urban design, such as parking and the influence of railway stations.

Table 2. Land use categories. Source: Litman (2005)

Built Environment	Open space
• Residential (single- and multi-family housing) • Commercial (stores and offices) • Institutional (schools, public offices, etc.) • Industrial • Brownfields (old, unused and underused facilities) • Transportation facilities (roads, paths, parking lots, etc.)	• Parkland • Agricultural • Forests, chaparral, grasslands • Wildlands (undeveloped lands) • Shorelines

In many travel studies, land use transport related measures namely on cycling have usually been named with words beginning with "D". Firstly, the concept of "3D" – density, diversity and design are advanced by Cervero and Kockelman (1997). Most studies are following this original concept in walking and cycling research field. In 2001, this "3D" model was extended to "5D" model by adding two additional "Ds": distance to transit and destination accessibility. "Ds" models are widely used in a global scale beyond North American and Europe. For example, Cervero et al. (2009) applied a "5D" model to investigate the influences of built environments on walking and cycling in Bogota, Colombia – the capital of a developing country, that is well known for its sustainable urban transport systems. However, the results of this study seem unsatisfactory because most factors in "5Ds" on non-motorized travel failed to achieve statistical significance. To date, the original "3D" concept has been developed to "7D" demand management, including parking supply and cost, demographics they are the sixth and seventh D included in a few studies. (Ewing and Cervero, 2010).

On the other hand, research is often based on combined data, land use impacts are often found to be greater when evaluated at a finer scale. Therefore researchers such as Litman (2005) and Sadek et. al. (2011) define among the previous factors other land use factors to avoid overlapping impacts, such as density, mix, connectivity, Parking Management, Transit Accessibility and the quality of the pedestrian environment, as summarized in Table 3.

Table 3. Land use factors. Source: Litman (2005) and Sadek et. al. (2011)

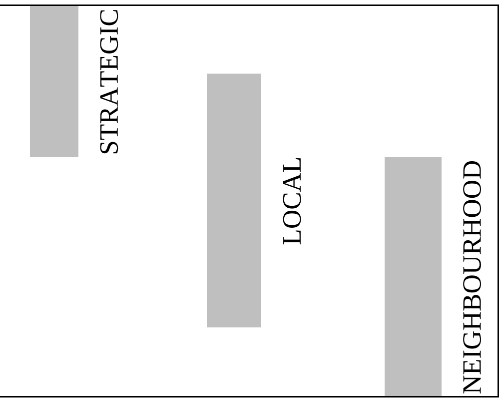
Factor	Definition
Density	People or jobs per hectare.
Regional Accessibility	A site's location relative to the regional urban centre, and the number of jobs and public services available within a given travel time
Centeredness	Degree to which commercial and other public activities are located in downtowns and other activity centres.
Land Use Mix	Degree to which residential, commercial and institutional land uses are located close together
Connectivity	Degree to which roads and paths are connected and allow direct travel between destinations
Roadway Design	Scale and design of streets, and how various uses are managed. Traffic calming refers to street design features intended to reduce traffic speeds and volumes
Walking and Cycling Conditions	Quality of walking and cycling transport conditions. (Active transport is a general term for walking, cycling, and their variants)
Transit Accessibility	Degree to which destinations are accessible by quality public transit
Parking Management	Number of parking spaces per building unit or hectare. Parking management includes pricing and regulations
Transportation Demand Management	Various strategies and programs that encourage more efficient travel patterns, often implemented as an alternative to road and parking facility expansion, and in conjunction with land use policy reform.

This table describes various land use factors that can affect travel behaviour.

Authors such as Stead et al., (2000), use different variables and scales to characterise land-use, characteristics that can affect mobility patterns that can be examined in three different spatial scales. Stead and Marshall, (2001) examined various studies of the influence of land-use on travel patterns and they recognised that there is no definitive way of deciding these categories, many of them overlapping within each other. Their study focuses on various aspects of urban form, ranging from regional strategic planning level down to specific local planning issues at a neighbourhood scale (see Table 4). At the strategic level, urban form concerns the location of new development in relation to existing towns, cities and other infrastructure, as well as size and shape of new development and the type of land use. While at the local level, structure of the city, the type of land use, concentration and development (related to clustering), diversity of land uses and density (housing and employment). Finally, the neighbourhood level intersects some of the features mentioned above and urban design (Meurs and Wee, 2004).

Table 4. Land use characteristics that can affect travel patterns. Source: Stead and Marshall, 2001.

LOCATION with respect to existing towns, cities and infrastructure
STRUCTURE of development – size and shape
LAND USE TYPE and overall mix
CLUSTERING/CONCENTRATION of development
LAND MIX – level and scale of mix
DENSITY of development (population and employment density)
LAYOUT of development (movement networks, neighbourhood type)



Two recent Portuguese studies, namely Pinho et al. (2007), concerning the Development of a Strategical Program for the 2nd Phase of the Oporto Metro Project, and Silva (2008), concerning a accessibility-based design support tool SAL (Structural Accessibility Layer) – a new approach in studying land use and transport planning for mobility management. Both studied and monitored mobility patterns in the metropolitan area of Oporto, by identifying the patterns of use, occupation and transformation of land uses in different scales (local and strategical) in order to have a better understanding of the mobility patterns in the region. These studies aim to combat the fragmented and disconnected territory of the region, given the much-needed territorial gains in competitiveness, environmental sustainability and social cohesion, which are key factors in the development of metropolitan area of Oporto.

Land use plays a significant role in the planning and implementation of all modes of transportation, therefore, the following subsections evaluates and studies the different land use factors primarily in terms of density, size, land use mix, distance, centricity, proximity to transport networks, road network type, roadway design, neighbourhood type, packing management and active transport (walking and cycling).

2.2.1. Density

Density refers to the number of homes, people or jobs per unit of area (acres, hectares, square-miles or square kilometres) (Stead, 1999). Population density may be linked to travel patterns for several reasons. Firstly, higher population densities widen the range of opportunities for the development of local personal contacts and activities that can be maintained without resort to motorised travel. Secondly, higher population densities widen the range of services that can be supported in a local area, reducing the need to travel long distances. Thirdly, higher density patterns of development tend to reduce average distances between homes, services, employment and other opportunities, which reduces travel distance. Fourthly, high densities may be more amenable to public transport operation and use, and less amenable to car ownership and use, which has implications on modal choice (Stead and Marshall, 2001).

It can be measured at various scales: site, block, census tract, neighbourhood, municipality, county, urban region or country. Density can affect travel activity in several ways (Litman, 2005):

- Increased proximity (geographic accessibility). Increased density tends to reduce travel distance to destinations and increases the portion of destinations within cycling distances.
- Mobility options. Increased density tends to increase the cost efficiency of sidewalks, paths, public transit services, delivery services, resulting in more and better transport options.
- Reduced automobile travel speeds and convenience. Increased density tends to increase traffic friction (interactions among road users) which reduces traffic speeds, and higher land costs reduce parking supply and increase parking pricing.
- Complementary factors. Density is often associated with other urban land use features such as regional accessibility, centricity, land use mix, roadway connectivity, reduced traffic speed, and better transport options, reduced parking supply and increased parking prices, which reduce automobile travel speed and affordability.
- Historical conditions. Many denser neighbourhoods developed prior to 1950 were designed for multi-modal access (with sidewalks, connected streets, local shops, transit services, limited parking, and regional accessibility), while newer, lower-density, urban fringe neighbourhoods were designed primarily for automobile access.

As previously mentioned, density tends to be positively associated with other land use factors that affect travel including regional accessibility, mix, roadway network connectivity, improved transport options and reduced parking supply. When evaluating the impacts of density on travel activity it is important to specify whether it considers aggregated density (density and its associated land use factors, sometimes called compactness) or disaggregated density (density by itself, with other land use factors such as mix, street connectivity and parking supply considered separately).

2.2.2. Mixing of land uses

Mix of uses refers to the degree to which different land uses are contained within a geographic area, generally a building, a street or a neighbourhood. It may be specified within the masterplan for a development area or a particular development site (Rodgers, 1997). Within predominantly residential areas ‘mixed use’ generally refers to the provision of local facilities which enable many day to day activities to be undertaken on foot and ensure good accessibility without the need for car use (Seaborn and Headicar, 2009).

The mixing of land uses may affect the physical separation of activities and therefore influence travel demand. The more mixed the land use, the greater the opportunity of activities and services within the immediate area. The hypothesis is that average travel distance per person is lower where land uses are more mixed. The mixing of land uses is measured using ward-level job ratio. This is the ratio of the number of persons employed to the number of residents available for work in the ward. It indicates the availability of local employment and to some extent the availability of local facilities (since local facilities add to the number of local jobs) (Stead, 1999). The way to quantify the ratio between housing and employment is through the ratio between the number of inhabitants and the number of jobs within a defined area. It is important, when defining this area that includes the administrative centres and the surrounding housing (Peng, 1997).

Social features in this aspect have much relevance because people do not always choose to abide by the location of their jobs, or it is not always possible to combine the jobs in the same area within the family residence. Diversity of mixed uses essentially affects the choice of transport mode time and the amount of travel distances, especially for mandatory trips that do not include work trips, such as trips to the supermarket or for trips in the middle of the day (Quade, 1996).

2.2.3. Settlement size

There has been a relatively large amount of research concerning the relationship between settlement size and travel patterns. The relationship between settlement size and travel patterns is unlikely to be simple due to the interplay of competing factors. Large metropolitan settlements are associated with low travel distance and transport energy consumption. In large urban areas shows no easily identifiable relationship between urban population size and modal choice (Stead and Marshall, 2001).

Settlement size may affect the range of local jobs and services that can be supported and may influence the range of public transport services, which can be provided. This depends on both the area occupied and by the number of inhabitants. Settlement size is a key factor influencing the range of jobs and services that can be supported and may influence the range of public services that can be provided locally. On the one hand small towns tend not to support as many services and facilities (which requires extensive travel distances) while on the other hand, large cities can motivate large distances between jobs and housing. In dense cities, the population tends to move to the suburbs in search of calmer environments and larger areas of housing. For these reasons, the relationship between the size and mobility patterns is not very explicit, for example, the distance may be greater if the city area is greater, but the social factors have a greater influence than the size of the city (Stead and Marshall, 2001).

Regarding the travel time due to city size, this is substantially higher in larger cities, because the densities are higher, the transport system are more complex, and more difficult to circulate. The frequency and the modal choice of transport are mainly affected by other conditions of land-use. The study of Stead (2000), which relates the distance to the city centre with the land use variables found that as the distance increases, travel frequency also increase. The same study concluded that the fact that smaller agglomerations do not have an effective system of public transport, it motivates the increase use of the car.

In conclusion the size of the settlement, is not one of the variables with the highest influence on mobility patterns, therefore this variable will manly influence the distance, the mode of transport, and consequently the energy consumed (Banister and Banister, 1995).

2.2.4. Distance of residence from the urban centre

Distance from the city centre also known as regional accessibility, the distance from the residence to the downtown area is a key factor influencing the accessibility to a number of facility types. The proximity or remoteness of these facilities from the residence has a strong influence on the distances needed to reach daily or weekly destinations. The accessibility to service facilities is very different in central and peripheral areas. Commuting distances work-residence is strongly influenced by how far away from the town centre the residence is located therefore the location of the residence relative to the town centre is one of the variables with the strongest effect on the weekly distance travelled (Naess, 2000).

The greater use of motorized transport lies in the fact that many residents of metropolitan regions live a significant distance from the city centre. There are very clear links between living in a peripheral neighbourhood and depending on the automobile as the primary mode of transportation for day-to-day travel. The farther people live from the city centre, the more time they spend behind the wheel. The proximity to the urban centre is likely to influence travel distance since many jobs and services are in urban areas. It is likely that travel distance increases as the distance to the nearest urban centre increases. Very high distances from urban centres may also influence the frequency of journeys, particularly for more optional journeys (such as social or entertainment purposes (Turcotte, 2005).

In summary, the increasing distance from home to the urban centre is associated with increasing travel distance, an increasing proportion of car journeys and increasing transport energy consumption. Trip frequency however does not vary significantly according to the distance between home and the urban centre.

2.2.5. Centricity

Centricity (also called centeredness) refers to the portion of employment, commercial, entertainment, and other major activities concentrated in multi-modal centres, such as central business districts, downtowns and large industrial parks. Such centres reduce the amount of travel required between destinations and are more amenable to alternative transport modes. People who live or work in major activity centres tend to rely more on alternative modes and drive less than in dispersed and more remote locations.

Frank and Pivo, (1991) found that automobile commuting declines significantly when workplace densities reach 50-75 employees per gross acre. While Barnes and Davis (2001) found that employment centre density encourages transit and ridesharing. Centeredness affects overall regional travel and not just the trips made to the city centre (Ewing et.al., 2002). For example, Los Angeles is a dense city but lacks strong centres and so is relatively automobile dependent, with higher rates of vehicle ownership and use than other cities with similar density but stronger centres (Eidlin, 2010).

2.2.6. Provision of local facilities

The provision of facilities and services can clearly reduce travel distance and increase the number of short trips that can be performed by non-motorized modes. There is little evidence collected on this subject however it is unknown how the location of facilities and services impacts travel patterns (Stead et al., 2000). Winter and Farthing (1997) reported that the location of local facilities and services in new residential areas can reduce the travel distances however does not necessarily mean that they alter the amount of non-motorized journeys. Hanson (2004) reports that the proximity to local facilities is positively associated with average distance, increasing journey frequency, although the effects of increasing journey frequency is not as strong as the effects of reducing trip length.

In summary from these studies, there is a mutual consent about the effects of local facilities and services on travel patterns. The provision of local facilities may overall contribute to less travel but might not contribute to any more travel by less energy intensive modes, such as walking and cycling (Stead and Marshall, 2001).

2.2.7. Proximity to transport networks

The proximity to transport networks also influences transport patterns and consequently the energy consumed. Better access to major networks especially rail networks, increases the speed of travel and increases the distance that will be able to be a covered in a fixed time. Transport networks can influence the development, both residential areas and employment development. Proximity to major transport networks can lead to transport patterns characterized by long trips and higher energy consumption.

Curtis, (1996) report that the proximity to major transport networks have a substantial effect on home-work distances, they concluded that proximity to highways and major road networks is associated with longer trips and higher car use. He also concluded that the proximity to rail networks are related to greater distance travel and less car trips. While Kitamura et al., (1997) reports that the distance from home to the nearest bus and train stations affect the modal choice. The proportion of car trips increases and the proportion of non-motorised trips decrease with increasing distance from the nearest bus stop, while the proportion of train trips decrease with increasing distance from the nearest rail station.

Although the proximity to main transportation networks influence transport patterns and consequently the transport energy consumption. Better access to main transport networks particularly railways and major road networks increase travel distances and speeds witch can be covered in a fixed time. Therefore, main transport networks influence both residential and employment development. The availability of residential parking can be related to the frequency of trips and modal choice, with the increase of availability residential parking increases the amount of car trips (Stead and Marshall, 2001).

2.2.8. Road network type

Transport network is considered to be a rather stable component of urban dynamics, as transport infrastructures are built for the long term use. Especially large transport terminals and subway systems that can operate for a very long period of time. The main contribution of the transport network to urban dynamics is the provision of accessibility. Changes in the transport network will impact accessibility and movements (Stead and Marshall, 2001).

The second basic element of an urban concept is the transportation network. In theory, networks are divided into three different categories, for motorised transport (and road network for the car), nonmotorised transport (network for bicycles and/or pedestrians), and for public transport.

According to Snellen et al. (2002), demonstrated that city network type, has a significant impact on travel distances. The number of motorised kilometres in cities with a ring network is significantly higher than the other network types. The number of trips per year tends to be higher in cities with a radial network as compared with cities with a grid network.

Cities with a radial network show an increased use of nonmotorised transport modes, both in number of kilometres and in number of trips for the home-to-work commute.

Area accessibility depends on the inter-connectivity of particular origins and destinations. That means that the layout of a road network influences the area's accessibility. Road network connectivity depends on road density in a certain area for each transport mode. Increasing a road network's connectivity increases the possibility of choosing routes and decreases the travel distance between origins and destinations. Higher road network connectivity significantly affects an area's accessibility and transport efficiency. In many cases there is intentional use of different levels of a road network's connectivity for different travel modes (certain areas are divided into smaller parts, in which there is good public transport connectivity as well as a high level of sidewalks and cycling routes; however, use of cars is usually required to make longer journeys).

A hierarchical road network results in congestion and decreases the use of non-motorized travel modes. Such a road network lacks any direct connection between minor roads; so most trips involve travel on major roads. A hierarchical road network decreases accessibility (the need to make longer trips to reach destinations), increases the probability of congestion (a higher level of road traffic on major roads) and seriously degrades the conditions for non-motorized travel modes (wider roads, a higher volume of traffic and travel speeds). This type of road network can be seen in many cities or towns that were built before the automobile era. While a traditional grid type of road network provides better accessibility due to the better connectivity of its origins and destinations. Suitable conditions for non-motorised travel modes can be secured by more intersections, which result in a slower traffic flow. A traditional road network is also less likely to stop functioning (blockage of one connection does not mean the collapse of the whole network).

From the point of view of land use and transport planning, however it is important to design road networks, which minimise their impact on the environment and establish suitable conditions for the quality of life in an area. This goal can be achieved by the modification of a traditional road network, which is characterized by short and inter-connected roads (low travel speed and traffic flow volumes, direct connections between origins and destinations). Accessibility can be increased by the location of a non-motorized network. Traffic calming measures are used in areas with a high traffic volume and increased traffic flow speeds. Improved road network connectivity reduces the travel distance between each origin and destination and can support the use of alternative modes of transport. An important outcome of increased connectivity is also a reduction in the number of vehicle-kilometres, which has a direct impact on the occurrence of congestion, a reduced number of traffic accidents as well as lower air pollution.

2.2.9. Roadway design

Roadway design refers to factors such as block size, road cross-section (lane number, widths and management, on-street parking, medians, and sidewalks), design speeds and speed control, sidewalk condition, street furniture (utility poles, benches, garbage cans, etc.), landscaping, and the number and size of driveways. Roadway designs that reduce motor vehicle traffic speeds, improve connectivity, and improve cycling conditions tend to reduce automobile traffic and encourage use of alternative modes, depending on specific conditions. Detailed analysis by Marshall and Garrick (2011) of travel patterns in 24 mid-size California cities found that roadway design factors significantly affect resident's vehicle travel. The found that per capita vehicle travel tends to:

- Decline with increased total street network density (intersections per square-kilometre);
- Decline with a grid street system (which provides many routes between destinations) compared with a hierarchical system (which requires traveling on major arterials for a greater portion of trips);
- Decline with on-street parking, bicycle lanes, and curbs/sidewalks;
- Decline land use density and mix, and proximity to the city centre;
- Decline with increased cycling and transit commute mode share;
- Increase with street connectivity (street link-to-node-ratio, which declines with more dead-end streets);
- Increase with increased major street network density (intersections per square kilometre);
- Increase with the number of lanes and outside shoulder widths on major roadways;
- Increase with curvilinear streets.

2.2.10. Neighbourhood type

Neighbourhood type is effectively a complex variable that is used to characterise areas of cities that are relatively homogeneous according to a range of attributes. These attributes typically include the age of development (such as pre-war or post-war), the style of development (traditional, conventional or neo-traditional for example) and the street network type, such as grid, loop and tree (Stead and Marshall, 2001).

Naess (2000) carefully explored the interrelationships between regional-scale and neighbourhood-scale environments, and travel behaviours. The location of an individual's residence close to the centre of a region increases the likelihood of that individual being surrounded by a high-density and mixed-land-use neighbourhood. Proximity to high-density and mixed-land-use neighbourhoods results in shorter distances to job opportunities as well as to local services. Shorter distances to destinations also imply that inner-city residents may choose to walk or bicycle instead of using motorized transportation. Thus, residents of old and inner-city neighbourhoods tend to show a higher tendency for walking.

Residents of walkable neighbourhoods took more walking trips to/from work only when the neighbourhood was located close to the central area or regional job canters. It is notable that even residents of walkable neighbourhoods rarely had jobs within a walkable distance from home. A more common pattern of work trips involved the combination of walking and other modes of travel, such as bus or rail. Most of the public transportation networks are designed to serve areas close to downtown or regional job canters. Therefore, those who live farther from such areas may have fairly limited access to the public transportation system and therefore tend to give up walking as a mode of travel to/from work even when their residential neighbourhoods have more walkable characteristics (Cho and Rodriguez, 2015).

Cervero and Radisch (1996) found those living in traditional neighbourhoods made two to four more walk/bicycle trips per week to neighbourhood stores than those living in nearby areas that were served mainly by automobile-oriented. Residents of mixed-use neighbourhoods, however, averaged similar rates of auto travel to regional shopping malls, suggesting that internal walk trips did not replace, but rather were in addition to external driving trips.

Although these findings may tend to support the commonly recognised association of 'traditional' neighbourhoods with pedestrian and transit orientation, and 'conventional suburban' neighbourhoods with car orientation, this does not necessarily imply causality between travel behaviour and either the land use or layout components of the neighbourhoods (Stead, 2001).

2.2.11. Parking management

Parking Management refers to the supply, price and regulation of parking facilities. More efficient management can reduce the parking supply needed, allowing increased land use density and mix, wider sidewalks and bicycle paths (bicycle lanes often conflict with on-street parking), and parking pricing.

Limited availability of residential parking may discourage car ownership and use, particularly if finding parking space close to home is difficult. Evidence from Kitamura et al., (1997), shows that availability to residence parking is linked both to the frequency of the trips and the modal choice, therefore the availability of residential car parking increases in average the number of trips per person decreases. Kitamura. et al. also suggest that residents with more parking spaces make fewer and longer journeys, will residents with fewer parking spaces make more journeys but theses ones are shorter. The study also stats that the availability of residential parking increases, the proportion of car journeys also increase, therefore residents with more parking spaces not only make fewer and longer journeys but also that these journey are more car based.

Evidence indicates that travel distance per person is lower by up to 7 kilometres per person per week in areas where there is a residential parking scheme. Thus, the evidence suggests that limited residential parking may reduce travel distance. It may be that there are both direct and indirect effects. The limited availability of parking may lead to more `rational' car use as residents seek to reduce the number of journeys and hence the number of times they have to search for a parking space on their return home (Guo and Ren, 2012).

The research of limited residential parking may also indirectly contribute to less travel by suppressing car ownership, which this study identifies as a strong determinant of travel distance. However, it is suggested that difficulties in finding a parking space may not necessarily deter car ownership or intentions to acquire additional vehicles even with increasing parking problems (Naess and Jensen, 2004).

2.2.12. Active transport (walking and cycling) conditions

The quality of active transport (walking and cycling, also called nonmotorised transport or soft modes) conditions can affect travel activity in several ways. Improved walking and cycling conditions tend to increase nonmotorised travel, increase transit travel, and reduce automobile travel (Buehler and Pucher (2010); Mackett and Brown (2011) and Sciara et. al. (2010)). Many surveys ignore nonmotorised links of motor vehicle trips. For example, a bicycle-transit-walk trip is usually classified simply as a transit trip, and a motorist who parks several blocks from their destination and walks for local errands is classified simply as automobile user. More comprehensive surveys indicate that non-motorized travel is three to six times more common than conventional surveys indicate. As a result, if official data indicates that only 5% of trips are non-motorized, the actual amount is probably 10-30% (Rietveld, 2000).

Cycling conditions are affected by (Litman, 2005):

- The quality of sidewalks, crosswalks, paths, bicycle parking, and changing facilities;
- Ease of road crossing (road width, traffic speeds and volumes, presence and quality of crosswalks) and protection (separation between traffic and non-motorized travellers);
- Network connectivity (how well sidewalks and paths are connected);
- Security (how safe people feel while walking);
- Environmental quality (exposure to noise, air pollution, dust, sun and rain);
- Topography (inclines);
- Land use accessibility (distances to common destinations such as shops and schools);
- And attractiveness (quality of urban design).

Sidewalks and path improvements tends to increase non-motorized travel, with impacts that vary depending on conditions (ABW, 2010, 2014; Schwanen and Mokhtarian, 2005; Sciara et al., 2010; Thompson et al., 2009). Each additional bikeway-mile per 100,000 residents increases bicycle commuting 0.075% (Dill and Carr, 2003). Ryan and Frank (2009) found that residents living within a half-mile of a cycling trail are three times more likely to cycle compared to other areas and that improved walkability around bus stops increases transit travel. International data indicates that the percentage point increase in non-motorized transport is associated with a reduction of 700 annual vehicle-miles, about seven vehicle-miles reduced for each additional active transport mile, data show that vehicle travel tends to decline as non-motorized travel increases (see Figure 3).

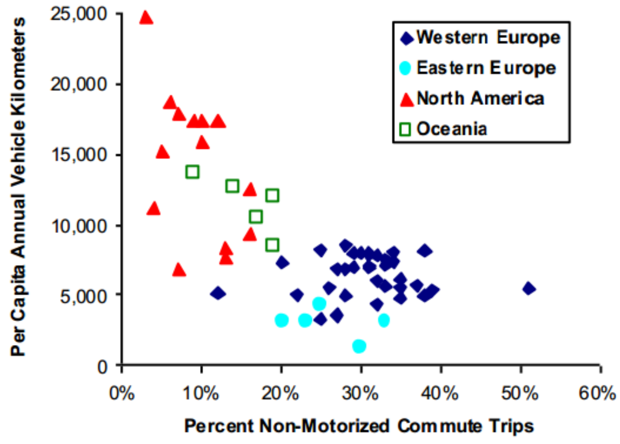


Figure 3. Non-motorized vs. motorized transport. Source: Kenworthy and Laube (2000)

2.3. Summary and discussion

The present work pretends to be a humble contribute to increase the knowledge about the importance of land use variables in the promotion of cycling.

The term built environment, is characterized as the design, construction, and management of buildings, spaces and products that have been developed or altered by people. It relates to land uses, transportation systems, buildings, parks, traffic systems, trails, housing and so forth. Built environment research over the past decade has sought to understand if its characteristics have significant effects on active transport; however, many causal pathways still need to be elucidated. Therefore, built environment planning decisions can have many direct and indirect mobility impacts. These impacts are often significant and should be considered when evaluating a particular policy or project.

Transport and land use is inextricably linked, whereby transportation infrastructure attracts land use development and in many aspects it is unlocked by the provision of high quality, integrated transport infrastructure and services.

Land use and land management issues are a great concern around the world, they are an issue involving many stakeholders, and with an impact on all economic and social sectors as well as the environment. Consequently, effective planning and management is needed to reconcile all stakeholders' objectives and to bring them all together in a way that results in sustainable land use. Insufficient knowledge regarding the implementation and performance of comprehensive land-use plans is a common problem in land use planning, especially between the link of built environment planning and soft mobility as an active transport mode.

Although, the lack of an agreed-upon conceptualization of "built environment" is apparent in the inconsistent approach to defining and measuring dimensions of the built environment in the empirical studies. Numerous studies from the field of urban planning have examined the link between the built environment and automobile use (Ewing and Cervero, 2001), but fewer have focused on the link between the built environment and walking or cycling (Saelens et. al., 2003). Although most of these studies are focused on North American and Australian cities, the findings provide a valuable and suitable framework for the evaluation of other urban situations.

The urban geography is continuously changing. Suburbanisation and urban sprawl have altered the classical monocentric city and given rise to new polycentric urban forms, however, urban sprawl is not an exclusively geographical phenomenon, it also has socio-economic drivers and consequences. Therefore, the goal is rather to manage urban sprawl by prioritising intensification and mixed-use development, providing transportation alternatives and housing choices, and preserving natural heritage, while still promoting targeted economic growth in order to reduce per capita the consumption of land use and energy, lower the cost of infrastructure and make transport more viable (Eidelman, 2010). Therefore, the actual city geography is not 100% prepared for cycling, however, city's geography, land use patterns, and street layout offer ample opportunity for development and could significantly enhance mobility and safety for both cyclists and all road users.

Chapter 3

Urban mobility: actual patterns

3. URBAN MOBILITY: ACTUAL PATTERNS

Much of the relevant travel behaviour literature focuses on improving our understanding of how the built environment influences an individual's travel mode choice, specifically the decision to drive versus walk, bicycle, or use public transport (Zhang, 2004).

Urban mobility can be defined as the manner and frequency of personal travel necessary to meet a specific need, in interaction with the space they inhabit and society (APA, 2004a). The Brundtland Report defends that urban mobility should promote economic development, the development of towns and cities, the quality of life of its inhabitants, as well as the protection of environment this report introduces for the first time the concept of sustainable mobility (United Nations, 1987).

According to Bertolini et al. (2008), factors such as size of the urban space, complexity of the activities, the availability of transport services and population characteristics influence mobility patterns. Currently, urban mobility is not just a simple connection between different locations of a metropolis area, but as an urban framework, that enhances the expression of desires and needs.

Urban mobility has risen dramatically over the past century, travel patterns are more diversified and random (APA, 2004b). The pattern of population mobility has changed, with the increase in the dispersion of residential areas and decentralization services and economic activities. Allied to this trend, we are witnessing today, a huge growth of car use.

The continued increase in greenhouse gas emissions is strongly associated with the transport sector. The increase of traffic congestion in time and space, the destruction and devaluation of public spaces, with the consequent deterioration of the urban environment, is becoming increasingly unsustainable. Therefore the need to find new mobility solutions that can mitigate the environmental and economic consequences of the motorization is a very important issue (APA, 2004b).

3.1. The evolution of urban mobility

The mode of transportation determines largely the possibilities of movement and even the degree of accessibility. Technology allowed an exponential increase of travel speed as well as the number of travellers. Important steps in the technological innovation of transportation modes, as well as some specific impacts upon the landscape (Antrop, 2004).

Thinking about the evolution of mobility naturally begins with walking and wheel. Before the Industrial Revolution, transportation was rudimentary. Goods were transported on river barges but this was a slow and costly. The railway network was non-existent, limited to wooden tracks and carriages pulled by horses. Advances in steam engine technology led to a number of industries adopting mechanisation. Trains (commercialized about 1830) and motor cars (first produced in the 1890s) displaced horses and other previous transport modes. Other means of transport such as canals, rails, roads, and airways have successively occupied shares of the overall length of the transport infrastructure, enabling the sequence of moving technologies.

According to Ascher (2010) mobility has significantly evolved in the past, under the influence of industrial evolutions. Following the first industrial revolution enabled by the invention of steam-powered technology, the railway industry emerged. The second industrial revolution with mass production enabled the emergence of the automobile industry and, closer to us, the third industrial revolution with digitalization enabled the emergence of computer-aided travelling (for example GPS in a car).

Today we are entering what could be called a fourth industrial revolution, represented by industry and technology convergence, leading to the emergence of for example clean energy vehicles or connected mobility solutions. This evolution is particularly noticeable over past years in network industries (such as telecommunication and media, utilities and the mobility industry) as well as in retail and healthcare industries where, driven by evolving customer needs and enabled by rapidly evolving technology, business models are continuously evolving (Audenhove et al., 2014).

3.2. Mobility paradigm shift

During the twentieth century and the beginning of this century, the world population experienced a quite significant growth - in 2010 more than half the population lived in cities and urban areas (UN, 2012). At the same time, development policies now give greater emphasis to issues related to the city itself and all those who reside and move in it.

In 1972, with the Stockholm Conference, Human Environment, held by the UN, gives the kick-off for a real and growing concern for the environment and the welfare of citizens. Since then they have been held numerous conferences with representatives of different countries and cities, which came out letters of intent and statements on measures and positions to be taken in relation to concerns of the contemporary world citizens, towards improving the quality of life and sustainable development (United Nations, 1972). Among many of the meetings, stand out, the Conference Rio 92 (UNCED, 1992), Jonesburg Declaration (United Nations, 2002), the Aalborg Charter 94 (1994), the Declaration of Hanover 2000 to 2007 Leipzig Charter (European Commission, 2007a), and more recently, the Rio+20 (2012) conference. Sustainable development, global warming, the quality of life and sustainable mobility are some of the issues widely discussed by scientific community, both for its scope or the growing importance they have on society issues that have implications and question the recent mobility system.

Mobility needs have grown exponentially, and its standards have changed significantly in recent decades, mainly due to the increasing use of individual transport, with negative consequences in terms of air quality, noise, health (Illich, 1974). Therefore, it becomes unavoidable to change the mobility paradigm, in which the mobility concepts sustainable and promoting the use of soft modes have been gaining ground in to perspective ensure the movement of people, goods and services with less environmental impact, economic and social. Alves (2012) argues that sustainable mobility should be based essentially on three main pillars: correct planning; investment in public transport and non-motorized transport; and restriction measures to car use, in coordination with each other.

3.3. Sustainable mobility

Although there is no universally accepted definition of sustainable mobility there is a broad consensus, as the main features that it should include (Steg and Gifford, 2005). The World Business Council for Sustainable Development states, "Sustainable Mobility is the ability to provide social needs without sacrificing other human values and the environment in the present or in the future". Fundamentally, sustainable mobility is one that allows the satisfaction of economic and social needs without exceeding certain levels of generated negative externalities of the transport system in an increase in the context of urban mobility.

In terms of urban space, this means a reduction in usage levels of car and boost the use of public and non-motorized modes, consolidating soft modes as a viable alternative. For this it is essential to control urban sprawl, rehabilitate the existing city and mix the uses and social groups, as a factor of integration, aspects that are necessarily for the management and planning (APA, 2004b). This concept assumes that citizens living in cities, towns, villages, equipped with conditions that provide them safe, comfortable travel, with acceptable travel times, affordable, energy efficient and with reduced environmental impacts (IMTT, 2012).

Banister, (2008) argues that to achieve true sustainable mobility, mutual cooperation is necessary between experts, researchers, policy makers, academics, practitioners and activists in the areas of transport, planning, engineering, sustainable modes and public transport.

In the 70s, the great aim was to increase the number of vehicles per person but currently, the paradigm begins to change and the emerging concern is the promotion of sustainable mobility, decreasing the dependence of the automobile and increase the number of pedestrians traveling through the change of citizens' habits.

One of the basic principles to improve urban mobility involves limiting the use of automobile, promoting pedestrian and bicycle traffic and improving public transport by adopting both a proper planning policy and transport managed efficiently. Sustainable mobility should be promoted through integrated policies that contribute to sustainable development of territories and society, creating sustainable cities in a whole, trained to achieve the following objectives (Banister, 2008):

- Reduction of travel distances;
- Increase of soft mobility and public transport;
- Mobility reduction with use of the car;
- Reduction of energy consumption;
- Promotion of intersectoral cooperation;
- Awareness of the population and;
- To promote the quality of life and general well-being.

The challenges are that taking in consideration the urban sprawl and extension, the sustainable mobility is no doubt a counter cycle issue. That’s why this work focuses basically on land use issues.

3.4. Urban mobility variables

A wide range of indicators representing travel behaviour have been employed in different studies, including number of trips (Ewing et al., 1996), travel distance (Morency et al., 2011,Stead et al., 2000 and Cervero and Kockelman, 1997), travel duration (Kamruzzaman et al., 2011 and Curtis, 1996) and transport energy consumption (Banister and Banister, 1995 and Næss, 1993). There are a variety of ways in which travel demand and modal choice can be measured, that will be discussed in more detail the following subsections. The literature review is divided according to five measures of travel patterns

1. Travel distance;
2. Travel time;
3. Journey frequency;
4. Modal split;
5. Transport energy consumption.

3.4.1. Travel distance

Since the amount of energy used for transport depends on distance travelled as well as mode choice, many previous studies have focused on the impact of urban form on travel distance. (Schwanen et al., 2004a). Among many studies about travel patterns, travel distance and its relationship between different land use characteristics can be divided in three different groups. Studies about the average journey distance Hanson (1982), Gordon et al., (1989), average journey distance by car Marshal and Banister (2007), Levinson and Kumar, (1997) and Schwanen et al., (2004a) finally travel distances by all kinds of transport modes Naess (1995); Stead (1999); Curtis (1996); Kenworthy and Laube (2000).

According to Stead, (1999) travel distance increase with increasing area per capita in a community, with the availability of different services and facilities and with car ownership.

Regression analysis at the individual level reveals that there are also land use characteristics that are linked with travel distance. These include ward population density and possibly the frequency of the bus service. The residents of wards where density is less than 10 persons per hectare travel further on average than residents of higher-density wards. Residents of areas with higher bus frequencies (more than one bus every hour) now appear to travel shorter distances than residents of areas that are less well served by bus.

In many studies, the increase of the distance from home to the urban centre is associated with increasing travel distance, an increasing proportion of car journeys and increasing transport energy consumption. Trip frequency however does not vary significantly according to the distance between home and the urban centre. The proximity to major transport networks may lead to travel patterns characterised by long travel distances and high transport energy consumption. Considering travel distance, many previous studies have indicated that a higher degree of urbanisation is associated with shorter travel distances in general as well as distance travelled by private car (Naess, 1995).

There are a number of socio-economic characteristics that are linked with travel distance; these include gender, age, individual employment status, the possession of a driving licence, household employment, household composition, household socio-economic status and household car ownership. Some of the conclusions of the study of Stead (1999) are that men travel further than women, people aged between 30 and 39 travel more than most other age groups, holders of a driving licence travel further than people with only a provisional licence and people without a licence, people in full-time work travel further than people in part-time work and residents of households in higher socio-economic groups travel further than residents of households in lower socio-economic groups.

The effect of car ownership increases mobility therefore increasing the frequency and the distance of the trip (Stead et al., 2000). Indirect effects such as local community and residential area densities influence travel distances indirectly through the accessibility to local service function. However these effects are modest compared to car ownership and distance to city centre (Naess, 1995).

Since car ownership is consistently the most significant socio-economic variable in explaining the variation in travel distance per person, the interactions between car ownership, other socio-economic characteristics and land use. The most important socio-economic effects on car ownership are the age profile of the area, the proportion of households with a high number of driving licences, household socio-economic status and household structure.

3.4.2. Travel time

Travel time variability has several distinct components, including differences in travel time from day-to-day, over the course of the day and even from vehicle-to-vehicle. Most research into travel time variability has focused on day-to-day variability in travel times (Noland and Polak, 2002).

Ewing (1995) reports that travel time increases as car ownership levels increase and that average travel time per person increases as the number of workers per household increases, reflecting the fact that where there is more than one worker in household, home location may not be near to the workplace of each worker and reports that travel time per person increases as household size increases.

Travel time between places depends on the speed of the transportation network, a function of traffic flow, which is strongly correlated with density. At uncongested levels of traffic, a one percent increase in traffic flow on a section of roadway increases travel time by far less than one percent; at congested levels, a one percent increase in flow increases time by far more than one percent (Levinson and Kumar, 1997).

Travel time is negatively related to density and size of a certain area, commuting time depends on the magnitude of the city, higher densities reduce automobile travel time up to a certain point. Higher densities could be expected to be associated with lower automobile use and shorter commute distances (Newman and Kenworthy, 2000). Because higher densities also lead to higher levels of congestion, the effect on commute time is questionable (Levinson and Kumar, 1997). The size of a metropolitan area is also relevant although some researchers have found little or no effect of metropolitan size on commute distance or time (Gordon et al., 1989; Levinson and Kumar, 1997), there is some evidence that, average commuting time tends to rise as urban areas become larger (Schwanen, 2004b).

The bicycle traveling time in comparison with other modes of transport depends on local conditions such as traffic, the number of crossings and regulatory measures for transit. Figure 4 presents a time comparison between different modes of transport in cities with congestion and high density centres.

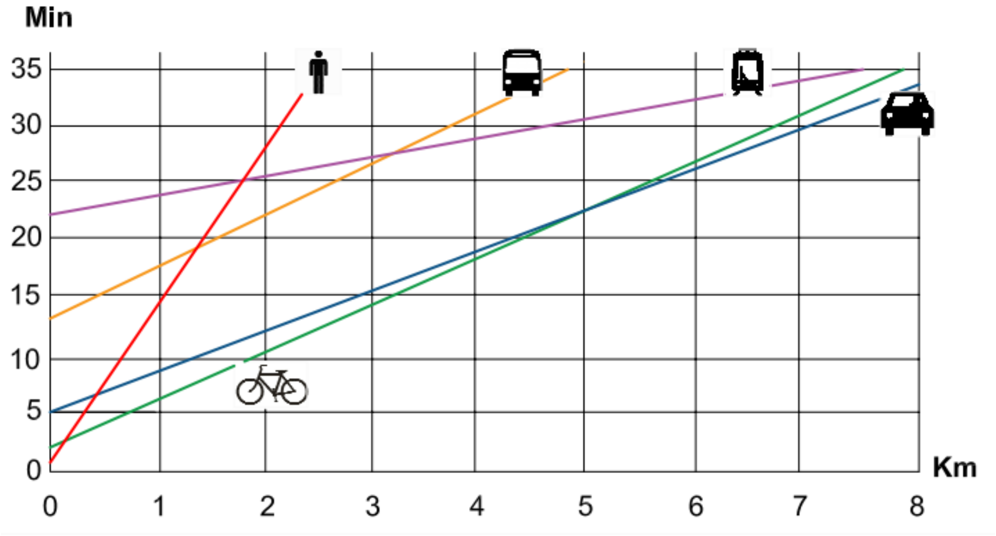


Figure 4. Comparative table of journey speeds in the urban environment in an 8 km distance range. Adapted from: European Commission (2000)

3.4.3. Journey frequency

Hanson, (1982) study shows that the provision of local facilities is associated with increased journey frequency although the effect of increasing journey frequency is not as strong as the effect of reducing trip length.

Journey frequency has remained relatively constant over the last decade whereas the average journey length has increased by almost one-fifth. According to Stead (1999), total journey frequency does not show a clear gradation with population density and there is little variation in trip frequency according to population density. The average journey frequency is reported to be close to 14 journeys per person per week. The highest trip frequency is 14.8 journeys per person per week (6 per cent higher than average) in areas where population density is between 1 and *5* persons per hectare. The lowest trip frequency is 13.0 journeys per person per week in areas where population density is more than 50 persons per hectare. Ewing et al (1996) reports that there is a weak significant statistical link between trip frequency and population density.

3.4.4. Modal split

The choice of transport mode is probably one of the most important classic models in transport planning. Mode choice behaviour reflects the availability of alternative modes to different groups as well as the local availability of goods and services. A lack of mode choice options restricts the movement of transport disadvantaged groups who can become socially excluded (Hine et al., 2012). The modal split between public transport and car driving is first and foremost influenced by car ownership (Naess, 1995). Main characteristics of public transport is that they will have some particular schedule, frequency etc., while on the other hand, private transport is highly flexible therefore provides more comfortable and convenient travel, and has better accessibility also. The issue of mode choice, therefore, is probably the single most important element in transport planning and policy making. It affects the general efficiency with which we can travel in urban areas. Therefore, it is important to develop and use models which are sensitive to those travel attributes that influence individual choices of mode (Mathew and Rao, 2007).

Modal classification corresponds to the characterization of transport modes, and this is achieved due to the way the movement is done, which essentially depends on two factors: the travel mode (motorized or not motorized) and the type of service (individual or collective), illustrated in Figure 5.

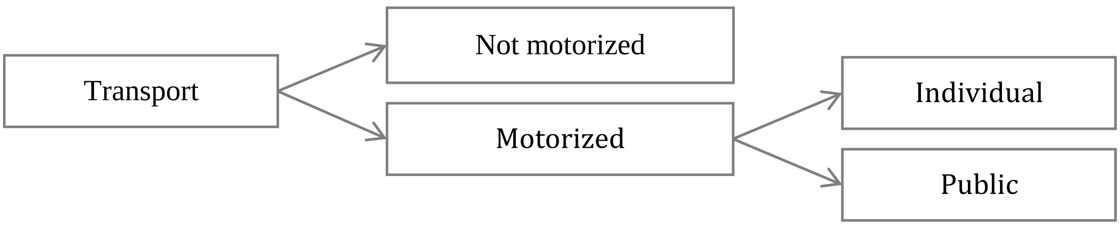


Figure 5. Transport classification. Source: IMTT (2011).

This is the sort commonly used in studies of mobility and transport. Essentially, this type of classification of different modes of transport allows a separation between individual and collective transport, being sectored, each depending on the infrastructure they use, after an initial division between the existence of engines (or not) in traveling. The assessment of the level of sustainability of the transport system, or mobility of a cluster implies an approach to different modes according to the modal classification (IMTT, 2011). However, it is necessary to reflect upon this type of classification, due to the fact that it is divided into motorized and not motorized transportation and therefore it may seem that the term “motor” is more valorised than soft modes in mobility and in transportation planning. This sort of classification may raise some questions, firstly how to classify E-bicycles, moped, bicycle with helper motor, motor driven cycle, Segway’s and other new types of power assisted bicycles, are they to be classified by motorized or not motorized transport? And if classified as “not motorized” the classification should be substituted to something more suited like active transport or soft transport. Secondly, “not motorized” should also be divided into individual and public transport due to the existence of nom-motorized public transport, such as public bicycle sharing systems.

3.4.5. Transport energy consumption

According to the European Environment Agency "the transport sector accounts for about one third of all energy consumption and is responsible for over a fifth of emissions of greenhouse gases." It is also responsible for much of urban air pollution as well as the noise and pollution. Since the 60s with the significant increase in car use at the expense of other modes of transport, this growth resulted not only in an increase of trips, but also implied a decrease of public transport travel and other modes (EEA, 2013).

According to Næss (1993) towns with high population have often a tendency to have a better public transportation systems, which may contribute to reducing the energy consumption for transportation while at a regional level indicate that a large population within a commuting region contribute to an increase in the energy consumption for transportation.

Transport energy use is of course dependent upon the modal share between private, public and non-motorised modes, but also upon the relative energy efficiency between modes. The data here show that energy consumption per passenger km is in every region significantly higher for cars than public transport. Rail modes (trams, light rail, metro and suburban rail) are in virtually every instance more energy efficient that buses in the respective regions (Kenworthy, 2003).

The use of energy in public transport systems in world cities is minimum compared to private transport, regardless of the significance of the transport task assumed by public transport, energy consumed per passenger km in public transport in all cities is between one-fifth and one-third that of private transport.

Naess, (1995) examine the effect of distance from the home to the urban centre on transport energy consumption. Transport energy consumption increases as the distance between home and the urban centre increases.

It is claimed car ownership has the greatest influence on transport energy consumption, followed by the distance between home and the urban centre, the proximity to local facilities from the home, income per capita and various other socio-economic factor (Banister et al., 1997).

3.5. Summary and discussion

The primary functions of transportation are to facilitate the movement of people and goods and to provide access to land use activities located within the service area. This chapter showed how advances in transportation technology have helped to determine the size, shape and density of urban areas and associated traffic congestion patterns. It provides a brief historical review - from ancient times to the present - of how transportation technology has shaped the size of urban areas over time, and highlights the connection between transportation technology and land use.

Many transportation and land use planners believe that strategies to reduce transportation demand via coordination of land use and transportation planning can contribute to meeting future mobility needs. This premise envisions the land use characteristics of density, mix of uses, urban form, urban design, activity scale, and contiguousness of development, playing a meaningful role in reducing the demand for vehicle travel by reducing vehicle trip frequency, reducing trip lengths and frequency, and altering mode choices for travel. Greater success in transportation-land use coordination offers the opportunity to slow the growth of vehicle miles of travel (VMT) and improve liveability characteristics of the urban environment.

Figure 6 portrays some of the factors that contribute to VMT. This conceptual model categorizes underlying land use factors and transportation system factors. These areas interact with each other and influences travel behaviour in different ways. Land use is one among many factors that are influencing the overall demand for vehicle travel. Land use factors are also a travel demand factors. As noted, land use characteristics influence the overall level of demand and mode of travel, thus affecting VMT. The nature of development can also influence the total level of demand as a result of the impact of land use on the components of travel behaviour.

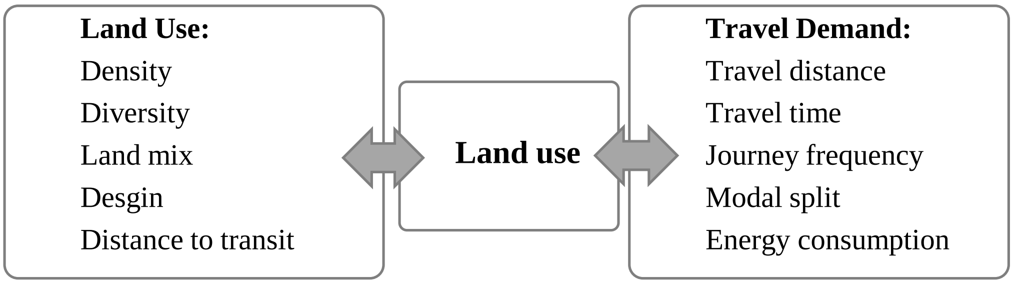


Figure 6. The role of land use in mobility strategies. Developed by the author

Literature shows that there are many different ways of structuring factors, land use related urban mobility factors, according to how they affect the choice of travel mode, travel time, journey frequency, modal split and transport energy consumption. In order to have a better understanding of the characteristics of travel patterns, so that transportation and land use planners will be able to plan better and more effectively the use of public transport and soft modes and at the same time discourage the use of private transportation.

Chapter 4

Land use and urban mobility

4. LAND USE AND URBAN MOBILITY

As evidenced in the previous sections 2 and 3, urban sustainability, land use and mobility are closely linked to transport, since these are a major source of pollution, energy consumption and reduction in quality of life of people in physical and psychological terms. In addition to the problems involved consumption and pollution transport, urban sustainability is also closely related to the growth and development of the cities, which often happens without planning, leading to health and mobility problems, and even social discrimination. Thus, variables such as density, land use, the design of public spaces, among others, are ways to manipulate the cities and suit them to the needs of the population. In addition to the land use characteristics, which are difficult to quantify and compare, greatly influence mobility patterns. The relationship between transport and land use is reciprocal, i.e. both land use influences population displacement mode, as the transport system influences the land use (Santos, 2012).

4.1. The relationship between land use and urban mobility

Over the last few decades, there has been a wide range of research concerning the interaction between land-use patterns and travel patterns. This section resulted in a wide range of literature concerning interactions between land use and travel patterns. However, the relationship between land-use characteristics and travel patterns is complex by the fact that different land-use characteristics are often associated with different socioeconomic factors, and that may affect travel patterns (Stead, 1999).

There are several reasons why some researchers and policy-makers suggest that land use characteristics should be used as an instrument to affect travel behaviour. Reasons are related mainly to the negative impacts of transport: environmental impacts and congestion. The general idea is that the overall level of travel may be reduced via land-use planning and that a modal shift from the car to alternative transport modes (Wee, 2002).

The effects of individual land use factors tend to be cumulative. Areas that contain a combination of land use density, mix, connectivity and walkability tend to have significantly lower overall per capita vehicle ownership and use, and higher use of alternative modes than average (Ewing et al., 2002).

Among the many land use variables listed in the chapter 0, section 2.2, the traditional land use variables considered in relation to travel behaviour are: density, diversity, design, destination accessibility and distance to transit. The impact that each of these variables has on travel behaviour, whether it's vehicle miles travelled or mode choice, is referred to as *elasticity*. It's "the percent change in the outcome variable (like vehicle miles travelled) when a specified independent variable (like density of dwelling units) increases by 1%.

Ewing and Cervero (2001) calculated the elasticity of per capita vehicle trips and vehicle travel regarding various land use factors, as summarized in Table 5. For example, this indicates that doubling neighbourhood density reduces per capita automobile travel by 5%. Similarly, doubling land use mix or improving land use design to support alternative modes also reduces per capita automobile travel by 5%.

Table 5. Typical elasticities of travel with respect to the built environment. Source: Ewing and Cervero (2001)

Factor	Description	Trips	VMT
Local Density	Residents and employees divided by land area.	-0.05	-0.05
Local Diversity (Mix)	Jobs/residential population	-0.03	-0.05
Local Design	Sidewalk completeness/route directness and street network density.	-0.05	-0.03
Regional Accessibility	Distance to other activity centres in the region.	--	-0.20

Note: This table shows the elasticity values of Vehicle Trips and Vehicle Miles Travelled (VMT) with respect to various land use factors.

Moudon and Stewart (2013) reviewed research on how various land use factors affect travel activity, and the tools available for modelling these impacts and related outcomes such as vehicle emissions and health co-benefits. The following Table suggests that design factors (density, diversity and design) can reduce per capita vehicle travel on the order of 10-20%, while accessibility factors can reduce automobile travel by 10-40%. These values can be used to predict how various types of land use management strategies that can help achieve transportation management objectives. Even greater reductions are possible if land use changes are reinforced by other TDM strategies (see Table 6).

Table 6. Typical elasticities of travel with respect to the built environment. Source: Moudon and Stewart (2013)

Category	Variable	VMT	Walking	Transit
Density	Household/population density	–0.04	0.07	0.07
	Job density	0.00	0.04	0.01
	Commercial Floor Area Ratio (FAR)	n/a	0.07	n/a
Diversity	Land use mix	-0.09	0.15	0.12
	Jobs/housing balance	-0.02	0.19	n/a
	Distance to a store	n/a	0.25	n/a
Design	Intersection/street density	-0.12	0.39	0.23
	Percent 4-way intersections	-0.12	-0.06	0.29
Destination accessibility	Job accessibility by auto	-0.20	n/a	n/a
	Job accessibility by transit	-0.05	n/a	n/a
	Jobs within one mile	n/a	0.15	n/a
	Distance to downtown	– 0.22	n/a	n/a
Distance to Transit	Distance to nearest transit stop	-0.05	0.15	0.29

Note: An extensive body of literature examines how various land use factors affect travel activity.

The following figure summarizes the findings in ranked order from the most significant factor to the least in achieving three outcomes. The variables are color-coded according to the categories defined above (see Table 7).

Table 7. Ranked order of the factors according the respective outcomes (Reduction in VMT, increase in soft modes and increase of transit use). Developed by the author

	Reduction in VMT	Increase in soft modes	Increase in Transit Use
1	Distance to downtown	Intersection/street density	Distance to nearest transit
2	Job accessibility by auto	Distance to nearest store	% 4-way intersections
3	Intersection/street density	Jobs-housing balance	Intersection/street density
4	% 4-way Intersections	Land use mix	Land use mix
5	Land use mix	Job within one mile	Household/population density
6	Job accessibility by transit	Distance to nearest transit	Job density
7	Distance to nearest transit	Commercial floor to area ratio	
8	Household/population density	Household/population density	
9	Jobs-housing balance	Job density	
10	Job density (no effect)	% 4-way Intersections (negative)	

Table legend

- Density
- Diversity
- Design
- Destination Accessibility
- Distance to Transit

4.2. Impacts of land use on urban mobility

The impacts of the effect of land use on urban transport are quite consolidated by many researchers. The basic concept is that each land use generates a certain type of traffic, which can be measured in number of trips to and from a certain destination. One of the main and most concerning land use related impact is the increase in traffic and congestion; however, this is not the only cause. Land use variables and their corresponding impact on their mobility patterns are described as follow (Martins et al., 2008):

- High density housing, employment, facilities and services can reduce the average travel distance, mobility travel vs. urban forms;
- A compact occupation with a mixed land uses (housing, employment, facilities and services) reduces the travel distance, with the consequent reduction of the use of motorized transport;
- High residential and employment densities, together with good accessibility and an efficient public transport system, leads to increase of public transport over the use of private transport modes;
- Mobility can influence land use through changes in accessibility of a local mobility vs. forms of urban settlement;
- A uniformed accessible transport system can lead to a territory with a dispersed occupation;
- Improved accessibility gives a territory greater attractiveness, which can lead to a new approach in urban development.

Land use related impacts on travel patterns are often synergistic (i.e. total impacts are greater than the sum of their individual impacts). For example, improved walkability, improved transit service, and increased parking pricing might only reduce vehicle travel by 5% if implemented alone, but if implemented together might reduce vehicle travel by 20-30%, because they are complementary (Litman, 2005). Therefore, all land use factors impacts will vary depending on specific conditions and the combination of factors applied. The following table summarizes the impacts of land use factors on travel behaviour (see Table 8).

Table 8. Summarize of some of the impacts of land use factors on travel behaviour. Adapted from: Litman (2005)

Factor	Travel Impacts
Travel Impacts	Reduces per capita vehicle mileage. Central area residents typically drive 10-30% less than at the urban fringe.
Density	Reduces vehicle ownership and travel, and increases use of alternative modes. A 10% increase typically reduces VMT 0.5- 1% as an isolated factor, and 1-4% including associated factors (regional accessibility, mix, etc.).
Mix Land Uses	Tends to reduce vehicle travel and increase use of alternative modes. Mixed-use areas typically have 5- 15% less vehicle travel.
Centeredness (centricity)	Increases use of alternative modes. Typically, 30-60% of commuters to major commercial centres use alternative modes compared with 5-15% at dispersed locations
Network Connectivity	Increased roadway connectivity can reduce vehicle travel and improved walkway connectivity increases non-motorized travel
Roadway design	Multi-modal streets increase use of alternative modes. Traffic calming reduces VMT and increases non-motorized travel
Active transport (walking and cycling)	Improved walking and cycling conditions tends to increase nonmotorised travel and reduce automobile travel. Residents of more walkable communities typically walk 2-4 times more and drive 5-15% less than in automobile-dependent areas.
Transit quality and accessibility	Increases ridership and reduces automobile trips. Residents of transit oriented developments tend to own 20-60% fewer vehicles, drive 20-40% fewer miles, and use alternative modes 2-10 times more than in automobile-oriented areas.
Parking supply and management	Tends to reduce vehicle ownership and use, and increase use of alternative modes. Cost-recovery pricing (users finance parking facilities) typically reduces automobile trips 10-30%.
Site design	More multi-modal site design can reduce automobile trips, particularly if implemented with improvements to other modes

4.3. Criticism of the relationship between land use and mobility patterns

Many researchers have a critical opinion about the relationship between land use and mobility patterns. One of the main criticism of the relationship between land use and mobility are reduced quality of life by reducing congestion and green spaces, among others. According to Silva (2007) there are however other critical issues involving land use related to urban mobility. These criticisms can be summarized into the following three key issues:

- The preference for larger homes with more amenities. In developed countries the families prefer low density urban environments, peaceful and away from the bustle of urban centres;
- The cost of fuel, as well as other costs associated with car ownership, are decisive for the choice of the mode. In this sense, public transport should be competitive in terms of price and frequency;

- The dispersion of housing and work, and the concept of living and working in the suburbs is not always possible because not always the population chooses or has the choice to work close to home.

Another major critic according to Stead (1999) is that many of the empirical studies concerning the relationships between land use and travel patterns is that the socioeconomic dimension is excluded from the variables of land use and its influence on urban mobility patterns.

4.4. From mobility to accessibility oriented planning

The old paradigm of transportation planning held that maximizing mobility was the primary purpose of the system, and the metric of success were defined in terms of vehicle miles travelled (VMT). The ultimate goal of transportation is to empower humans to meet their own goals by connecting where they are with where they want to be. Traditional transportation planning has placed "mobility" at the top of the transportation hierarchy; policies are routinely evaluated in terms of their contribution to the mobility goal (see Figure 7).

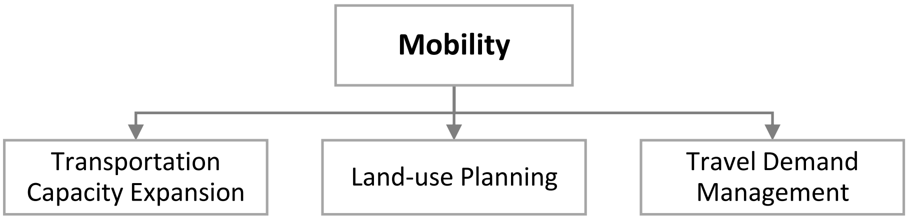


Figure 7. Mobility based measures. Source: Levine and Arbor (2012)

Mobility is one of three means to the end of accessibility, the other two, proximity and conectivity. In this approach, mobility is not an end itself but a means to the end of improving access to destinations. Granted there are a few exceptions, such recreational transport related activities, but, for the most part, users of the transportation system are concerned with reaching their destination. This interaction is also, what truly drives economic and social health. Mobility no longer holds the trump card in an accessibility paradigm, but it must compete with land use arrangements and other alternatives (see Figure 8).

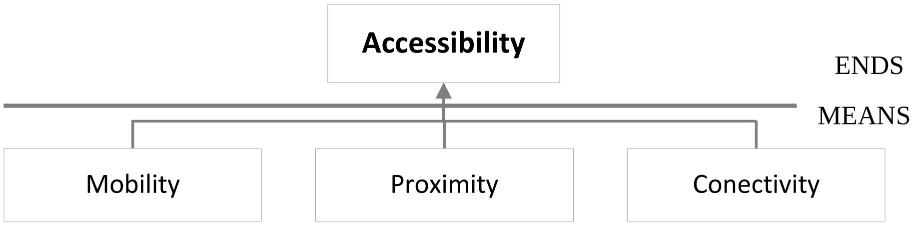


Figure 8. Relationships among mobility, proximity, connectivity, and accessibility. Source: Levine and Arbor (2012)

The paradigm shift from mobility to accessibility brings multimodal travel options and the interconnections between transportation and land use into sharper focus. According to Litman (2011), an efficient transport system is multi-modal, encouraging travellers to use each mode for what it does best: cycling for short trips and public transport for travel on congested urban corridors, and automobile travel when it is truly most efficient overall, taking into account all impacts. Accessibility and mobility based measures favour different types of transport users and modes, different land use patterns, and different solutions to transport problems. Mobility and accessibility perspectives are compared below (see Table 9).

Table 9. Mobility and accessibility perspectives. Adapted from: Litman (2011)

	Mobility	**Accessibility**
Users	Transport users are mainly motorists, since most person- and ton-miles are by motor vehicle, but recognizes that some people rely on non-automobile modes, and some areas have large numbers of transit, rideshare and cycling trips	Transportation users consist of people and businesses that want to reach a good, service, activity or destination. It recognizes that most people use various access options, and so cannot be classified as simply a motorist or transit rider.
Modes	Considers automobiles most important, but values transit, ridesharing and cycling where there is sufficient demand, such as downtowns and college campuses, and so justifies devoting a portion of transport funding to transit, high occupancy vehicle (HOV) and cycling facilities. Supports an integrated view of the transportation system, with attention to connections between modes.	Considers all access options important, including all transportation modes, and mobility substitutes and delivery services. Integrated view of transportation and land use systems, connections among modes and between transport and land use conditions. Values modes according to their ability to meet users' needs, and does not necessarily favour longer trips or faster modes if shorter trips and slower modes provide adequate access. Supports a wide range of transport funding, including mobility management and land use management strategies.

Table 9. Mobility and accessibility perspectives (continuation). Adapted from: Litman (2011)

	Mobility	**Accessibility**
Land use	Highway access and parking is most important, but transit and HOV access are also desirable in areas where density and demographics concentrate enough riders. The best location for public facilities has a combination of convenient roadway access, adequate parking, transit service, and cycling routes.	Land use is just as important as mobility in the quality of transportation, and different land use patterns favour different types of accessibility. The distribution of destinations, land use mix, network connectivity and cycling conditions all affect transportation system performance. The best location for public facilities has a combination of convenient proximity, roadway access, transit service and walkability
Transport Problems and Solutions	Defines transportation problems in terms of constraints on physical movement, and so favours solutions that increase motor vehicle capacity and speed, including road and parking facility improvements, transit and ridesharing improvements, high-speed train, aviation and intermodal connections. Little consideration to cycling and alternative modes except where they provide access to motorized modes.	Accessibility-based planning expands the range of transport problems and potential solutions that can be considered. Transport problems include any cost, barrier or risk that prevents people from reaching desired opportunities. Solutions can include traffic improvements, mobility improvements, mobility substitutes and more accessible land use.
Measurement	Mobility is measured using travel surveys to quantify person-miles, ton-miles, and travel speeds, plus traffic data to quantify average automobile and transit vehicle speeds. In recent years techniques have become available to evaluate multi-modal transportation system performance, such as transit and cycling Level of Service ratings.	Accessibility is evaluated based on the time, money, discomfort and risk (the generalized cost) required to reach opportunities. Access is relatively difficult to measure because it can be affected by many factors. For example, access to employment is affected by the location of suitable jobs, the quality and cost of travel options that reach worksites, and the feasibility of telework. Activity-based travel models and integrated transportation/land use models are most suitable for quantifying accessibility.

Accessibility is harder to measure than mobility, because it requires taking into account land use, mobility and mobility substitutes, but most accurately reflects the ultimate goal of transportation, and allows widest range of transport problems and solutions to be considered. For example, an accessibility perspective may identify low-cost solutions to transportation problems, such as improving local walkability; encouraging land use mix so common destinations such as stores, schools and parks are located near residential areas; and improving communications services for isolated people and communities (Litman, 2011).

Accessibility reflects both mobility (people’s ability to travel) and land use patterns (the location of activities). This perspective gives greater consideration to nonmotorised modes and accessible land use patterns. Accessibility tends to be optimized with multi-modal transportation and more compact, mixed-use, walkable communities, which reduces the amount of travel required to reach destinations, see Figure 9.

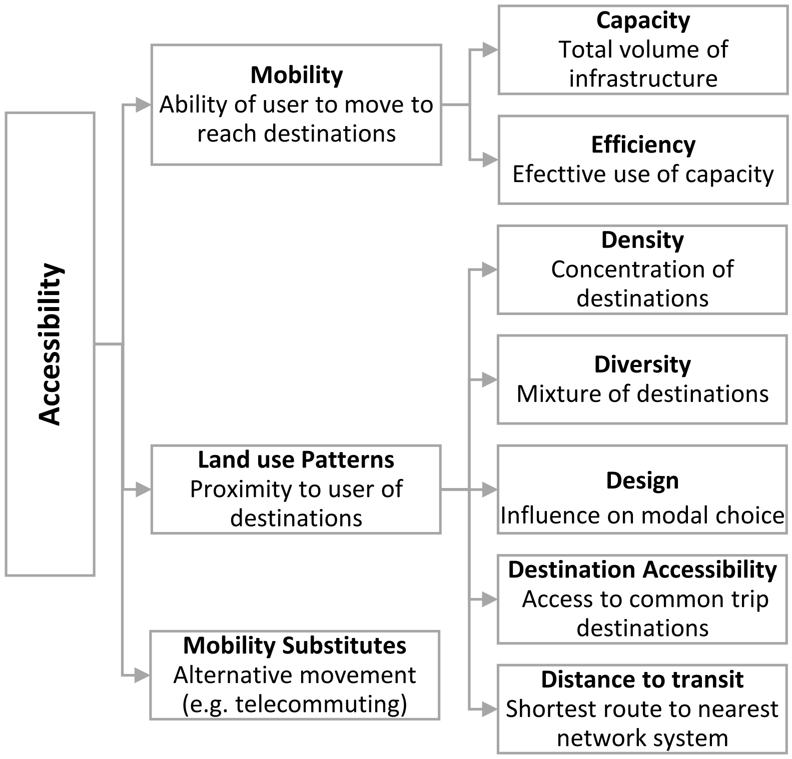


Figure 9. Simplified flow chart to represent the essential contours of an accessibility based measure approach. Adapted from: Nairn (2010)

4.5. Summary and discussion

The territorial structure of the urban space is a strong element conditioning urban mobility policies due to the rigidity that characterizes urban spaces. Being defined by variables such as size, morphology/design, layout and infrastructure (including transport) networks and the location of economic and social activities. These aspects affect crucially the model organisation of urban space and, in particular, their mobility patterns.

Conventional transport planning often overlooks some of these impacts, particularly when evaluating a single policy or project. The relationship between transportation and land use are complex. Comprehensive analysis of transportation-land use impacts, includes:

- Impacts of lands used for transportation facilities.
- Impacts on the location, type and cost of development.

- Impacts on accessibility and travel options.
- Impacts on travel behaviour.

Therefore, there is still a long way to go before there is a common definition and methodology to measure the relationship between land use and urban mobility. It may not even be possible due to the fact that built environment reflects multidimensional and multi-scalar characteristics due to the complexity of the concept.

Conventional planning tends to evaluate transport system quality primarily based on mobility, using indicators such as average traffic speed and congestion delay (Litman, 2011). However, efforts to increase vehicle traffic speeds and volumes can reduce other forms of accessibility, by constraining pedestrian travel and stimulating more dispersed, automobile-oriented development patterns. Improving high occupant vehicle (HOV) travel and favour it over car driving can reduce congestion increase personal mobility (person-miles of travel) without increasing vehicle mobility (vehicle-miles of travel).

The paradigm shift from mobility to accessibility brings multimodal travel options and the interconnections between transportation and land use into sharper focus, therefore, accessibility is either implicitly or explicitly included in the measurement of the built environment. In practice, density is often used as an implicit proxy for overall accessibility, as denser places have more facilities and opportunities nearby. Likewise, the distance to the closest facility is an explicit measurement of accessibility. Route characteristics such as street connectivity are other explicit accessibility measures, while infrastructure quality has a clear impact on accessibility. Therefore, accessibility cannot be separated from the built environment, as several of the physical features of the built environment are closely linked with, and influence urban patterns.

Chapter 5

Bicycle mobility: actual paradigm

5. BICYCLE MOBILITY: ACTUAL PARADIGM

Although cycling as a mode of transportation can moderate traffic congestion, improve environmental quality, and yield health benefits, it accounts for a small share of all commute trips (Handy and Xing, 2011). Many issues can be appointed about bicycle commuting such as travel time, physical needs, safety and cost. Travel time depending on the spatial structure of municipalities; the adequacy of cycling infrastructure; whether detours have to be made; waiting time at crossings, etc. Physical needs, comfort: this depends on the quality of infrastructure, and on physical conditions, such as weather and flatness of surface, but also on pollution levels, in some cases combined with temperature. Traffic safety concerns, the risk of being injured because of interaction with motorised transport modes. Risk of bicycle theft can be an issue specifically in big cities, and may also include the risk of vandalism. If this risk is high, one might be reluctant either to use a bicycle at all or to use a high-quality bicycle that could encourage the rider to make longer and more frequent trips (Keijer and Rietveld, 2000). Monetary cost of bicycle use includes the costs of parking bicycles and maintenance costs (Rietveld and Daniel, 2004). Therefore, there are many aspects to take in consideration when deciding to use or not the bicycle as a mean of transport, and there for the difficulty of the implementation of the bicycle as a day to day, transport mode.

5.1. The evolution of bicycle mobility

In addition to factors such as spatial structure, geography, morphology and climate conditions that have direct impact on bicycle use, political strategies are essential to improve and have a high level of bicycle use. Due to the evolution of use of the bicycle and its increasing benefits in the twentieth century, political strategies are encouraging the use of the bicycle in Europe (Bossaert and Canters, 2007).

In the late nineteenth century, the bicycle was introduced in Europe. In the beginning the bicycle was used only for leisure, latter on 1900-1920, there was a transformation, used mainly by the middle class and lower income workers used it as their main mean transport mode. Between the 20s and 30s, despite the success of the bicycle, politics focused on the development of motor traffic means (Bossaert and Canters, 2007).

According to Bossaert and Canters, (2007), the decline of the bicycle started in 60's, the three main reasons are as follow:

- Firstly, most European cities grew through a process of suburbanization with effect of increased circulation distances, consequently the increase of car use;
- Secondly with the increase in household income and the low car prices, many people started buying cars and the bicycle began to be associated with a negative image;
- Finally, in the eyes of politicians, only people who had financial problems used the bicycle as a transport mode, and the car was the symbol of progress, mobility and freedom.

In the 80s and 90s, with the increase car use lead to problems such as congestion and environmental problems the growing attention of citizens on environment and health aspects, politicians began to see the bicycle as possible solution to these problems.

The European Council in March 2007 set a target to reduce by 20% of greenhouse gas emissions in the EU by 2020, and it favours bicycle use. The European Organization for Cyclists are developing a project to develop a network for cycling by 2030, consisting of 12 cycling routes across all of Europe. According to the Organization, the extent of these routes is about 30,000 km, made up of existing regional and national lines (European Commission, 2007b).

Despite the increasing effort to integrate the bicycle with other means of transportation, there is little reported statistics about cycling. Unlike cars and other vehicles, bicycles are not all registered. According to these considerations, the total of bicycles being used cannot be correctly estimated. For the purposes of political decision, bicycle sales offer some indication of access and popularity. Between 1998 and 2003, sales increased approximately 13% to an estimated 16.5 million bicycles by 2003. In that period, sales increased more in France, reaching close to 3.3 million bicycles, much more that total sales in Italy and the United Kingdom (European Commission, 2007b).

In 2007 broke out the concept of renting public bicycles, focusing its attention on the bicycle use in relation to urban development. However, since 2008, the growth rate has slowed down, especially in Central Europe. Barcelona and Paris are considered to be two of the cities with the best bicycle rental system, while others are trying to reduce the cost of bicycles and developing individual solutions to their problems (Spicycles, 2009).

5.2. Bicycle use and commuting

Cycling presents a number of advantages over other modes of transport, given the pros and cons of commuting (see section 5.4). Compared to car commuting, cycling is environmentally sustainable, it requires limited space, bicycle infrastructure is relatively inexpensive, it results in a limited noise production and improves public health (Hilbers, 2008). In addition, cycling offers individual benefits: Cycling is a cheap form of transportation, it improves the health of the individual, cycling can sometimes prove to be faster than other transport modes – especially in urban areas – and enables individuals to avoid traffic jams.

Nevertheless, even for short distances many individuals do not consider the use of the bicycle as a mean of transport. Short distances up to 7.5 kilometres, 36% of all trips are still made by car, and 35% are made by bicycle (Ministry of Transport and Public Works and Water Management, 2009). The proportion of bicycle use decreases (to 15%) and proportion of car use increases as the distance of the journey increases. This means that a larger amount of journeys could be done by bicycle. In other words, despite the fact that cycling is an option for many, a considerable amount of people choose to use other means of transportation. Even in the Netherlands, which has a bicycle-friendly infrastructure and where cycling has a positive image, many people choose not to cycle in situations where cycling could be a highly appropriate transport mode. In addition, not all cyclists commute on a daily basis, due to other reasons, such as the weather and safety conditions (Susilo and Stead, 2007).

5.3. Developments of cycling in Europe and in Portugal

Decades ago, the bicycle was the means of movement par excellence largely in many countries. Whenever there was a road or path, the bicycle was king, from North to South Europe (European Commission, 2000). Usually, the cities were well adapted for this type of transport, but with the changing the paradigm for cars, pedestrians, bicycle users and public transport were relegated to third plan (Compenhagenize 2013, 2015). With increased car parking, many of the trips started to become motorized, especially in southern countries, where the bicycle remains to be seen, mostly as a means of out-dated transport and used mainly for leisure.

In 1997, Portugal had the lowest value of bicycle users in the European Union while in 2000, according to Table 10, it was the fourth country with the lowest mobility by bicycle in Europe, and the second with the most car use (Rietveld and Daniel, 2004).

Table 10. Mobility type in Europe in 2000. Source: Rietveld and Daniel (2004)

Country	Bicycle (%)	Walking (%)	Motorized Vehicles (%)	Public Transport (%)
Netherlands	6.66	2.96	76.11	14.27
Denmark	5.48	2.52	73.79	18.20
Germany	2.47	3.16	76.52	17.85
Belgium	2.42	2.86	78.64	16.09
Sweden	1.95	2.76	76.09	19.20
Finland	1.82	2.79	79.05	16.34
Ireland	1.62	3.23	77.83	17.32
Austria	1.11	3.42	71.02	24.21
Italy	0.97	2.60	80.19	16.24
Greece	0.63	3.25	76.43	19.68
United Kingdom	0.6	2.83	84.18	12.39
France	0.49	2.65	79.12	17.75
Portugal	0.26	3.01	82.54	14.11
Spain	0.18	3.35	78.77	17.70
Luxembourg	0.00	3.05	78.66	18.29
EU 15	1.42	2.89	79.07	16.61

In 2007, a survey in the Member States of the European Union revealed that 53% of subjects used individual transport for commuting, 21% resorted to public transport and 24% moved in soft modes (APA, 2004b). In Portugal, 15% of respondents used the pedestrian mode in daily commuting, but only 1% of trips were made by bicycle (see Figure 10).

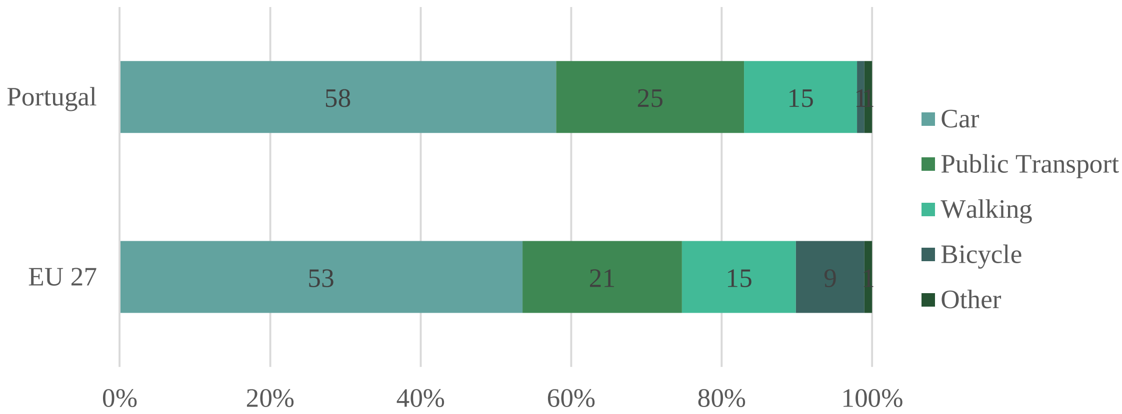


Figure 10. Modal split in the EU in 2007. Source: IMTT (2011b)

According to the chart below (Figure 11), in the same year, Portugal was the third Member State with the fewest journeys made by bicycle, above only Malta and Luxembourg. In 2010, although the percentage movements had increased (1.6%), equalling Spain continues to register a poor use of the bicycle. Even with the visible reduction of cycling mobility from the year 2007 to 2010 in Figure 11, this reduction is visible even in countries where this mode of transport is more popular; however, Netherlands remained the Member State with the highest bicycle use.

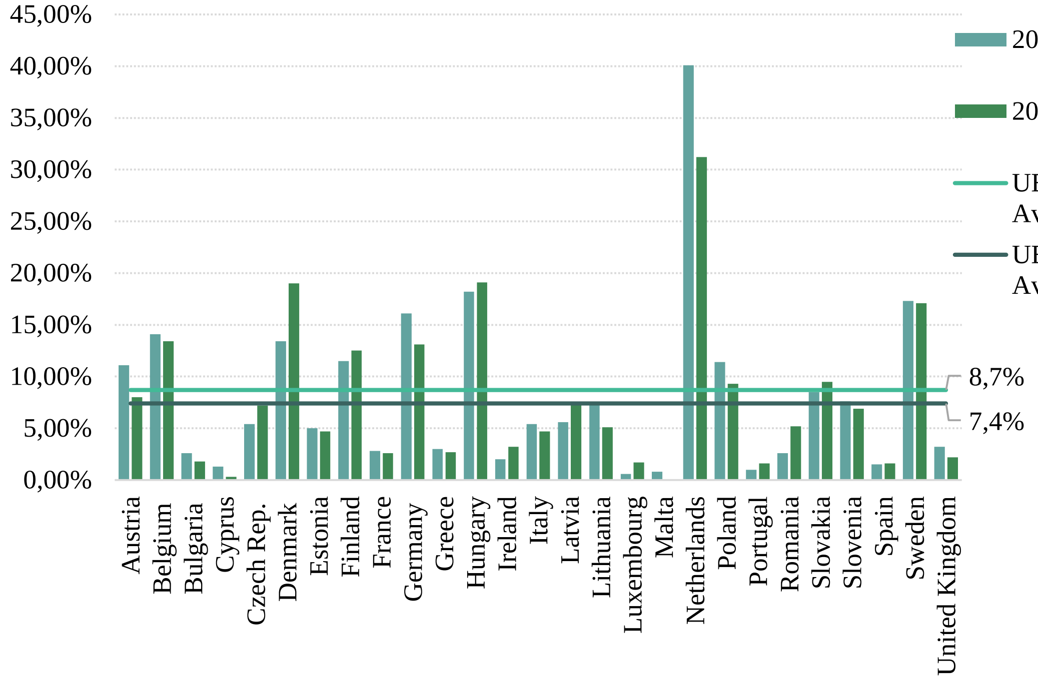


Figure 11. Percentage of journeys made by bicycle in the EU27. Source: Eurobarometer, 2007 and 2011

The Census in 2011 was the first statistical data in Portugal, to consider the bicycle as a separate transport mode and to provide data at a regional level. The results showed that only 0.5% of the Portuguese uses the bicycle on their daily travels. Despite the low value of bicycle commuting, this data is an important starting point to begin to set policies and incentive strategies, at a local and neighbourhood level.

Recently, a Danish consultant Copenhagenize (Table 11) published a ranking of most cycling friendly, respectively presented the latest bicycle mobility references. According to the barometer, Portugal continues way behind many European countries and just ahead of Bulgaria, Romania and Malta (ECF, 2013; Compenhagenize, 2013 and 2015)

The ranking is visible in Table 11, which presents the twenty friendliest cities of the bicycle 2013 and in 2015 resulted from scores of different parameters that evaluate issues such as the structures, security or culture of the bicycle. Two cities in Portugal were evaluated, Lisbon and Porto, but neither on made ranking qualification.

Table 11. Ranking of the most bicycle friendly cities in 2013. Source: Compenhagenize (2013 and 2015)

	2013		2015
1	Amsterdam (Netherlands)	**1**	Copenhagen (Denmark)
2	Copenhagen (Denmark)	**2**	Amsterdam (Netherlands)
3	Utrecht (Netherlands)	**3**	Utrecht (Netherlands)
4	Seville (Spain)	**4**	Strasbourg (France)
5	Bordeaux (France)	**5**	Eindhoven (Netherlands)
6	Nantes (France)	**6**	Malmo (Sweden)
7	Antwerp (Belgium)	**7**	Nantes (France)
8	Eindhoven (Netherlands)	**8**	Bordeaux (France)
9	Malmo (Sweden)	**9**	Antwerp (Belgium)
10	Berlin (Germany)	**10**	Seville (Spain)
11	Dublin (Ireland)	**11**	Barcelona (Spain)
12	Tokyo (Japan)	**12**	Berlin (Germany)
13	Monique (Germany)	**13**	Ljubljana (Slovenia)
14	Montreal (Canada)	**14**	Buenos Aires
15	15.Nogóia (Japan)	**15**	Dublin (Ireland)

While the European Cycling Federation launched the index of cities, a barometer of bicycle mobility in Europe, based on modal split data, road safety, market volume, bicycle tourism, number of national organizations in support of cycling mobility (see Table 12).

The discrepancy, or delay, between Portugal and other European countries may result from a number of factors, visions and policies that the country has advocated. The segregation of land uses, the absence of an attractive and safe urban design within the urban areas and increased travel distances associated with urban sprawl.

Table 12. European barometer of cycling mobility in 2013. Source: ECF (2013).

Position	Country	Score	Position	Country	Score	Position	Country	Score
1	Denmark	125	**10**	United Kingdom	80	**19**	Luxembourg	52
	Netherlands	125	**11**	France	78	**20**	Poland	47
3	Sweden	119	**12**	Slovenia	77		Latvia	47
4	Finland	114	**13**	Czech Republic	69	**22**	Cyprus	41
5	Germany	105	**14**	Ireland	65	**23**	Portugal	36
6	Belgium	100	**15**	Estonia	56		Spain	36
7	Austria	95		Italy	56	**25**	Bulgaria	30
8	Hungary	91	**17**	Latvia	54	**26**	Romania	30
9	Slovakia	88		Grease	54	**27**	Malta	15

5.4. Benefits of bicycle commuting

There are many, many good reasons for bicycle commuting, recreational cycling and creating a strong bicycle culture in general. Bicycle commuting can increase mobility, reduce energy consumption, reduce air and noise pollution and considered by many the most energy efficient transport mode. Moreover, the bicycle is the fastest and most efficient mean of transport for short urban routes, and improves accessibility to the population among others; also, the many benefits of a bikeable city are vast and can be propelled by investments in NMT infrastructure (see Figure 12).

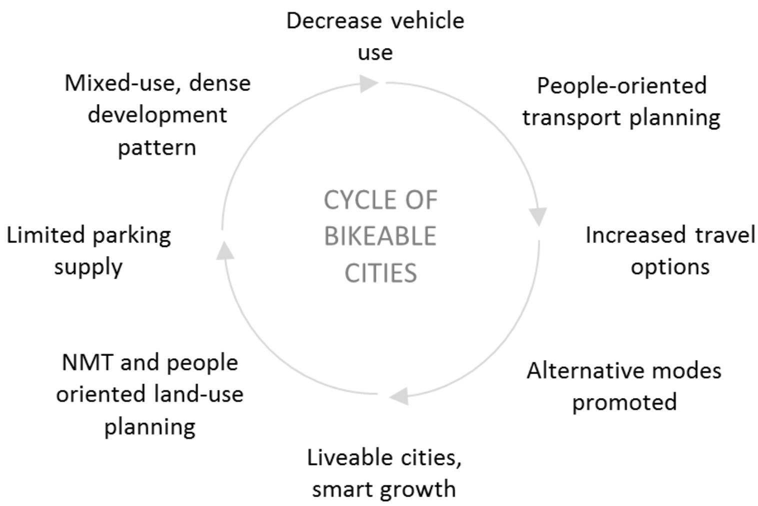


Figure 12. Benefits/Cycle of bikeable cities. Adapted by: UNEP (2010)

The European Commission mentions that "the potential or proven benefits of cycling may be established in a comprehensive way" these benefits are of various kinds (European Commission 2000):

- Economic: declining share of the household budget devoted to the car, reduction of working hours lost in traffic jams and reduce medical expenses due to regular exercise;
- Political: reducing energy dependency and saving non-renewable resources;
- Social: democratization of mobility, greater autonomy;
- Ecological: does not use fossil fuels and does not generate greenhouse gases.

Any trip made by bicycle instead of the car creates considerable economic benefits both for the individual and for the urban community. Among the main benefits the following can highlighted (European Commission, 2000):

- Total lack of impact on quality of life in the city (neither noise nor pollution);
- Preservation of monuments and gardens;
- Minor land use, both for moving and for parking and therefore better profitability of land uses;
- Less degradation of the road network and reduction of new infrastructure;
- Reduction of congestion and the economic losses which they entail;
- Larger automobile circulation flow (with rational use of the car);
- Greater power of attraction of public transport;
- Better accessibility to typically urban services;
- Considerable gain of time for cyclists in short to medium distances.

Despite the positive attributes, the bicycle has some limitations. The main factors mentioned, discouraging the use of bicycles as a mode of transport are (Chapadeiro and Antunes, 2012):

- Limited range of action;
- Sensitivity to ramps;
- Exposure to weather and pollution;
- Physical vulnerability of the cyclist;
- Vulnerability to theft.

5.5. Factors that affect cycling use

The factors involved in choosing the bicycle as a mode of transport by users, in general, can interfere direct or indirectly in the decision of the use of bicycles. Thus, the distinction of the nature of cycling factors can present some grey spots, therefore it is necessary a better understanding of these factors, given their essential role in promoting political and strategic decisions aiming to encourage bicycle travel (FHWA, 1992).

In this section, the factors that affect the level of cycling will be studied, many of this factors are mentioned previously, this factors are subdivided into five main groups for a better understanding of each one: Built-environment, natural environment, Socio- economic factors, psychological factors and finally factors concerning cost, travel time, effort and safety. As travel is a matter of connecting locations between each other, starting with the spatial context: the built environment that concerns mainly urban form, the infrastructure and facilities at work. Second group focuses on the natural environment, including landscape, weather conditions and climate, which are particularly important for non-motorized transport modes especially bicycle commuting. The third group of determinants is composed of socio-economic variables, a category of determinants in travel behaviour including socio-economic and household characteristics. The fourth group focuses on psychological factors, including attitudinal aspects such as habits, reason to cycle or not, social norms and perceived behaviours. Finally, the Fifth group is composed with aspects related to cost, time, effort and safety. Although all the factors will be discussed in this section, the variables relating land use and travel patterns and how this factors influence bicycle commuting will be in focus. All the factors discussed in this section are summarized below in Figure 13, variables relating land use and travel patterns and how this factors influence bicycle commuting will be in focus.

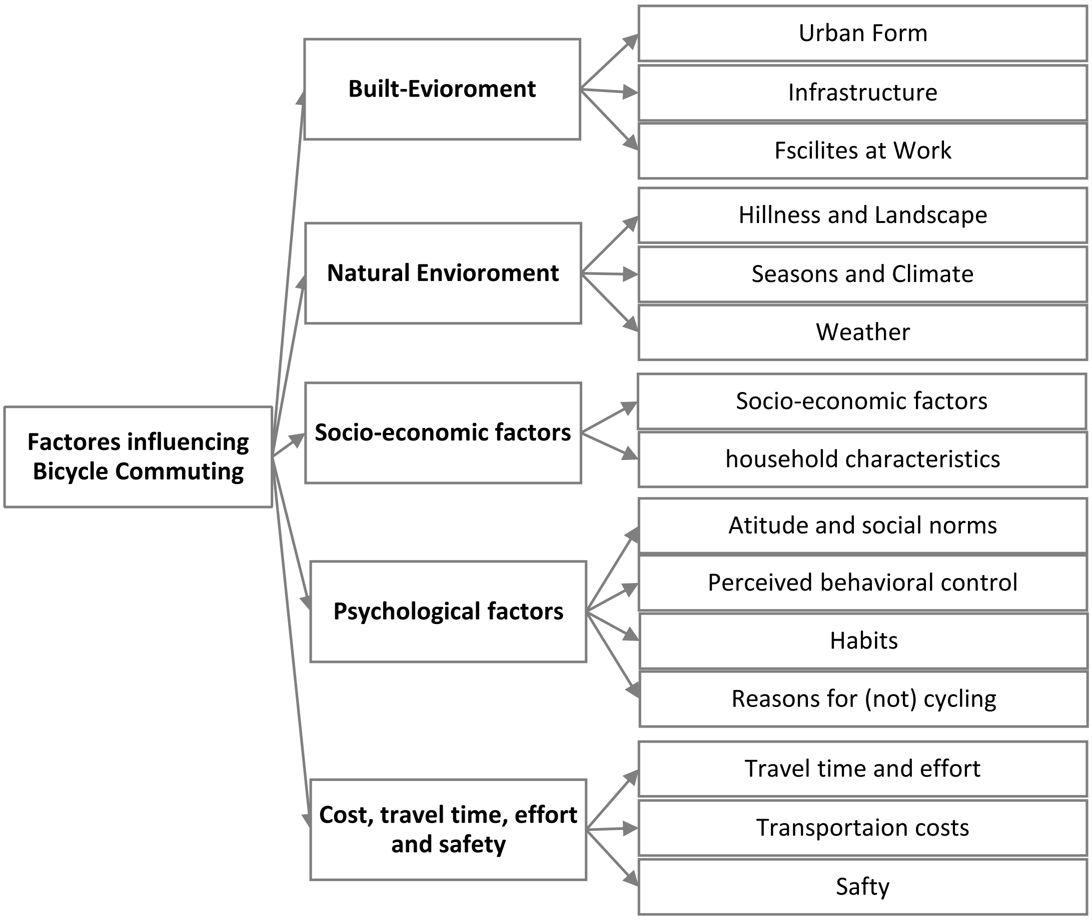


Figure 13. Factors influencing bicycle commuting. Developed by the author

5.5.1. Built-environment

A large number of studies have examined the relationship between the environment and travel patterns. These studies have been reviewed in a number of papers (Crane, 2000 and Ewing and Cervero, 2001). Although the effects of the environment on cycling, certain landscape related aspects, such as hilliness, which would seem particularly important for cycling, are under-researched in mode choice studies (Saelens et al., 2003). This section describes three categories of built environment characteristics: urban form, infrastructure and facilities at work.

Urban Form and travel distance

Travel distance, either commuting distance or the distance between activities, is an important factor to take in consideration when investigating transport modes, by cycling, or by other transport modes (Rietveld, 2000). An increase in the distance travelled results consequently in an increase in the time and effort needed for travelling. Therefore, a decrease in the cycling share of commuter trips and the frequency of bicycle commuting.

In general, the increase in trip distance results in having a much lower cycling share as a mode choice (Zacharias, 2007; Pucher and Buehler, 2008) and commuting (Cervero, 1996; Timperio et al., 2006 and Parkin et al., 2008).

Most bicycle research identifies distance as a significant factor; bicycle commuters tend to live closer to their work than other types of commuters (Cervero, 1996). The resistance of cycling increases disproportionately with distance due to the physical effort required (Van Wee et al., 2006). However, the maximum travel distance differs between individuals and genders. Studies suggest that women cycle shorter distances to work than men (Garrard et al., 2008), and with Howard and Burns (2001) suggesting 6.6 km for women compared to 11.6 km for men.

The importance of distance is further reflected in the relationship between town and city size and the mode share. In the Netherlands, small, medium-sized cities have the highest bicycle share, dare to the result of the proximity of the destinations involved (Martens, 2004; Rietveld and Daniel, 2004).

The bicycle does not merely serve as a transport mode, but is also used by some commuters to reach a main mean of transport (train station or bus stop). Studies from Keijer and Rietveld, (2000); Rietveld, (2000); Martens, (2004) have identified a relationship between distance and the chosen means of transport, distances between 0.5 and 3.5 km the bicycle is quite often used.

The network layout also influences cycling commuting, because it affects distance. According to Southworth (2005), a denser road structure is more suitable for non-motorized transportation, because distances are generally smaller. However, neither Moudon et al., (2005) neither Zacharias, (2007) find significant empirical evidence that can confirm the influence of the density of roadways and block size on cycling. Land-use concepts, such as new urban designs and the notion of the compact city, link higher density levels with higher shares of non-motorized travel therefor in denser urban areas, distances between locations are shorter, and consequently can be connected easier on foot or by bicycle. These studies find that higher densities lead to a higher cycling share. Furthermore, higher densities are related to lower levels of car ownership and car use (Litman, 2005), which has a positive effect on cycling. Witlox and Tindemans (2004) find that inhabitants of city centres choose the bicycle as a mode of transport more often than residents of the suburbs. The impact of density on cycling frequency is that made by Dill and Voros, (2007), who conclude that people living closer to city centres cycle more and more frequently.

Mixed land functions in a neighbourhood reduces travel distances, increasing cycling’s share as a transport mode choice (Cervero and Duncan, 2003; Pikora et al., 2003; Litman, 2005 and Pucher et al., 2008). The presence of services and facilities such as convenience stores, offices, fast-food restaurants, hospitals and multifamily housing in a neighbourhood has a positive effect on cycling (Cervero, 1996; Cervero and Duncan, 2003; Moudon et al., 2005).

In conclusion, travel distance can be a discouraging factor for cycling, and has a negative influence on whether individuals choose to commute by bicycle. There is not much evidence about the effect of distance on cycling frequency. Factors contributing to shorter travel distances, such mixed land-use, having a denser network layout and higher density, affect bicycle commuting positively.

Infrastructure

Infrastructure concerning the bicycle comes in a number of forms: bicycle paths, bicycle lanes and ‘normal’ streets (with or without markings). In some cases, car-parking facilities may be adjacent to such facilities, resulting in potential interactions between cyclists and drivers. In practice, it is often assumed that it is safer to separate cyclists from the rest of the traffic, therefore the tendency to prefer bicycle paths to bicycle lanes than cycling on roads that do not have any bicycle facilities.

Research confirms that the type of bicycle infrastructure matters. Cycling users prefer bicycle paths (Taylor and Mahmassani, 1996) and prefer bicycle paths to both bicycle lanes and roads without bicycle facilities. Wardman et al. (1997); Stinson and Bhat, 2005) and Hunt and Abraham (2007) suggest that countries with more cycling facilities have a higher modal split share of cycling and higher levels of bicycle safety. Preferences for particular cycling facilities differ across socio-economic groups, and across experienced and non-experienced cyclists. Inexperienced cyclists, women and younger cyclists tend to consider bicycle facilities to be more important (Garrard et al., 2008). For experienced cyclists, bicycle lanes are not considered to be more desirable than wide curb lanes (Taylor and Mahmassani, 1996).

The question of bicycle infrastructure is very much related to safety. There is two types of safety: objective and subjective safety. Objective safety is ‘real’ safety for cyclists, measured in terms of the number of bicycle-related incidents per million inhabitants. Subjective safety refers to how individuals perceive safety, and is mostly measured in terms of the stated safety experience of users. Klobucar and Fricker (2007) argue that the effect of bicycle infrastructure on objective safety remains unclear, but that subjective safety levels are higher when dedicated bicycle facilities are present. Petritsch et al. (2006) conducted research into objective cycling safety. They suggest that close to road intersections, bicycle side paths should either be close to roadways, or the speed of travel should be reduced in order to increase the likelihood of car drivers detecting the cyclist. They also suggest that side paths should be constructed for roads with speeds over 40 mph (65 km/h), rather than adjacent roadways, because this results in lower accident rates.

Car parking facilities can lead to more dangerous situations for cyclists, because car drivers need to cross bicycle facilities in order to park. Travelers rate roads without parking as safer than roads with adjacent parking (Stinson and Bhat, 2005). More specifically, Stinson and Bhat, (2004) suggest that parking adjacent to roads is considered to be less problematic in urban or suburban areas than in rural areas, possibly because cyclists are more used to parked cars in urban or suburban areas. Not all space or infrastructure adjacent to the road, such as parking facilities, is perceived to have a negative effect on safety. (Noland and Kunreuther, 1995).

Cyclists tend to prefer roads with two lanes for motorized traffic to four-lane roads (Shankwiler, 2006). The explanation for this may be that on four-lane roads, car drivers are forced to pay greater attention to other car drivers as well as cyclists, resulting in their attention being distracted from cyclists. This could be the reason why Dill and Voros, (2007) found that cyclists have a negative perception of roads with high-traffic intensities.

The second infrastructure aspect, continuity of bicycle infrastructure (either separate lanes or marked sections on roads where a bicycle facility is present throughout the route), is also important, because the existence of a route segment with no cycling facilities could deter some people from cycling. (Stinson and Bhat, 2004) expect cyclists to prefer routes with more continuous facilities, and indeed find that cyclists have a negative perception of the sudden ending of a facility (Stinson and Bhat, 2005). This seems to be more important for inexperienced than for experienced cyclists. In some countries, cycling facilities can end at different locations on a road. In countries where vehicles drive on the right-hand side of the road, the ending of a facility is considered to be most acceptable if it is on the right-hand side of the road, and least acceptable if it is located on the left-hand side of the road (followed by an ending at an intersection) (Krizek and Roland, 2005). This finding is probably related to safety: if a facility ends on the left-hand side of the road, cyclists have to cross the road, which might be perceived as being dangerous. Meanwhile, inexperienced cyclists consider cycling infrastructure facilities on bridges to be important (Stinson and Bhat, 2005). Although Aultman-Hall et al. (1997) conclude that cyclists do not prefer pedestrian bridges to road bridges when selecting their routes, Stinson and Bhat, (2004) suggest that cyclists do indeed prefer pedestrian bridges. Therefore, it would seem that while cyclists do have a preference for bicycle infrastructure on bridges, this does not cause them to make detours or change routes in order to use these facilities.

Third, having more bicycle paths has been found to result in a higher share of cycling (Pucher and Buehler, 2008). Constructing bicycle paths increased the bicycle share on some locations by 1–2%. According to Dill and Voros, (2007), people tend to say that they would cycle more often if they had bicycle paths, and if these were easy to reach and well connected to useful destinations. However, Moudon et al., (2005) report that the presence of more bicycle infrastructure does not have a significant effect on cycling as transport mode. There might be a two-way relationship between the presence of bicycle infrastructure and cycling rates: the presence of infrastructure might not only result in more cycling, but a higher cycling frequency could also stimulate the construction of bicycle infrastructure.

Fourth, stop signs, traffic lights and other traffic-controlling systems are necessary for regulating traffic, but can also cause irritation due to delays. Stopping and accelerating cost cyclists a disproportionate amount of effort. Rietveld and Daniel (2004) conclude that fewer people cycle in cities that have large numbers of stops. More specifically, Stinson and Bhat, (2004) find that cyclists generally avoid traffic lights when choosing a route. These findings do not correspond, suggesting that cyclists dislike traffic lights, but that they might prefer to avoid route segments that are perceived in a more negative way.

Traffic control mechanisms do not always discourage cyclists. Stinson and Bhat (2004) found that there is a higher tendency for cyclists in urban areas to avoid traffic lights and experienced cyclists tend to have a more negative perception of stop signs than more inexperienced cyclists. They argue the reason is that experienced cyclists feel more confident and safer in traffic, and consider travel time to be more important. Stinson and Bhat (2004) conclude that commuters find street crossings less inconvenient than other cyclists, but that crossings still have a negative effect on bicycle use. Since the presence of other road users can make cycling trips more time-consuming and dangerous, most studies assume that lower speeds and lower levels of traffic have positive effects on bicycle mode share (Shankwiler, 2006).

Little research has been conducted into the effect of surface quality. The literature that does exist suggests that older people, women and experienced cyclists attach more importance to a smooth surface (Bergström and Magnusson, 2003).

To conclude, in general, the results indicate that cyclists have a preference for dedicated bicycle infrastructure. Cyclist’s options are based on subjective notions of safety. They also prefer to have access to continuous bicycle infrastructure and roads without parking. Cyclists think that stop signs and traffic lights are inconvenient. It remains unclear whether the presence and continuity of dedicated bicycle infrastructure increases bicycle mode share or cycling frequency.

Facilities at work

As day-to-day commuting is in focus in this section, commuting to work will be considered because the decision to cycle to work or not, might be affected by the facilities at their place of work. Therefore, in this section is discussed topics about the bicycle and car parking, bicycle parking storage facilities for clothes and the availability of showers.

Hunt and Abraham (2007) find out that bicycle commuters consider safe bicycle parking to be important. The strongest preference is for bicycle lockers, followed by bicycle enclosures and finally by bicycle racks. Taylor and Mahmassani (1996) report that cyclists show similar preferences for bicycle lockers when travelling to public transport services and facilities. Cyclists with more expansive bicycles attach more value to parking facilities (Dickinson et al., 2003). Hunt and Abraham (2007) suggest that for people with expensive bicycles and younger people, this perception of importance is related to the value of their bicycles.

Commuters consider the presence of showers, changing facilities and lockers to be important (Abraham et al., 2002). According to Taylor and Mahmassani (1996), however, showers do not have a significant effect, and the presence of shower facilities does not seem to result in higher frequencies of cycling to work (Stinson and Bhat, 2004).

To conclude, having no facilities at work has been cited as a reason not to cycle (Moritz, 1998). When facilities are provided, people prefer safe parking over showers and lockers (Hunt and Abraham, 2007). Of all parking facilities, cyclists most prefer bicycle lockers. Although cyclists apparently value having access to showers and parking facilities, the presence of such facilities does not appear to affect bicycle mode share and cycling frequency.

Environmental factors have been found to influence bicycle use. Uncertainty continues to surround the effects of many factors, however. Shorter distances, a greater mix of functions and access to facilities are all factors that increase cycling share. Having a denser network layout and higher densities would seem to have a similar effect, but this remains unclear. Cyclists have a negative perception of traffic lights and stop signs, but it is unclear whether this affects frequency or mode choice. The effect of the presence of more cycling infrastructure and the extent to which this infrastructure is continuous remains an open question. Most research shows that cyclists and non-cyclists prefer to have access to cycling facilities. Based on these findings, there is a need for extra research about the relationship between cycling and the environment. Few research studies have focused on the extent to which the built environment influences a person's decision to cycle, and even fewer studies have looked at cycling frequency.

5.5.2. Natural environment

Natural Environment is an important factor when bicycle commuting is taken in consideration compared to motorized transport, whether a person chooses to cycle is strongly determined by landscape, hilliness, weather and climate. In this section, weather refers to the daily weather conditions, whereas the term climate describes the weather over a specific time period. Not all regions have the same attractive natural environment, while other regions the attractiveness for cycling depends on the seasons. Therefor this section describes how the bicycle mode share can be affected by weather conditions and the landscape.

Hilliness and Landscape

Most of the studies about mode choice rarely consider landscape characteristics. For motorized vehicles the landscape and changes in altitude change is not an important factor. For cyclists the presence of slopes increases the amount of effort they need to make and therefor a tendency for less bicycle commuting as a modal choice.

Studies of Timperio et al. (2006) and Parkin et al. (2008) demonstrate that slopes have a negative effect on bicycle use. For example, the City of York, slopes between 3% and 5%, has a cycling share of 13.1%, meanwhile in the city of Bradford characterized by steep slopes and has a cycling share of 0.8%.

Moudon et al. (2005), however, find that slopes have no significant effect on bicycle share for all trips, the fact that the personal factors covered in the study play a larger role than the environmental factors. Furthermore, most of the cyclists in Moudon et al. (2005) study were recreational cyclists, who might actually prefer cycling on hilly terrain. Another explanation is offered by Stinson and Bhat (2005), who argue that cycling downwards might compensate for the extra effort required to cycle upwards. Stinson and Bhat, (2005) also distinguish between experienced and inexperienced cyclists: the latter tend to prefer flat or hilly environments to mountainous ones, whereas experienced cyclists prefer hilly environments to flat or mountainous terrains for commuting. However, this preference for hilliness is probably not representative as far as the average cyclist is concerned. The importance of attractive built environment, is mentioned in the theoretical academic literature (Southworth, 2005), and experts acknowledge its importance in stimulating cycling (Pikora et al., 2003). Gatersleben and Uzzell (2007) report that being in an attractive environment is mentioned as one of the most positive aspects of cycling, although this is not statistically confirmed: Moudon et al., (2005) for instance, find that the presence of a park has a non-significant effect on cycling share.

To conclude, the presence of slopes has in general a negative impact on cycling. It is unclear whether this variable is involved with other related factors. The previous studies conclude that hilliness preferences of experienced cyclists are more 'adventurous' than the average cyclist. Although studies cannot identify the influence of the number of slopes, and that a cities area's topography can be interpreted differently, depending on a cyclist's level of experience.

Seasons and Climate

Stinson and Bhat, (2004) and Guo et al. (2007) report that in the USA, cycling in the summer is more common than in other seasons. In Australia, Nankervis, (1999) study finds that more people cycle in summer (over 20% of all travellers) and autumn, compared with winter and spring. The exact decline in cycling during the winter differs across regions (Stinson and Bhat, 2005). Regions with low winter temperatures, such as Canada and the North-East and Midwest American Regions, have a higher decrease in winter than regions with milder winters. Not only do people cycle less in winter, but according to Bergström and Magnusson, (2003), in Sweden, the maximum distance cycled decreases from 20 km in summer to 10 km in winter. The same study identified a similar effect for shorter distances: in summer, only 25% of people travel by car for journeys up to 3 km, whereas in winter, almost 40%. Seasons are not only related to weather conditions, but also to hours of daylight therefore the studies of Stinson and Bhat, (2004) and Gatersleben and Appleton (2007) prove that darkness has a negative effect on commuting by bicycle. In particular, women cyclists care more about the presence of daylight than men (Bergström and Magnusson, 2003).

The evidence of the impact of climate changes on cycling is scarce. Dill and Carr, (2003) find that the cities with the lowest bicycle mode share experience, on average, over 100 days of rain a year however three of the top six cities for cycling also have over 100 days of rain. Pucher and Buehler, (2008) suggest that other factors play a more important role of seasons and climate, they base this assertion on the fact that Canadians cycle more than Americans, despite the colder climate.

Weather

While climate is about conditions varies over seasons and years, weather varies from day to day, and daily decisions can affect cyclists' daily decisions as a result. Precipitation – or the chance of rain – is often mentioned as the most negative aspect and as a reason of not to cycle (Nankervis, 1999). Women, recreational cyclists and commuters who also cycle in winter have a greater aversion to rain (Bergström and Magnusson, 2003). A contrary result is presented by Cervero and Duncan (2003), who found rainfall to have an insignificant effect on cycling. This is explained by the fact that rainfall can be measured in several ways: the number of rainy days, the number of inches per day, the chance of rain and others. These measures can have different effects on cycling, it is plausible that contradictory patterns could emerge.

While cyclists consider rain and snow to be the most negative weather aspects, a number of other weather-related factors also affect bicycle use, including temperature (see Figure 14). More specifically, an increase in temperature results in higher cycling percentages (for temperatures between 8.6°C and 10.3°C) (Parkin et al., 2008). Nankervis, (1999) finds that cyclists perceive cold temperatures (<17°C) to be more unpleasant than hot temperatures (>30°C). Temperature and weather conditions does not always influence bicycle commuters choice, Bergström and Magnusson (2003), stat that one reason for this could be that some commuters have little choice but to cycle; if they are dependent on travelling by bicycle, they cycle regardless of the weather conditions.

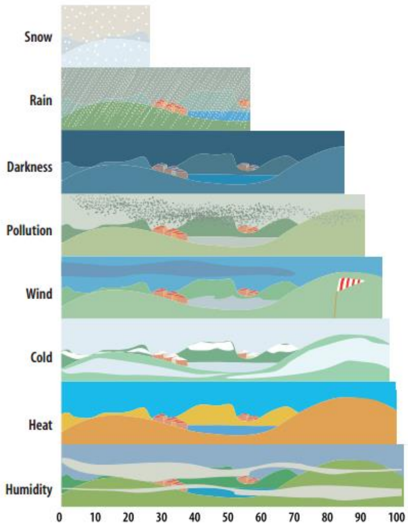


Figure 14. Influence of atmospheric conditions on bicycle use by commuters. Source: European Commission (2000)

The natural environment has a large influence on both the decision to cycle and the frequency. Hilliness is considered a negative effect on cycling. Experienced cyclists actually prefer hilly environments. Weather has a large influence on the cycling frequency. The chance of rain, low temperatures and darkness result in people choosing alternative transport modes. Commuters are less influenced by temperature than other cyclists, implying that many people only choose to cycle for leisure purposes when the weather is pleasant. Little evidence is known about the effect of wind, despite that wind clearly influences the amount of effort made by the cyclist (Parkin et al., 2008). Future research should focus not only on climate and weather conditions, which cannot be changed, but also on measures and facilities that might reduce the weather's negative effects.

5.5.3. Socio-economic factors

Commuting behaviour is obviously strongly linked to personal and household characteristics. Mode choice studies have shown that there is a strong relationship between mode choice behaviour and gender, income and age (Cervero, 2002). This section discusses the relationship between cycling and gender, age, income, vehicle ownership (both car and bicycle), a person's employment situation, household structure and several other socio-economic factor

Socio-Economic and Household Characteristics

Most research conclude that men cycle more than women (Räsänen and Summala, 1998; Shaw and Gallent, 1999, Pucher et al. 1999; Dickinson et al., 2003; Rietveld and Daniel, 2004; Rodríguez and Joo, 2004 and Moudon et al., 2005). The reason for this does not lie in the distance travelled to work, because women tend to live closer to their places of work than men (Dickinson et al., 2003). Only a few researchers did not find that men cycled more than women (Witlox and Tindemans, 2004; Parkin et al., 2008), they even found that in the active working population women cycled more than men for all trips, whereas non-working age groups, they found that men cycled more. It appears that the impact of gender on cycling also varies county to country. In countries with low cycling rates, men tend to cycle more; while in countries with high cycling rates, such as the Netherlands and Belgium, cycling is also popular among women (Garrard et al., 2008).

The relationship between cycling and age is also ambiguous. (Pucher et al., 1999; Moudon et al., 2005; Zacharias, 2007 and Dill and Voros, 2007) all conclude that cycling levels decline with age. According to Kitamura et al. (1997), however, age is not a significant factor. Elderly people are sometimes physically incapable of cycling, and they mention age as a reason not to cycle. While a relationship between age and cycling evidently exists, it is unclear whether it is a universal one.

The relationship between cycling and income is even less clear. One would expect having a high income to have a negative impact on cycling, because at an aggregate level, having a high income results in less cycling (Pucher et al., 1999). However, Parkin et al. (2008) conclude that in England and Wales, there is a link between lower incomes and a lower bicycle share for commuting. They suggest that economic deprivation may function as a proxy for crime, safe storage, bicycle availability and image issues. Dill and Voros (2007) find a positive connection between income and commuting by bicycle, suggesting that people who earn more tend to cycle more often. However, Witlox and Tindemans (2004) and Guo and Ren (2012) report a negative relationship between cycling and income; while according to and Zacharias (2007) income has no significant effect.

The relationship between a person's income and cycling thus remains unclear. This unclear relationship may stem from two potential consequences of having a higher income. In our view, on the one hand, having a higher income enables a person to spend money on a bicycle, which in turn increases bicycle use. Moreover, wealthy people may also pay greater attention to their health, and therefore cycle more. On the other hand, having a high income implies that one is able to spend more money on transport in general, including buying a car (Witlox and Tindemans, 2004). Car ownership has a strong negative effect on cycling mode share. Cervero (1996); Kitamura et al. (1997);Dill and Voros, 2007 and Guo and Ren, 2012 among many other authors conclude that having fewer cars increases cycling frequency. Some cite needing a car for their work as a reason for not commuting by bicycle (Moritz, 1998). As car ownership results in less cycling, bicycle ownership logically increases the probability of individuals cycling.

A person's employment status affects bicycle use. Among employed individuals, part-time workers commute more frequently to work by bicycle than fulltime workers (Boumans and Harms, 2004), perhaps because they tend to live closer to their work. Household structure also influences the chance that an individual cycles. Compared with an average of 6.4%, Ryley (2006) found that individuals without children (16%), students (17.9%), those in-between jobs (11%) and part-time workers without children (8.1%) are more likely to cycle, as are people who work fewer than 40 hours a week, or who are divorced or widowed (Moudon et al., 2005).

There is a relationship between socio-economic factors and cycling, there is a lack of clarity on both the direction and its causality of this relationship. The evidence of the relationship between cycling, age and income differs according to different researchers. Most of the research discussed above simply uses survey results to draw links between socio-economic factors and cycling. The research tends not to examine whether these are causal relationships, therefore it is unable to draw a clear and universal conclusion. Moreover, large differences exist between different countries, perhaps due to the impact of differences in countries' social and built environments, and economic circumstances. These uncertainties indicated may result for example, by the significant differences between countries. Social values and attitudes may play a key role in this respect.

5.5.4. Psychological factors: attitudes, social norms and habits

Recent studies have focused on attitudes and other psychological factors on travel behaviour and mode choice. This section examines what is currently known about the impact of psychological factors on cycling. Psychical factors such as attitudes, norms, perceived behavioural control and habits will be analysed. The second part of this section discusses people's perceptions of what makes it possible to, and prevents them from, cycling to work. This section is structured differently from the previous sections, because psychotically research tends to be more theoretical. Therefore, this section is based mainly on theoretical research findings.

Attitudes and social norms

Attitudes play a key role in the distinction of two main theoretical theories that have been applied in mode choice research studies: the theory of planned behaviour (TPB) (Ajzen, 1991) and the theory of interpersonal behaviour (TIB) (Triandis, 1989, 1997). Attitudes can be defined as the expectation of all the outcomes of any activity, and the personal value of these outcomes. People's attitudes towards car use are generally more positive than people's attitudes towards cycling (Dill and Voros, 2007). Anyhow, Dill and Voros show that having a positive attitude towards cycling increases the likelihood of commuting by bicycle. It is not only cyclists who tend to be more positive about cycling; Gatersleben and Appleton (2007) find that people who are considering cycling to work are also more positive about cycling than others. The importance that individuals attach to aspects such as the health-related benefits of cycling also has an impact on cycling for commuting purposes. Having a negative perception of the consequences of car use also stimulates cycling (Stinson and Bhat, 2005).

According to the TPB, not only personal attitudes, but also perceived social norms are key factors affecting decision-making. When applying the TPB to the case of people cycling to a university, Bamberg and Schmidt (2003) found that social norms had no significant impact. However, De Bruijn, et al. (2005) found that cyclists experience a more positive social norm than non-cyclists. De Geus (2007), meanwhile, concludes that cyclists perceive more support for cycling, and more often have a cycling partner. These findings indicate that social norms do indeed play an important role. It is assumed that there is a relationship between other social aspects, such as cycling's public image and the general attitude to cycling within a particular country or region's culture and bicycle use (Pucher, Komanoff, and Schimek, 1999). Dill and Voros (2007) provide evidence for this relationship: if an individual's co-workers cycle to work, then it is more likely that the individual will cycle as well. Furthermore, according to De Geus (2007), if employers offer financial support for cycling, which can be seen as evidence of a positive attitude towards cycling, then there is a higher chance that the recipient will be a cyclist.

Perceived Behavioural Controls

A third aspect of the TPB is perceived behavioural control; that is, a person's evaluation of the possibility of performing certain behaviour. Gatersleben and Appleton (2007) and De Geus (2007) show that individuals who do not commute by bicycle perceive more barriers and problems to commute by bicycle than bicycle commuters. Bamberg el al. (2003), meanwhile, show that compared to non-cyclists, cyclists perceive more possibilities for cycling.

Habits

Both the TPB and the TIB, most of the studies reviewed are based on the assumption that decisions are made on the basis of rational evaluation. The existence of habits, however, puts the validity of this assumption into question. The process of breaking a habit might result in mode reconsideration and possibly mode change. For example, simply experiencing what it is like to commute by bicycle to work may persuade some people to change commuting modes (Rose and Marfurt, 2007). Stinson and Bhat (2004) show that cycling more in one's free time results in a higher frequency of bicycle use for commuting they also conclude that cycling to work over a long period of time results in higher frequencies. Moreover, bicycle use during childhood can affect adult cycling behaviour. Cycling as a child increases the likelihood of cycling as an adult (Dill and Voros, 2007). However, there is no evidence of a relationship between adult bicycle use and having cycled to school as a child. Not only do individuals' cycling habits affect their cycling behaviour, while Verplanken et al.(1997) suggest that having a habit of using other modes of transport has a negative impact on bicycle use.

Reasons for (not) Cycling

In the studies of Bergström and Magnusson (2003); Stinson and Bhat (2004)Gatersleben and Appleton (2007), many of the respondents cite many reasons for (not) cycling. The reasons given for cycling include, health reasons, exercise/fitness, fun, flexible, convenient and enjoyment of attractive scenery. Gatersleben and Appleton (2007) found when they questioned novice cyclists; some of these reasons (namely, fitness, fun and being outside) were cited before the individuals in question had tried their commutes. These individuals were later disappointed by the experience. On the other hand, novice cyclists found that some of the factors that they had expected to be negative, such as traffic safety, became more positive in practice. Overall, compared to car drivers, walkers and public transport users, cyclists evaluate their journeys to work as more relaxing and exciting (Gatersleben and Uzzell, 2007).

Questionnaire respondents and experts identify a number of cycling's more negative aspects as reasons not to cycle. These include: too dangerous, too much traffic, bad weather, personal factors (too busy), lack of daylight, inconvenience, lacking sufficient fitness, uncomfortable, lack of time, being tired, too much effort, the bicycle being an uncharacteristic transportation mode and difficulties with trip-chaining (Noland and Kunreuther, 1995). Dickinson et al. (2003) have found that some factors are more important for specific groups. Women, in particular, cite the difficulty of combining a journey with picking up children or shopping as a reason for not cycling. Some factors are mentioned as both advantages and disadvantages: 'convenience', for example, occurs on both lists, this might be a reflection of either of the extensiveness of the term, or the fact that when it comes to cycling, cyclists and non-cyclists have different notions of "convenience".

Attitudes, social norms and habits influence a person's decision to cycle to work. If a person has a more positive attitude towards cycling, there is a higher probability that they will cycle. The existence of habits, however, means that people do not always select modes of transport once they have rationally evaluated all of the potential outcomes. Habits can affect mode choice and frequency: if a person is used to using a certain form of transport, they are unlikely to search for new options. As a result, some modes of transport, such as the bicycle, are not taken into consideration. When it comes to commuting, one would expect the same factors to be significant as for cycling in general, with the additional influence of being in the habit of cycling in one's free time affecting mode choice for commuting.

5.5.5. Travel time, cost, effort, safety and dangers

Travel time, cost, and effort are features that derivative from a utility theory. Utility theory assumes that each individual acts to maximize his or her utility. When applied to mode choice, utility theory assumes that an increase in the time, cost and effort of a travel option will result in a decrease the probability of choice of specific transport mode. This section is based on how cost, travel time, effort and safety affects bicycle commuting as a transport mode choice and trip frequency (Stinson and Bhat, 2004).

Time travel and effort

Travel time and effort influences bicycle commuting. In particular, experienced cyclists prefer short travel times (Stinson and Bhat, 2005; Hunt and Abraham, 2007). According to Parkin et al. (2008) the time spent travelled by bicycle in some aspects is considered to be three times more unpleasant than the time travelled for other modes. The convenience of a trip declines with an increase in the travel time, which is not the case for other modes of transport because they can accomplish longer trips in basically the same time and with less effort (Noland and Kunreuther, 1995).

An increase in travel time results in having to expend more effort. Having to make a greater effort generally results in having a less positive attitude to cycling (Gatersleben and Uzzell, 2007), longer travel times and having to expend more effort would leads to less cycling and more motorized commuting. Some cyclists choose to cycle specifically because of the effort needed), and they may even prefer slightly longer commuting distances. As with safety, cyclists attach the highest value to cycling's comfort level (Noland and Kunreuther, 1995).

Transportation Costs

Travel costs affect mode choice. Cycling is relatively cheap, and according to Bergström and Magnusson (2003), this is one of the main reasons why commuters choose to cycle. Not only is the cost of cycling important, but the cost of other forms of transport also plays an important role (Noland and Kunreuther, 1995 and Rietveld and Daniel, 2004). Pucher and Buehler, (2006) discovered a relationship between bicycle use, petrol prices, income and car use when comparing data from the USA and Canada. One should note, though, that Dill and Carr (2003) did not find a similar pattern for petrol prices within the USA. Petrol prices do probably affect people's choices, but the relatively minor differences between different states do not show this effect. Bamberg et al. (2003) has identified another cost-related effect, providing free public transport reduces bicycle use. Paying people to cycle, however, would have a positive effect on cycling levels: research suggests that if people in Britain were to receive two pounds each day they cycled to work, the level of cycling would almost double (Parkin et al., 2008).

Safety

Safety is considered one of the main issues when bicycle commuting is taken in consideration and it is often mentioned as a reason not to cycle. If there is a risk of having an accident, people will cycle less (Pucher and Buehler, 2008). Not only is objective safety an important factor, but subjective safety also plays a critical role. It appears that people remember what they perceive to be dangerous route segments better than 'normal' route segments (Shankwiler, 2006). Not all people have similar perceptions of what it means to be safe. For example, safety seems to be less important for people with high incomes (Johansson et al., 2005), and for men than for women (depending on the city 15.9% and 10%, for men, compared to 4.6% and 3.9% for women). Importantly, many consider that cycling is less safe than walking, driving a car or using public transport, but cyclists gave the highest rating for bicycle safety. Countries in Europe with high levels of cycle use tend to be less risky for cyclists. In Denmark, people cycle over 900 kilometres a year and it is a far safer country to cycle in than Portugal, where barely 30 km is covered by each person by bicycle annually. Figure 15 shows bicycle travel per inhabitant per year (km) and number of cyclists killed per billion km (Barnett, 2001).

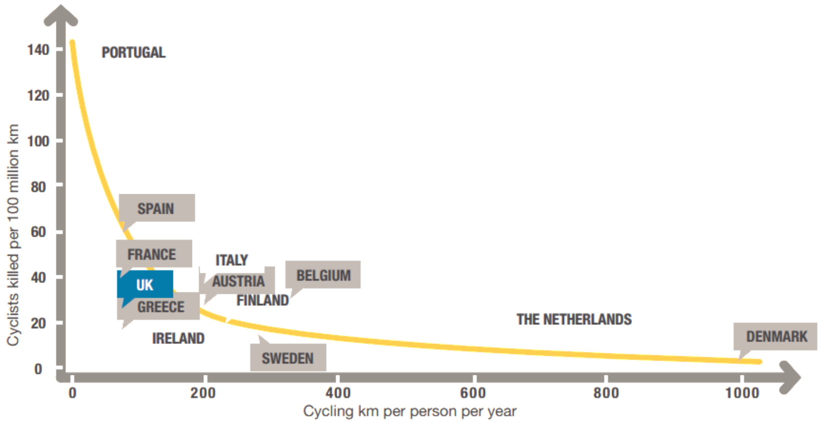


Figure 15. Fatalities by bicycle travel per inhabitant per year (km) and number of cyclists killed per billion km. Source: Barnett (2001)

The cost, travel time, effort needed and safety of a trip are important factors for cyclists. All of this four aspects affect mode choice. These four aspects are always considered and compared to other transport modes, for example, if the cost of another mode of transport becomes more expensive, then levels of cycling increase. Little evidence is known about the frequency of bicycle commuting. The perceived value and the real value of cost, time and effort is important for people's decisions weather to choice a specific transport mode. When safety measures are token in account this aspect is a good example of the notions of real and perceived values. Cyclists give a higher safety value than non-cyclists, which may reflect the different ratings used by different transportation users, or could result from different experiences.

5.5.6. Overview of the cycling factors

There are many reasons to encourage cycling, and in recent years, governments and academic researchers have renewed their interest in the topic. In order to develop policies that encourage cycling, we need a better understanding of the factors that influence cycling behaviour. Empirical knowledge on bicycle use may be dispersed; therefore, it is necessary to have a better understanding of the factors previously mentioned. The aim is to identify the main variables of bicycle commuting, and for bicycle commuting frequency. Finally, the previous findings do not simply enhance the understanding of the use of the bicycle as a transport mode, but also other forms of motorized travel. The main conclusions of this section that emerges from literature is as follows:

- The built environment affects a person’s choice to commute by bicycle. Cycling share is influenced by the following factors: distance, mixed functions, services and facilities, block size and density, the presence of bicycle infrastructure and its continuity, traffic lights and stop signs, land use, parking facilities and facilities at work such as lockers and showers at work. Of these factors, distance is probably the most important.
- A climate with moderate temperatures and little rain increases the share of bicycle commuting. Bad and uncertain weather negatively affects a person’s decision to cycle.
- The relationship between socio-economic factors and cycling is unclear. Certain socio-economic aspects differ between countries. In most countries, men cycle more than women. In those countries in which cycling is very common, such as Belgium and the Netherlands, women cycle more.
- Car ownership has a negative effect on cycling; logically, bicycle ownership has a positive effect.
- Most research merely mentions or examines the relationship between socioeconomic factors and cycling, but does not allow to make any inferences about the connexion of this relationship.
- There is a relationship between commuting by bicycle and people’s attitudes and perceived values. More cycling may result from positive perceptions of cycling or negative perceptions of car use. If the individual’s social surroundings have a positive opinion of cycling, then there is a higher chance that the individual in question will cycle.
- It is thought that individuals sometimes decide whether to commute by bicycle by comparing cycling with other transport options, in terms of cost, travel time and safety.
- Travel time and safety seem to be more important for cycling than for other modes of transport.

Finally, only a few amount of studies has focused specifically on commuting by bicycle. Most of the research focuses either on bicycle use in general, or on commuting in general, and pays only limited attention to the bicycle as a mean of transport and in other studies many of these factors are frequently not included. The main findings about the influence of land use and cycling variables that affect mode choice and frequency can be seen in the following table (see Table 13); the references can be found in Table A1 in the appendix A.

Table 13. Main findings about the influence of land use and cycling variables that affect mode choice and frequency. Developed by the author

	Determinants	Influence		References
		Mode choice	Frequency	
Built-Environment	Function mixture	higher density increases bicycle share	people living close to the city/town centre cycle more	[14] [20] [9]
	Density	higher density corresponds with more cycling	people living closer to the city/town centre cycle more (decrease from 56% to 46% of non-cyclists closer to the centre)	[19] [11] [9]
		residential densities have no effect	no correlation	[27]
	Trip distance	increase results in less cycling (according to 27% of non-cyclists, compared with 2% of cyclists)	no correlation	[19] [33] [32]
	Cycling infrastructure	Positive effect depending on the quality and type of infrastructure	no correlation	[12] [31] [38]
	Adjacent car parking	No significant correlation	no correlation	[31] [32]
	Number of bicycle paths	more cycling infrastructure results in more cycling (increase of 1-2%, but probably depending on location)	no correlation	[22]
		no correlation	no effect	[16]
	Traffic lights	more traffic lights in a city corresponds with lower cycling levels	no correlation	[31] [26]
	Shower at work	if present more cyclists	no correlation	[12]
		no effect	no effect	[31]
	Network layout	no significant effect on cycling	no correlation	[16] [37]
	Bicycle parking	no correlation	no correlation	[18] [31] [7] [15] [35] [12]
	Continuity of cycling facilities	no correlation	no correlation	[31] [32]
	Locker at work	no correlation	no correlation	[12]

Table 13. Main findings about the influence of land use and cycling variables that affect mode choice and frequency (Continuation). Developed by the author

	Determinants	Influence: Mode choice	Influence: Frequency	References
Natural environment	Temperature	unpleasant temperature corresponds with less cycling;	unpleasant temperature corresponds with less cycling	[2]
		cold more unpleasant than heat	no correlation	[17]
	Season	more cycling in summer and autumn (20% to 10%; 40% to 25%; differs between locations)	no correlation	[11] [32]
	Hilliness	less cycling with hills	no correlation	[31] [26] [27] [19]
		no significant effect on cycling	no correlation	[16]
	Rain	negative effect on cycling	no correlation	[17]
		no effect	no correlation	[4]
Socio-economic factors	Gender	men cycle more than women	men cycle more than women	[25] [29] [9] [27] [16]
		women cycle more than men	no correlation	[36]
		no effect	no correlation	[19]
	Car ownership	car ownership decreases cycling	car ownership decreases cycling	[5] [13] [29] [31] [21] [11] [19]
		car ownership has no effect	no correlation	[16]
	Age	cycling declines with increase	no correlation	[24] [16] [37] [9]
		age is not significant	no correlation	[37] [19] [13]
	Income	positive connection between income and cycling	no correlation	[24] [32] [9]
		negative connection	no correlation	[36] [21] [28] [11]
		no significant connection	no correlation	[8] [37]
	Employment status	no correlation	part-time workers commute more frequently by bicycle	[3]
Psychological factors	Habit	a cycling habit increases the cycling share	a cycling habit increase the cycling frequency	[34] [31]
	Attitude	cyclists have a more positive attitude towards cycling	no correlation	[9] [10]
	Perceived social norm	cyclists have a higher perceived social norm	no correlation	[6]
		no effect on being a cyclist	no correlation	[1]
Cost, travel time, effort and safety	Safety	a reason not to cycle	no correlation	[23] [26] [30]
	Cost of other means of transportation	if higher, more cycling	no correlation	[26] [23]
	Travel time	no correlation	no correlation	[32] [12]

5.6. Summary and discussion

Cycling offers a number of advantages over other modes of transport. Compared to car commuting, cycling is environmentally sustainable, it requires limited space, bicycle infrastructure is relatively inexpensive, there is limited noise production and it improves the public health. For the individual, cycling is a healthy and cheap form of transportation, and can sometimes prove to be faster than other transport modes, especially in urban areas.

The factors determining cycling, as found in literature, can be categorized as follows: the built environment, the natural environment, weather conditions, socio-economic characteristics, attitudes, norms and habits. Distance seems by far the most important factor. Other characteristics of the built environment that have a negative effect are traffic lights and stop signs. On the other hand, a higher function mixture, the presence of bicycle storage facilities, smaller block size, higher density, the presence and continuity of bicycle infrastructure facilities, as well as bicycle parking facilities and showers at work, influence cycling positively. Therefore, built environment does have an effect upon levels of bicycle ridership. The presence of cycling facilities and the distance of a station to a destination are both factors that share a statistically significant relationship with the level of ridership at a station. This suggests that a greater, more connected network of bicycle facilities of any sort should be created within cities in order to increase levels of bicycle transportation.

The relationship between socio-economic factors and cycling is ambiguous in the scientific literature. The effect of some socio-economic aspects differs between countries. For example, in most countries men cycle more than women, whereas in countries in which cycling is very common, such as Belgium and the Netherlands, women cycle more.

The natural environment has a large influence on both the decision to cycle and the frequency. Hilliness has in general a negative effect on cycling, but experienced cyclists actually prefer hilly environments. Rain, low temperatures and darkness result in fewer people cycling. Nevertheless, commuters are less influenced by temperature than other cyclists, implying that the weather effect is smaller for trips that have to be made and cannot be postponed, or only for a limited time, opposed to recreational cycling trips.

From the literature review, several recommendations are provided for future research. It can be concluded that many bicycle research studies only examine a limited number of factors, and more attention is needed for bicycle-specific factors, such as gradients and weather conditions. Moreover, relatively little is known about the factors affecting cycling frequency, as most research only focuses on mode choice. The literature review also gives the impression that attitudes play a more significant role in mode choice than that that has so far been assumed. Therefore, a focus on attitudes and people’s social environments in research on the choice to cycle to work and cycling frequency could lead to new insights. Finally, while in some countries cycling has been addressed in academic research, such studies are lacking in other countries. In order to gain better insights into the transferability of knowledge, bicycle research should be conducted across a wider range of countries.

Chapter 6

Challenges and promotion of cycling

6. CHALLENGES AND PROMOTION OF CYCLING

Cycling as a mode of transport has many advantages for both cyclists and society: low-cost, low polluting and a health-improving way to travel. In light of these benefits, a growing number of cities in the world are implementing policies and strategies to promote cycling.

Cities face many challenges in the process of encouraging cycling, two of the most significant challenges in increasing cycling as a mode of transport. Firstly, identifying the most effective ways to spend the limited resources that have been allocated to cycling and, secondly, justifying the allocation of a greater share of their limited transport resources to cycling (Handy et al., 2014).

There are many possible strategies and policies to promote cycling, they can be grouped into the various categories, such as: travel-related infrastructure, end-of-trip facilities, transit integration, promotional programs, bicycle access and regulations (Dill et al., 2013).

6.1. The importance of policies and measures

Recognizing the many benefits and potentials of bicycle use, as mentioned previously in section 5.4, many countries have defended an increase in bicycle use to improve population's health, reduce air pollution, greenhouse gas emissions, traffic congestion, noise, traffic accidents and other harmful effects of motorized transport modes (Dill et al., 2013).

According to European Commission (2000), governments of each member-state should at least try not to consider the bicycle as a minor mode of transportation in relation to other motorized transport modes. The bicycle in the city should occupy the same statues as the car and public transport as an urban transport mode. Therefore, the bicycle should be considered as an equivalent transport mode, taking into account the potential of each mean of transportation and the cost of the required equipment.

Encouraging people to ride bicycle is not an easy task, therefore, it is important to have a better understanding of the factors that affect the decision to use the bicycle or not (see section 5.5), while issues related to climate or demographic aspects are some of the issues that cannot be controlled by politicians (Sener et al., 2009).

Policies at national level, according to the OECD (2004), may promote the use of bicycle and facilitate the implementation of measures in urban areas as following:

- Establishment of an integrated framework of national policies with clear objectives, goals and actions in coordination with national agencies, regional and local authorities, cycling associations, bicycle users and with the bicycle industry;
- Proposing a regulation and guidelines for the development and implementing friendly policies for the bicycle at regional and local level;
- Improve the safety of bicycle users, encouraging reduction of the speed of motorized traffic where necessary;
- Conducting research on policies and measures to promote and encourage the bicycle use and disseminate the knowledge produced to local governments and other relevant stakeholders;
- Improve data collection on cycling travel and bicycle user s' behaviour so that there is a better understanding of the current situation, trends and potential of cycling;
- Monitoring the progress of the objectives to be achieved and conducting an evaluation of the result of the implementation of policies implemented towards bicycle use.

A single policy cannot by itself promote bicycle use, therefore, it is necessary well-integrated and coordinated policies. Cities that have the largest number of trips made by bicycle have been making efforts to ensure security and well-designed infrastructures for bicycles. Following the good examples in practice of the Netherlands and Denmark, the policies should focus on the following aspects to increase bicycle use:

- Implementation of an urban policy that considers the bicycle as an alternative mean of transport and require therefore a structured plan;
- Connecting bicycle infrastructure in the city with urban and suburban neighbourhoods;
- Improve or implement secure bicycle parks in urban centres and major attractors poles as train stations and subway;
- Keep the bicycle paths in good condition and with good signage making its users feel safe;

- And providing a good connection between the existing network, bicycle lanes and recreational pathways, including long distance bicycle rides and bicycle paths along the main roads.

The main objectives and goals for national policies and plans to increase the use of bicycles are in degree of decreasing importance OECD (2004):

- The promotion of security in sharing public roads;
- Reducing environmental problems and improving air quality;
- Strengthening the role of the bicycle as a mean of transport and increase the modal share;
- Reducing congestion and car use;
- Improving mobility;
- Health promotion, physical activity and reduction with health care costs;
- Leisure and tourism promotion;
- Development and maintenance infrastructure;
- Integration of all sustainable modes of transport;
- Finally reduce bicycle theft.

6.2. Challenges in implementing an effective policy

Policy implementation is one of the major problems faced by developing nations. Due to the complexity, uncertainty and unpredictability implementation process of turning a policy into practice, it is quite common to observe a gap between what was planned and what actually occurred as a result of a policy.

According to OECD (2004) one of the main challenges encountered in implementation of an effective policy to promote and incrementing of cycling it is the financial constraint. The budget for investments in favour of the bicycle is very limited and in general, rarely seen as a priority. In many countries, there is little information available on the impact of increasing the number of bicycle users. Institutional barriers are also encountered because the bicycle theme involves several actors at national level several ministries and the regional and local authorities consequential resulting in lack of coordination between the various stakeholders can cause problems in the implementation of policies aimed for cycling.

Safety measures is considered one of the major barrier found in promoting bicycle. Users feel very vulnerable in urban areas, by sharing the public road with motor vehicles. This safety issue becomes even more accentuated when considering children, the elderly and women who are more sensitive to risk perception.

Insufficient understanding of technical and technological issues is considered to be another challenge (OECD 2004). Improving engineering can improve cycling conditions through a safer, more complete and more convenient network. Frequently the design of the network and or the infrastructure has many problems, starting with poor quality and with many interruptions, due to the conflict of interests between different road users therefore jeopardizing the safety referred above. The lack of awareness of the benefits of a regular use of bicycle does not help to implement these policies. The European Parliament (2010) proposes a five categories frame intervention (see Table 14) each with a specific set of measurements, engineering, reinforcement, encouragement, evaluation and education. For each category, the main stakeholders are listed and at what level the measures should be implemented.

Table 14. Intervention measures to promote the use of bicycles by category. Adapted from: European Parliament (2010)

	Description	**Stakeholders**
Engineering	Infrastructure (cycle paths, bridges, signalling routes, safety signs) Frequent road maintenance Traffic Calming Articulation of cycling with other means of transport	National governments Consulting Companies
Education	Educating motor vehicle drivers to share the road Safety programs for children and adults Safety Campaign Bicycle driving Trainers Route maps with bicycle lanes routes Bicycle Sites Government Partnerships to promote safety	Private associations and business communication Organizations with volunteers
Incentive	Incentives to improve bicycle use (Incentive programs in the community, advertising and marketing, events planning online travel, safe routes)	Private associations and business Organizations
Reinforcement	Policy support the use of bicycles Raising awareness of vehicle drivers motorized by the police to share the road and lead to security near bicycle users Bicycle patrols Application of laws both drivers motor vehicle as user bicycle	Departments national transport Departments police local
Evaluation	Change in modal share of cycling Number of accidents, injuries, thefts Kilometres of cycle paths Bicycle paths interconnection rating provide transportation options	European Commission National Government local government

6.3. Strategy measures for cycling

This section explores strategies and their capacity to encourage cycling as an alternative mode of transportation. The existing cycling strategies themselves vary in their extensiveness and implementation success. It is important to identify policy areas that have an impact on cycling and suggests practical ways that councils can truly make a difference to encouraging more cycling. Among the many strategies related to encouraging bicycle use (e.g. education, heath, engineering, social aspects) There are two types of policy measures that can be employed by councils or governments to promote cycling. To shift from an automobile dominated environment to a bicycle friendly urban design, and change attitudes towards cycling, municipalities can implement both “hard” and “soft” interventions, see Table 15. A combination of both infrastructure and programs are perhaps necessary to successfully support cycling (Clarke, 2012 and Pucher et al., 2010).

“Soft” measures are aimed at encouraging cycling through education, promotional activities, and media campaigns. Includes pricing of alternative modes, education, complex information exchanges, information provision, public relations and promotional campaigns, etc., (Krizek et al., 2009; McClintock, 2002 and Pucher et al., 2010).

“Hard” transport policy measures include physical improvements of infrastructure for public transport, increased costs for car use, and control of road space (prohibition and rationing of car use). Although these measures may be necessary to achieve car-use reduction, they are difficult to implement because of public opposition and political infeasibility (Gärling and Schuitema, 2007).

The implementation of “hard” measure interventions can also influence individual perceptions, as road users become more aware of cyclists, increasing road safety. Interventions within the built environment are intended to make cycling more appealing among users to substitute trips made by automobiles. However, this approach is associated with higher costs. Among the many benefits of healthy daily travel choices, the goal for both “soft” and “hard” measures are to change travel habits.

Pucher et al. (2010) found, through their review of international cycling promotion programmes, that while there is currently little evidence to prove that these interventions have a positive effect on cycling numbers on their own, when they are combined into a comprehensive promotion strategy they are more effective.

Table 15. Different measures according to type of intervention “hard” or “soft”. Developed by the author

		Type of measure
“Hard” Measures	Provision of improved travel options	• End of trip facilities • Cycle lanes / paths • Crossing facilities • Provision of pool bicycles • Provision of cycle parking • Provision of bicycle amenities • Integration with other transport modes • Proper signage • Maintenance
	Incentives to use more sustainable modes	• Reduce availability of car parking spaces • High Occupancy Vehicle priority • Traffic calming areas • Reduced speed limits • Enforcement • Provision of cycle parking
	Land use and urban design	• Transit Oriented Developments • Streetscape improvements • Creation of shared zones • Street layout • Design of public land • Parks and recreational space • Mixed land uses, such as locating shops below apartments and offices near houses • Increased street connectivity by having fewer dead-end streets and smaller blocks • Encourage a dense and diverse mix of services, amenities, jobs, and housing types in areas well-served by frequent, high-capacity transit • Locate major trip generators near rapid transit stations or along transit corridors • Street lighting, trees, benches, and other amenities
“Soft” Measures	Promotional cycling campaigns	• Website travel information page • Cycling information on marketing materials • Site access maps • Travel information packs • Notice boards / screens promoting benefits of cycling
	Educational cycling trainings	• Commitment to fund cycling training, subsidise bicycles / equipment • Cycle training

6.3.1. “Hard” measures

“Hard Measures” focus mainly on cycling mobility support infrastructure, which when designed and implemented correctly, they have the duty to promote the increase in number of bicycle users in urban areas. They most commonly involve physical changes, such as improvements to infrastructure. “hard” measures seek to change the attributes of travel and discourage behaviours. They can also include taxes and regulations which can perhaps be described as 'semi-soft' measures as they are more persuasive than physical and seek to influence choice.

The interventions from “hard” measures mostly require changes to the built environment changes that would increase the access, attractiveness, safety, comfort, and security of non-motorized transport. Additionally, they may stimulate changes in perceptions, attitudes, and other psychological factors similar to those anticipated by “soft” measures (Krizek et al., 2009). The basic required “hard” measures for cycling-are (Cyclecities, 2014):

- Construction of appropriate cycling infrastructure (bicycle tacks and lanes) to ensure traffic safety and connectivity;
- Introduction of general integrated transport measures (pedestrians and cyclists only zones, traffic calming measures, 30 km/h speed limit zones, expensive parking policy, difficult access to the centre of the city by car and easy coming by bicycle etc.);
- Introduction of special integrated transport measures (expensive entrance fee to come to the city by car, common bus- cycle lanes etc.);
- Providing supporting cycling systems (Bike-sharing system, safe bicycle storages, bicycle rentals etc.);
- Introduction of new special traffic detailed arrangements (open one way streets for cyclist in both directions, open blind streets for cycling, “Sharrow", Bike box, advanced stop line, shared space etc.);
- Introduction of unique sign posting system and colouring of the cycling surfaces;
- To introduction of regular maintenance and renovation of existing cycling surfaces.

6.3.2. “Soft” measures

"Soft" and "mind-set" measures reinforce in most cases effectiveness of "hard" measures within the urban transport and seek to change behaviours, attitudes and ways of thinking. “soft” measures are considered as awareness raising campaigns and provision of information to increase levels of walking, cycling, car sharing and use of public transport and to encourage a reduction in the use of the private car. Often the expression “public relations for cycling” is used synonymously. They are distinguished from “hard” measures, which are provisions of infrastructure. Soft Measures are considered to be one of the most important instruments for a cost-efficient promotion of cycling. On the one hand they aim to change habits and perceptions to overcome barriers to cycling (awareness rising campaigns). On the other hand “soft” measures can be used to spread information, to educate and to teach experts (Clarke, 2012).

Since many cities in Central Europe currently are facing the problem of bad, unsafe and insufficient cycling infrastructure, improving the cycling network might be more important for these starter cities. Implementing “soft” measures will foster the use of bicycles, which can lead to increasing safety problems wherever the infrastructure is in bad conditions.

If the aim of the measures is to keep the users of the bicycle, which already do regularly and increase the use of this means of transport in the group of recreational cyclists or even non-cyclists, Dufour (2010) argues that there are three major categories of promotional activities communicate the message:

- Specific training and educational programs that address directly some groups with greater potential for potential bicycle captivation, for example, school children: School should draw mobility plans that include specific measures to adoption of soft modes.
- Individualized Promotion which identifies individuals who are likely more receptive, providing them with personalized information.
- Information activities and awareness campaigns that can be adapted Specific target groups.

In this context, it is worth highlighting some ongoing initiatives develop in Portugal, such as the Project "**Bike Buddy**" of Mubi, which is a group of volunteers who provide to follow new users in the first missions urban context, sharing their experience, advising new users about routes, equipment, safety, legislation and shortcuts to facilitate the cycling trips through the city (Mubi, 2012). The "**Sexta de bicicleta**" an initiative that challenges people to commit themselves to use the bicycle every Friday to ride their bicycle. The **"Bike to Work"**, similar to the previous, but integrated in the European Mobility Week. It is held once a year in cities around the world, including many Portuguese Cities, such as the "European car-free day", which is held annually on 22th of September, that aims to reduce car traffic in cities and encourage the use of public transport and soft modes. The movement "**Massa Crítica**", addressed in the case study of Lisbon, brings together users bicycle as a means of transport to carry out an urban ride every Friday, in cities across the world. In the city of Aveiro there are many on-going projects and initiatives such as "**Quintas a pedal para a UA"** initiative that aims challenges the academic to commit themselves to use the bicycle every Thursday. **"Ciclaveiro"** a group of citizens that aim to promote the use of the bicycle as a daily transport mode and promotes community indicatives such as bicycle workshop, bicycle tours, bicycle shop window competition among other initiatives. Moreover, the project **"Compromisso pela Bicicleta"** and **"Plataforma Tecnológica da Bicicleta e da mobilidade suave"** mentioned in section 1.2, all "soft" measures initiatives to promote the use of the bicycle.

6.4. Methodology of the Impact analysis

The methodology used throughout for this study is divided into three main points:

1) Literature review

This study begins with analysis and definition of concepts related to land use and cycling mobility.

2) Analysis of case studies

The choice of the case studies analysed results from a number of factors that the author considered comprehensive and sufficiently distant in order to obtain a set of strategies that allow replication, with due adaptation. Justification of the case studies:

Amsterdam: Due to being one of the cities analysed that has one of the highest mobility cycling rate in the world and being second in the index of the friendliest cities bicycle published by Compenhagenize consultant. Despite the differences orographic between Amsterdam and most of the Portuguese cities, this case becomes a relevant case study due to present cycling culture (Sootfreecities, 2001).

Seville: Seville was another city analysed the merits of multiplying the cycling mobility index in a short time. In addition to the importance of analysing the strategies that allowed, within five years to make the bicycle as an intrinsic part of the population and because this city is the with the closest resemblance to Portugal, both weather and orographic similarities and even in their culture (Walker, 2015).

Lisbon: It is the city with the lowest value of cycling mobility, among the case studies, but the option to incorporate relates to the fact that the capital and the urban environment with the greatest volume traffic in Portugal. Where the bicycle may in the future find their space and contribute significantly to solve some of the city's problems (CML, 2015).

Copenhagen: Cycling is a significant mode of transport in Copenhagen in trips to both work and school as well as leisure Today there are almost 390km of bicycle roads, of which 320 are cycle tracks, 15 of cycle lane, 40 of green cycle route. Building them started in the beginning of the 1900s, since then the number of cyclists never stopped growing and the demands for better cycling conditions increased. Nowadays, problems of energy and pollution have added an international perspective to the Copenhagen cycling tradition (Sootfreecities, 2001).

London: is one of the cities with the least tradition in promoting the use of the bicycle. However, during the decade much has changed, the number of cyclists has more than doubled the total number of cycling journeys raised by 5%. However, London is still fighting, 432 cyclists were seriously injured or killed on the roads in 2014 (Allan, 2016).

Berlin: Cycling in Berlin is a significant form of transport in the German capital. In that past decade, Berlin has experienced a long trend towards more cycling. The city has improved the infrastructure for bicycles in many aspects. Cycling doubled to 12% modal share by 2008 and reached 13% in 2013 (Sootfreecities, 2001).

3) Analysis of the different strategies of each country is implementing to have a better understanding how to promote the use of the bicycle. The last step consists in defining an Impact analyses, mentioned in section 1.2 of strategical measures, after the lessons learned from several case studies, and the confrontation of these in terms of benefit/cost.

6.5. Analysis of “hard” and “soft” strategies measures

There are many possible strategies to promote cycling can be grouped into various categories of travel-related infrastructure, end-of-trip facilities, transit integration, promotional and other programs, bicycle access, and regulations. National governments can help implement cycling policies in local areas in a variety of ways, including the establishment of a national policy framework or strategy that sets out the legal and regulatory instruments for safe and efficient bicycle use and the provision of adequate financial support – especially for cycling infrastructure facilities and development. Table 16 presents the cycling plans/programs and their respective summary of their main objectives of the European cities analysed. The strategy measures of the plans will be investigated aiming to seek the different “hard” and “soft” measures, planed-implemented in the different cities aiming to detect lacking and different cycling measures.

Table 16. Cycling plans/programs and summary of their main objectives. Developed by the author

Country	Cycling Plan	Objectives
Copenhagen (Denmark)	Copenhagen city of cyclists Bicycle account 2012 (2010) Sustainable Urban Transportation Think Denmark (2016) Collection of Cycle Concepts 2012 (2012)	• Promoting safer cycling – a strategy • Collection of cycle concepts • Increasing the modal share • Making the city more bicycle friendly
Amsterdam (Netherlands)	Dutch Bicycle Master Plan and Road Safety (1997) Dutch Bicycle Master Plan – Description and evolution in a historical context (1999) Long-term Bicycle plan 2012-2016 (2012) Cycling in the Netherlands (2009)	• Overview on the results and findings of relevant studies and experiences • Methods and implementation strategies for the promotion of cycling
Berlin (Germany)	National Cycling Plan ‘Ride your bike!’ 2002-2012 (2012) New cycling Strategy for Berlin (2011)	• Initiate new methods and implementation strategies for the promotion of cycling i • Supply recommendations for actions • Make a contribution towards creating a bicycle-friendly environment
London (United Kingdom)	National Cycling Strategy (1996) Cycling Revolution London (2010) Brent Cycle Strategy 2016-2021 (2016) Human streets – The Mayor’s Vision for cycling, three years on (2016)	• Increase cycle use • Achieve convenient cycle access to key destinations • Improve cycle safety and Reduce cycle theft • Provide traffic management schemes and cycle parking facilities
Seville (Spain)	Cycling plan of Andalusia CPA 2014-2020 (2014) Plan to promote the bicycle as a transportation mode (Plan de la Bicicleta de Sevilla) (2007) Methodological guide for the public bicycle systems implementation in Spain (2007)	• Bicycle sharing programs are and how should they be better implemented • Best practices and describes the most relevant in Spain • Measures to integrate bicycle in the intermodal system • Development measures, emphasizing the idea of the bicycle as transportation
Lisbon (Portugal)	Ciclando – National Plan for the Promotion of Bicycle and non-motorized modes (Plano de Promoção da Bicicleta e outros modos Suaves 2013-2020) (2012) Cycling implementation plan (2015)	• Promotion of more sustainable means of transport • Combine the economic development of cities and and accessibility with improved quality of life, healthier lifestyles, environmental and reduce energy dependence.

The table below, corresponds to the main measures of city and nation plans adopted in the cites of Amsterdam, Seville, Lisbon, Copenhagen, London and Berlin (see Table 17).

Table 17. Main measures to adopted or to be implemented according to cycling plans. Developed by the author

		Amsterdam, Netherlands	Seville, Spain	Lisbon, Portugal	Copenhagen, Denmark	London, United Kingdom	Berlin, Germany
Provision of cycling measures	End of trip facilities	●	●	●	●	●	●
	Complete Cycle lanes / paths	●	●	●	●	●	●
	Junctions and Crossing	●			●	●	●
	Provision of a public bicycle system	●	●	●	●	●	●
	Provision of cycle parking	●	●	●	●	●	●
	Integration with other transport modes	●	●	●	●	●	●
	Proper signage	●	●	●	●	●	●
	Maintenance	●	●		●	●	●
Incentives to use more sustainable modes	Car parking management	●			●		●
	Traffic calming areas	●	●	●	●		
	Reduced speed limits	●	●	●	●	●	●
	Enforcement/Legislation	●	●	●	●	●	●
Land use management	Streetscape improvements	●			●		
	Creation of shared zones	●		●	●		
	Street layout	●			●		●
	Redesign of public places	●	●	●	●		●
	Mixed land uses, such as locating shops below apartments and offices near houses	●			●		●
	Increased street connectivity by having fewer dead-end streets and smaller blocks	●					
	Encourage a dense and diverse mix of services, amenities, jobs, and housing types in areas well-served by frequent, high-capacity transit	●			●		
	Locate major trip generators near rapid transit stations or along transit corridors	●					●
	Street lighting, trees, benches, and other amenities						
Promotional cycling campaigns	Website travel information page		●	●	●		
	Special bicycle events can raise the profile of cycling in the community	●	●	●		●	●
	Cycling information on marketing materials	●			●	●	
	Site access maps/Cycling maps		●	●	●	●	●
	Travel information packs	●		●		●	●
	Notice boards / screens promoting benefits of cycling						
Educational cycling	Commitment to fund cycling training, subsidise bicycles / equipment	●	●	●		●	●
	School and Adult Cycle training	●	●	●	●	●	●

According to the previous table is possible to notice that all the analysed cities have extensive cycling strategy plans to promote the use of bicycles, including both “soft” and “hard” measures. Most of the measures to promote cycling are measures directly associated to the bicycle itself, in particular infrastructures (cycling paths, cycling lanes, bicycles streets), bicycle parking, end of trip facilities, etc. Other measures such as incentives measures related to sustainable mobility, land use measures, promotion and educational however less explored are land use measures.

Land use cycling related measures are not very common among most European cities, most city plans either are cycling plans or territorial plans, and most of the time the plans are not integrated. Amsterdam, Copenhagen and Berlin have integrated many land use measures in their cycling plans to promote the use of the bicycle. It is difficult to compare the strategies of the previous cities due to the fact that they are the three best European examples, both culturally and cycling numbers, therefore their plans have different strategical goals, maintaining the number of cyclists, expanding and maintaining cycling networks, reduce bicycle theft and improve bicycle parking.

Both the cities of London and Seville have made tremendous progress in recent years in both the promotion and the modal split as well as in terms of stimulating bicycle traffic since these cities have installed Bicycle Sharing Systems.

Lisbon is one of the worst cases at a European level and has one of the highest rates of automobile use and lower bicycle use, although in recent years Lisbon has been trying to promote cycling, by implementing strategies both from the national and regional cycling. Both of these cycling plans are very similar strategies compared to the other cycling plans analysed, however lacking the integration of land use measures.

6.5.1. Provision of improved cycling options

Infrastructure and facilities

Infrastructure dedicated to bicycle use and require investment space. However, an integrated and uniform network of bicycle paths can improve significantly the attractiveness and safety of those who use or want to start using the bicycle. A strategically mapped network can connect sources and destinations of quickly and provide safer conditions, separating the traffic bicycles motor (OECD, 2004).

Austroads (2010) also emphasizes the importance of creating a global network and continued safe and attractive routes for bicycles and end travel gear, justifying it with the example of countries that have achieved significant levels of use of the bicycle, which made sustained investments in networks and facilities. End of trip facilities should be developed, considering introducing regulations, such as planning policies and standards construction, to enforce the provision of facilities. They must also be created and available best practice guides in the design and supply of infrastructure.

The European Commission (2000) highlights the importance of quality of the surface (reducing the risks of falling) and bicycle paths. The construction of infrastructure should take into account the definition of routes by bicycle users in the paths should be both coherent, direct and pleasant, and these routes should be both safe and comfortable.

The quality of cycle networks should be reviewed, to ensure that all existing facilities do play a net positive role, for less confident cyclists at least. Quality as well as quantity of cycling provision is important and the former needs to be given more emphasis, in initial design and construction and in maintenance. Attention to detail is so important, avoiding sharp upstands, barriers and posts, and poor lighting, signing and lining, and ensuring route continuity and coherence, for example overcoming barriers such as rivers, main roads and railways and not being truncated at difficult junctions (Jones, 2001).

It is also important to ensure that the routes in a cycle network go where cyclists want. Davies et al. (2003) suggest giving priority to routes, which serve schools, railway stations, large employers and town centres, with additional priority to routes that serve leisure and utility purposes, for example linking town centres and countryside. Creating short cuts and new direct links for cyclists tends to be appreciated; if social safety is not overlooked in some cases such as routes across parks, it may be necessary to sign alternative routes for use after dark. Some authorities have now begun to develop dual networks, to suit the differing needs of more and less confident cyclists, with the former concentrating on more direct main roads routes and the latter making more use of cycle paths, shared paths and back streets, even if these are substantially longer.

Bicycle improvements benefit existing and new users, can increase cycling activity, and reduce driving. Although many cyclists can comfortably share road space with motor vehicles, particularly when traffic speeds and volumes are moderate and traffic lanes are sufficiently wide and smooth, many people are reluctant to cycle without special facilities. Increased cycling tends to improve public fitness and health. Bicycle facilities tend to have network effects so benefits increase as the network expands. A short, isolated length of bicycle path may provide minimal benefit, while a link that connects two isolated cycling networks or provides a shortcut that can provide larger benefits.

Junctions and Crossings

Junctions and crossings are where actual and perceived risk to cycle safety are highest, and usually represent the most uncomfortable parts of any journey for cyclists. The design or adaptation of junctions to facilitate and encourage cycling should provide convenient, comfortable passage through the junction, catering for all possible manoeuvres and wherever possible matching desire lines (Kinight et al., 2011).

Approximately 75% of reported accidents involving cyclists occur at or near a road junction and cyclists are over-represented as a proportion of total casualties at intersections. Designs should mitigate these risks without introducing excessive detour or delay for cycle users (Bakr, 2011).

All different categories of junctions: crossings, priority junctions (where vehicles on one route have priority over an intersecting route), signal controlled junctions, and roundabouts, have to be designed and/or adapted so that of these junctions are safer, more coherent and comfortable for cycling, while maintaining optimum accessibility for pedestrians.

Junctions can be intimidating and unfriendly to cyclists, when considering cycling in urban areas, it is worth bearing in mind that encouraging short trips by bicycle can lead to inexperienced cyclists taking to the road, and providing friendlier infrastructure can improve the experience of all cyclists, including experienced riders.

Provision of a public bike system

Public Bike Systems (PBS, also called Bike Sharing and Community Bike Programs) provide convenient rental bicycles intended for short (less than 5 kilometre), utilitarian urban trips. A typical Public Bicycle System consists of a fleet of bicycles, a network of automated stations where bicycles are stored, and bicycle redistribution and maintenance programs. The basic characteristics of European city bicycle systems can be seen in Figure 16. Bicycles may be rented at one station and returned to another. Use is free or inexpensive for short periods, this allows urban residents and visitors to bicycle without needing to purchase, store and maintain a bicycle. Public bicycles tend to benefit users directly, by providing convenient and affordable transport. They can provide additional benefits by increasing cycling activity and substitute for automobile travel (either alone or in conjunction with public transit).

European City Bike Systems
Everyday and commute cyclist as a target group
Planned to work together also with public transport
Variable organization methods (finance/operation)
Often a subsidized service
Easy and fast availability for the customers
Registration of customers (no anonym use)
Automated rental and return
Utilization of smart cards
Concise network of rental points
Free use during the first 30 minutes
The possibility for one-way cycling trips (return in any rental point)

Figure 16. Basic characteristics of European city bicycle systems. Source: Vaismaa et al. (2012)

Bicycle parking

Bicycle parking is an important part of a bicycle plan as it provides security for bicycle users at their destinations. According to the Buehler (2012), the fear of bicycle theft is one of the reasons why people don't own a bicycle or use the bicycle as often as they would like. Therefore, bicycle racks and lockers must be well anchored to the ground to avoid vandalism and theft.

Convenience to the user is the most important aspect of bicycle parking. This is especially true in the case of bicycle commuters, who are generally under strict time constraints. If bicycle parking facilities are not convenient, there is little likelihood that cyclists choose to use them. The distance of bicycle parking from a cyclist's destination strongly influences whether or not they are willing to park there. One of the major advantages generally associated with bicycle commuting is that it is a nearly point-to-point transportation solution, involving minimal effort to park close to a destination. Quality bicycle parking solutions can help reinforce this view of bicycle commuting and make it a more attractive means of transportation.

To be able to influence people's choice of transport mode, the bicycle infrastructure must meet a number of demands. The cyclist wants effective, comfortable and safe connections for every journey. The following factors should be considered when locating bicycle parking facilities (see Table 18).

Table 18. Quality factors concerning bicycle parking. Source: Vaismaa et al. (2012)

Quality factor	Explanation
Attractive	Parking must attract cyclists and be compatible with the surroundings as well as good-looking
Easy to use	Using the bicycle stand must be sufficiently simple and fast
Situated in a visible place	Parking must be situated in a logical and visible place, so that it is easy to find
Safe	It has to be possible to lock the bicycle and parking must be protected from thefts and vandalism. Good lighting and clear route to the parking creating social safety
Well Placed	Parking must be close to the destination and accessible. It cannot cause a barrier, especially for pedestrians. Parking must also be connected to the cycle track network
Easy to maintain	The parking space must be easily maintained, so that its attractiveness and functionality remains throughout the year
Enough capacity	The capacity of the parking space must be sufficient also during rush hours and all cyclists must have the possibility to leave their bicycles to the parking space

Bicycle parking therefore is an essential part of each journey travelled both at the beginning and end of the trip. Parking solutions encourage people to cycle and increase the quality of cycling. The planning of bicycle parking must be as essential a part of promoting cycling as building good quality road connections or other infrastructure. Often parking is forgotten from the planning process and solutions that are made hastily at the last minute do not fulfil the requirements and many times crating parking problems (Vaismaa et al., 2012).

End of Trip facilities

End-of-trip facilities include secure bicycle racks, lockers and change rooms where staff can shower, change and secure their belongings before starting work. End-of-trip facilities must be well designed, thoughtfully located and promoted to regular and casual users. A high standard of end-of-trip facilities should be provided at workplaces to encourage employees to walk and cycle to work (DTMR, 2011).

Cyclists may choose not to bicycle to work because riding even short distances results in a sweaty commute. Compared to individuals without access to end-of-trip facilities, commuters with showers, personal lockers, and bicycle parking are almost five times more likely to ride longer distances to work and/or other destinations (DTMR 2011).

According to Buehler (2013) combined supply of bicycle parking, clothes lockers, and cyclist showers has a statistically stronger influence on bicycle commuting than the provision of bicycle parking only. Compared to no trip-end facilities for cyclists, both bicycle parking and showers combined and bicycle parking alone are related to more bicycle commuting.

Trip-end facilities at work appear to be significant determinants of cycling to work. Compared to individuals without any bicycle facilities at work, commuters with cyclist showers, clothes lockers, and that the combined supply of bicycle parking, clothes lockers, and cyclist showers has a statistically stronger influence on bicycle commuting than the provision of bicycle parking only.

Integration with other transport modes

According to OECD (2004) the connections between bicycle facilities and public transport is an important factor to increase intermodality, the better the articulation between transport systems may reduce the dependency on private transport.

Many trips cannot be held only by bicycle or public transportation, because they do not offer enough flexibility, therefore, it is necessary to improve intermodality (connection between different means of transport). Thus, implementing bicycle-sharing systems, provision of parking services at the main transport terminals, permission to carry bicycles on public transport such as trains, metro and buses, can improve intermodality between different transport modes (European Parliament, 2010).

The bicycle and public transit can make a good team in an attempt to overcome the dominance of the automobile, the combination providing an alternative to the car for longer distance trips. Bicycles make it possible for a large number of passengers to access trains stations without having negative effects on the local urban environment and also help overcome problems of overflowing parking lots around transit stations. According to Hamre and Buehler (2014) it is necessary to provide a good alternative to the car, the complementarity between the two modes needs to be improved. This means safe and convenient bicycle access to public transport stops, being able to leave a bicycle safely at public transport stops and being able to take it on board public transport vehicles (Buehler, 2013). In addition, the public transport service must be reliable and with frequent connections and therefore a sufficient number and quality of parking facilities at public transport stations is needed.

Signposting

The bicycle network should have a good sign posting system to enhance its coherency, indicating the shortest or quickest way from one destination to another. The bicycle network signposting system should be complete and independent. There should be uniformity in the signposting system so that cyclists are informed in the same manner each time and know what to expect. There also needs to be continuity in the sign posting system. When a destination is mentioned, it must be repeated until it has been reached, correct sign posting may increase cycling use by indicating shorter and safer routs (Litman et al., 2001).

Maintenance

Even good facilities can soon deteriorate without adequate maintenance and, in some cases, acquire such a poor reputation that many cyclists will avoid them altogether. To achieve adequate maintenance there need to be clear performance standards, and adequate staffing and revenue funding covering the maintenance of both on- and off highway routes, with reference to surface quality, signing, markings and cutting back intrusive vegetation. Regular inspection is vital as well as clear and well publicised mechanisms for reporting defects. Maintenance issues for cyclists also need to be thought through in the case of general roadworks, for example in ensuring that any necessary diversion routes are well signed. Since most cycling occurs on public roads, roadway maintenance is an important part of accommodating cycling.

6.5.2. Incentives to use more sustainable modes

Traffic calming and Traffic management

There are several techniques to slow down, limit or completely remove motorized traffic, including speed bumps, one-way streets or even road closures. In this context, bicycle users obtain an advantage over motorized transport modes and benefit from the reduced presence of motorized vehicles (Koorey, 2003). The opening of one-way streets for bicycle transit is an alternative way to promote the use of the bicycle in city centres, these measures have been adopted in many European cities and accidents have decreased (European Parliament, 2010). Traffic signs and signalization for bicycles is another important aspect concerning traffic calming because it indicates shorter and more direct routes, allowing users to reduce travel times and finding safer routes (European Parliament, 2010).

Speed limits

For Koorey (2003), where the speed limit is 30km/h, for example, bicycle users can coexist safely with cars without special facilities. In residential areas, commercial and close to schools and streets with high traffic but also with many pedestrians and bicycle users that speed limits should be implemented below 50km/h.

Speed reductions can be achieved by means of physical traffic calming measures or through the implementation of lower speed limits or both. Many European cities including Freiburg in Germany and Graz in Austria have opted for 30km/h zones in built up areas. Reduced speeds are beneficial to both the actual and perceived safety of cyclists. It is far more pleasant to ride a bicycle under a 30km/h speed regime than a 50km/h regime (Zuks, 2002).

The European Parliament (2010) also highlights the importance of reducing the limit speed to 30km/h as a measure to help control traffic vehicles in residential areas and near schools. If necessary, some engineering measures such as thresholds and narrow traffic lanes may be necessary to achieve the desired vehicle speeds (Litman, 2012). As well as improving safety, lower speeds also result in more freedom of movement for cyclists, smoother traffic flow, less noise and greater liveability (Zuks, 2002).

Car parking management

Sometimes to build bicycle paths, it is necessary to take away car parking, therefore, it is necessary to create parking strategies and these should be developed before construct any other infrastructure. A common problem when trying to implement cycling strategies is the conflict raised when parking needs to be remove to make space for cycle lanes (Koorey, 2003).

Development of a parking strategy is a useful way of capturing the desired outcomes of both council and the community. Priorities for making space can be developed in different situations; for example, parking may be less desirable on an arterial route compared with a commercial district. A move to shift more on-street parking to off-street locations can help to provide more corridor space for all road users. The use of parking charges and limited car parking numbers can also make people think twice about taking the car (Litman, 2012).

Enforcement

Just as poor maintenance can give the impression that cyclists are still regarded as second-class road users so can poor enforcement. If cycle facilities, or shared bus and cycle lanes, are blocked by parked cars or drivers allowed to abuse areas banned to through motor traffic, cyclists will be discouraged. The same is very much also true of drivers who are allowed to ignore speed limits with impunity. A failure to enforce speed limits will in turn make it harder to tackle the problem of poor riding behaviour including cyclists taking to riding on pavements because of their fears of riding on the road being aggravated by regular speeding by motor traffic. Adequate enforcement is essential in encouraging mutual respect among different road users (Litman et al., 2001).

6.5.3. Land use planning

Land use planning plays a fundamental role in encouraging cycling, especially in a long-term perspective. Higher density developments, steering most development to areas well served by public transport and local facilities, and detailed layouts designed to promote safe, convenient and attractive direct routes are all essential to encouraging cycling.

The California Air Research Board (CARB) identified land use strategies that can be implemented to improve the efficiency and facilitate the use of transit, pedestrian, and other alternatives to single-occupant motor vehicles (Dagang, 1995). The CARB study identified nine land use strategies to promote nonmotorised transport. The strategies are provided below:

1. Concentrated activity centres: Encourage cycling by creating "nodes" of high density mixed development, which can be more easily linked by a transit network.

2. Strong downtowns: Encourage cycling by making the central business district a special kind of concentrated activity centre that can be the focal point for a regional transit system.

3. Mixed use development: Encourage cycling by locating a variety of compatible land uses within cycling distance of each other.

4. Infill and densification: Encourage cycling by locating new development in already developed areas, so that activities are closer together.

5. Increased density near transit stations: Encourage transit travel by increasing development density within cycling distance of high capacity transit stations.

6. Increased density near transit corridors: Encourage transit travel by increasing development density within a cycling distance of a high capacity transit corridor.

7. Pedestrian and bicycle facilities: Encourage pedestrian and bicycle travel by increasing sidewalks, paths, crosswalks, protection from fast vehicular traffic, pedestrian-activated traffic signals, and shading

8. Interconnected street network: Encourage bicycle travel by providing more direct routes between locations and ease traffic congestion by providing multiple routes between origins and destinations.

9. Strategic parking facilities: Encourage non-automobile modes of transport by limiting the parking supply, and encourage carpooling by reserving parking close to buildings.

The first six strategies indorse increasing density of development at various spatial scales, and mixing land uses so that a variety of activities and facilities will be close together. While bicycle facilities (strategy 7) and interconnected street networks (strategy 8) are accomplished directly by governmental policies that may influence land use patterns by changing accessibility. In addition, because these two strategies involve direct modifications of transportation networks, they may also directly affect travel demand patterns. The influence of the modified accessibility on travel demand may be evaluated directly with a travel demand model that includes walk and/or bicycle mode choices. Parking restrictions, (strategy 9) may be accomplished directly by government agencies and so may be considered a land use policy.

According to Santo and Mildner (2010) several planning and design elements can make a city more cyclable for daily activities. Cities and counties generally control land use by adopting comprehensive land use plans. Land use plans are implemented through zoning ordinances and other regulations, as well as infrastructure investments. The concepts in the following table address both land use and urban design strategies to promote cycling in urban areas and their corresponding effects in promoting cycling (see Table 19).

Table 19. Strategies to promote cycling in urban areas. Source: Santo and Mildner (2010)

Strategy	Why it may promote cycling
Mixed land uses, such as locating shops below apartments and offices near houses	Reduces bicycle travel time by shortening the distance between origins and destinations
Increased street connectivity by having fewer dead-end streets and smaller blocks	
Increased housing and employment density, e.g., more houses per acre	
Increased density near transit stops and station	Reduces bike travel time to transit, making cycling more attractive than park and ride
Sidewalks, bike lanes, bike boulevards, and trails	Increases perception of safety
Crosswalks, bike and pedestrian traffic signals	
Street lights, trees, benches, and other amenities	Increases perception of safety; enhances aesthetics

Land use strategies can assort to the respective land use factors, mentioned in previous sections (see section 2.2) can to nearly all places with high levels of transit demand and productive transit service (see Table 20):

- Major DESTINATIONS and centres are lined up in reasonably direct corridors making them easy to serve efficiently by frequent transit;
- DISTANCE to frequent transit is minimized by creating an urban structure of well-connected streets around which to focus:
- urban DESIGN including safe, comfortable, and direct pedestrian and cycling routes;
- higher levels of residential and employment DENSITY;
- DIVERSITY of land uses and housing types;
- DEMAND management measures that discourage unnecessary auto trips.

Table 20. Strategies related to land use factors. Adapted from: Translink (2010)

Destinations	**Distance**
Focus on high demand destinations along frequent transit corridors and limit growth elsewhere	Create a supportive urban structure by introducing a fine-grained network of pedestrian- and bicycle-friendly streets. If block sizes are too big and streets are too discontinuous, distances will be too far to cycle
Density	**Diversity**
Place the highest residential and employment density near to frequent transit stops, stations, and exchanges and step these densities down to transition to surrounding neighbourhoods.	Diversity of uses, especially those which animate the streetscape; provide a mix of housing types, tenures, and price points; and a good jobs-housing balance so that people are never too far from work, shopping and other destinations.
Design	**Demand Management**
Design a public realm that is bicycle friendly. Bring buildings up to the sidewalk, animate them with active frontages, provide amenities	Demand management measures like parking pricing to discourage unnecessary driving. No matter what changes are made to the built environment, if it is still significantly cheaper and easier to drive, most individuals with a choice won't shift to cycling,

While each of the land use measures are important in shaping travel behaviour, some aspects of built form are more permanent than others (Figure 17). For instance, once a neighbourhood is established, its location and its street network become very difficult to change over the long term, whereas building form and the uses within buildings change more readily along with market trends.

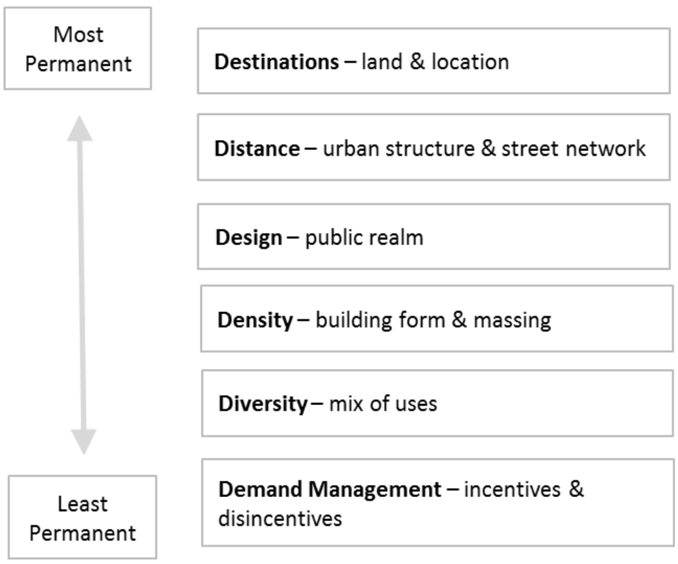


Figure 17. Permanency of land use measures. Adapted from: Translink (2010)

Likewise, to be effective, all must be implemented at all spatial scales of planning (mentioned in section 2.2) - starting at the regional scale and moving down to the community, neighbourhood, and scales.

- At the regional scale, urban centres and frequent transit corridors are identified to provide the basic framework for shaping regional growth.
- At the community and neighbourhood scales, frequent transit stops and stations provide the focus around which to create a fine-grained network of well-connected streets and foster higher density, mixed-use, walkable neighbourhoods.
- At the site scale, buildings are oriented toward transit facilities and the wider public realm to enhance the pedestrian experience.

Land use and networks have a very slow change and the most permanent elements of the physical structure of cities. Large infrastructure projects require a decade or more to be implemented, and once in place, are rarely abandoned. The land use distribution is equally stable; it changes only incrementally.

6.5.4. Promotional cycling campaigns

Cycling still often has a poor image in many countries and tends to be regarded mainly as a dangerous means of transport, of appeal only to low income people who cannot afford cars. Promotion of cycling has started to receive more emphasis in partnership with wider travel awareness and health campaigns and in partnership with other public bodies and also commercial and voluntary organisations (Jones, 2001).

Marketing is increasing a port of the transport strategy of cities as a way to increase the modal share of cycling. More and more cities have noticed that people cannot be attracted to cycling only by improving infrastructure, increasing services or enabling a safe mobility environment. The awareness of potential cyclists of good mobility possibilities can be achieved with the help of active informing and marketing. When people's awareness of alternative modes of transport grows and their use is increased, and the volume cars can be reduced at the same time. The main marketing measures to promote for cycling are as follow (European Commission, 2000).

With the help of different kinds of cycling **festivals and events**, people have the opportunity to hear about the advantages of cycling and gain personal experiences in a fun, but at the same time educational way.

Billboards, posters or ads that raise attention are an effective way to make people ponder the use of alternative forms of transport and their own mobility, as we as its impact on the environment, or even advertising cycling as a modern and fun mode of transport can help increase the modal share.

While with the help of **cycling maps**, people can be enticed to cycle on certain routes and find the best areas of the city for safer and shorter cycling routes. The cycling routs can also go through cultural targets, such as historical monuments, museums and commercial areas. The map guides people to sights, but also encourages making the trip by bicycle.

Finally, the importance of **monitoring cycle use**, by different groups, for different trip purposes, should also be emphasised, to help assess the impacts of various forms of promotion of cycling and to help provide evidence on specific questions such as the extent to which increased leisure cycling is helping to encourage use of bicycles for other ‘utility’ purposes. These kinds of high profile campaigns really influence the traveling behaviour of people, but they help to change attitudes towards alternative modes of transport in a positive manner. However, it has to be kept in mind that it is not profitable or safe to organize cycling campaigns unless the mobility conditions are already on a good eve and the possibility to cycle quickly and safely already exists.

6.5.5. Educational cycling trainings

Education and encouragement programs help overcome cycling some barriers (ignorance, social stigma, a habit of driving), can help increase the use of the bicycle and reduce motor vehicle travel. An important part of safer routes to school projects is the training of young cyclists, as well as providing safer access routes and bicycle parking at schools, and including relevant curriculum content. At the same time there is increased recognition of the importance of high quality on-road adult cycle training, to give confidence to adults returning to cycling (James and Brög, 2001). Expanding adult training is also one way in which the problem of irresponsible cycling, which attracts regular local press coverage, can be addressed, although there is a difficult challenge in ensuring that those who most need to benefit from training do in fact receive it. Such programs tend to have synergistic effects with facility improvements. On the other hand, education and encouragement programs can fail or increase risk of cycling if the conditions are poor (European Commission, 2000).

6.6. Impact analyses of the measures

How effective is each strategy? The strategy evaluation process validates each strategy's ability to achieve its goals by increasing cycling numbers and cycling safety. Likewise, the evaluation also takes into consideration the cost to achieve the goals. Table 21 below provides an overview of the general cost effectiveness of strategies outlined according to the "hard" and "soft" measures analysed previously. Levels of effectiveness generally correspond to investment levels. Therefore, the benefits of cycling measures are determined by the degree of its usage, translating their potential to achieve a mode shift (from motorized modes to cycling) and safety issues. Individual cycling measures, however, differ considerably with regard to their cost-benefit efficiency.

The question is how to measure or project these benefits and how to relate with their costs. Furthermore, what is the impact of infrastructural measures on cycle use in general? Costs for measures may vary considerably according to the type of measures. Some solutions offer clearly positive effects even with relatively low expenditures. The purpose of the benefit-cost analysis is to provide transportation planners with information to estimate costs of the different types of bicycle measures. Using a cost-benefit analysis, policymakers can project how much measures will increase or decrease cycling. It is important to note that a cost-benefit analysis takes into account all the relevant costs and benefits, including not only direct costs but also indirect costs and externalities.

In order to conduct the study of the cost-benefit of the cycling measures with the greatest impact to encourage bicycle use, it was necessary to compile the limited number of existing research. The studies analysed are as follows:

- New Ways to Go Public Investment in Cycling (Erznoznik, 2014);
- Cycling, the European approach (Bypad, 2008);
- Cycling: the way ahead for towns and cities (European Commission, 2000);
- Benefits and Costs of Cycling Infrastructure Investment (Thiemann-Linden et al., 2012).

Table 21. Cost effectiveness of cycling measures. Developed by the author

	Type of measure	Mode Shift Effectiveness			Safety Effectiveness			Cost		
								€	€€	€€€
"Hard" Measures	End of trip facilities	●				●		●		
	Complete Cycle lanes / paths			●			●			●
	Junctions and Crossing		●				●			●
	Provision of a public bicycle system			●	●				●	
	Provision of cycle parking	●				●				●
	Integration with other transport modes		●		●				●	
	Proper signage	●				●			●	
	Maintenance		●			●			●	
	Creation of shared zones		●			●			●	
	Traffic calming areas		●				●	●		
	Reduced speed limits		●				●	●		
	Enforcement/Legislation		●			●		●		
	Demand management- measures that discourage unnecessary auto trips	●			●				●	
	Diversity- mixed land uses, such as locating shops below apartments and offices near houses		●			●				●
	Distance- increased street connectivity by having fewer dead-end streets and smaller blocks		●			●				●
	Density- encourage a dense of services, amenities, jobs, and housing types		●			●				●
	Destinations- locate major trip generators near rapid transit stations or along transit corridors		●			●				●
	Design - including safe, comfortable, and direct pedestrian and cycling route, street lighting, trees, benches, and other amenities	●				●			●	
"Soft" Measures	Website travel information page	●			●			●		
	Special bicycle events can raise the profile of cycling in the community		●			●			●	
	Cycling information on marketing materials		●		●				●	
	Site access maps/Cycling maps			●		●			●	
	Travel information packs	●				●		●		
	Notice boards / screens promoting cycling	●			●			●		
	Commitment to fund cycling training, subsidise bicycles / equipment	●				●			●	
	School and Adult Cycle training	●				●		●		

Table 21. Cost effectiveness of cycling measures (Continuation). Developed by the author

Table Legend					
Mode Shift Effectiveness		**Safety Effectiveness**		**Cost**	
	Low		Low	€	Low
	Moderate		Moderate	€€	Moderate
	High		High	€€€	High

Summary findings of the previous table are categorized in Table 22, where high, medium, and low indicate the effectiveness –based on the adaption of literature and policies where there is enough evidence to draw a conclusion – of how important a strategy is for increasing cycling. Areas where the impact relationship of the cost-benefit is higher than other categories of measures. Based on this evaluation, investing in "hard" strategy measures have higher impact on mode shift and safety aspects than softer measures. However, the combined effect of "hard" and "soft" measures have a positive effect on promoting cycling, therefore, supporting strategies should only be implemented after adequate infrastructure is in place.

Table 22. Summary matrix showing the efficacy of the different categories of strategies. Developed by the author

	Type of Strategy	**Mode Shift Effectiveness**	**Safety Effectiveness**	**Cost Effectiveness**
Hard	Provision of improved cycling measures	High	Moderate	High
	Incentives to use more sustainable modes	Moderate	Moderate	Moderate
	Land use Management	Moderate	Moderate	High
Soft	Promotional cycling campaigns	Low	Low	Low
	Educational Cycling Programs	Low	Low	Low
	Combined "Hard" and "Soft" Strategies	High	High	Moderate

Research has shown that investments in bicycle transport are promising in terms of cost-ratio aspects: paths and parking facilities for bicycles are far less expensive than for car infrastructure. Moreover, increased cycle use helps minimise the consequential costs of traffic in areas such as environment, health, and land use. However, cycling promotion still needs a solid and sustainable financial background to improve local conditions. Therefore, it is recommended to define measures of high priority (more impact with less financial effort). This ensures efficient use of the small cycling budget and/or funds that is dedicated to cycling. Infrastructure costs are associated with the initial construction of the infrastructure and its expenses, excluding maintenance and upgrades. They can range from relatively low (e.g. the installation of signs and traffic management equipment) to intermediate (e.g. construction of bicycle lanes on the existing road network) to high (e.g. construction of bicycle tracks and off-road paths). All these costs are highly dependent on the cost of resources, the labour wages and other organizational/implementation investments. Usually the costs are proportional to the investment complexity and scale. According to German experiences it can be assumed that expenditure of cities for cycling issues range from 0.5 to 15.0 euros per inhabitant per year, irrespective of their size, are likely to have the following funding needs per inhabitant per year (FMTBUB, 2012):

- around 6.0 to 15.0 euros for the construction, maintenance and operation of the infrastructure and about 1.0 to 3.0 euros of this for routine maintenance alone;
- around 1.0 to 2.5 euros for parking facilities in the public realm;
- and around 0.50 to 2.0 euros for “soft” measures (communications, service, etc.).

Together with other measures (e.g. cycle hire stations), these results in funding needs in total 8 to 19 euros per inhabitant per year for the individual towns and cities if they are to achieve their objective of providing a good overall standard.

Incentives to use more sustainable modes regarding traffic management policies also have a large effect on the uptake of cycling. These policies are more closely related to traffic regulations and city planning rather than infrastructure. However, they have been included here because they play a key role mainly concerning road safety in general. Additionally, they have a greater impact on safety rather than increasing cycling use directly, and have a lower investment cost than cycling infrastructure, since most of these measures require little investment, for example signage, road markings, etc.

Land use and the built environment have a positive effect upon levels of bicycle ridership. Due to a higher function mixture, the presence of bicycle storage facilities, smaller block size, higher density, the presence and continuity of bicycle infrastructure, as well as bicycle parking facilities and showers at work, have a positive influence on cycling. This suggests that a greater, more connected network of bicycle facilities of any sort should be created within cities in order to increase levels of bicycle transportation. However, land use impacts can be difficult to evaluate because they are numerous, most are difficult to quantify as well as monetize. Uncertainty of the cost-effectiveness of land use measures are due to unpredictable outcomes due to the long time span of the measures, inherent knowledge and incomplete analysis, especially concerning the relationship of the impact/benefits of land use on cycling, resulting with time with on information, analysis, technology changes, and political changes.

Promotion and training costs are related to the resources spent in order to ensure that the efficiency and effectiveness of the infrastructure and other “hard” measures are maximized. The costs of these campaigns vary widely from campaign to campaign. The starting situation in terms of cycling numbers and infrastructure are of great influence on these costs, therefore, the better the existing infrastructure and cycling numbers, the less costs associated with promotional incentives are needed. For example, the Radl Hauptstadt Munchen bicycle campaign costs were 0.70 euros per inhabitant and according to the city, the cost-value ratio had a positive outcome, therefore, “soft” measures are usually associated with lower costs. However, they also acknowledge that ‘soft’ measures cannot replace ‘hard’ cycling measures, but it can enhance the impact of infrastructure investment (Sassen, 2011).

Due to the fact that only very few cities have a continuous budget for bicycle mobility. A benefit-cost analysis of cycling measures is essential for cities with low budgets. Opting for low cost measures in relation to their benefits can improve cycling conditions and at the same time, improve safety for all road users. When deciding on measures to improve the cycling, consideration of low-cost measures as a serious alternative to cost-intensive reconstruction measures are recommended. This could include, for example, turning a parking lane into a cycle lane and painting pictograms on lanes.

The outcome of the quality of a cycling plan is always a mixture of infrastructure and of promotional measures, depending on the quality level of cycling policy and the level of bicycle use, there is more or less emphasis on infrastructure. This balance between these measures can be observed in Figure 18.

Despite the absence of a direct correlation between the actual efforts done on cycling policy and the effects on cycle use or traffic safety it becomes, therefore, according to the following figure, it is clear that the kind of necessary and justified cycling measures differ according to the level of cycling use in a city or a region. For example, in a city with a low cycle use it is logical to invest in infrastructure and traffic safety before stimulating and promoting bicycle use. It would even be unsafe to promote bicycle use via campaigns or school projects if it is unsafe or uncomfortable to cycle.

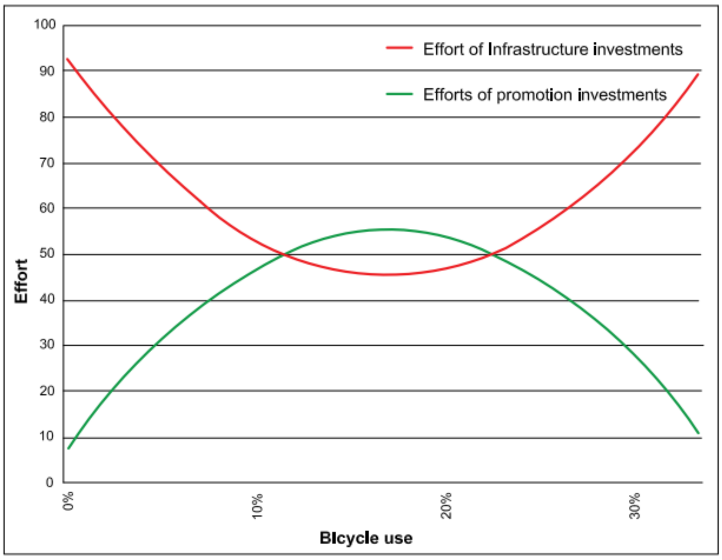


Figure 18. Balance of infrastructure measures and promotion measures. Adapted From: Bypad (2008)

The effectiveness of cycling measures differ according to the modal share and the level of development of a city/region (see Table 23).

Table 23. Objective type of strategical measures according to modal share. Adapted From: Bypad (2008)

Modal share	Goal	Main Principals
< 10%:	Make cycling possible, safe, comfortable	A basis level of bicycle facilities (cycle lanes, bicycle parking, traffic calming zones) should be implemented before a city / region starts stimulating cycle use through campaigns, information, etc. The city should communicate on all the cycle measures they are taken and which advantages cycling has
10-20%	Convincing more people to use the bicycle	In this stage, there is still a big potential for shifting from car trips to cycle trips. The city should communicate actively about the advantages of cycling and al kind of promotion initiatives should be started (school, employers). A continuous improvement of the cycle conditions (comfort, safety) is necessary
> 20%	Keep people cycling	In this stage, most of the short distance trips are made by bicycle (or public transport). It is not necessary any more to convince people of the advantages of bicycle use, but the challenge is to keep people on the bike. As the user demands are changing continuously the attention to new investments in cycle comfort, safety is again vital for this stage.

For Portuguese cities and others in which the level of bicycle use is under 10 %, the cheapest way to stimulate cycling is by starting with promotion campaigns (e.g. cycling to school campaigns, health campaigns) however, it is not safe and even immoral to only stick to promotional campaigns, especially when it is still unsafe an uncomfortable to cycle. Taking the decision to invest in safe bicycle infrastructure or traffic calming zones in a city with a low bicycle use is the most difficult but only right decision in the whole process of improving the bicycle policy. In many cities, especially in the ones with low bicycle budget, the main focus has been on promotion and gaining press attention, but on long terms this does not necessarily increase the level of cycling. However, the positive combined effect of “hard” and “soft” measures promoting cycling, mentioned previously, should not be implemented together in cities with low modal share and should only be implemented until adequate infrastructure is in place. Therefore, in these case, land use planning can play a fundamental role on a long-term perspective. Planning for higher density developments and them to areas that are well served by public transport and local facilities, as well as detailed layouts designed to promote safe, convenient and attractive direct routes, are all essential to encourage cycling in cites with a lower modal share.

6.7. Summary and discussion

Provision of convenient, safe, and connected cycling infrastructure is at the core of promoting cycling. A key purpose of infrastructure should be to protect cyclists from cars, which is identified as a major barrier. Aside from specific infrastructure for cyclists, the way entire neighbourhoods and communities are built affects levels of active travel, since community design determines whether trip origins and destinations are sufficiently close to each other to be covered by bicycle. Policies that improve cycling can boost active travel as an access mode to transit, while policies that make car use less attractive will increase the competitiveness of cycling. Moreover, there is clear indication that policies to promote cycling as an active travel mode will work best when implemented in comprehensive packages; These may include infrastructure and facility improvements, pricing policies, and education programmes to achieve substantial shifts towards active modes, always combining “soft” with “hard” modes.

Policies influence bicycle use and can be effective in sustaining high levels of cycling and strengthening its culture. The influence of policy measures is evident from many studies. One of the most influential is the benchmark study from the “Dutch Cyclists Union” that showed a positive correlation between bicycle use and the quality of cycling facilities in Dutch cities.

The following Figure 19 describes the procedure that should be adopted in order to achieve a more successful implementation of a cycling community in order to get people to use the bicycle, not just as a transport mean but also for pleasure. There is still remains a considerable uncertainty on the precise effects and outcomes of certain measures, due to the fact that cultural, economic and political aspects of each country, are different. Therefore, there is not standardised measures to encourage bicycle use.

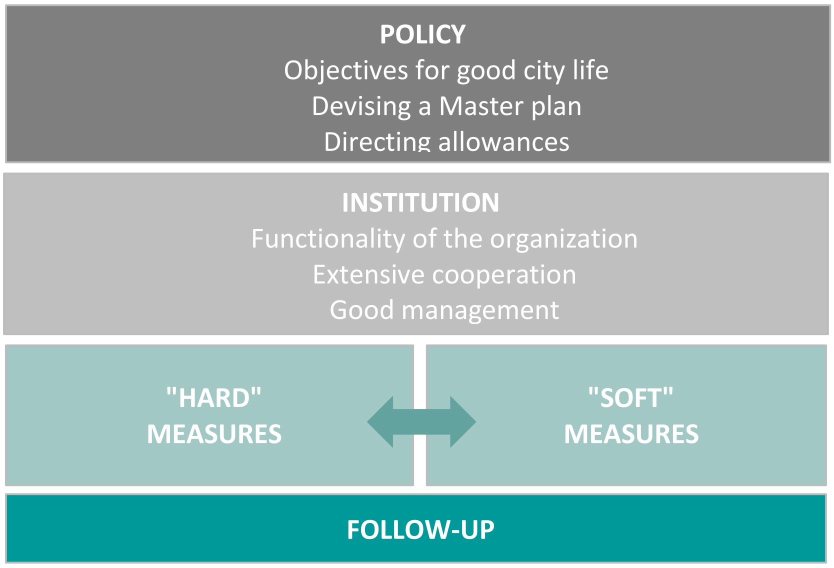


Figure 19. Procedure of a successful transportation plan. Developed by the author

The implementation of “hard” and “soft” measures promoting cycling, mentioned previously should not be implemented light-headedly due to the fact that every different cycling measure, differs considerably regarding their cost-benefit efficiency. If it isn’t implemented correctly the outcome of the measure can be unsafe for cyclists. Land use measures can play a fundamental role in a long-term perspective. Planning for higher density developments, steering most development to areas well served by public transport and local facilities, and detailed layouts designed to promote safe, convenient and attractive direct routes may be the essential “key” to encourage cycling as an alternative urban transport mode.

Therefore, it is still necessary to develop and perform a cost benefit analysis on an ‘Urban Master Plan for Cycling’. Such an analysis would give insight of the gains and costs of a total ‘package’ of cycling measures that would be able to predict a more precise outcome – a major argument to policy makers to give more attention to cycling. Developing such a method would be a great addition to the extending knowledge on the effects of cycling, public policy on cycling and on raising cycling numbers in the urban environment.

Chapter 7

Final Remarks

7. FINAL REMARKS

This section presents the main conclusions and suggestions in order to give continuity to this work.

7.1. Conclusions

The aim of this dissertation is to determine the factors affecting bicycle commuting by studding the relationship between land use and urban mobility. Built environment has significant effects on active transport; however, many causal pathways still need to be elucidated. Therefore, built environment planning decisions can have many direct and indirect land use impacts on cycling. These impacts are often significant and should be considered when evaluating a particular policy or project. Commuting offers benefits in terms of economic propensity, but it can also affect society negatively, for example, car commuting can result in congestion and negative impacts on the environment, while cycling offers a number of advantages over other modes of transport, is environmentally sustainable, requires limited space, the required infrastructure is relatively inexpensive and can improve public health. For the individual, cycling is a healthy and cheap form of transportation, and can sometimes prove to be faster than other transport modes, especially in urban areas and for short distances.

In the vast majority of the western world, finding ways to increase active travel is becoming a key objective of policies and plans. The health, environmental, financial and even psychological benefits derived from the active pursuit of cycling, have been continuously demonstrated, not only by theoretical scientific research, but also by practical and empirical evidence. However, the budget for investments in favour of the bicycle is very limited and, in general, rarely is seen as a priority, therefore, a better understanding of the cost/benefit relationship among the many strategical measures is necessary. For that reason, it is possible to conclude that land use measures can play a fundamental role in the longer-term perspective. Furthermore, planning for higher density developments, steering most development to areas well served by public transport and local facilities, and detailed layouts designed to promote safe, convenient and attractive direct routes, may be the essential “key” to encourage cycling as an alternative urban transport mode. However, this approach is associated with higher costs. Based on this evaluation, investing on "hard" strategy measures have proven to have a higher impact on mode shift and safety aspects than softer measures. However, the combined effect of "hard" and "soft" measures have a positive effect in promoting cycling, therefore, supporting strategies should only be implemented until adequate infrastructure is in place.

As mentioned previously, in order to promote cycling it is necessary to take into account the many factors that affect bicycle use, therefore, it is essential integrated land use-transportation policies in order to benefit in a long term perspective. However, cycling planning needs to take into consideration the modal share and the level of development of each region, due to the fact that different strategical measures have different outcomes and can vary considerably from region to region. Therefore, each country/region needs to adapt the existing strategies and solutions in order to take full advantage of the measures implemented, in this sense, the "Compromisso pela Bicicleta" was created.

One of the main goals of this thesis is to contribute to the project "Compromisso pela Bicicleta", namely to the IMPACT initiative, by suggesting practical cycling measures and tips that each respective subscriber can undertake in order to reach the projects goals. The list of strategical measures, are as follows:

- <u>Local or sub-regional governmental management entities:</u> most of the more physical measures can only be undertaken by these entities, especially land use and infrastructural measures. These can be achieved creating bicycle sharing systems, cycling infrastructure and integrated network, creating shared and traffic calm areas and measures that discourage unnecessary car trips (increasing parking prices). These measures are essential to ensure that other organizations and institutions can contribute more effective and safely, since in most cases they can only implement "soft" measures. As previously mentioned, the promotion of "soft" measures should be preferably combined with "hard" measures.
- <u>Educational institutions:</u> universities can create bicycle sharing systems, a stricter car parking policy, amenities and facilities both for bicycles and bike users, create and promote cycling projects and events and, finally, wider cycling research and investigation. As for primary and high schools, they should promote cycling by teaching how to ride bicycles safely, as well as teaching the road code and promote home-school bicycle commuting.
- <u>Health and social solidarity institutions:</u> these entities can create and promote campaigns related the health benefits of cycling, such as, creating cycling events to generate

social integration, for example organising bicycle events for the elder citizens, allowing them to be healthier, more conscious about the benefits of cycling as well making them feel more integrated.

- Enterprises (trade, services, industry): can create amenities and facilities such as lockers, showers and safe parking for bicycle users, benefit workers, as well as bicycle users, by creating campaigns and events that promote bicycle, for example, shop owners can give a discount for people that use cycling as mean of transportation to their facilities.
- Third sector organizations and informal civil social organizations: can facilitate the collaboration between the various companies, organizations and bicycle activists in order to create bicycle events, such as cycle related debates, campaigns, cycling tours, competitions, workshops and expositions.

There are many ways to improve and encourage cycling. Although most communities are implementing some of these strategies, few are implementing land use cycling related measures. Most of these strategies only affect a portion of the total travel, so their impacts appear modest, being seldom considered the most effective way of solving a particular problem. However, they provide multiple and synergistic benefits, whereby when all impacts are considered, many communities can justify more support for cycling.

7.2. Future developments

Based on this study, this section offers recommendations for further research.

Firstly, more generally, an improved understanding of the determinants of active travel behaviour is required to improve and develop new and more effective measures to promote cycling. Of particular interest is the area of Land use - both with regards to land use planning, as well as better understanding on how land use affects cycling and how that relationship may encourage as an active travel mode. Land use cost-effectiveness studies would also be useful as a tool for policy and decision-makers.

Secondly, in order for cycling to contribute to as an active transport mode, it is crucial to understand how it can be promoted in subgroups of the population least likely to engage in cycling. This implies considering the equity distribution of policy, program, and infrastructure interventions to promote cycling.

Thirdly, this thesis has focused on the effect of the built environment on travel behaviour. It is without doubt that built environment plays an important role in the consideration of whether or not to cycle and on the route choice of cyclists. Moreover, it can be assumed that attitudes and norms on cycling are connected with the presence and quality of the bicycle infrastructure. A thorough research on the experience of bicycle facilities, and how these facilities affect individual attitudes, would offer insight into how the built environment affects cyclists and this would offer policy makers practical input on bicycle infrastructure facilities.

Fourth, additional factors could affect bicycle commuting, which could be addressed in future research. These include, but are not limited to the following aspects: (1) the identity of the commuter and his/her social identification with different groups, (2) the built environment, (3) the fixed weekly commuting patterns of some commuters, such as needing a car on certain days to pick up children, but having a choice on the remaining days.

Finally, additional research is necessary to test the effectiveness of cycling measures to encourage non-cyclists to start cycling and part-time cyclists to cycle more frequently. In addition, the effectiveness of current initiatives and policies have not been investigated well. Many initiatives and policies are based on common sense and current use without proof of their effect and outcome. It would be advisable not only to concentrate on finding creative new strategies, but also to carefully examine the outcome and unwanted side-effects of the current and past measures on cycling.

Chapter 8

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Appendix A

APPENDIX A

Table. A. corresponds to the References of the Table 13: Main findings about the influence of land use and cycling variables that affect mode choice and frequency

Table A. References of the Table 13

	References		References
[1]	Bamberg et al., 2003	[**20**]	Pikora et al., 2003
[2]	Bergström and Magnusson, 2003	[**21**]	Plaut, 2005
[3]	Boumans and Harms, 2004	[**22**]	Pucher and Buehler, 2006
[4]	Cervero and Duncan, 2003	[**23**]	Pucher and Buehler, 2008
[5]	Cervero, 1996	[**24**]	Pucher et al., 1999
[6]	De Bruijn et al., 2005	[**25**]	Räsänen and Summala, 1998
[7]	Dickinson et al., 2003	[**26**]	Rietveld and Daniel, 2004
[8]	Dill and Carr, 2003	[**27**]	Rodríguez and Joo, 2004
[9]	Dill and Voros, 2007	**[28]**	Schwanen and Mokhtarian, 2005
[10]	Gatersleben and Appleton, 2007	**[29]**	Shaw and Gallent, 1999
[11]	Guo et al., 2007	**[30]**	Southworth, 2005
[12]	Hunt and Abraham, 2007	**[31]**	Stinson and Bhat, 2004
[13]	Kitamura et al., 1997	**[32]**	Stinson and Bhat, 2005
[14]	Litman, 2005	**[33]**	Timperio et al., 2006
[15]	Martens, 2004	**[34]**	Verplanken et al., 1997
[16]	Moudon et al., 2005	**[35]**	Wardman et al., 1997
[17]	Nankervis, 1999	**[36]**	Witlox and Tindemans, 2004
[18]	Noland and Kunreuther, 1995	**[37]**	Zacharias, 2007
[19]	Parkin et al., 2008	**[38]**	Bjorklund and Isacssin, 2013