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Factors influencing the development of the urban cycling. A case study of three European cities: Brussels, Copenhagen and Vienna.

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Introduction: From the concept of urban sustainability to the promotion of the utilitarian biking

In Europe, 60% of the population lives in an urban environment and 85% of the EU GDP results from activities in cities. Nevertheless, they are responsible for 40% of the CO_2 emissions and 70% of other pollutant emissions. Among the CO_2 emissions rejected within European cities, 25% comes from the transport system. Furthermore, the European Union looses hundred billions of Euros every year because of traffic congestion problems inside city centres. It represents 1% of the European GDP. Finally, one out of three deadly accidents occurs in urban areas [EURO2007]. In this context and in order to achieve the objectives of the Copenhagen climate change Conference of 2009[1] , solving transportation problems is one of the major target in order to "*build cities in balance with nature*" [REGISTER2006].

As they are at the centre of the transport networks, cities attract flows that are largely inevitable. Nevertheless the current situation of most European cities is the result of previous mobility policies which facilitated the use of car instead of other mobility choices. This situation can easily be illustrated in the sentence of of the previous French president George Pompidou: *We must adapt cities to cars*".

However, today the situation has changed. New urban transport policies have been developed in line in order to reduce the car domination and so reduce traffic congestion, gas emission and noise pollution without restraining the economic growth. In other words, the new transport policies have to be sustainable.

The Sustainability is a complex concept based on three pillars: environmental, social and economical aspects. It was firstly defined by the Brundtland Commission in 1987. According to this commission every sustainable policy "h*as to finding ways to meet current needs while leaving enough "natural capital" to allow future generations to sustain a similar, or improved, standard of living"* [TOMLINSON2003]. Because of the complexity of the topic, there are diverse definitions when it comes to apply it to the transport sector. But according to the World Business Council for Sustainable Development, we can define the sustainable transport as "*the ability to meet the needs of society to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values today or in the future"*[RIVER2001]. Within this framework, different options exist to achieve the target of the definition: developing clean

1 Reduce the CO_2 emission of 20 to 30% in Europe for 2020

motorised vehicles (hybrid vehicles, electric vehicles, hydrogen vehicle, public transport…..), promoting less car incentive life style (car pooling, car sharing…) and encouraging the development of non motorised transport modes (walk, cycling, kick scooter, roller skating…). These alternatives can't provide a perfect sustainable solution if they are considered alone. But it can be assumed that the coalescence of different choices in a given context would give the best result.

In the context of this master thesis, we decided to focus on the development of one non-motorized transport mode: the bicycle. But is utilitarian bicycle really sustainable? This point will be examined in the next section.

1 Is utilitarian biking really sustainable compared to other modes of transport?

In order to answer the question, we will look at it through three points of view characterizing the sustainable concept as defined during the earth Rio Summit of 1992: ecological, economical and social.

1.1 Is utilitarian biking ecologically friendly?

If we except the CO_2 send out to produce it, a bicycle nearly doesn't emit any gas. According to Van Hout,because bicycle only use muscle power, the utilitarian biking avoid problems with air pollution, global warming, smog and fine particules. Moreover CO_2 emissions could be reduced by 3-4% by replacing short car journeys by bicycle trips. Furthermore the utilitarian biking is almost silence. Therefore it use could reduce the problems related to noise pollution like insomnia, stress and mental disorder [VAN HOUT2008].

An other main advantage of the use of bicycle is the gain of space that could be done in urban transportation infrastructures. According to Dekoster & Schollaert,, a car take seven times more place than a bicycle (see figure 1). Moreover, a two meter cycle track is able to unroll 5200 cyclist per hour [DE GEUS2007] . Finally, twelve bicycle can be parked on one car park .This save of space allows to make city centre more attractive, avoid urban sprawl and useless space consumption. To conclude, we can also notice that the utilitarian biking is the most energical efficient way to move.. A cyclist only need 1/5 th of the energy spend by a pedestrian to travel one kilometre [VANDENBULCKE2009]

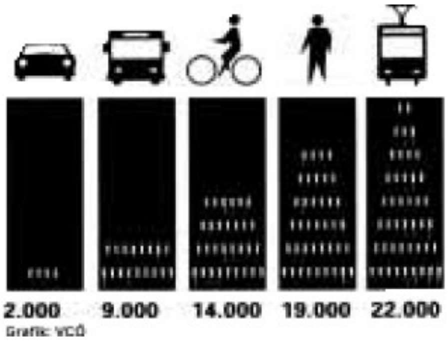

Figure 1: Number of car crossing a 3,5 m wide space during a one hour period.

Source: HORVATH2006

1.2 Is utilitarian biking socially acceptable?

The first main social benefit of biking is the improvement of health. According to Andersen, people who cycle to go to work lower down their mortality rate by 28%. Moreover a study made in Ondense (Denmark) noticed that people that cycle are more active in other fields than non cyclists [EGE -].Several studies made in different countries and several authors showed that a regular physical activity had a strong impact in the reduction of the disease risk. According to them, the practice of a moderate physical exercise like biking could reduce hypertension by 30%, cardiovascular disorders by 40%, and breast and colon cancers by 25 to 50% [EGE -].Nevertheless it could be argued that biking in an urban environment could be unhealthy because of the air pollution. However a study made in Amsterdam by Van Wijnen, showed that car drivers are much more exposed to air pollution than cyclists if we except the total amount of dust by kilometre (see figure 2).

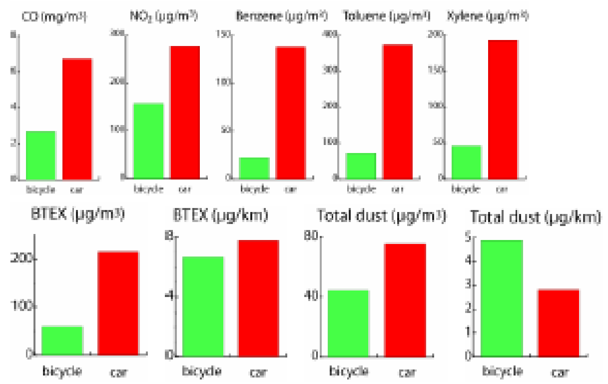

Figure 2: Exposure to pollutants by bicycle and in a car

Source: EGE-

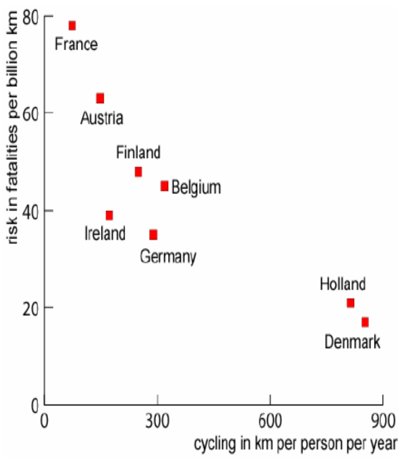

Figure 3: Cycling risk versus cycling intensity in European countries

Source: EGE-

Another argument against the practice of cycling in an urban environment could be the lack of safety. Indeed, cyclists as motor-bicyclers are less protected and more easily injured in case of an accident with other road users (especially car drivers). This is confirmed when the risk of fatalities/injuries per kilometre is calculated [VANHOUT2008]. Nevertheless, according to Christian Ege, the risks for cyclists tend to be smaller in countries where people cycle a lot [EGE -]. Indeed, the Netherlands and Denmark are the safest countries to cycle if we compare the risk in fatalities per kilometre versus the number of kilometres cycled per year for European countries. (see figure 3 above). Moreover, the example of Copenhagen shows that it may possible to increase the number of cyclists and decrease the number of serious accidents for cyclists. In 20 years the proportion of kilometres cycled in Copenhagen increased by 140% compared to 1990, while the proportion of seriously injured cyclists decreased by 25% [COPENHAGEN2008].

Furthermore, we can argue that cycling is more socially acceptable than other modes of transport because it is more accessible to a large part of the population. Indeed, a bicycle is affordable to people who can't drive a car like children. A study by Fotel & Thomsen showed that the increase of mobility due to the use of bicycles improved their social and physical developments [EGE -]. Furthermore, it is a cheap mode of transportation on short distances. On the seven first kilometres and at an average speed of 15 km, a cyclist goes faster than a car or public transports (bus or tramway).It is due to the fact that a cyclist has almost never to look for a parking spot and has to stop less during a journey. As a result, the bicycle makes a wider range of destinations more easily accessible (see figure 4) [VANHOUT2008].

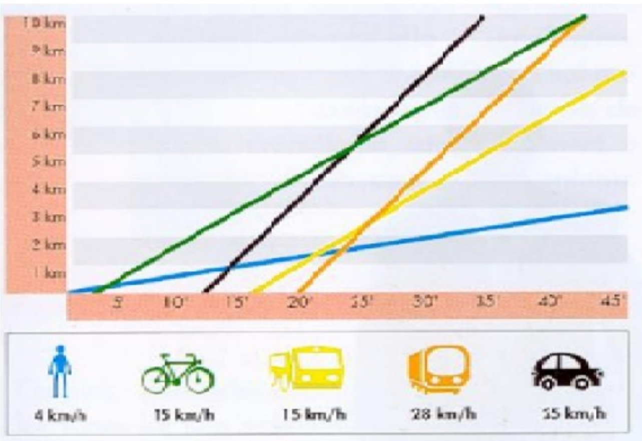

Figure 4: Comparative table of journey in an urban environment

Source:European commission

Finally, it is often mentioned that cycling would improve social relations because the bicycle is a noiseless transport mode; the cyclist is not locked up in a passenger compartment and therefore can easily communicate. Nevertheless this hypothesis may be doubtful. As far as we know, no study found a particular relationship between the daily use of a bicycle and an improvement of the social relation between individuals. It may create the opposite effect. Indeed, the effort required to cycle may restrain the willingness to speak. Furthermore, in countries where the cycling level is high, people cycle more because it is a quick mode of transport (see below). This means that people are more focused on reaching their final destination than making ties with others.

1.3 Is biking economically viable?

First of all, promoting the use of the utilitarian biking is a way to save time and money for individuals and the whole society. A bicycle is relatively cheap, as a low purchase and doesn't need to be refuelled. Furthermore, it has no parking costs. Therefore a bicycle is affordable to many people.

Secondly, a cyclist needs less space and less road infrastructure than a car driver and destroys less the road surface. These elements can enable to reduce the road costs for the state [BLACK2002].

Thirdly, an increasing share of the utilitarian bicycle creates more space on the roads and reduces the economical cost of congestion because workers and goods are less stuck in traffic jams. In Belgium, traffic jams amounted to 154.1 millions of Euro in 2006 [LAWSON2006] .

Fourthly, promoting utilitarian cycling is a good way to reduce the health security cost by reducing cardiovascular disorders, diabetes, hypertension and breast cancer. Besides, according to the World health organization, it would increase the productivity (by 20 to 52%) [WHO1999].

Finally, the traffic department of the city of Copenhagen showed that each kilometre made by a car in Copenhagen cost six times more than one made by a bicycle[2][RøHL2009]. Ege also added that if walking increased by 30 % and cycling by 50%, the total benefit for the whole society would be around three billions of Euros [EGE -].

Cycling does not only allow to save money. It can also create an economical value. According to a survey made in Breda (The Netherland), the development of the utilitarian biking let to maintain or develop the local retail business, because cyclists are more loyal and go back more often to the same shops [MARTENS2004]. Furthermore, in a study made by Buis and Wittink, it has been found that with a significant decrease in car trips (around 50%), 240,000 jobs would be created, mainly in the public transport and bicycle sector [BUIS2000].

2 The account in the study took the following elements: Time Costs, Vehicle Operating Costs, Prolonged Life, Health benefits, Accidents, Perceived safety, Discomfort, Branding / tourism, air pollution, Climate change, Noise, Road deterioration, congestion

2 Conclusion

Developing the utilitarian cycling is probably the best option to organize a sustainable transport if we take into account the three pillars of the concept of sustainability. We can also notice that most of the benefits come from a decrease in negative externalities (pollution, noise, degradation of the road infrastructure,traffic jam,...), due to the over use of cars.

As Van Hout notices it:”Utilitarian cycling has to be developed in urban areas because there is just too much to gain from it” [VANHOUT2008].Therefore many cities considered the development of the utilitarian bicycle positively. The improvement of its use could enable to solve a lot of problems met daily by city workers (civil, servant, social workers, politicians, traffic engineers,...).Nevertheless, the rate of development of the utilitarian bicycle is quite different from one European city to another one . It can vary from nearly 0% of the total journeys to work (Praha, Barcelona, Madrid, Roma, Napoli Zaragoza) to more than 20% (Aalborg, Aarhus) or even more than 35% (Kobenhavn) (see figure 5) [EEA2009].

Hence we can ask ourself what factors influence this practice?

This question will be answer in the next chapter trough a large litterature review on the topic.

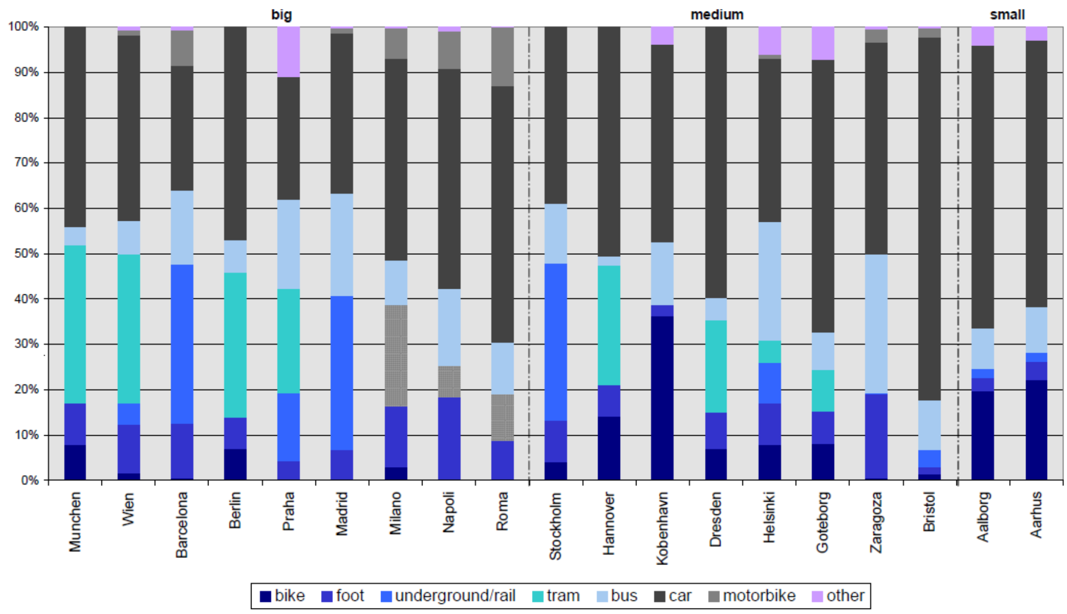

Figure 5: Percentage of journey to work

Source: Urban ecosystem in Europe report 2007

The state of the art :

Factors influencing the propensity to cycle

1 Introduction

Many factors influence the practice of bicycling in an urban context. The characteristics of the utilitarian bicycling are different from the other transport modes. Indeed car or public transport are less influenced by factors such as the weather, the hilliness, the distance, the road structure, the perceived safety, the age.... Moreover, the utilitarian bicycle is influenced by other factors than those influencing cycling for leisure or for sportive purposes [HEINEN2010]. Thus, a specific literature about this topic exists. It covers different scientific fields like urban planning, traffic engineering, city transport policies, demography, economy, sociology, cultural studies, history, According to Heine a comprehensive overview of all the factors influencing the utilitarian bicycle doesn't exist [HEINEN2010]. This situation is due to the fact that most of the factors are not independent from each other and can play a more or less important role according to the country or the city studied.

2 A conceptual framework

Many authors use an ecological model. This gives a good framework to *"examine the multiple effects of social elements in an environment"* [THING-TOOMEY2006]. Many authors distinguish four categories of factors that could influence the propensity to cycle: the built environment, the natural environment, the socio-economical conditions and the psycho-cultural behaviour. One can notice that all the categories are related to each other and even overlap themselves, Particularly the two last group of factors. Therefore some authors ([XING2004],[VAN HOUT2008], [ABRAHAM2002]) only define three family of factors: individual factors , social environment conditions and physical factors (see Figure 6).

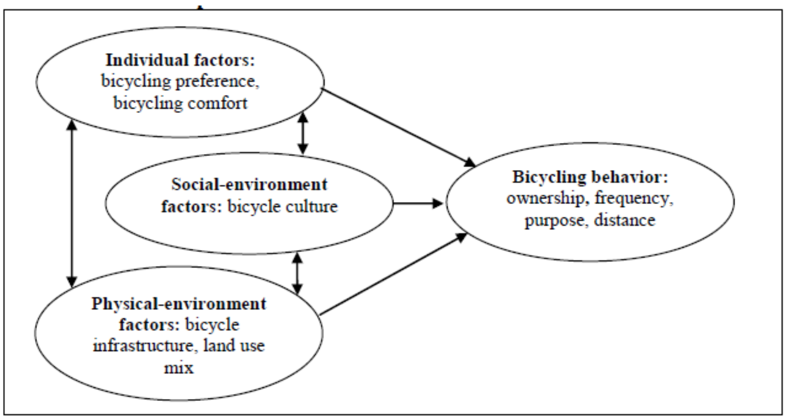

Figure 6:Conceptual model made by Xing et al

Source: Xing 2004

Finally, some other authors, like Rietveld, use cost benefit model [RIETVELD2004]. The main idea under this last type of model is to identify the costs and benefits of cycling, and analyse elements of the local context that may advantage or disadvantage the practice of cycling. This kind of model is useful to analyse factors related to the natural environment, the urban fabric or the socio economical situation (age, income, educational degree...). It enables to objectify and quantify how each factor influences the bicycle use in a specific urban area. Nevertheless, these models have some difficulties to integrate elements related to behaviour. One of the reasons is that they take the hypothesis that people only act in a rational way.

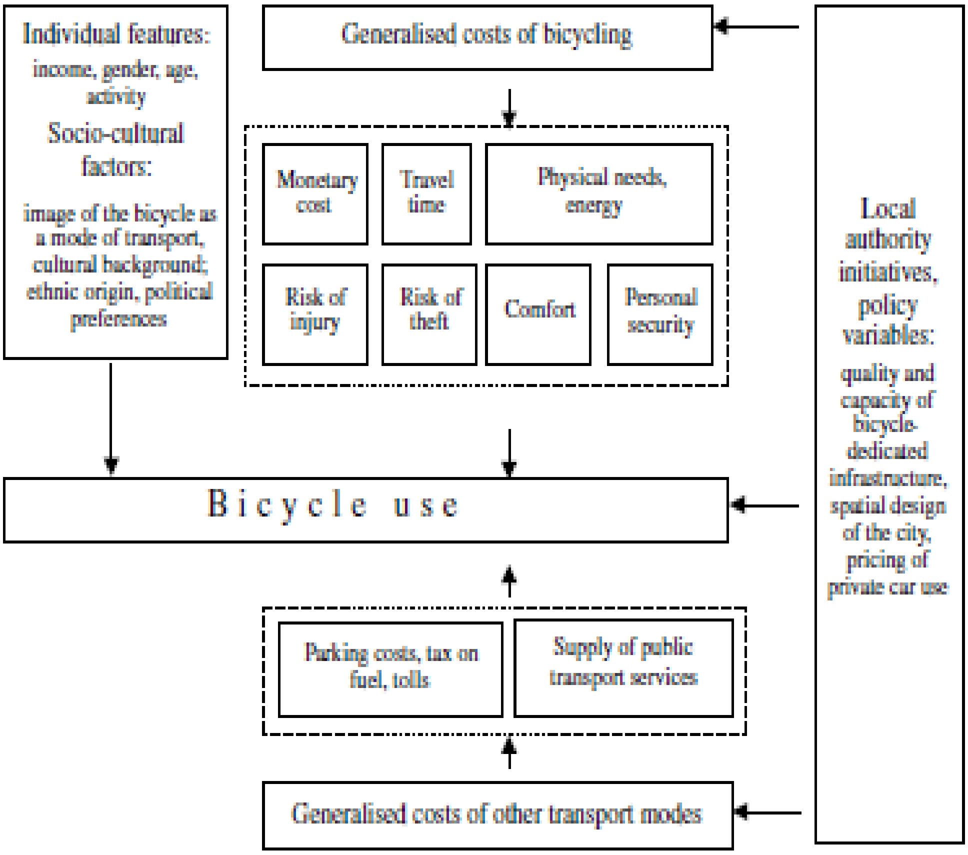

Figure 7: Cost model made by Rietveld

Source: Rietveld 2004

In the following sections we will examine more into details how main factors identified in the litterature may influence the propensity to use a bicycle for utilitarian purpose.

3 The natural environment

As a cyclist has to drive by himself and is less protected from the exterior elements, the natural environment could play an important role in the practice of the utilitarian biking. In the literature related to the topic, two types of factors are usually recognised as majors elements influencing the propensity to cycle: the topography and the weather.([HEINEN2010],[RODRIGUEZ2004], [RIETVELD2004],[XING2004],[PARKIN2007],[NANKERVIS1999],[RICHARDSON2000])

3.1 The topography

The topography is often quoted in survey as a reason not to cycle given the fact that the presence of slopes increases the amount of energy needed to make a journey. Through a statistical logic model, Rodriguez and Joo showed that the more a journey was delaying because of the hilliness of the topography, the less important were the journeys made by bicycle. According to them, above 8 minutes of delay, less than 5% of the trips is made by bicycle [RODRIGUEZ2004].

In a study comparing different cities in the Netherlands, Rietveld and Daniel found that a hilly shape would have the effect to decrease the bicycle use by as much as 74%. According to the authors this element mainly explains the relative low cycling rate in Rotterdam, Maastricht and Harlem compared to the high average cycling rate of the rest of the Netherlands [3][RIETVELD2004].

Nevertheless, it seems that the way how slopes are distributed on the territory of a city also plays an important role. For example, the city of York (UK) with slopes of more than 3% on only 5% of their territory has a cycling share of 13.1%. Meanwhile Bradford (UK) with slopes of maximum 3% but distributed throughout its surface has a cycling share of 0.8% [PARKIN2007].

Nevertheless it doesn't mean that developing the utilitarian biking is impossible in hilly town. For example, Basel (Switzerland) has a cycling share of 15% while the city is situated in the middle of the Jura mountains [VANHOUT2008]. Moudon in a study made in the state of Washington (USA) found out that individual and cultural factors may play a more important role in the decision to cycle [MOUDON2005].

3 Rotterdam, Maastricht and Harlem have a respective biking share of 20.92%, 21.05% and 25/72%. The average value for the all the Netherlands is 35,1%

3.2 Weather and Season

Unlike car drivers, cyclists are not protected from bad weather. Therefore, the climatic conditions could be a second important factor influencing the bicycle use on a daily basis. Different elements of the local climate may influence the bicycle use. In the literature, the temperature, the rainfall, the wind and the lightening are often taken in account in order to evaluate this influence ([RICHARDSON2000],[NANKERVIS1999] ,[HEINE2010]) .Nevertheless it is important to distinguish two different effects: the general influence of the seasonal regime and the day -to -day influence of the weather. In a study made in the metropolitan area of Melbourne, Richardson assumes that temperature and the lightening can be related to the local seasonal conditions. Meanwhile the rainfall and the wind are more linked to the day- to -day weather conditions [RICHARDSON2000].

3.3 Seasonal influence.

It is generally admitted that the propensity to cycle during the Winter is lower than during the Summer or the Autumn [NANKERVIS1999]. In a study made in Sweden, Bergström and Magnussen found out that during the Summer only 25% of the people travelled by car for journeys shorter than 3 km, whereas in the Winter, almost 40% of these people travelled by car for the same distance. They also noticed that the number of bicycle trips decreased by 47 % from Summer to Winter. The Municipality of Copenhagen estimated in 1989 that during the Winter the use of the bicycle was reduced by about 30% in average, 40% during a rainy Winter day and 66% if it snowed [COPENHAGEN1989].

In his study Richardson assumes that this winter effect is mainly due to the decrease of temperature during this period. According to the statistical model developed in his study for the city of Melbourne (Australia), 100% of the cycling trips are made at 25°C. Meanwhile, at 15°C, 70% of the utilitarian cycle trips continue to be made (see figure 8) [RICHARDSON2000].

Lightening also plays a role, even if this one is less important. Through a survey made in the UK, Gatersleben and Appletont showed, that 24% of the respondents noticed that the darkness was a negative element [GATERSLEBEN2007].

Nevertheless, as Pucher and Buehler suggest it, the seasonal influence can be overcome by other factors as it can be shown by the example of the city of Oulu in Finland where 30% of the biking trips are made by bicycle while the average temperature during the year is around 2,5°C[VAN HOUT2008].

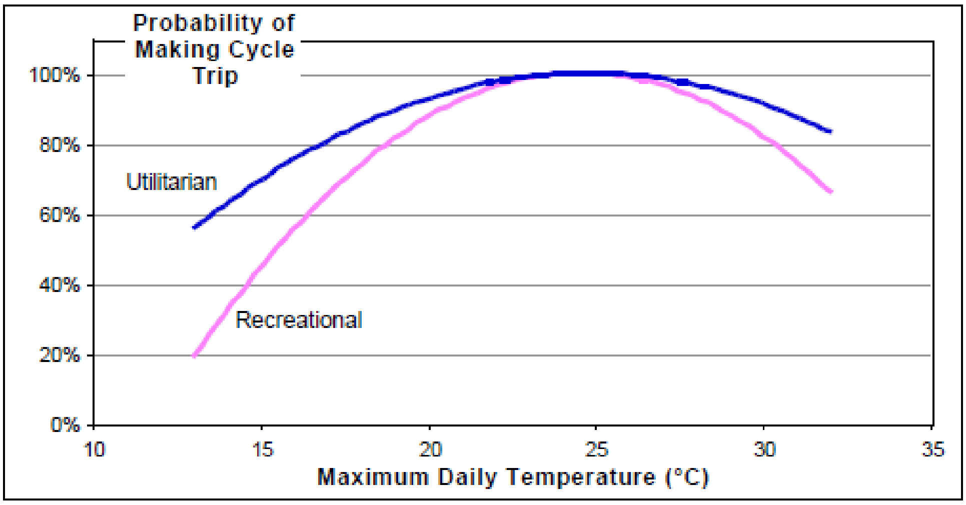

Figure 8: The propensity to make cycle trips as a function of temperature

Source: Richardson 2000

3.3.1 The day to day weather influence

As the weather changes from one day to the other, it can affect the decisions to cycle or not on regular basis.

As a direct result, many studies mention the rainfall (or precipitations) as one of the main reasons not to cycle ([NANKERVIS1999],[GATERSLEBEN2007]). According to Richardson up till about 5 mm per day, there is no real effect on the cycle use. But further, precipitations have a strong effect in reducing the cycle flow. If it rains 10 mm per day, only 25% of the trips by bicycle are made (see figure Error: Reference source not found) [RICHARDSON2000]. Nevertheless, it seems according to Brandburg that daily cyclists are less sensitive to the rain than other cyclists. This could be the result of a habit to cycle under the rain. But a better reason may be that most of the biking trips in urban areas are made in maximum 30 minutes. Therefore, if we exclude some days of "heavy rain", it may always be possible to commute by bicycle. This may explain why authors like Rietveld or Nankervis, found out that the rainfall is marginally significant .[NANKERVIS1999][RIETVELD2001].

Finally, another element that may influence the propensity to cycle is the wind. A strong wind may act as a slope and may increase the effort that the rider has to produce. Though no real study focusing on the effect of the wind on the utilitarian biking seems to exist. Nevertheless it may be that like in the case of rain, wind is marginally correlated with the cycling use [RIETVELD2004].

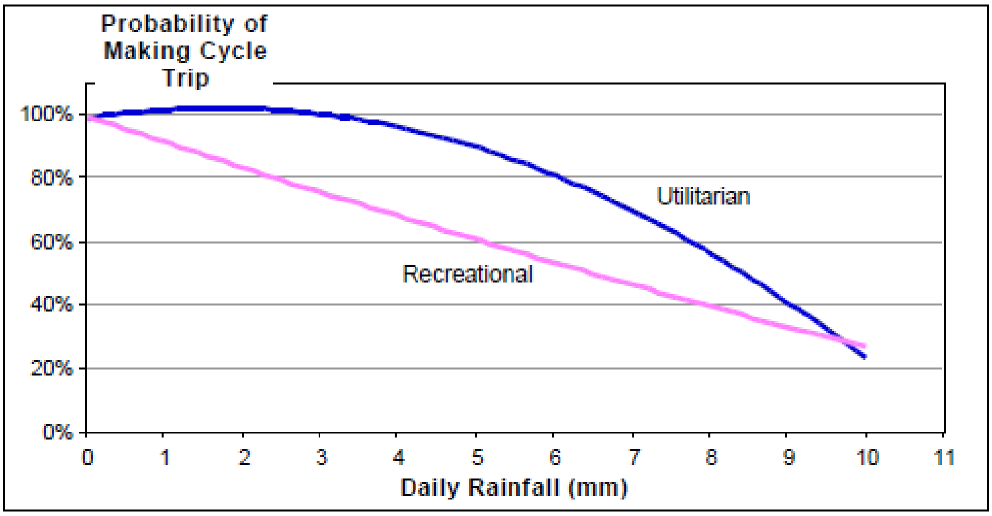

Figure 9: The propensity to make cycle trips as a function of rainfall

Source Richardson 2000

To summarize the idea developed in this section, we can affirm that the question of the topography makes consensus in the literature. Other physical element like the rainfall seems to play a more or less important role according to the local context and the experience of the cyclist.

4 The built environment

The shape of the built environment is more and more recognized by the academic literature to have an important role on travel behaviour . Indeed it has a direct impact on the time of a journey as well as the comfort of a travel made by bicycle. Factors related to the built environment can be considered as the second main group of elements that may influence the propensity to cycle for utilitarian reasons.

4.1 Time, accessibility and distance

The time to commute by bicycle in between home and work is one of the major reasons to cycle or not [CERVERO2003]. In Copenhagen, 54% of the bicyclers mention it as the main reason to commute by bicycle every day [COPENHAGEN2008].

Like for other transport modes, the time needed to make a journey by bicycle is highly correlated to its accessibility. But, for a cyclist this accessibility is connected to the physical effort required to reach a place. This last element disproportionally increases with the distance. Now, the distance may be the first factor influenced by the urban structure [BROWNSON2009]. Therefore, all the elements that can potentially increase the distance of a journey made by bicycle have to be taken in account. Through the literature, four main elements that may influence the distance can be identified : the size of the city, the land use mix, the density and the street layout.

4.1.1 The size of the city

It is often mentioned that small cities are more “cycleable” than big cities. Mc Donald and Burns suggested that the maximum acceptable distance was around 6.6 km for a woman and 11.6 km for a man [McDONALD2007]. This result may lead us to think that big cities are not really adapted to the bicycle, at least for women. In a study made in the Netherlands, Rietveld confirmed this assumption. He proved that small and medium size cities had the higher level of bicycle use. Rietveld explains this result by the fact that in small cities, streets are less crowded by cars, the distance are shorter compared to more important towns and the level of public transport facilities are less developed [RIETVELD2001]. Nevertheless it can also be argued that big cities have a larger set of destinations within the first 5 km. Hence taking into account the size of the population or the physical extension of the urban fabric as a proxy is not enough to estimate the bicycleability of a city [VAN HOUT2008].

4.1.2 Land use mix and density

Increasing the land use mix[4] reduces travel distance and therefore allows more cycling trips. Indeed, the neighbourhood with the right mix of residential and office buildings, shops and public facilities, avoiding people to make long distance trips. According to Krizek, households located in a well mixed area travel an average distance of 3.2 kilometres by journey versus 8.1 kilometres for households located in mono-functional areas [KRIZEK2003]. Davidson also adds that the presence of worksite amenities (like a bank, a cafeteria a post office or a childcare centre), may reduce the average weekday car travel by 14% [DAVIDSON1994]. Nevertheless, the degree of sufficiency in a neighbourhood highly depends on the socio-economical composition of the inhabitants. [CERVERO1995] For instance a neighbourhood populated with a young population has to provide enough schools or sport facilities in order to avoid local families commuting a too long distance.

But the land use mixity is not the only element that could reduce the travel distance. The density may also play a role. Indeed it can be assumed that a high residential density correlated with a high working density would reduce the car use, simply because local inhabitants would find a job near their living place [SCHWANEN2005].In a study comparing the car dependency of 50 cities around the world[5], Kenworthy confirms this hypothesis. He found out that there is an exponential relationship between density of people and the car use. As we can observe it on the figure 9: the more the population density increases, the more kilometres made by car per capital decreases. [KENWORTHY1999].

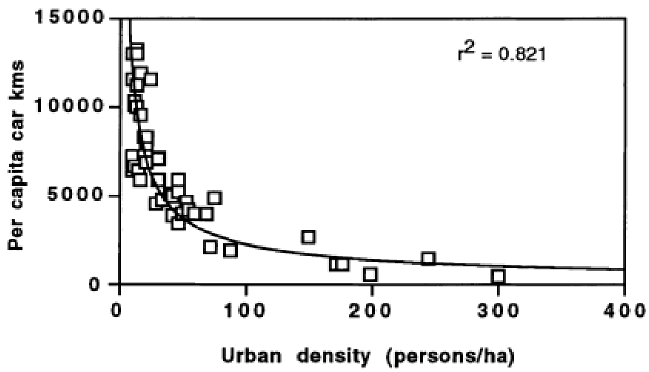

Figure 9: Population density versus car use in 50 cities around the world

Source:Kentworky 1999

4 The land use mix refers to locating different types of land uses (residential, commercial, institutional ….) close of each other [LITMAN2010].

5 The study include 13 American, 6 Australian,7 Canadian, 11 European and 9 Asian cities.

Pouyanne theoretically justified this relationship by the fact that a high density allows the following elements [POUYANNE2004]:

- A better accessibility: the number of reachable destinations at a given distance increases.
- A superior congestion level of the road network and as a result, a decrease in the car use efficiency which increases the use of other transport modes like the bicycle.
- An easier use of different transport modes within one journey.

Empirical studies seem to confirm those hypothesis ([PARKIN2007],[WITLOX2004], [ZAHRAN2008]). For instance, Cervero found out in a study made in the San Francisco Bay (USA) that the number of jobs by square unit was positively correlated to the probability to make a trip by bicycle [CERVERO2002]. In the Netherlands, Rietveld also noticed that the addressed density decreased the average journey distance.

4.1.3 The street layout

By influencing the directness, the street layout plays an important role on the distance of a journey. According to different studies ([LITMAN2010],[ZACHARIAS2005]), the density of the road, system and the connectivity[6] between buildings blocks are important. Indeed, a hierarchical road system with many dead-ends provides less acceptability and increases the distance to the final destination. While a fine grained road network reduces the difference between the distance network and the crow flies distance .Larco, notices that increasing the connectivity in sub-urban multi-family areas can double the number of trips made by bicycle or walk to the local public facilities [LARCO 2010]. Nevertheless, a too important connectivity increases the number of crossroad s and as Fajans points it out, cyclists try to avoid them because it increases the energy needed for a journey. Indeed,each time a cyclist stops, it requires him a great effort to recover the speed he had before he stopped [FAJANS2001]. Furthermore it would also increase the number of alternative roads for car users. Therefore, Frank and Hawkins also estimate that a change from a quadratic neighbourhood to an area ,in which pedestrian and cycling traffic are allowed but in which automobile traffic is blocked at certain crossroads, would increase the connectivity for bicyclers and pedestrians by 10% [FRANK2000] (see example10 bellow).

To conclude the first part of this section, it can be said that the relation between the land use, the density and the street layout has an influence on the propensity to cycle because it affects the

6 In this context, the connectivity refers to the degree to which a road system is connected

journey distance. Nevertheless this effect is indirect and only works if people live and work in the same area.

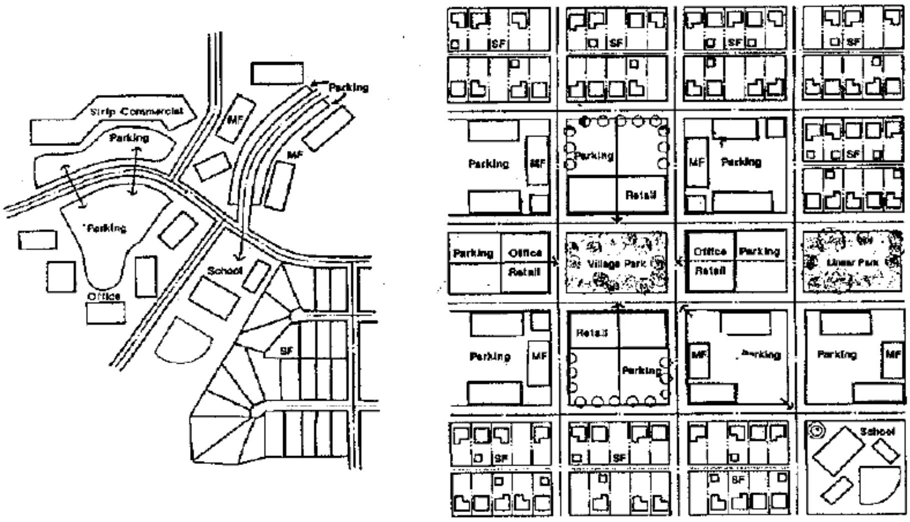

Figure 10: Comparing hierarchical and connected road systems

Source Lidman 2002

4.2 Cycle roads and biking facilities

In the literature, planned cycle roads and the presence of biking facilities are largely recognized as key elements to improve the quality of a journey made by bicycle and therefore to promote and increase the bicycle use. Statistically, it has been showed by Pucher that countries with a well developed biking infrastructure, like the Netherlands, Denmark or Germany, have on average a higher bicycle share [PUCHER2008]. One of the main reasons of this relationship between biking facilities and the bicycle rate is that a good development of the biking infrastructure increases the objective safety[7] and the subjective safety [KLOBUCAR2007]. Through a survey made in Edmonton (Canada), Abraham also added that good bicycle lanes reduced the travel time and therefore had an impact on the likelihood to cycle [ABRAHAM2002]. In the following section we will identify the different bicycle infrastructures usually built by cities in order to improve the comfort of the cyclist.

7 The objective safety refers to the real safety for cyclist according to the statistics

4.2.1 Cycle way, cycle path and cycle lane

We can identify three types of cycle road:

- The cycle **way**: the cyclist is completely isolated from the rest of the motorised traffic.
- The cycle **path**: the cyclist has his own delimited and separated area, alongside the road.
- The cycle **lane**: the cyclist has to follow a lane marked on a portion of the road, but not physically separated from the rest of the traffic.

In the literature, the term “off-road facilities” includes the two first types of cycle road, while the term “on road facilities” only refers to the last type.

Image 1: A cycle way

Source: google image

Image 2: A cycle path

Source google image

Image 3: A cycle lane

Source: google image

Even if cycle road is the safest solution, different studies showed that cyclists rather prefer to be close to the motorised traffic ([NOEL2003], [MARTENS2004]). Two main reasons can explain this preference. First, cycle ways are often isolated from shops and office buildings. Therefore, for short distances, using cycle ways can increase the distance to the final destination. Secondly, those roads are less enlightened and cyclists are more often isolated from the rest of the population, which increases the feeling of insecurity. Cycle ways seem in fact, more adapted to recreational cycling and or long distance trips. Cycle paths seem to be the right consensus between a good connectivity to retail and work areas, safety and security requirements. Nevertheless, some inconveniences of this type of bicycle roads have to be pointed out. First of all, they can't be implemented everywhere. According to the Danish directorate, in order to implement two sidewalks, two cycle paths and two cars lines, the minimal size of the street has to be 22 m large and such a width is not available in old city centres [JENSEN2002].

Secondly, according to several accident studies made in Germany, crossing a set-back cycle path appears to be 11,9 times riskier than cycling straight on the road with a bicycle lane (see figure 11) [MARTEN2002].

Thirdly, it can also be added that cycle paths located alongside a roundabout place cyclists outside the main observation zone of entering motorists and then increase the crash probability [ALLEN1999].

Finally, a cycle lane may in increase the risk of theft because there is no real separation between ciclysts and the rest of the motorized traffic.

There are no perfect solutions to resolve those objective safety problems. One answer would be to implement specific traffic lights for cyclists, but it would increase the complexity of traffic management at each crossroad. A less complicated solution would be to implement bicycle lanes close to crossroads or roundabouts. Indeed when a car is getting close to them, it tends to reduce its speed and so, the risk of injury would diminish. Furthermore, the reintegration of bicyclers in the road traffic makes them more visible for car drivers. Finally, the implementation of other road improvements like bicycle box could allow cyclists to cross intersections more easily (see figure 12) [JENSEN2002].

To conclude this section we have also to notice that the coherence of the bicycle network and the road maintenance are as much as important as the bicycle road themselves. Indeed, a badly maintained and incoherent network may fluster bicycle users and, as a result, increase the risk of injury as well as the lack of safety. For instance, 42% of Swedish cyclists argue that road surface quality is a contributory factor to accidents. [JENSEN2002].

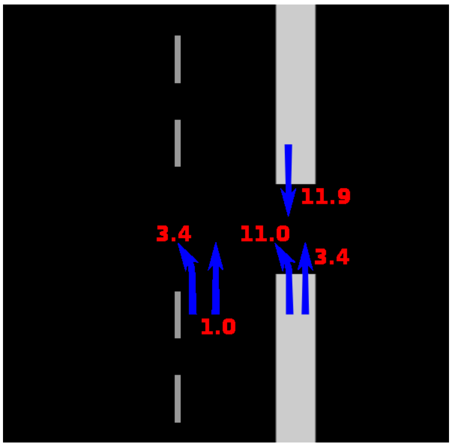

Figure 11: Crash risk of side path

Source [MARTEN2002]

Figure 12: Ideal crossroad for cyclist

Source: municipality of Toronto

4.2.2 Other road improvements

In addition to bicycle roads, city planners developed other bicycle infrastructures in order to improve the safety and the road conditions, or decrease the journey distances. In this section we will quickly review some of the most current ones.

4.2.2.1 Shared bus lanes

Shared bus lanes allow cyclists to take lanes devoted to buses or taxis. This kind of initiative has the main advantage to give the priority to two different road users. On the one hand, it gives the possibility to cyclists to use main road axes which are safer. On the other hand, it avoids buses being stuck in traffic jam. Furthermore, it doesn't create any disturbances between those two road users because the average speed of a cyclist and a bus in an urban area is virtually the same. Nevertheless, like for bicycle paths, the risk of crash at crossroads is quite important.

Noël showed that shared bus lanes in Quebec (Canada) had even an influence on the cyclist route's choice [NOEL2003].

4.2.2.2 False one-way streets

False one-way streets allows cyclists to travel in the opposite direction of one way streets. In an urban environment this devise enables to create short-cut, reduced distances and avoid cyclists to drive through the main and crowded street axes.

This apparatus seems to be quite safe because cyclists and drivers see each other when they intersect. In our knowledge no study found a negative effect on traffic safety, it even calms the car traffic [PUCHER2010].

4.2.2.3 Advanced stop lines

An advanced stop line (also called Bicycle box) is a road marking at crossroads allowing cyclists and sometimes other types of vehicles (like buses) to be in front of the rest of the traffic.

This arrangement enables cyclists not to queue between the motorized vehicles during the red phase at traffic lights. Furthermore, cyclists turning to the offside can adopt a prominent position to cross the junction, whereas cyclists going on the nearside have to wait on a specific location while traffic passes on the inside. Nevertheless this arrangement has one main default. When the light is green, cyclists turning on the offside of the junction don't have any space to wait until the light turns red for the traffic going straight. This can increase the risk of crash between cyclists [JENSEN2002].

4.2.2.4 Bicycle traffic signals

Bicycle traffic signals have the advantage to slow down the traffic flow and can reduce the possibility of right-angle collisions by giving to cyclists their own time period to cross the junction. However, they can increase the risk of rear-end crashes. In addition, the implementation of an excessive number of traffic lights would make a bicycle journey less competitive compared to a car journey and would make the travel unpleasant for the cyclist[8] [MILWARD2006].

4.2.2.5 Bicycle parking spots

Good parking spots can drastically reduce the risk of thefts [ZUKS2003]. There are a lot of different kinds of bicycle spots. Nevertheless they can be classified into two main categories: long-term and short term parking.

Long-term bicycle parking facilities provide a high degree of security and a good protection from the weather. They are implemented for situations in which the bicycle is left for a long period of time. We usually find them close to apartment blocks, schools, train stations…. These facilities can also take the form of lockers, cages or bicycle room in buildings.

Short-term parking facilities provide a means of locking the bicycle frame as well as both wheels, but do not provide accessories and security or weather components. They are usually used in locations where bicycles are visible. We can distinguish three types of short-term facilities:

- The post: It is the simplest parking facility. The bicycle can be locked directly through the frame of the bicycle. But in some cases, it requires a specific lock (see image 4) [RAATS 2000].
- The bicycle racks: This parking facility was mainly used 20 years ago. The bicycle can be locked through the front or the back wheel. They are mainly used for high volume bicycle storage. Nevertheless the bicycle is not attached and can be more easily stolen (see image 5) [AASHTO1999] .

Image 4: A post

Source: google image

Image 5: A bicycle racks

Source: google image

8 Fore more details, see chapter *The build environment* , section the *street layout*

- The U Rack: It is perhaps the most common parking facility today. It has the main advantage that the bicycle can be locked in different ways. Furthermore it can be placed alongside walks without taking too much space (see image 6).

Image 6: A U Rack

Source: Google image

4.2.2.6 Facilities linked with public transport

Enabling bicycles in public transport gives the possibility to cyclists to make easily long journeys (above 7 km) or to avoid some landscape difficulties. Three types of cycling facilities linked with public transport can be distinguished:

- Convenient infrastructures giving access to public transport stops. For instance, special steps for bicycles. Those ones enable the cyclist to have an access to underground halt without having to carry his bicycle (see image 7).
- Dedicated places for bicycles in tramways. In a tramway or in a subway, those ones can be installed at the end of a vehicle. Mounted bicycle carriers can also be added on buses or taxies (see image 9).
- Finally, covered parking spots enabling a bicycle to be parked for a long period (see image 8).

Image 7: Special steps for bicycles

Source : Copenhagen municipality

Image 9: Mounted bicycle carrier

Source: google image

Image 8: Covered parking spot in a train station

Source : city of Amsterdam

Image 10: Dedicated biking places in a regional express train

Source: SNCF

4.2.3 Bicycle sharing system

The bicycle sharing is a public transport system based on the renting of a bicycle for a short period (from a few minutes to one or two days maximum). This system is made of a street-based rental station network that allows users to hire and return a bicycle. This system provides an easily accessible alternative to motorized travel and allows people to make short trips easily. Moreover, it makes also possible to shift from other forms of transport to bicycles and the other way round.

This kind of bicycle infrastructures sometimes considered as new types of public transport, has known a strong development since its first real enforcement in Copenhagen in 1995. According to the Metro bicycle company[9], about 160 bicycle sharing systems were at work at the end of 2009. Most of them (around 140) were located in Europe. As it is shown in the figure 13, in Europe, bicycle sharing systems were mainly implemented in countries where the use of the bicycle is low, like in Spain, France or Italy where respectively 54, 29 and 24 municipalities are equipped.

In some cities, this system is free of charge (like in Copenhagen). But most of the time, the customer has to pay to rent the bicycle according to the period of time he uses it. This transport service is generally provided by the local authorities in partnership with a private company. Around twenty different companies are present on the world market. Nevertheless two main companies dominate the worldwide market: JCDecaux and Clear channel. Those two companies provide this service to the local authorities in exchange of new free publicity spots. This can be problematic when the publicity provider is not the same from one municipality to another inside the same urban area.

9 Metro bicycle is a North America’s first bicycle sharing consulting company

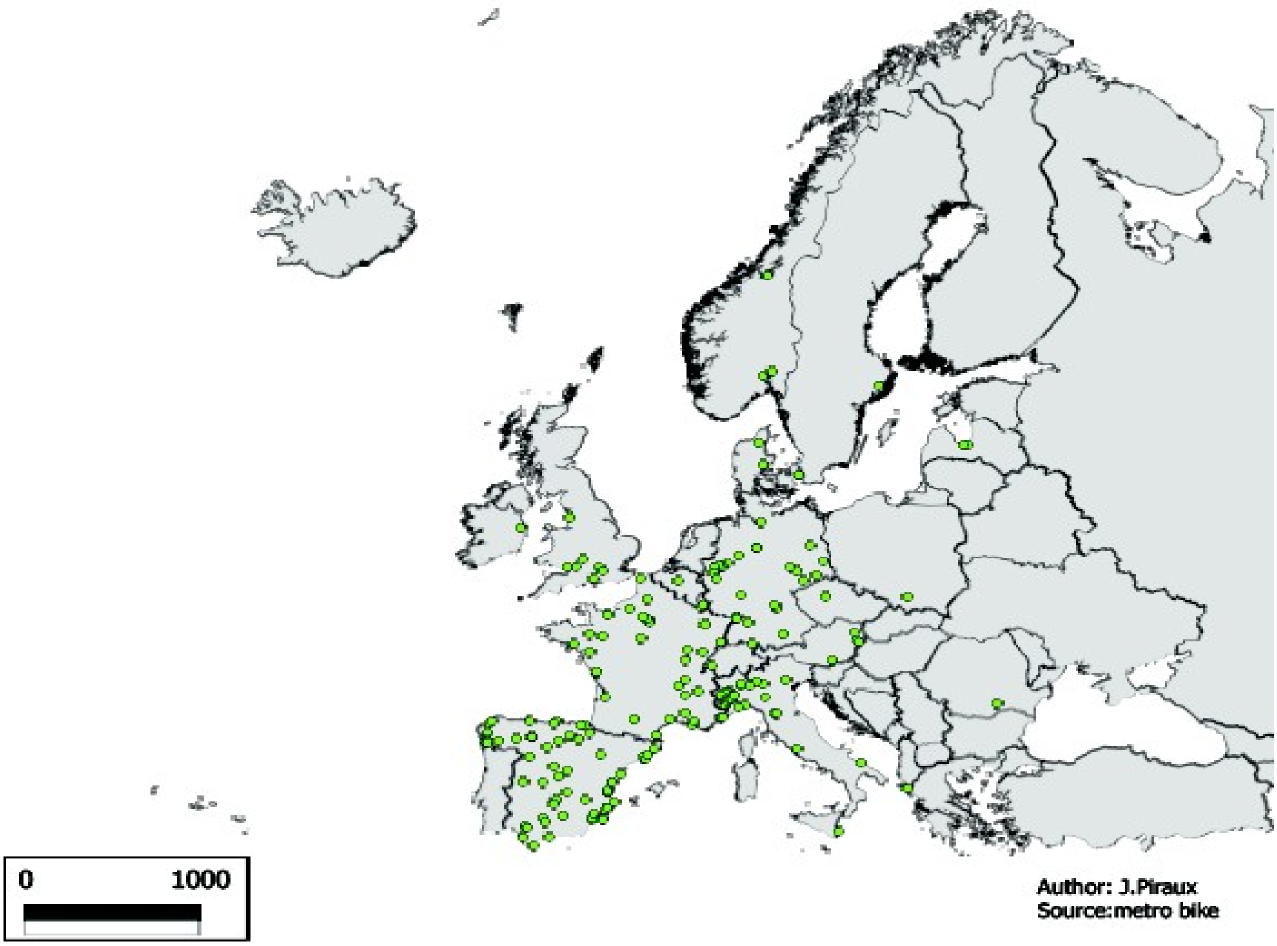

Figure 13: Map of European municipalities providing a bicycle sharing system

As we can see, technical solutions to improve the comfort and the safety of cyclists are numerous. But none of them are universal. They have to fit the characteristics of the majority of cyclists in a giving area and have to be adapted to the local urban environment.

5 The socio-economical conditions

Throughout surveys about transportation habits, several studies tried to find a relationship between cycling and the socio-economical situation of bicyclers ([WITLOX2004],[MOUDON2005],[PARKIN2007],[ZACHARIAS2005],[XING2004]), .Most of them take in account six different factors: age, gender, status and income, vehicle ownership, employment situation and household structure.

5.1 Age

From a broad point of view, it seems that the bicycle use declines with age [MOUDON2005],[ZACHARIAS2005].For example, Wiltox and Tindemans noticed that in Ghent (Belgium), about 20% of the people between 12 and 25 years old daily cycled. This number was reduced to almost 11% for people belonging to the 25-65 age group and even less for those above 65 years old [WITLOX2004].Rietveld and Daniel also showed that the over representations of high school or universities in some cities in the Netherlands increased the bicycle use [RIETVELD2004]. The age circles or the fact that children are not allowed to drive a car are often mentioned as other major explanations ([XING2004],[RIETVELD2004],[HANDY]). Nevertheless as Pucher or Wardman found out, this relationship is more ambiguous for countries where the bicycle is highly used. Indeed, in countries where it is more usual to commute by bicycle, the bicycle use increases slowly with the age (see figure 14). For instance in Germany, people of 65 years and above nearly cycle twice more than people aged between 18 and 25 years (7% versus 12%). It seems in fact that the relationship between the age and the bicycle practices exists but it is unclear whether it is a universal one [PUCHER2010].

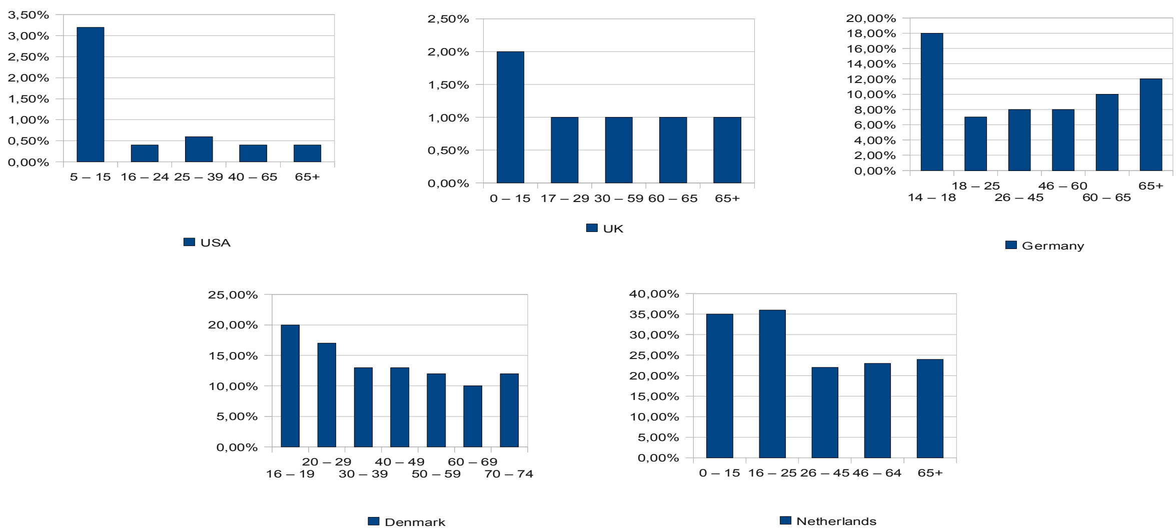

Figure 14: Bicycling share of trips by age group in the Netherlands, Denmark, Germany, UK and USA (2000-2002)

Source: Pucher 2010

5.2 Gender

Many studies found out that females are less likely to cycle than men [VANHOUT2008]. In Brussels, for instance, 68.79% of cyclists are male [OBSERVATOIR 2009]. Different elements can explain this. As we already mentioned it, women accept to cover a less important distance than men: 6.6 kilometres according to McDonald [McDONALD2007]. Furthermore, a lot of women have to take care of small children not able to bicycle in an intense urban traffic. Finally, it seems that women perceives car traffic as more dangerous compared to men and are less confident to use their bicycle in a crowded traffic situation. According to a survey made by the Australian Associated Motor Insurers, 46% of women don't cycle because they perceive car drivers as too aggressive [GARRARD2008].

Nevertheless, this general observation seems not to be true everywhere. A few studies made in countries in which bicycling is popular (the Netherlands, the north part of Belgium) found that men did not necessary cycle more than women [DE GEUS2007]. According to a study made in Ghent (Belgium) in 2004, Wiltox and Tinderman even found out that women between 25 and 65 years old cycled more than men of the same age group [WITLOX2004].

5.3 Status and income

The literature is quite divided about the impact of the income on the bicycle level. At an aggregate level it often appears that the status and income are negatively correlated to the bicycle use. However, this relationship is less clear at an urban level and when the utilitarian bicycle is only considered in the case study ([MOUDON2005],[STINSON2003],[PARKIN2007]). It can be possible that this non-defined relation stems from two potential consequences of having a higher income. On the one hand, having a higher income allows somebody to have easy access to good expensive bicycles, which in turn increases the bicycle use. Pucher pointed out that this is particularly true in countries in which people do not usually own a bicycle [PUCHER2008]. But on the other hand, having a higher income enables a person to spend more money on other transportation modes [HEINEN2009].

The relationship between the cycle rate and the employment status is even less clear. Some authors found out a significant relationship. For instance Parkin pointed out that in England and Wales people with a high education level cycled less than the average of the population, whereas unemployed people, part-time workers commuted by bicycle more frequently [PARKIN2007].Rietveld also found that in the Netherlands, people with the highest income and a high employment status cycled less than the average even if the Netherlands is a bicycle friendly country [RIETVELD2001]. But some other studies found exactly opposite results or no real correlation between the employment status and the bicycle use ([MOUDON2005], [HEINEN2009]). For example, Winter, in a survey made in 53 Canadian cities, observed that people with a post secondary degree have 20% more chances to cycle than people with less than a secondary certificate [WINTER2007].

5.4 Car ownership and transportation cost

Conversely to the previous criterion, most of the studies concerning the bicycle use agree that the car ownership has a strong negative effect on the cycling rate ([CERVERO2003],[PARKIN2007], [VANHOUT2008]). In a study made in Portland (USA), Dill showed that households with less than one car per adult had at least 10% more probability to cycle to go to work [DILL2006]. To this study, Pucher added that there is a strong correlation between the bicycle use and petrol prices. Furthermore, he added that compared to the USA, the higher cost of owning and maintaining a car in Canada explains the higher rate of bicycle commuters in this country [PUCHER2008].

Other authors also found out other cost-related effects ([RODRIGUEZ2004],[WARDMAN2007]). According to Bergström, most of the daily cyclists choose this transport mode because it is the cheaper one [BERGSTROM2003]. Wardman et al noticed that in the UK, if people would be paid two pounds to cycle to work the cycle level would double. But he also emphasises that the price of the public transport is a big deterrent and may reduce the bicycle use [WARDMAN2007].

5.5 Household structure

A clear relation between the bicycle use and the presence of children has been found in the literature. According to Rietveld or Moudon students and individuals without children are more likely to cycle. But once more, the tendency is less strong in countries where the bicycle use is higher. In those countries, people developed technical solutions to overcome the problem of caring small children. In Copenhagen, for instance, 25% of all families with two children have a cargo bicycle (see image 11) [COPENHAGEN2008].

We can conclude from this last section that socio-economical factors influence the propensity of different groups of people to cycle within a city or a country, but play a secondary role when it comes to consider the propensity to cycle of citizens of a city or a country as a whole. In our opinion, socio-economical factors play an indirect role by influencing our perception of the urban environment, the social values or our psychocultural behaviour (see next section).

Image 11: A cargo bicycle

Source:Carrier bicycle.com

6 The psycho-cultural behaviour

The last section showed that the relationship between socio economical factors and transport modes choice remains unclear or can even be contradictory. A reason for this uncertainty lies in the existence of social norms concerning attitudes and habits when people come to consider their transport mode. If a person is used to a certain form of transport, he has the tendency not to take into account other options. The existence of these habits, social norms and attitudes can reflect the culture that a group or a society has about a particular transport mode.

6.1 Attitude and social norms

The way how people perceive the bicycle influences its use [HEINEN2009],[VANHOUT2008], [GATERSLEBEN2007],[PARKIN2007][PARKIN2007]). Two main factors can affect this perception: the attitude (how someone personally evaluates the outcome of cycling) and the social norms (how the social norms given by a society or a smaller group affect the propensity to cycle). In a study made in England, Gatersleben and Appletion found that the attitude to cycling was correlated with the likelihood to cycling and the awareness of the benefits to cycle . They distinguished five types of attitudes toward cycling:

- Pre-contemplation: people who have never contemplated cycling believe they would feel strange on a bicycle and that others would also perceive it as strange if they cycled. Cycling is something that other people do like young and fit men.
- Contemplation: people who never tried to commute by bicycle but seem to be more aware of the benefits of cycling. Nevertheless they don't commute by bicycle because they believe that the local environment is not appropriate (lack of cycle lanes, hills, weather…).
- Prepared for action: people who have the intention to cycle soon. They perceive slightly less environmental barriers, but have more personal barriers such as work and family commitments.
- Action: people who have just started to cycle on a regular basis. Generally those people overcross personal barriers but environmental barriers still remain important enough not to cycle every day.
- Maintenance: people who have been cycling for more than six months on a regular basis.

Those people overcross the environmental and personal barriers and consider the bicycle as the best option to commute from their house to their working place.[GATERSLEBEN2007]

The relation between social norms and the propensity to cycle is less clear. However, de Geus or Bruijn through studies made in the north of Belgium noticed that people cycling with a partner or working in a social environment where cycle is seen positively, had more probability to cycle every day. De Geus also added that there is a link between the economical and ecological awareness of the social environment [DE GEUS2009].

6.2 The habits

Taking into account only social norms and attitude would be based on the assumption that decisions are made according to rational choices to follow our own social norms or predefined attitude. But the existence of habits put this hypothesis into question [HEINEN2009]. Verplanken or de Geus showed in two different studies that if habits already existed, people didn't always consider all the information about their transport mode choice, [DE GEUS2009], [VERPLANKEN1997].Dill and Voros also showed that cycling as a child increased the likelihood of cycling as an adult and therefore increased the possibility that an adult would consider the bicycle as a transportation option.

Of course the existence of habits is directly correlated with the two previous points. Nevertheless, it also depends on the cycling experience. Indeed the experience and the habit will make the cyclist more confident about his capacity to cycle in different conditions. Through an internet survey made in the USA, Stinson and Bath pointed out that daily cyclists had totally different needs. In general experienced cyclists are far more sensitive to factors related to the time and cycling comfort but are less sensitive to safety issues. While inexperienced cyclists have the tendency to overemphasize the distance to work, the risk of theft and the potential road dangers due to the automobiles as well as the lack of cycle roads. But on the other hand, travel time and delays are less important for non experimented cyclists [STINSON2003].

Breaking habits is a long process that takes a lot of effort in terms of education and promotion. Anyway, where does this commuting habit come from? In a historical study comparing 8 European cities, de la Bruheze showed that after a first growth between 1920 and 1950, the bicycle use declined until 1970. Then it remained stable or even rose again until 2000. The general decrease of the bicycle use for 25 years after the Second World War can be explained by the overall expansion of the car use [HORVATH2006]. But it can be observed that the decline was less important in cities where the bicycle use is the strongest nowadays (like in Amsterdam or Copenhagen) . It can also be noticed that a high bicycle use during the 1920's and the 1930's is not necessary correlated with a high use today. For instance, Antwerp had a high bicycle share around 1920 but has one of the lowest bicycle shares nowadays. Conversely, today Copenhagen has one of the highest bicycle shares but had a relative low bicycle use in the 1920's (see figure 15) [BRUHEZE1996].

Those last few examples show that transport choices can change over the time. How can this phenomenon be explained?

Habits, but also attitudes and norms in transport mode choice are also largely influenced by another factor: the transport policy. Indeed this last criterion can explain the decline of the bicycle practice after the Second World War but also why it substantially re-increas in some cities after the oil crisis of the beginning of the 1970's. Moreover, it can also be argued that transport policies are the image of norms, attitudes and habits of a society. Of course, policies measures also reflect the importance given by a society to a certain problem and somehow are the image of habits, attitude and norms [ZUKS2003]. How transport policy can influence the propensity to cycle? This point will be developed in the next point

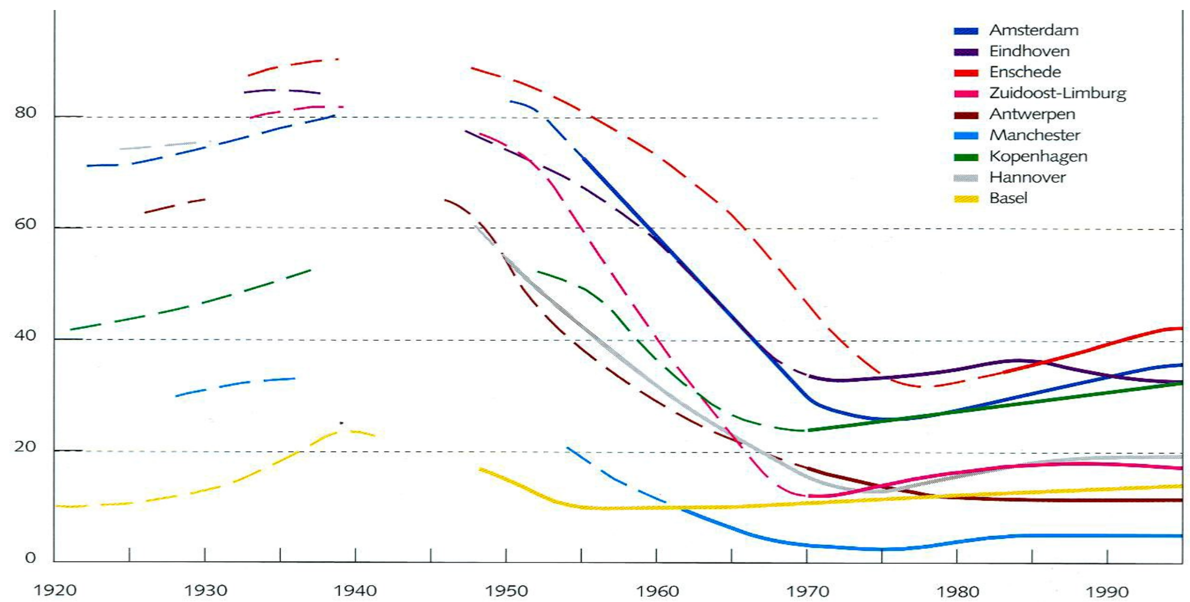

Figure 15: Evolution of the bicycle use in night European Cities
Source: Bruhèze 1996

6.3 The bicycle policy

According to results found in the literature, the policy in favour of the bicycle works best when push and pull measures are taken in order to increase the bicycle competitiveness [VANHOUT2008]. To achieve a significant increase in the bicycle's share of the modal split, Zuks defined five axes of political actions: implementing and improving the bicycle infrastructure, promoting cycling through publicity campaign, improving the cycling safety, integrating the bicycle in mobility and land use plans and finally restricting the car use. In the next sub points, the principal pro bicycle policies will be reviewed.

6.3.1 Implementing and improving bicycle infrastructures

As we have already mentioned it, a good cycle network will improve the subjective safety and decrease the journey time. In order to meet those targets, a first step would be to plan and improve a coherent cycling network providing a direct connection to the main points of interest in the city (centre, central business district, universities…).Coherence also means that the network has to be continuous and the design has to be similar everywhere in order to not confuse the users. Furthermore, the network has to be designed in order to minimise travel time by giving the priority to cyclists and/or by providing them short cuts via false one way street for example [ZUKS2003].

A second step would be to provide a safe bicycle infrastructure by adapting it to the importance of the motorised traffic. The Danish road directorate estimates that less than 30 kph and 5000 motor vehicle bicyclers can be mixed with the local traffic. Beyond this limit, off road infrastructures have to be implemented (see graph 16). The design of intersections has also to be adapted to the local situation to avoid crash.[10] [JENSEN2002].

Thirdly, in order to improve the comfort of the cyclist, planners have also to take into account two major elements of the physical environment like the slope (make it as short as possible). Furthermore, the road surface is important as well. Rietveld found out that the quality of the road surface was correlated with the degree of satisfaction of cyclist policies in Dutch municipalities [RIETVELD2004].

Finally, it can be pointed out that providing secured parking closely located to main destination would decrease the risk of theft and the feeling of insecurity.

10 For more detail see thee chapter: cycle way, cycle path and cycle lane

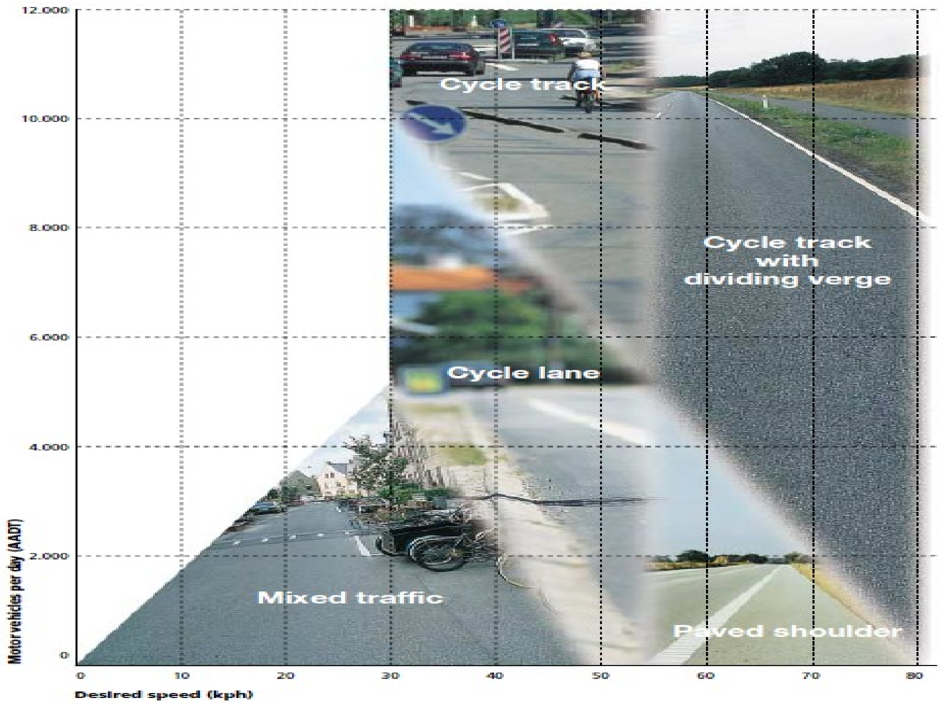

Figure 16: Example of separation principle according to the speed limit and the importance of the motorized traffic

Source: Jensen 2002

6.3.2 Promoting cycling

The provision of infrastructure is insufficient to achieve a substantial shift to cycling [ZUKS2003]. Hulsmann stated that a bicycle friendly climate is essential for the acceptance of the bicycle by the local inhabitants [HULSMAN1997]. A positive biking climate can be implemented by good communication policies emphasizing the social, economical and environmental benefits of cycling. Those ones can be set up through the media, the educational system, biking lobby groups or biking centres. Nevertheless, promotion campaigns should also aim to make other road users aware of cyclists' needs and behaviour in order to remind people that the bicycle is a serious form of transport.

Finally, the local authorities can also promote or support local biking demonstrations, like critical mass[11] days without cars or other biking events.

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11 *"A Critical Mass is a bicycling demonstration typically held on the last Friday of every month in over 300 cities around the world. Those events, originally founded in 1992 in San Francisco, were created with the idea of drawing attention to how unfriendly the city was to cyclists"*
Source: Richard Madden: *London: How cyclists around the world put a spoke in the motorist's wheel. The Daily Telegraph 15 December 2003*

6.3.3 Improving the subjective safety

The bicycle is almost always perceived as one of the riskiest transport modes for commuting because the only real existing protection is a bicycle helmet[12]. Hence, cycling policies have to provide a combination of measures to improve the subjective safety. As we have already seen it, the subjective safety largely depends on the cyclist's experience. Therefore a good bicycle education is important and has to include handling bicycle aspects, road sense and road rules. A special attention is required for children. Indeed, children have problems to understand signs and signals, judge car speed and anticipate manoeuvres. The subjective safety of young cyclists can be improved through the implementation of cycling courses in the scholar program. Another option consists in the implementation of on roads awareness campaigns near by school.

Finally, the driver's education is important too because as the presence of cars makes cycling unsafe, motorists need to be aware of the right, needs and habits of cyclists [HULSMAN1997].

6.3.4 Integrating the bicycle in mobility and land use plans

Recognizing the bicycle as a true commuting transport mode in the mobility and land use plans is a strong positive signal that can be given by the public authorities.

It also enables to develop synergies with public transport. Those synergies are really important to overcome the car dominance. The combination of the bicycle with public transport has two main advantages. First it provides to the cyclist an alternative to make long distance trips or avoid some landscape difficulties (like hills). Besides, bicycles increase the catchment area around transit station from about 7 square kilometres [ZUKS2003]. Nevertheless, the complementarities between those two transport modes need to be highlighted by providing convenient bicycle accesses at public transport stops, allowing people to take their bicycle on board and by providing safety parking spots [LITMAN2010].

Taking into account the bicycle in land use plans can also be beneficial. Indeed the re-establishment of high density areas through a policy of reurbanisation can reduce distances and therefore make both the bicycle and public transport more attractive. This can be done by using available land within the city, by giving incentive to live close to the city centre, by discouraging land use segregation and by strengthening the importance of local centres of activities instead of important regional centres.

12 A bicycle helmet is the only protection that can really save a cyclist from dying in case of important crash

6.3.5 Restricting the car use

Restricting the car use is one of the most important ways to increase the bicycle competitiveness [VANHOUT2008]. According to Tolley, the restriction of the car use “*needs to be part of a holistic policy that encourages alternative modes of transport and spatial arrangements conductive to their use”* [TOLLEY1997].

Three main tools can be used to restraint the car use: lowering the speed limits, increasing the car use cost and reducing the space available for automobiles.

A speed reduction can easily be realised by implementing traffic calming measures[13] or by lowering speed limits in central or residential areas. Nevertheless, it has to be noticed that these kinds of measures will not reduce the motorized traffic in areas where the speed is already low because of cars overcrowding problems.

A reduction of the space devoted to cars can be achieved by restricting the accessibility of motorised traffic in some areas, reducing the car parking space and confining the number of street lanes on the major axes [JENSEN2002].

Among the car restrictive policies, the increase of the car use cost is maybe the strongest policy tool and has the strongest positive influence on bicycle use [VERVERS2006]. It is possible to increase the car use cost directly by increasing the motor vehicles taxation or indirectly by increasing parking fees or gas prices[14].

Nevertheless we have to be aware that these kinds of policies are unpopular, represent an important political risk and can't be easily applied in cities where the bicycle use is low.

To conclude this, it can be said that most of the policies developed in this last section are in fact related to the different factors influencing the propensity to cycle. It means that the bicycle use can be increased everywhere. Nevertheless this increase will largely depend on the policy measures taken in certain places by local politicians. It has also to be pointed out that those policies reflect the importance of the bicycle for a giving community and therefore can reflect their psycho-cultural behaviour.

13 See chapter *Cycle roads and biking facilities*

14 See chapter: *The socio-economical conditions*

7 Conclusion

Through theoretical and empirical studies, the review of the literature showed that factors influencing the propensity to cycle are numerous and varied. But it is still unclear which factors play a key role because most of the factors examined in the previous pages are connected factors, interacting with each others and playing a more or less important role according to the local context.

But some evidence comes out of the literature:

1. The topography seems to be the most important physical factor influencing the use of the bicycle.
2. By playing on the time, the comfort and the safety of a journey by bicycle, the characteristics of the urban environment play an important but indirect role in the decision to cycle.
3. The relation between socio-economical factors and the propensity to cycle are not really clear at a large scale.
4. There is a link between commuting by bicycle, social norms, attitude and habits which come from the history and the policies of the city or country studied.

Practical case studies: Brussels, Copenhagen and Vienna

After a large overview of the literature in the previous part, some of the concepts we have developed will now be more deeply studied. In the framework of this work, it would be impossible to study all the factors influencing the propensity to cycle. Therefore, the research of this study will only focus on elements influencing the bicycle use at a “city scale” in three European cities: Brussels,Copenhagen and Vienna.

The second part will be structured as follow. A first introductory chapter will describe the actual mobility situation in the three cities, the general methodology followed in this report as well as the source used. Then each of the factors chosen will be studied through a systematic comparison between the three cities. Finally the last chapter will summarize the results and discuss how each factor has the ability to influence the propensity to cycle in the case of each study and in a more general context.

1 Introduction

1.1 The bicycle situation in the three cities

Different reasons led us to choose those three cities. First, the bicycle use has increased in those cities over the last 10 years. As it can be seen on the figure 17, this evolution was fast in the case of Copenhagen or relatively slower elsewhere but follows more or less the same regular progression. Nowadays at least 5 % of the people use the bicycle to commute from home to their working place in the three case studies.

Secondly, the local governments have included the bicycle as a utilitarian mode of transport in their mobility plan since the beginning of the 21st century. In addition, different measures have been planned to improve the quality of the bicycle conditions in order to increase the journey made by bicycle.

Thirdly, the three towns can be ranged in the same size category. Distances between the city centres to the first periphery are similar (from maximum 9 to 13 km) and the population density is comparable (between 4000 and 6500 inhabitant/km² for more or less 1 million to 1.6 inhabitants). But before discussing about methodological issues, the following subsections will first introduce some facts and figures about the mobility in those three cities.

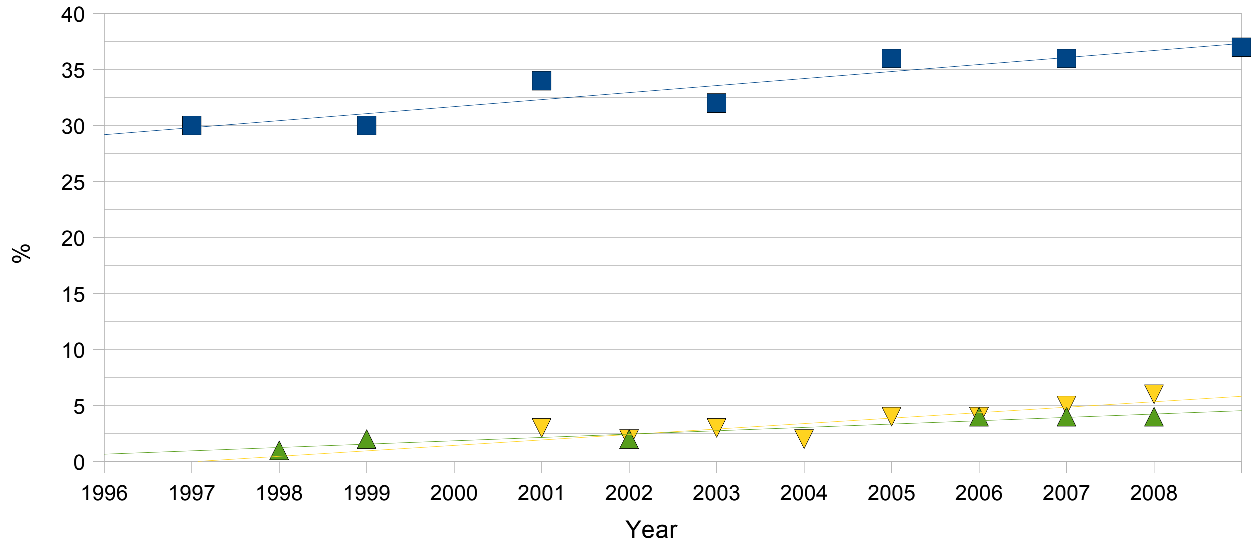

Figure 17: Bicycle share into the journey modal split

In blue:Copenhagen, in yellow:Vienna, in green:Brussels.

Source :Municipalities of Copenhagen and Vienna, Observatoire du vélo en region de Bruxelles-capital

1.1.1 The Brussels region

Located in the centre of Belgium, Brussels is divided into 19 different municipalities, has an extent of 164 km², a population of 1.06 millions of people and a density of 6500 inhabitants per square kilometre (see map 1 in the appendix). From the city centre to the boundary of the region, the maximum crow flies distance is 9 kilometres. Moreover, according to the last mobility survey made in 1999,70% of the journeys are made within 7.5 km [MOBEL2001]. The same study also showed that 56,6 % of the trips were made by car, 13.4% by public transport and 1.7% by bicycle. The high level of the motorised journey can be partly explained by the high number of commuters. In 2009, They represented 24% of all journeys made in Brussels [BYPAD2010]. Nevertheless, since 1999 the situation has changed. Between 1998 and 2009, the bicycle observatory of the Brussels region observed a constant increase of the number of cyclists, around 13% each year [OBSERVATOIR 2009]. In 2009, between 8 and 9 AM, 4500 cyclists have been observed on average (see figure 18). Nevertheless, inside Brussels, the bicycle use is not the same everywhere. Indeed, more cyclists have been observed inside the Pentagon (the historical town) and around the European Quarter than in the West or the South of the city (see map the red point on the 2 of the appendix). For instance, 15 times more cyclists have been observed in Merode (European Quarter) than at the West Station. Finally, the bicycle observatory estimated that the bicycle rate into the modal split was around 4%

in 2009 and could reach 5% in 2010. If we take into account that the number of passengers in the public transport has increased to reach 40 % [COURTOIS2008], we could assume that the percentage of trips made by car is nowadays around 50% [MONITEUR2009].

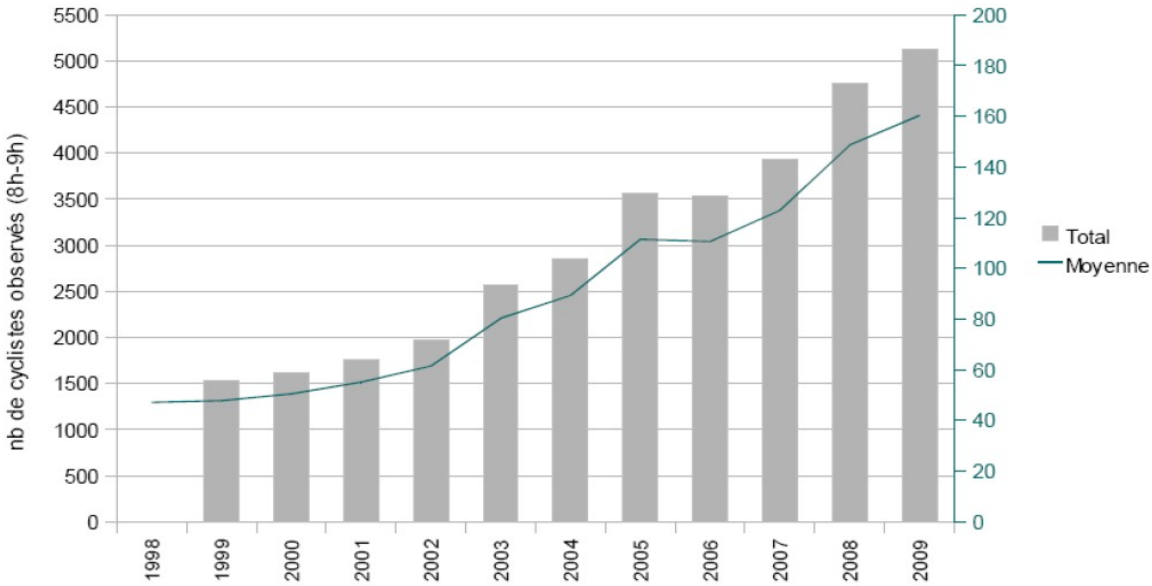

Figure 18: Evolution of the average number of cyclists in Brussels between 8 and 9 AM

Source: Observation du vélo en région de Bruxelles-Capital, rapport 2009

1.1.2 Copenhagen and the surrounding municipalities

Due to a particular urban planning[15], Copenhagen has a broad extent of 2561 km².This area is too wide to be studied in details in the framework of this master thesis. Therefore we decided to restrict our study to the municipality of Copenhagen and the 10 municipalities located at a maximum of 10 km from the city centre (see map 3 in the appendix). This urban region covers 248 km² and 0.98 million of people are living within it.

Within this area, people commute around 12 km per day in total[16]. In the municipality of Copenhagen, 37% of the people commute every day by bicycle [COPENHAGEN2008]. In other words, around 150,000 people cycle to work every morning. People using car or public transportPossible consequences for cyclists

If we follow the previous result obtained by Lidman, Cervero or Pivo[17], it can be pointed out from the last descriptions of the urban fabric that the importance of the continuous dense urban fabric in Brussels and Vienna clearly advantages the practice of the bicycle. Indeed such kind of urban

15 See chapter The influence of the urban fabric
16 According to the national Danish institute
17 See chapter the Build environment in the first part of this work

settlement has the main advantage to have a mixed land use and be highly populated. These characteristics have the advantage to reduce journey distances. In the Brussels case, a good complementarity between the central business district and the rest of the continuous urban fabric can even be an important advantage for cyclists living in the central part of the city.

Nevertheless, the quick decrease of the urban density in Brussels and less importantly in Vienna could be a disadvantage for bicycle users coming from outside of the continuous urban fabric.

The urban fabric of Copenhagen doesn't present such disadvantage. Indeed the large extent of the dense discontinuous urban fabric combined mix with non residential units all over the city can be a factor favourable to cyclists by reducing the journey distance between home and the working place or the local shops.

1.2 Synthesis

Paradoxically, Copenhagen seems to have the most favourable urban fabric even if density of the streets network as well as the intensity of the urban structure are comparatively less developed than in the two other cities. To overcome that weakness, Copenhagen has developed since the end of the Second World War, an original land use plan concentrating urban settlement alongside some axes of development. This specificity made the couple train and bicycle able to compete with the car. Secondly, the relative high density of residential areas combined with non residential land use in the municipalities just surrounding the town of Copenhagen increases the chance to make short journeys. Therefore it makes the bicycle more attractive. Furthermore, one can assume that the chance for a local inhabitant to use the bicycle is higher in that kinds of land use settlements.

Brussels and Vienna present a more classical European urban shape. They are good examples of industrialized cities shape according to the dominant transport mode if we follow the urban model found by Schaeffer and Sclar [SCHAEFFER1975]. The largeness of their continuous urban fabric coupled with a dense road network is able to offer a large range of possibilities to reduce journey distances and/or to develop alternative routes where the bicycle is a privileged transport mode. But the quick decrease of the urban fabric linked with a mono-functionality of the land use in some cases clearly disadvantages the use the bicycle compared to the car in the peripheral part of those cities. represent respectively 31% and 28% of the modal split in 2008[COPENHAGEN2008]. But here also commuters from the surrounding municipalities have an influence on the modal split. If we consider only the inhabitants of the Copenhagen municipality, the cycling share reaches 55% [COPENHAGEN2008].

Within the municipality of Copenhagen, most of the cyclists use main axes to reach the city centre from the periphery. We can also add that cyclists coming from the North and the North West are twice more than cyclists coming from the peninsula of Amager or from the South West of the city(see map 4 in the appendix) .

1.2.1 The city of Vienna

Vienna is situated in the East of Austria and is divided in 23 different districts (see map 5 in the Appendix). With an extent of 414 km² and a population of 1.68 millions of inhabitants, Vienna is the largest urban area studied in this work. Nevertheless if we only consider the wideness of the urban fabric within the boundaries of the city, Vienna has an extent of 252 km²[18] which makes it more comparable to the two other cities studied. Moreover, the maximum distance from the city centre to the limits of the city is 13 km. It can explain why the average path length of citizens in Vienna is 5.4 km . Nevertheless, the cycling share is 5%. People in Vienna rather prefer using public transport (35%), the car (32%) or going on foot (27%)[RUSCH2009].

Within Vienna, cyclists are mainly concentrated around the historical city centre, between the Gürtel and the Ringstrasse which are mostly in the northern part. We can also notice that Danau city in the North East of Vienna attracts cyclists as well. Outside those two areas, the bicycle traffic is weaker and represents 6.5 % of the bicycle traffic[19].

Even if the different figures above are not directly comparable, the size of the three towns, in term of urban extension, makes them a possible place to cycle. Nevertheless the three cities present different profile in terms of mobility. Brussels is really a car dominated city whereas Copenhagen and Vienna have a more balanced modal split between the different transport modes. Finally, we can point out that bicyclers are more present in some part of the cities.

1.3 General Methodology

As we pointed it out in the conclusion of the first part of this paper, a lot of different factors can influence the propensity to cycle. Studying all of them in the framework of this work would be impossible. Therefore, we selected some factors. This selection was made according to the impact

18 Own calculation base on data provided by the GMES atlas

19 Own calculation base on data of Sniker and Partner verkehrsplanung

of the bicycle found in results published in the literature (see previous part), their relevance at a city scale, the time needed to analyse them and the data available. The factors studied will be the topography, the urban fabric the economical accessibility to different transport mode and finally, the development of the bicycle infrastructures. As the different elements considered here are not directly related to each other, a specific methodology will be defined at the beginning of each chapter. But their study will be made both through qualitative description and quantitative analysis of variables. In order to have a geographical overview, most of the analysis will be made via a geographical information system (GIS). Finally to summarize the different results, the main variables will be standardized and a final "cyclability ranking" will be made to explain the work.

1.4 Data and sources

The three case studies were based on data available in the literature or provided by Eurostat, the European Environmental Agency, the NASA, national statistical offices and the cities themselves. Nevertheless, as we don't have any direct access to some geographical data, a non usual type of source will be used: *OpenStreetmap*.

Created in 2004, OpenStreetMap (OSM) *is a non-commercial, privately owned collaborative project to create a free editable map of the world*[20]. This project is supported by private companies like Google or Yahoo as well as some universities like the University of Oxford or the University College in London.

OSM is mainly inspired by the Wikipedia concept. Every user can contribute to the creation of new maps. Basically each map is based on governmental sources (like the European Corine Land Cover database, Lansat 7 and the Yahoo satellite images or GPS surveys). But users can also add other information according to their observations on a specific field. Like, streets names, one way street, shops, cycle road, public transport, stops ….Those informations are the main interest of OSM for this work.

Like on Wikipedia, the accuracy of the information can be doubtful. But as the creators of the project noticed it:

"*The essence of a wiki-style process is that all users have a stake in having accurate data. If one person puts in inaccurate data, maliciously or accidentally, the other 99.9% of people can check it, fix it, or get rid of it. The vast majority of good-intentioned participants can automatically correct for the few bad apples*[19]".

20 *http://en.wikipedia.org/wiki/OpenStreetMap*

Furthermore, for important areas (like cities), some users created special internet web pages on which the coverage and the exactness of different information provided by the map can be checked. For instance, the creators of the Vienna maps assume that 99.5 % of the streets are digitalized into the OSM database. Nevertheless as the authors of the OSM notice it, the best way to check the accuracy of a map is to compare it with other sources. Therefore we decided to compare the open street maps data of the three cities with satellite images and maps from Google map. We first made a general comparison to see if the general urban structure of the cities was respected. In a second time, we decided to make the same comparison at a smaller scale. As we had the opportunity to live in the three cities taken as case studies, we decided to take the neighbourhood we lived in as cheeking areas to be more accurate. Finally we checked the identity of the users.

The comparison shows that the OSM maps respect the global structure of the cities and are quite similar to the Google maps or even show more local information than this last one. For example tramway lines and different points of interest are directly visible from the OSM maps[21].

Concerning the identity of the users, most of them are anonymous. Nevertheless in the case of Vienna it has to be pointed out that the OSM map is partly maintained by a private company: Compass Group. This firm is an internet publisher providing geomarketing information. It created the first Austrian mapping portal (Plan.at) in 1997.

Those last elements let us think that the OSM is a robust data set sufficient for the needs of our research.

21 The maps 7 of the appendix shows one of the comparison realized for the city of Vienna

2 The topography

Within the literature research, the topography was the only physical element that made a consensus[22]. A hilly landscape negatively influences the bicycle use. In order to evaluate the importance of the hilliness, the topography was analysed through observations made on topographical maps and by measuring the average slope by geographical units. The topographical maps and the slope measures rely on Digital Elevation Models coming from the ASTER GDEM project[23] . The topographical maps were extracted by using the script *r.contour* of the GIS software GRASS. And the slopes were calculated with the scripts, r.slope.aspect and v.rast.stats of the same software.

2.1 Copenhagen

Due to its localisation alongside the cost of the Øresound, Copenhagen is not really bumpy (see maps 8 and 9 in the appendix). With an average altitude of 8 meters above the see level, the peninsula of Amager is the lowest part of Copenhagen. On average, the slope does not go over 2% .The rest of the city is slightly hillier. From the coast to the interior of the land, the altitude slowly increases to reach a maximum 30 meters above the see level in the North West of the city (see maps 8 and 9 in the appendix). Nevertheless, the slopes never reach 4 %. The most “difficult” steepness are located in the North-West of Copenhagen and in the municipalities of Gentofte, Gladsaxe and Herlev (the red circle on the map 8).

2.2 Vienna

Vienna is located at the beginning of the South part of the Vienna Basin. The Western part of the city is bordered by the foothills of the Alps. Those hills present a strong steepness, sometimes above 7 % and are 300 to 400 meters higher than the rest of the city(see maps 10 and 11) . Nevertheless, they are located in the less dense urban area of the town. Moreover, the Vienna Valley divides them into two parts and gives a flatter access to the urban centre. Therefore, this hilly part doesn't constitute a real obstacle to cycle.

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22 See first part section 3. The topography

23 The ASTER GDEM project is a project made by The Ministry of Economy, Trade and Industry of Japan (METI) and the National Aeronautics and Space Administration of the United States (NASA). All the digital Elevation Models have a resolution of 30 m

The difference in altitude in the rest of the city is not so important. From the bottom of the Western hills to the bank of the Danube, the relief decreases slowly and gradually from above 150 m(see map 10 in the appendix). On average the slopes never go over 5% (see map 11 in the appendix). Nevertheless, we can notice that the intervals between isolines in the ten districts are much closer from each other than in other districts located close to the city centre. In this area, some steeps can present a slope of more than 5 % (see the red circle, map 10). They can therefore constitute a real obstacle for cyclists. Finally, the Eastern part is even flatter than the Western part.

2.3 Brussels

Brussels is located on an asymmetric part of the Senne Valley. Due to this topographical characteristic of the relief, Brussels can be divided into two parts, the low Brussels and the high Brussels.

The lowest part is the less hilly area of the city. From the Western periphery to the centre, strong slopes[24] are relatively rare even if the average slope is this area is around 3 to 4 % (see map 13 in the appendix). Moreover, different branches of the Senne river (like the Molembeek) created vale which makes circular roads not always easy to cycle.

The relief of the high Brussels is much more complex and hillier. This part of the city is separate from the city centre by a steep slope toping over 5% nearly everywhere(see red circle, map 12 in the appendix). Moreover, some runnels (like the Malbeek or the Woluwe) cut the Eastern landscape of the city. The basins of those affluents of the Senne River are also characterized by strong slopes. Those two elements make some Brussels neighbourhood on average really sloping, particularly in the Far East or the South of the town. Nevertheless, we can observe that from the North to the South, ridges go all over this part of the Senne Valley. This particularity makes radial journeys flatter in the Western part of Brussels (see map 12 in the appendix).

2.4 What has to be remembered

The three cities present a completely different profile. The topography of Copenhagen as well as the one of Vienna are really adapted to the practice of the bicycle. Conversely, cycling in Brussels is much more difficult because of the hilliness of the topography.

In order to summarize our previous descriptions with one single quantitative data, the average slope for each city was calculated. In order to stick better to the reality, non-urbanized settlements were

24 According to Wilson a strong slope is a declination superior of 5% [WILSON2004]

excluded from the calculation[25]. The result confirms what has been told previously. Copenhagen and Vienna have a similar average slope of around 1.5%, while the average incline of Brussels is much higher, above 4.5%.

25 It meanly concerns the Vienna Forest and the Soigne Forest

3 The urban fabric influence

The literature review has shown that the general urban shape, the street layout and the land use mix had an effect on the journey distance and therefore could influence the propensity to cycle. Those last three elements were studied in details in the following subsections. First the general urban pastern was analysed through observations based on the GMES urban[26] atlas and OSM data (streets and transportation network). Then, the density of the street grids was analysed through the cross roads' density. Finally, the land use mix was studied via observations made on data provided by the GMES atlas. This last one has the advantage that all the different types of land use are referenced into 21 categories identical for all large European cities.

In order to fit better to the urban pastern, all the non urbanized areas were excluded from the analysis.

3.1 The general urban shape

Vienna and Brussels present the same kind of urban development. Both cities were developed around a medieval city centre since the nineteenth century. The result is a radio concentric plan characterized by radial axes going from the city centre to the periphery and concentric boulevards. Those last ones correspond to old pre industrial boundaries of the city, transformed in promenade boulevards and avenues during the second part of the nineteenth century. In Vienna, it namely equates to the Ringstraße and the Gürtel. In Brussels it will correspond to the *petite ceinture* and the *grande ceinture* (see map 14 and 15 in the appendix). Before the advent of the car as a dominant mode of transport, this kind of city shape had the main advantage to allow an easy access to the city centre. Moreover, the collective live was enhanced by the centrality of the historical city centre [VANDERMOTTEN2004]. Nevertheless such urban plan is hardly adaptable to the progress of the urban planning and the motorized traffic [BRUNET1993]. Indeed the centrality effect of the old town centralizes the traffic on the concentric boulevards. Furthermore, compared to a quadratic street grid, the concentric scheme is less advantageous for walkers and cyclists. In fact, if we consider that cyclists try to follow the shortest way available, circular main axes can appear as obstacles that force cyclists to increase their journey distance.

This phenomenon is particularly visible in Brussels where the two main concentric axes (the *grande* and *petite ceinture*) (see map 14 in the appendix) were adapted to the motorized traffic during the

26 The GMES urban atlas is a land use map atlas made by the European Environmental Agency

1950's and the 1960's [HUBERT2008]. Such adaptation of the city to the cars was planned in the late 1940's and the early 1950's through the plan of Henri Hondermarcq, Minister of the Belgian Road Administration. The aim of this plan was to make Belgium the centre of the "*Occident*" and therefore the centre of the future European Union [HONDERMARQ1964]. In this framework, Hondermarcq planned to totally refurbish the main radial and concentric axes in order to increase the car traffic capacity. Only three years were necessary to transform completely the *petite ceinture* in a series of small tunnels, develop or redevelop a part of the *grande ceinture*, build the first step of the motorized ring road in the periphery and enhance the motorized capacity of the main radial axes [HUBERT2008]. According to the sociologist Michel Hubert, the universal exhibition of 1958 in Brussels played an important role in the transfiguration of the main Brussels axes. Those major infrastructural works enabled to transpose inside the city a picture of modernity that the exhibition of 1958 wanted to spread. Therefore, the Expo 1958[27] appeared for politicians of that time to be a deadline and accelerated the political decisional process. Furthermore, the celerity of the project didn't give enough time to the civil society to react against this important infrastructural work . After 1958, the transformation of the radial and circular principal roads slowly continued until the 1970's and even in some cases during the 1980's (Hall gate tunnel and Leopold II tunnel). Nowadays, the first circular belt around the historical city centre is made of height different small tunnels allowing cars to cross the Eastern part of the belt without being stopped by any crossroads or any traffic lights (see example image 12). Moreover, the *petite ceinture* is directly connected via the Belliard tunnel to the North Eastern part of the external motorized ring road (see map 14 in the appendix). Furthermore, if we look at the pastern of the Eastern part of the *petite ceinture*, we can notice that pedestrians and cyclists are relegated on the external part of the boulevards. A clean and continuous cycle way or cycle path is even not available alongside the road even if the belt is 60 to 70 m large [DEMEY1992].

Image 12: Entrance of a tunnel on the petite ceinture

Source:La libre Belgique

27 Official name of the Exhibition

Because of the credit crisis of the 1970's and the opposition of local inhabitants, the original plan for the *grande ceinture* was not totally executed [HUBERT2008]. Nevertheless, some parts of this second circular belt present the same profile as the first belt. It is namely the case of the Louise Avenue and on the Eastern part, between the Etterbeek barracks and the Montgomery roundabout. If we exclude this two road sections, the rest of the *grande ceinture* is less devoted to the motorized traffic. The different boulevards are divided into two or three car lanes in both ways and a tramway line located in the middle of the road axe (in the South Eastern part) or the external side (in the North-East).

Even if such urban motorways were a sign of modernity 40 years ago, nowadays they symbolize for non motorists the car domination inside the city centre of Brussels [HUBERT2008]. Moreover, it enables a high number of cars to penetrate directly from the periphery into the heart of the city.

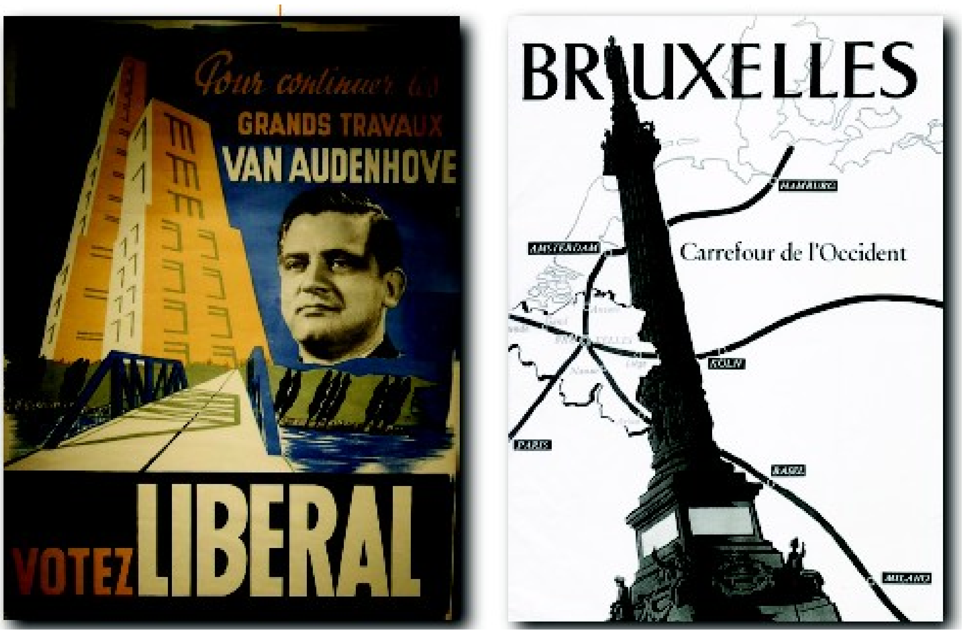


Image 13: The Van Audenhove plan and Brussels crossroad of the Occident

Source: HUBERT2008

Such developments of the urban road system are less visible in Vienna. Even if the Ringstraße and the Gürtell were adapted to the motorized traffic, their general road aspect is still close to the original plans made during the nineteenth century (see image 15 and image below 14). Furthermore, we can notice that on the Ringstraße, there is a specific place for each transport mode. Motorized vehicles only occupy two or three lines in the middle of the roads (see image 16). The Gürtel on the other hand, has a similar profile to the *second ceinture*. Like in Brussels, this important concentric road around the city centre can appear as an infrastructural barrier to walkers and cyclists. Nevertheless, this barrier effect would be less important than in Brussels. Indeed, if we exclude the Margaretengürtel tunnel, all the motorized traffic is on surface. This regulates and slows down the motorized traffic at each traffic light. If we take into account that the Gürtel is one of the busiest road axes in Europe [VIENNA2009], it demonstrates that the barrier effect is much more due to the importance of the infrastructure dedicated to the motorized traffic. But it has also to be pointed out that motorways located in the South of the city centre end up really close to the centre and therefore give an easy access to central areas for cars coming from the South (see map 15 in the appendix).

Image 15: The Burgring (section of the Wiener Ringstraße) about 1872

Source:Ausstellungskatalog: Blickfänge einer Reise nach Wien - Fotografien 1860-1910 - Aus den Sammlungen des Wien Museums

Image 14: The Burgring Nowadays

Source: google image

Image 16: The Ringstraße, view from a car driver

Source: google image

Copenhagen partially presents the same radio concentric shape. Some main axes (Nore Allé, Østerbogade, and Åboulevard) link the city centre to the first real circular main axe. Nevertheless this last one is located five to seven km from the historical town. In order to compare, the second concentric belt of Brussels or Vienna is situated at a maximum distance of four to five km from the city centre. In fact, the artificial lakes built to defend the city during the middle Ages have never been replaced by a "promenade" boulevard during the nineteenth century or by a four lane city ring during the 1960's (see map 16 in the appendix). Therefore the first concentric main axe is missing in Copenhagen. But the city really differs from the two previous ones at a larger scale. Indeed, instead of being planned in a concentric way, the greater Copenhagen is shaped like a hand with five fingers (see image 17). The authors of this pattern, Peter Bredsdorff and Sten Eiler Rassmussen, had the idea in 1947 to define five axes around which future urban developments would take place [VEJRE2007]. From a first approach, such urban shape can be criticized because it increases the distance between the suburban areas and the city centre. Nevertheless, an analysis of the transport network shows that the regional express train network is based on the fingers of the hand, whereas the highways are built between them (see map 16 in the appendix). This settlement of the transport network of the great Copenhagen makes train stations closer to residential areas than the exits of the suburban motorways. Furthermore, the longitudinal profile of the urban fabric makes collective transport more efficient because the potential users are concentrated alongside the railway. Combined with the train, the bicycle can therefore constitute an easy alternative to the car.

Image 17: The Copenhagen finger plan

Source: Niels Jensen, city of Copenhagen

The overview of the city shapes and the analysis of the principal road structure prove that we are here in front of two different urban pasterns. On the one hand, the special city structure of Copenhagen favours the use of the train to access the city centre. In this context, the bicycle represents a good complementary transport mode between the train stop and the final destination. On the opposite, the transformation of the Brussels concentric boulevards privileges to use the car in order to access the city centre. It thus disadvantages the use of alternative transport modes. Finally, Vienna presents an in-between situation where the main concentric axes allow the use of different transport modes.

3.2 The street network

The street layout influences the journey distance and therefore can advantage the bicycle use. Indeed, a fine grained road network reduces the difference between the distance network and the crow flies distance and therefore may advantage the bicycle use [LITMAN2010]. Qualifying the street layout at the scale of a city is not an easy work and can give unclear results. Therefore, in order to reduce the complexity of the analysis, the road network will be studied through one single variable: the crossroads density. This one offers the advantage to quantify the "smoothness" of the road network.

The street density measures were based on OSM street layer and calculated with the script intersection lines of the GIS software: QGIS. The output was manually cleaned to correct aberrant points and intersections with boulevard roads or roundabouts, which would otherwise be considered as multiple intersections.

The study was made at the postal code scale for Copenhagen, at the municipality scale for Brussels and at the district scale for Vienna. These scales were selected because they represented more or less the same area by unit. It has also to be noticed that the municipality of Brussels was divided into three parts (Brussels centre, Brussels Laeken and Brussels Louise) in order to isolate the historical centre from the rest of the city. To make the comparison easier, a "crossroad density ranking" was also realized (see figure 19).

With an average of 86 crossroads per square kilometre, Vienna has the densest urban grids. Brussels follows at the second place with an average of 74 junctions per square meter and then Copenhagen arrives with a score of 62. In the three cases, the density of the road network proportionally decreases from the distance from the city centre and confirms what has been told in the last section (see maps 17,18,19 in the appendix). The figure 19 (see below) shows in more details that the historical centres of Vienna and Brussels clearly present the densest street grids with respectively 167 and 162 cr/km²[28]Copenhagen's historical town (represented on the map 18 under the name of København V and København N) has around 20 cr/km² less than Brussels.

The same phenomenon can be observed for areas located around the medieval centre. Viennese and Brussels neighbourhoods have a more important "smoothness" road network with values around 100 to 120 cr/km². We can even notice that some central neighbourhoods of Copenhagen have a crossroad density equivalent to some Viennese districts (12, 14, 18) located after the Gürtels boulevards (see map 19 in the appendix).

Nevertheless, this order has not to be followed for the municipalities or district located on the second urban belt. Viennese districts still present on average a more developed road network, but Brussels and Copenhagen municipalities and postal zones present an equivalent crossroads density. (with cr/km² between 60 and 80).

Finally, the figure 19 shows that the geographical areas located on the border of the cities present more or less the same values.

From this analysis, we can point out that the relative high road network densities of Brussels and Vienna city centres can comparatively advantage the bicycle use in those cities. Indeed, this characteristic of the urban density offers the possibility to the cyclists to take the most direct itinerary or avoid the main axes crowded by the motorized traffic. Moreover, it gives the possibility to urban planners to adapt some secondary axes to the bicycle use and therefore create a road network in which the bicycle is the preferred transport mode.

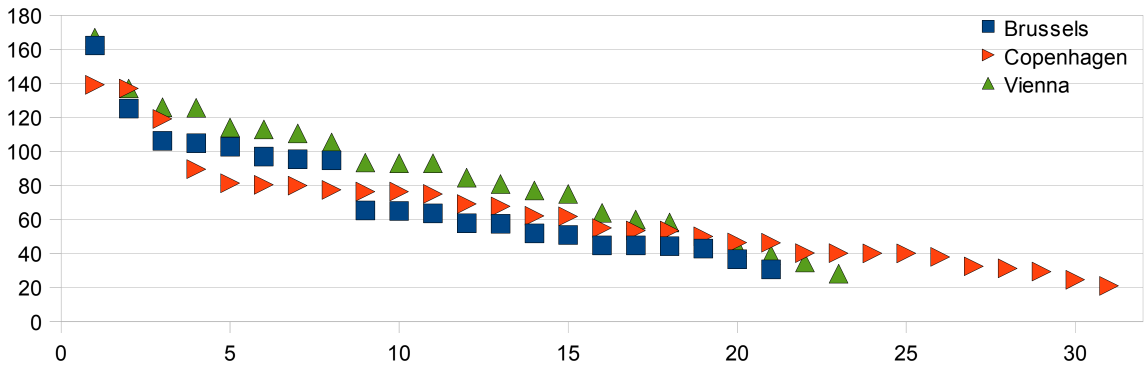


Figure 19: Crossroad density ranking of Brussels, Copenhagen and Vienna

Source: Own calculation

28 cr/km² :crossroad by square kilometres

3.3 The land use mix

According to the literature, a good land use mix can reduce the travel distance and therefore promote the bicycle. In order to evaluate the land use mix, some studies ([WINTER2007] [CERVERO2003] and [CERVERO2002]) commonly used the entropy index as a measure of land use heterogeneity, like the Shannon index: Land use mix = $-\sum(pi)in(pi)/ln(k))$[29]. This measure has the advantage to capture the overall evenness[30] of the distribution of key land uses. Moreover the variables of the Shannon index are all included between 0 and 1. The more the variable is close to one, the more the area considered has a balanced land use. This characteristic makes the index easy to understand. In a first step of this research we calculated the Shannon index on the basis of the data provided by the GMES urban atlas. But we quikly realized that the results were not really relevant, for different reason: first an indexes measuring the heterogeneity of the land use don't give any information about the possible complementarity of the different land use types. Areas with the same overall proportion of uses will receive the same index value, even though some of them have uses in large zones and others have uses in really smaller interspersed units [HESS2008] , even if the Shannon index equally weighs all categories of land use. It does not take into account the fact that an area split between offices and industrial uses does not have the same travel implications than one area split between residential and retail uses. The figure 18 below shows some examples for which the index values are identical but have different transportation implications.

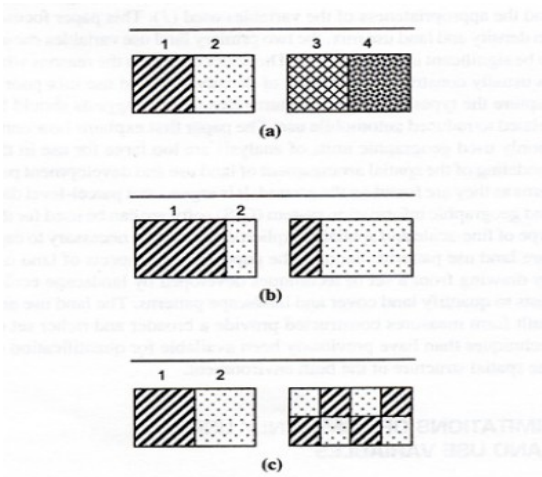


Image 18: Three pairs of land use situation that have different transportation implications but have the same entropy index

Source:Hess2008

29Where pi is the proportion of each type of land use types and k the number of different land uses included in a given area

30 In the context "evenness" has to be understood as the relative abundance or proportion of a type of land use among a given territory.

Within the literature, the debate about the quantification of the land use influence on the bicycle use is still open. Some authors, like Hess, introduced alternatives indicators taking into account:

- The land use types considered as a proxy for trip origin and destinations
- The land use functional complementarities which capture the presence of origins and destinations that are likely to be linked by travel
- The land use spatial complementarities which ensure that functional complementary land uses are considered within adequate proximity for the trip mode.

Unfortunately, it wasn't possible to calculate Hess's indicators with the data available in the GMES atlas. Therefore, this study was limited to a single study of the geographical extension of different types of land use. Nevertheless, the three criteria described above were taken into account in the selection of the categories studied. Four different classes were selected:

- The Continuous Urban Fabric (S.L[31]. > 80%)
- Discontinuous Dense Urban Fabric (S.L.: 50% - 80%)
- Discontinuous Medium Density Urban Fabric (S.L.: 30% - 50%)
- Discontinuous Low Density Urban Fabric (S.L.: 10% - 30%)
- Discontinuous Very Low Density Urban Fabric (S.L. < 10%)
- Industrial, commercial, public, military and private units

It has to be specified that airport and port areas were included in the last categories. Moreover it has to be noticed that by the label *Continuous Urban Fabric*, the GMES atlas defines areas dominated by residential uses but mixed with other types of land use inside a dense urban fabric. On the other hand, by the term *Discontinuous urban Fabric*, the atlas designates areas exclusively occupied by single or multifamily houses. Finally, all the figures below were based on the data provided by the GMES atlas.

3.3.1 The city centre and the surrounding areas

Logically, the three urban centres are mainly occupied by a mix of continuous urban fabric and non residential units (see map 22 in the appendix). In Copenhagen and Vienna, those types of land use are well mixed. Conversely, in Brussels, there is a clear segregation between them. Some neighbourhoods are entirely occupied by working and retail areas whereas others are only occupied by a continuous urban fabric. From a first approach, this mono functionality of the different parts of

31 S.L: sealing land

the city centre can appear as an obstacle to the bicycle use because it can centralise the daily motorized commuting traffic. Nevertheless, the relative small size of the exclusive working and retail areas as well as their central location make them quite complementary to the rest of the continuous urban fabric. For example, if one makes the hypothesis that a cyclist is able to cycle at the average speed of 12 km, the time to reach the historical town from the European quarter will be 5 to 10 minutes. Furthermore, 85% of the continuous urban fabric is reachable within 25 minutes from this neighbourhood (see map 20 in the appendix). In comparison, one of the main office quarters in Vienna (Danau city) is less easy to reach. Indeed, due to its location alongside the Eastern bank of the Danube, Danau city is situated by bicycle at 10 to 15 minutes of the city centre and beyond 25 minutes for a cyclist coming from the Western part of the Gürtel (see map 21 in the appendix).

It has also to be pointed out that Vienna or Brussels have a relative large continuous urban fabric compared to Copenhagen. Indeed, as the graph below shows it, this land use type has more or less the same extent in Brussels and Vienna (respectively 26 km² and 28 km²) but only occupied 19 km² in Copenhagen.

3.3.2 Outside of the continuous urban fabric

Outside of the highly dense urban corps, two urban developments are here in opposition. In the Brussels case, as well as the Viennese case, the urban fabric becomes more and more discontinuous and characterized by suburban settlement (see map 22 in the appendix). This is mainly the case in the South of Brussels or in the Western part of Vienna where houses with a more or less large garden become the norm. In those parts of both cities, suburban land-uses represent more than 50% of the urbanized territory. The satellite views of the "Prince d'Orange" neighbourhood in Brussels and some quarters of the 13 districts in Vienna illustrate well this reality see (see image 19). But according to the figure 1, it can also be mentioned that the suburban phenomenon is much more important in Brussels compared to Vienna if one takes into account the size of the city.

Copenhagen presents a different profile; a large part of the territory (76 km²) is in fact occupied by a discontinuous but dense urban fabric. Moreover, as shown on the map 22, this land use type can be found all over the city. The distance to the city centre seems not to affect the intensity of the urban fabric. Compared to the two other cities, suburban settlements[32] are marginal (see figure 20), they represent all together nearly 9% of the urbanized lands of Copenhagen while they stand for nearly 16% in Brussels and 15% in Vienna. It has also to be noticed that outside of the city centre, non

32 According to the definitions given by the GMES atlas, suburban settlement designates a land with a sealing land (S.L.) under 50%.

residential units are distributed between the discontinuous dense urban fabric settlements and ensure a good land use mix all over the city.

Finally, we can also add that non residential units in Copenhagen as well as in Vienna consume much more place compared to Brussels. (See figure 20 below). But the relative small size of the Brussels region can give a wrong image of the reality. Indeed, due to a border effect, some important non residential areas, like the airport area, are not included in the present analysis.

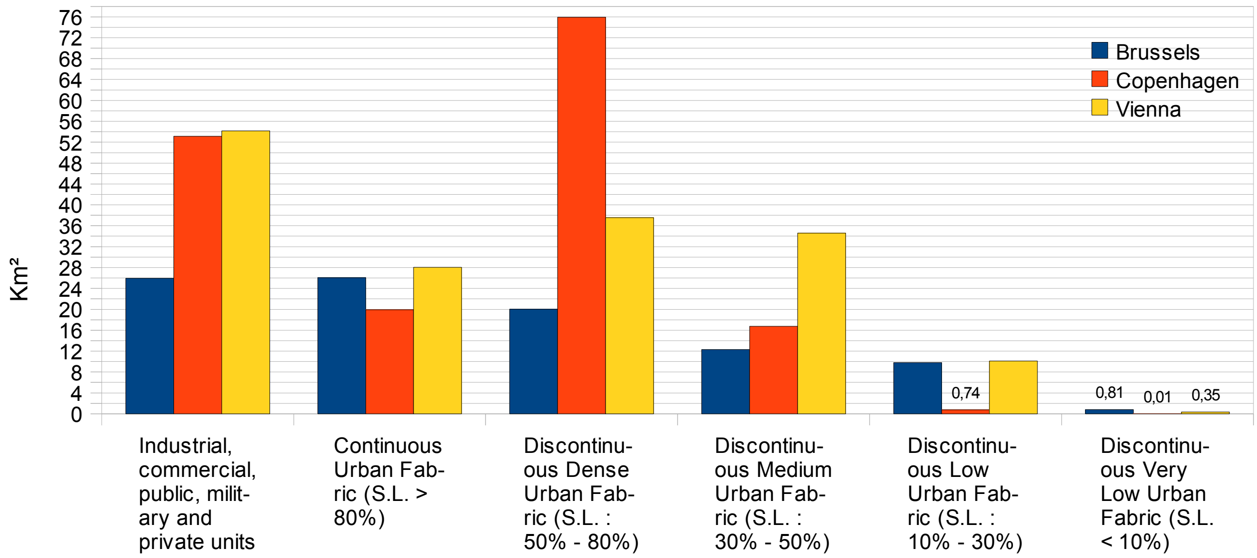


Image 19: Satellite view of a suburban area in Vienna and Brussels

Source: Google earth

3.3.3 Possible consequences for cyclists

If we follow the previous result obtained by Lidman, Cervero or Pivo (see chapter the built environementin the first part), it can be pointed out from the last descriptions of the urban fabric that the importance of the continuous dense urban fabric in Brussels and Vienna clearly advantages the practice of the bicycle. Indeed such kind of urban settlement has the main advantage to have a mixed land use and be highly populated. These characteristics have the advantage to reduce journey distances. In the Brussels case, a good complementarity between the central business district and the rest of the continuous urban fabric can even be an important advantage for cyclists living in the central part of the city.

Nevertheless, the quick decrease of the urban density in Brussels and less importantly in Vienna could be a disadvantage for bicycle users coming from outside of the continuous urban fabric.

The urban fabric of Copenhagen doesn't present such disadvantage. Indeed the large extent of the dense discontinuous urban fabric combined mix with non residential units all over the city can be a factor favourable to cyclists by reducing the journey distance between home and the working place or the local shops.

3.4 Synthesis

Paradoxically, Copenhagen seems to have the most favourable urban fabric even if density of the streets network as well as the intensity of the urban structure are comparatively less developed than in the two other cities. To overcome that weakness, Copenhagen developed since the end of the Second World War, an original land use plan concentrating urban settlement alongside some axes of development. This specificity made the couple train and bicycle able to compete with the car. Secondly, the relative high density of residential areas combined with non residential land use in the municipalities just surrounding the town of Copenhagen increases the chance to make short journeys. Therefore it makes the bicycle more attractive. Furthermore, one can assume that the chance for a local inhabitant to use the bicycle is higher in that kinds of land use settlements.

Brussels and Vienna present a more classical European urban shape. They are good examples of industrialized cities shape according to the dominant transport mode if we follow the urban model found by Schaeffer and Sclar [SCHAEFFER1975]. The largeness of their continuous urban fabric coupled with a dense road network is able to offer a large range of possibilities to reduce journey distances and/or to develop alternative routes where the bicycle is a privileged transport mode. But the quick decrease of the density of the urban fabric linked with a mono-functionality of the land use in some suburban area clearly disadvantages the use the bicycle compared to the car.

4 The economical accessibility to other transport mode

As it was noticed in the first part of this work, the real influence of socio-economical factors on the propensity to cycle still remains unclear. The literature pointed out that individual factors such the age, the social status, the income… could influence the decision to cycle or not. Nevertheless, this influence could be negative or positive according to the context. For example, Parkin and Rietveld proved that a high income was negatively correlated to the bicycle use in England and in the Netherlands ([RIETVELD2004],[PARKIN2007]) whereas Winter et al demonstrated it was the opposite in Canada [WINTER2007]. In fact, socio-economical factors play an indirect role by influencing our perception of the urban environment. Finally, most of the studies, including indicators, work with desegregate data and only consider a limited number of people. The present master thesis works at a city scale and highly focuses on global factors that can influence the decision to cycle every day. Therefore the research will only be focused on the socio-economical factors that influence the propensity to cycle at an aggregate level: the transportation costs.

This cost-related study was made with the hypothesis that the high cost of other transport modes would positively influence the propensity to cycle. Unfortunately, standardized and comparable data about the purchase price and the maintenance cost of a bicycle are not available. Therefore, only two types of transportation costs were considered: the car related cost and the public transport related cost.

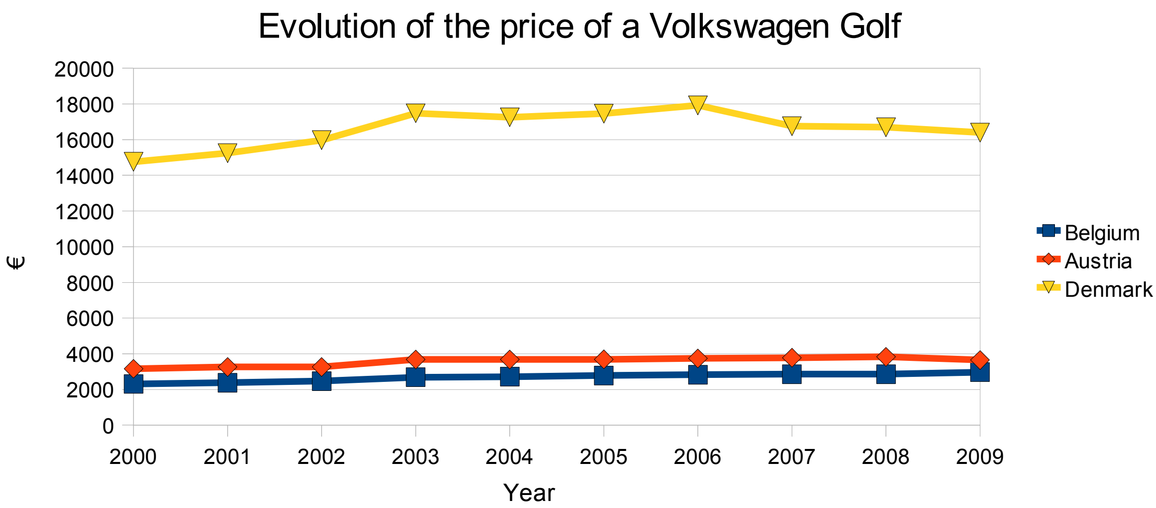
4.1 The car cost

In order to make the analysis comparable from one city to another as well as more concrete, the study was be made for one specific car model: The Volkswagen Golf. Furthermore, four different variables were be analysed: the gasoline, the car purchase including and excluding tax and the yearly road taxes. In a first step, the absolute cost of this car for local inhabitants was compared. Then the car cost in terms of taxes, gasoline cost and purchase cost was calculated on the short-term (one year) and on the middle term (five years), with hypothesis that the owner rides 50,000 km a year, the car consumes five litres per kilometre and the different tax prices stay stable during the period.

To avoid the living cost effect results on the calculation, were finally compare to the average income of a family with two children.

The table bellow that gasoline prices in Brussels and Copenhagen are similar and 0.24-0.26 € cheaper than in Vienna. Considering that the capacity of a Golf gasoline reservoir is 55 litres, it represents a difference of 10€, each time that the car is refuelled. Nevertheless this difference is non-essential if the living cost is taken into account.

The results concerning the purchase cost of a car are much more interesting. According to data provided by the European Commission, Denmark highly taxes the acquisition of a car. In 2009, a Golf cost 11,031€, tax excluded, in Denmark. Tax included, the same car cost 27,431€. It means that the taxation cost (16,400€) for a new Golf was more expensive than the price of the car itself. In the two other cases, the difference between the price tax excluded and tax included was much lower. It amounted to more or less 3,650€ in Austria and a bit less than 3,000€ in Belgium. This high taxation rate is not new. According to the data provided by the European Commission, the taxation cost was around 2,000€ higher three to five years ago.



Source: European Commission -car price report 2000, 20001, 2002, 2003, 2004, 2005, 2006,2007, 2008, 2009, 2010

Figure 21: Evolution of the price of a Volkswagen Golf

The yearly road taxation follows the same trend. Road taxation in Denmark is nearly 8 times higher than in Belgium and 3.6 times higher than in Austria. Moreover, the Danish State added an environmental tax of 455€ for the car model that we considered in this study. In term of taxation, a Golf costs 2015€ per year in Copenhagen. In comparison it costs 203, 81€ in Brussels and 512€ in Vienna (see figure 21). If the gasoline consumption and the purchase of a new Golf are taken into account, it means that this car costs 33,576 € in Copenhagen, the first year of use. It represents more or less a difference of 12,600€ compared with Brussels or Vienna. This difference even increases by 55%, if the cost of the same car is calculated for the five first years.

Finally the comparison with the average income for a family with two children confirms that the high taxation rate in Denmark overcomes the living cost. It is particularly true if the car cost for the first year of use is compared with the average income. In Brussels and in Vienna, a Golf cost in terms of taxes and Gasoline, represents respectively 103,88% and 114% of the average income, whereas it constitutes 126,15% in Copenhagen. Nevertheless, the difference between the three cities is less important if the same calculation is made on the first five years (see figure 28). Those last results enable to conclude that the high taxation level at the purchase of a car is the strongest deterrent not to use a car in Copenhagen. Whereas the relative low taxation rate in Brussels and Vienna makes cars more accessible. It can also explain the high number of passenger car per inhabitant in these two last cities, respectively 48%[33] and 40%[34]. Furthermore it has to be noticed that corporate cars are less taxed in Belgium than in Austria or in Denmark. Indeed, in those countries, employees have to pay a tax on the current value of the car (Denmark) or according to the acquisition price (Austria). In Belgium, employees are not explicitly taxed on the value of the corporate car used for private purpose but only on a fixed kilometre-rate. Secondly, the Belgian taxation system allows the employees as well as the employers to save up money. Indeed, on the one hand the employee can lay aside the purchase of a car, the maintenance and insurance cost, the vehicle taxation and the gasoline. In total it represents a saving of 400-500€ per month for the employee [COCA2007]. On the other hand, it allows the employer to reduce the gross salary of the employee and therefore diminish the payroll tax paid by the company. Thirdly, it has to be noticed that companies can't deduct the tax on value (VAT) on the purchase of a vehicle in Denmark and Austria whereas in Belgium, it is partially the case [NAES-SCHIDT2009].

Those differences in the taxation regime have the consequence that Belgian companies offer more easily a car to their employees without allowing them to consider other alternative transport modes even if they live close to their working place. According to a study made in 2005 by the Federal Mobility and Transport Agency, 42% of the cars in Brussels were corporate vehicles.

4.2 The public transport cost

The analysis of the public transport cost for users of the three cities was done through two different variables: the price of a simple ticket to travel inside the inner city and the cost of an adult one- year subscription. As in the previous section, those prices were first compared in absolute numbers. In a second time, the subscription cost was related to the local income. Nevertheless, in order to simplify

33 SPF économie
34 Statistik Austria

the calculations and give a clearer image of the reality, the tariffs considered here were related to a fictive net pay. This last one was equivalent for the three cities[35].

The prices for a single ticket are similar in Vienna and Brussels. They amount to respectively 1.8€ and 1.6€. A one way pass in Copenhagen costs 3€. The prices for one subscription follow the same logic. A one- year ticket costs 449 € in Vienna, 473€ in Brussels and nearly 600€ in Copenhagen (see figure Error: Reference source not found). However, if the price of a one- year subscription is related to the daily cost, it has to be noticed that the Copenhagen year ticket offers the best discount compared to the price of a single ticket(1,35€).

The comparison with the fictive salary shows that it represents in fact the same share of the salary in the three cities: between 2 or 3 %. It therefore indicates that the public transport costs are equivalent if we take into account the local living cost. So, it can be assumed that the cost of the public transport influences the mobility behaviour in a similar way in Brussels, Copenhagen or Vienna.

4.3 Conclusion

To conclude this economical chapter, we can point out tha the price of the public transport doesn't play an important role if public transport is used on a regular basis. Meanwhile the purchase price and the tax regulation seem to be the strong variables that can influence the transportation behaviour and therefore influence the bicycle use. During an informal talk Niels Jensen, urban planner at the municipality of Copenhagen, mention that " *the Danish State traditionally increase the car tax since the end of the 60 in order to find extra revenue. One of the main reason is due to the fact that Denmark doesn't produce directly cars. Therefore each time that a Danish is buying a car, Danish money leave the country*". We were not able to prove if it was true assumption . Nevertheless, if it is. It would mean that the relatively high use of the bicycle is partly due to the fact that a car and it use, is expensive in Denmark since at least 30 years. So, it might that Copenhagen citizen partly cycle because of an economical necessity.

35 The equivalence of the salary was determined by the UBS report "”Prices and Earnings Around the Globe - 2009 edition”

	Brussels	Copenhagen	Vienna
Average income for a family with two children in €	20172,8	26614,9	18334,7
Gasoline price tax incl (€/l)	1,46	1,48	1,22
Car price tax incl in €	17101	27426	17340
Motor vehicle taxes in €	203,81	2015	511,2
Environmental taxes in €	0	435	0
Total taxes in €	203,81	24,5	511,20%
Car cost the first year in €	20954,81	335,76	20901,20%
Car cost during five year in €	36370,05	581,76	35146,00%
Car cost /revenue the first year	103,88%	126,15%	114,00%
Car cost /revenue on five year	36,06%	43,72%	38,34%

Figure 22: The car cost in number for 2009

Sources: Eurostat, SPF économie, Statistics Denmark, Statistik Austria and the European commission -car price report 2010

	Brussels	Copenhagen	Vienna
Price of an adult year subscription in €	473	600	449
Price of a simple ticket in €	1,6	3	1,8
Cost of an adult year subscription by day in €	1,3	1,64	1,23
Discount	0,3	1,36	0,37
Fictive Salary (per month)	1750	2042	1685
Share of the salary	2%	3,00%	2,00%

Figure 23: Figure 1: Public transport price in €.

Source: STIB, MOIVA, Wiener Linen

5 The development of the bicycle infrastructure

The aim of this last chapter before concluding the present work is to present and analyse of what is done and plan in term of bicycle infrastructures by the public authorities. Therefore, the study presented in this section was mainly based on the bicycle plan from the three cities and an analysis of their existing bicycle network. The present chapter focus on three elements of the bicycle infrastructures: the development of the bicycle network, the complementary actions took to make the bicycle more competitive and finally the functioning of the bicycle sharing system

5.1 The development of the bicycle network

From a large point of view, we can broadly observe that two different strategies were developed. Copenhagen and Vienna emphasis the development of a cycle route network partially or totally segregated from the rest of the motorized traffic. Whereas Brussels cycle network is more base on bicycle lane and an integration of cyclists into the rest of the traffic. The development of those bicycle route network will be the topic of the three following sections.

5.1.1 Copenhagen: a network build during one century.

With a network of 1082km[36], the bicycle route network is large and nearly covered every part of the city and is principally base on bicycle path or bicycle way mainly settle on the main axes of the city. The map 23 in the appendix only shows the bicycle network of Copenhagen municipality. In the author knowledge, a bicycle map representing the area considered in this study doesn't exist. Nevertheless, the map present in the appendix mainly represent a important part of this network

Image 20: Bridle path along the lacks in 1910

Source: The Danish royal library

The construction of the Copenhagen bicycle network, started already at the

36 It include the bicycle network of Copenhagen as well as the network of the other municipalities took in account in this work.

beginning of the 20th century. Around 1900 the bicycle was more a mode of transport for the wealthy. Nevertheless, in 1902, the Plumbers trade Union already encouraged its members working as freelancer to cycle. Quickly other workers union took the same initiative. Those new utilitarian cyclists made new demands of road surface because cobbled paving was uncomfortable and unsafe to cycle on. Moreover, Nails from horseshoes posed a constant threat of puncture [JENSEN2002] .Around 1910, cyclists obtained that the bridle paths paved with loose stones along the Lake in Copenhagen could instead be used by cyclists. Indirectly planners realized that curb and planks intended to keep the loose surface in place were a good way of separating cyclists from the rest of the road users. The bridle paths formed the model for Danish cycle track. In 1912 50 km of new cycle path were already made inside the municipality Copenhagen.

But the real take off of the bicycle network happened between 1930 and 1950-1955. During this 20-25 years, 40% of the actual bicycle path were build inside the municipality of Copenhagen and it can be assume that the other municipalities followed the same trend (see figure 24 bellow). Different elements can explain this development. First, as we saw it on the graph made by De la Brueze (see figure 15 page 37), the 1930's were the golden age of the bicycle everywhere in Europe and Copenhagen didn't make exception[BRUHEZE1996]. But it has also to be mentioned that the lake of oil during the war period and the import ban on car until 1955 push also city planners to continue to settle new bicycle paths [COPENHAGEN2009].

After this period, the cycle network continued to growth but as a lowest rate until nowadays (see figure 24). During the 1960's and the 1970's, the Copenhagen road system underwent considerable expansion. But cycle path were appropriate to create room for cars and new roads or streets were often build without cycle path. This had the main consequence to break up the bicycle network. However, some new housing developments were established with bicycle way entirely separated from the motor roads and assured the cycle network expansion.

The oil crisis of 1972 as well as the increase of the environmental consciousness spawns a collective awareness about alternative to the car. In the late 1970's and in the beginning of the 1980's the Danish bicycle federation organized massive demonstrations in order to put pressure on politicians to improve the bicycle infrastructures. Since then, the bicycle become a political issue that influence the local electoral elections [JENSEN2009].

During the 1990's until today Copenhagen made massive investments in bicycle-friendly infrastructure. Nowadays the development and the maintenance of the cycle network represent, one third of the road budget [COPENHAGEN2008].

We can finally note that the way how to conceive bicycle network also change during the 1990's and the 2000's. Local authorities continued to developed cycle path and cycle way. But also developed cycle lanes to fulfil gaps in the cycle network. They also allowed cyclists to use bus lane and implemented false one way street for bicycler (see next section). Those kind of new implementation shows a willingness to integrate the bicycle with the other transport mode and break with the Danish tradition to separate the bicycle from the rest of the road traffic.

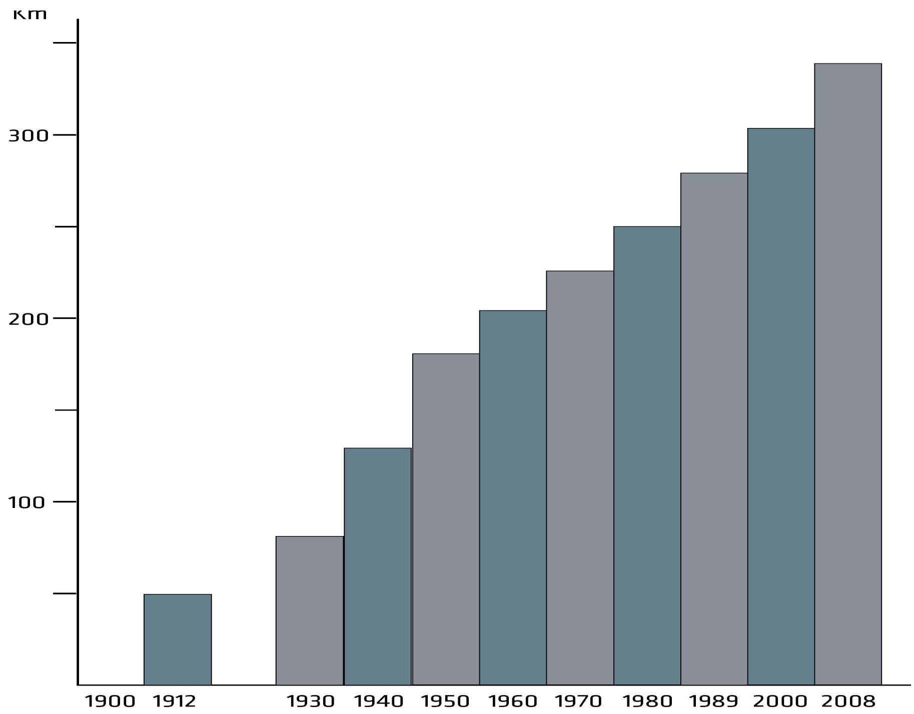


Figure 24: Development of the cycle path network in the municipality of Copenhagen

Source: Niels Jensen, city of Copenhagen

5.1.2 Vienna : a recent but structured bicycle network

The bicycle route network of Vienna is also base on bicycle path and therefore present some similitude with the one of Copenhagen. But it development is much more recent. In 1990, the Viennese bicycle network had an extend of 1150. But 83% of this network was constructed within the last 20 years. Indeed, in 1990 only 196 km of cycle path or lane existed in Vienna. Even if data are not available for the period 1991-1995, the figure 25 shows that the construction of the bicycle network was quite regular. In average 60,5 km of cycle lane were built during the last two decades. The city of Vienna divided the bicycle network in three different parts [VIENNA2009]. The primary network is made of 374 km and cover most of the main road axes (see map 24 in the appendix). Then with an extend of 420 km the secondary network connect the different district and neighbourhood within each other (see map 25 in the appendix). The primary and the secondary cycle route system are today made of bicycle path or bicycle path. Finally a tertiary network of 356 km, insure connections inside districts and residential areas. But, this last one is an “hybrid” network where cyclists have to share the road with other users .Like in Copenhagen, bicyclers are allowed to use one way street in both sense and share lanes with buses.

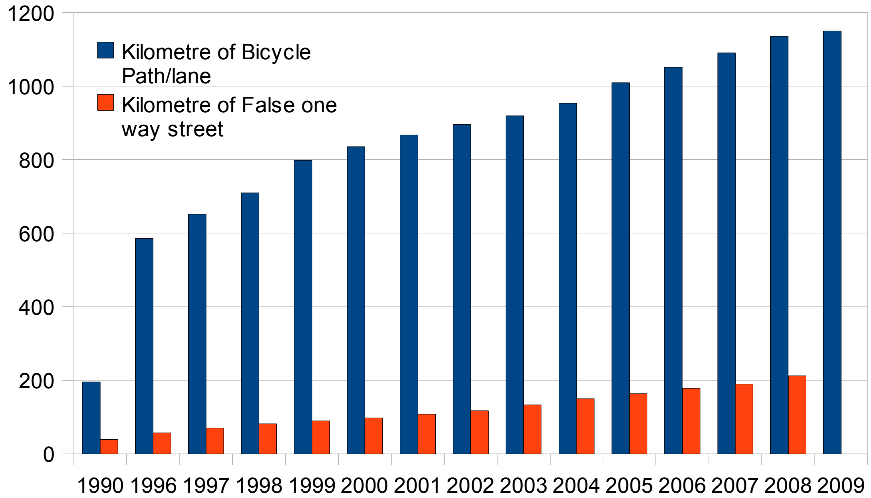


Figure 25: Evolution of the Viennese bicycle network since 1990

Source: Municipality of Vienna (MA46)

5.1.3 Brussels: An hybrid bicycle route network still under construction

Brussels has the most recent cycle network of the three cities analysed in this work. Indeed,even if the mobility Iris I of 1998, already mention the importance of a good bicycle network. The Brussels bicycle route system will only be concretely planed with the bicycle plan of 2005-2009. According to this last one, two different network have to be implemented [BRUSSELS2005]. The first one will be based on the main regional roads (see map 26 in the appendix). This network will consist of a succession of cycle paths, cycle lane or bus lane open to cyclists. But due to a lack of place on some streets, this network will sometimes be reduced to a road marking suggesting where cyclists have to cycle.

Image 21: Specific traffic sign of a Brussels cycle route

Source: the BYPAD report 2010

In parallel 19 regional cycle routes are also planed for middle and long distance journeys. Typically, those last one will borrow local roads, where traffic is less dense, slower and therefore less stressful for cyclists.Further, those cycle route will also be planner to take in account the topography. 17 of the cycle route will be radial routes connection the city centre to the periphery and 3 will surunding the town (see map 27 in the appendix).Moreover, the regional cycle routes, will be connected to a green "promenade" route surrounding Brussels and link to other cycle routes located outside of the Brussels boarder. In term of infrastructures, this second cycle network will mainly be based on marking draw on the road.Nevertheless, the different cycle routes will be indicated by specific traffic signs [BRUSSELS2005].

According to the bicycle plan of 2005-2009 those projects had to be finish for 2009. But nowaday a lot of bicycle lane and path still need to be build or even draft. At the begining of 2010, 158 km of cycle route where setle on regional roads. It represents 50% of all regional streets. Concerning the regional cycle routes,only 80 km were build.As we can notice it on the map 27 in the appendix, most of them are located in the Eastern part of the city where the practice of the bicycle is the highest in Brussels.The BYPAD[37] report of 2010 explain this delay by a lack of civil servant working on bicycle projects as well as the lack of intitiative of the Brussels municipalties to invest and built new cycle routes even those last one are subsidize by the Brussels region [BYPAD2010].

5.2 Extra measures to make the bicycle more competitive.

Two common measure were took in the three cities to increase the competitiveness of the bicycle: The creation of false one way street for bicyclers and the suppression of free parking spot in the city centre.

In Copenhagen as well as in Vienna, the first measure was mainly took to fulfil gaps in the bicycle network and therefore giving the possibility to cyclists to take short cut. In Copenhagen this measure is relatively resent and was .with the bicycle plan of 2004-2012, Nowadays, they are mainly present in the historical town (see map 23 in the appendix) [COPENHAGEN2002]. On the opposite, in Vienna, the establishment of false one way street for bicycle followed the construction of the bicycle network. Today, cyclist use 190 km of false one way streets [VIENNA2009]. Finally, in Brussels this measure was generalize to all the city since 2004. Nowadays 90% of the one one way streets are usable in both sense by cyclist [BYPAD2010].

Concerning the second measure, the three town, decided to define zones where car driver have to pay to park their car. In Vienna, one zones single zone was define. This last one encompass, the

37 The Bicycle policy audit (BYPAD) in an NGO supported by the European commission. It aim is to evaluate the evolution of bicycle policies in European cities.

central districts (from 1 to 9) as well as the 15th and 20th.In this area, a car driver as to pay 1,8€ per hours. In Brussels in Copenhagen the parking cost depent of the centrality of the place. The figure 26 bellow shows the average price for a parking spot in the three cities. If we take in account the living cost, those prices are similar. On the other hand, a fees is much more higher in Copenhagen than else where.

	Brussels	Copenhagen	Vienna
Parking cost for 1h in € in average	1	2,5	2
Parking cost for more than 1h €	2	2,51	1,8
Cost of the First fine in €	15	67	21

Figure 26: Parking cost

Source: Municipalities of Brussels, Copenhagen and Vienna

More specifically, Vienna and Brussels, took also measures to reduce the car speed. In Vienna, it mainly concern all the urbanized zone (see maps 28 and 29 in the appendix). In Brussels this measure is more dedicated to residential areas [HORVATH2006]. Nevertheless, in September 2010, the historical city centre was totally transformed in low speed areas (Max 30 kph).

In Copenhagen, such initiative doesn't exit if we except some streets in the old city. Nevertheless, Copenhagen authorities took measure to reduce the car accessibility in some neighbourhoods [COPENHAGEN2002]. The example of the Vestebro neighbourhood in the South west of Copenhagen is quite illustrative of this policy. Vestebro is a old industrial and popular area. In the framework of a revalidation of the place during the 1990's Copenhagen authorities decided to restrict the car accessibility of one major Boulevard of the city, the Sønder Boulevard. Today, the access to this main road axes by car is only possible through the Eastern part and the North part. The Western exit of the Boulevard as well as the streets located is the South were transformed in dead end or in one way streets. This has the main consequence to reduce the number of car passing by the neighbourhood and offer the possibility to non motorized users to enjoy the Boulevard that was transformed in a “strip park” (see image 22) [SUNE200].

Image 22: The Sønder Boulevard

On the right view of the central part of the Boulevard. On the left, the end of the Boulevard.

Source: google image

5.2.1 What must be remembered

Through this last section, it has been put in evidence that Copenhagen “ grew up” during the 20th century with it bicycle network. This last one the consequence t of a good urban planing but also the result of pressures put on politician first by works union and later by the Danish cyclist federation to consider the bicycle of as one entire transport mode. Nevertheless, it doesn't mean that the a bicycle network is product of the local urban planing. The example of Vienna shows that it is possible to implement a complete bicycle network in 20 years

5.3 The bicycle-sharing systems

During the last 10-15 years, a lot of European cities implemented a bicycle sharing system. The three cities studied here didn't make exception[38].

5.3.1 Copenhagen, a free bicycle sharing system

Copenhagen was one of the first city in the world to put into action this kind of system in 1995. The bicycle sharing system is free of charge and work like a shopping cart system in a supermarket: to unlock the bike from a stand, users have to insert a deposit of 20 DKK (3€) in a small box located on the handlebar of the bicycle. After use, users have to replace the bicycle in one of 110 racks to got the money back. The system is manage by a non profitable company supported by the Municipality of Copenhagen and the Danish State. But to insure the maintenance of the bicycle the foundation is also financed by the publicity.

At the beginning, of the project in 1995-1996, the bicycle sharing system became quickly popular and participated to build the reputation Copenhagen as one bicycle friendly city [SANTOS2006]. But gradually bicycle became less and less use. According to Santos, different reason may explain this:

- The use of the bicycles are limited to the historical town which make them non attractive for local inhabitant (see map 30 in the appendix).
- In order to insure the long duration of the bicycles and make them cheap and easily recognizable, their design are simple. On those bicycle there is no basket, no gear switch and no lamp. Therefore, they are not really comfortable to cycle (see image 23 bellow).
- There are only 2000 bicycle available whereas the municipality of Copenhagen estimate that since 1997 5000 are needed to meet the demand.
- To use a bicycle a user doesn't need to be identify. The entire system if therefore base on the honesty of people. This increase the risk of theft and vandalism.

38 For more information see chapter section 4.2.3 of the state of the art

According to a study made by the municipality of Copenhagen bicycle are today, mostly use by tourists or kids that use them as toys [JENSEN2009]. By consequence, most of the private sponsors disappear and the foundation managing the bicycle system find more and more difficulties to maintain and renew the bicycles. The project is therefore collapsing and would need to be refurbish. But in the actual author knowledge, public authorities are not intend to do so.

Image 23: Bicycles from the bicycle sharing system of Copenhagen, Brussels and Vienna

In the left corner,a Copenhagen bicycle, in the right corner a Brussels Bicycle and in the middle a Viennese bicycle.

Source : google image

5.3.2 Brussels and Vienna: a bicycle sharing system owned by a private company

The Viennese and the Brussels bicycle sharing system are more recent. The Viennese system was implemented in 2002. The Brussels one was fifthly put into action in 2006 and then renewed and extended in 2009 [SAILLIEZ2010]. Both systems are not free of charge and are own by the same private company :JCDECAUX[39]. Therefore they are working in a similar way: first the customer has to register himself through the internet or at any bicycle station. Then to rent a bicycle, customers have to insert a subscription card (or a credit or debit card) into an interactive terminal available at any bicycle station. This last one immediately releases a bicycle attached to a stand.

39 In Vienna, the management of the bicycle sharing system is realized through by the company Gewista owned at 60 % by JCDECAUX

Finally, Customers return the borrowed bicycles when they have finished with them to any bicycle station in the city. The money is then automatically levy on the bank account of the client.

In term of price the bicycle sharing system of both city are relatively cheap. Nevertheless one can deduct from the figure 27, that the bicycle system of Brussels is a bit more expensive than the one of Vienna under 3 h of usage. Moreover, the registering fees are more expensive in Brussels. Indeed, In Vienna, the client only pay once 1€. Whereas in Brussels the system is base on a subscription limited in time (1 day, 7 days or one year). Therefore, the Brussels bicycle sharing system is less interesting. Especially on the long term point of view. Those prices may be explain by different elements. First of all, Vienna was the first city where JCDECAUX implemented a bicycle system. Therefore, the company lowered the price in order to insure the success of the project. Secondly the quality are provided by JCDECAUX is more high in Brussels than in Vienna. Indeed, bicycle are technologically more advanced in Brussels (7 gear shifts vs 3 gear shifts in Vienna). Moreover according to our own experience, the Viennese bicycle seems to be more heavy. Secondly, one can also notice that the number of bicycle stations in Brussels are more important than in Vienna.(155 vs 76[40]).Therefore the logistical management of the bicycle sharing system in Brussels is more complex and may cost more than in Vienna. Finally,a last reason might be that the city of Vienna offered 600000€ of subvention to launch the project whereas in Brussels, JCDECAUX financed everything under one's own steam.

Period (in minute)	Price (in €)	
	Brussels	Vienna
0-30	Free	Free
30-60	0,5	Free
60-90	1	1
90-120	2	1
120-180	2	2
>180	2 per extra 30min	4 per extra 60min

Figure 27: Fare of the bicycle sharing system in Brussels and in Vienna

Source: http://www.citybikewien.at/, http://www.villo.be

Even if there is some differences between both system exist, it has to be recognized that they both offer a better service to their customers than the bicycle sharing system of Copenhagen to their users. A first strong difference is the quality of the bicycles. As we already mention it, Copenhagen bicycle are simply designed and doesn't offer any extra facilities. In Brussels and Vienna, bikes are equiped of a lamps, a basket and have shift grids (see image 23 above).

40 Own calculation base on the websites: http://www.citybikewien.at/ and http://www.villo.be the 12/08/2010

Then, to borrow a bicycle customers have to identify themselves. Therefore it reduce the temptation to mutilate or steal the material. But maybe most importantly, the bicycle station network is not only limitated to the historical town. As it can be observed on the maps 31 and 32, bicycle station are spread around the city centre within a circle of 3,5 to 4 km in both cities. Those last three arguments may explain the relative success of the projects. In Vienna , the development of the bicycle sharing system was strong, between 2002 and 2007. During that period, the number of jouneys made by bicycles provided by JCDECAUX were increasing by 32,5% each year. But today, this growth is not so important any more. In 2008-2009, the increase was around 8% by year. (see figure29 bellow).[GEWISTA2010] On can also note that most of the customers use the bicycle in Vienna for a short period of time. In average 22 min which means that most of them use the bicycle sharing system for free. Moreover most of them are locals. Indeed 75% of the people using the service pay or identify themselves with an Austrian bank card.

In Brussels, the novelty of the project[41], doesn't allow to make a similar analyse. Nevertheless, according to two articles published in the Newspaper *La libre Belgique.* The success of the Brussels bicycle sharing system is more important than in Vienna. Indeed, after one year, the number of journey made with the bicycles were around 205000 [LALIBRE2010A]. This number is equivalent to the results obtained in Vienna at the end of 2004 (see figure 29). But this last summer, the Brussels bicycle sharing system knew a real boom. As we can notice it on the figure 28, in 4 months, 295000 journeys were done which means an increase of 60%. Moreover the number of long term customers[42] quadrupled and the number of short term customers knew an increase of nearly 57% [LALIBRE2010B]. This spectacular increase is maybe provisional and is partly due to the fact that the one year subscription is free of charge until the end of 2010. Nevertheless it also shows that the Brussels bicycle sharing system is popular for the moment. In comparison Vienna never knew such growth.

41 In Brussels, the new bicycle sharing system was launched in may 2009

42 A long term customer here denominate here a customer with a subscription of one year. A user with a subscription of maximum 7 days is here considered as a short term consumer.

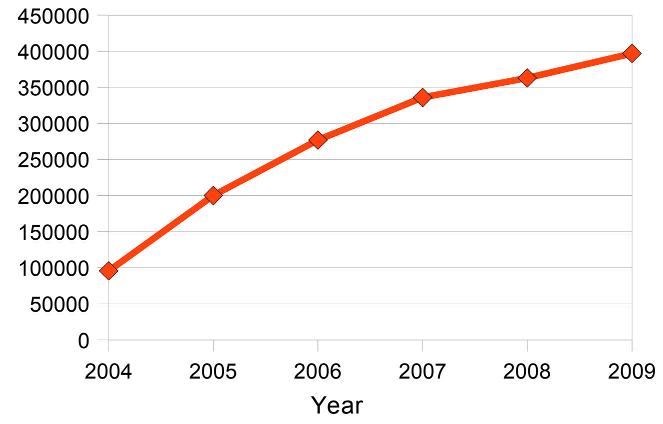


Figure 29: Number of journeys made with a bicycle of the Viennese bicycle sharing system

Source:Gewista magazine

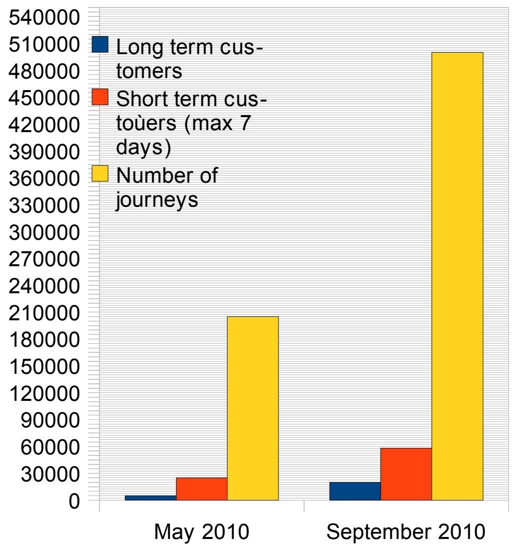


Figure 28: The Brussels bicycle sharing system in numbers

Source:La libre Belgique

The two last examples, show that a bicycle system can work even if users have to pay for the service. Nevertheless, we have to mention that JCDECAUX is a private company providing advertising space. As such,it first target is to provide highly visible publicity spot to their client. On the opposite the aim of public authorities is to increase the number of cyclist by making them more visible as well as improving the mobility or the environment [SAILLIEZ2010]. This difference in term of goal might be conflictual. Indeed JCDECAUX will always try to implement a bicycle station on the most visible place available, sometime without taking in account if this station will be useful for their customers. An other risk is that some neighbourhood would be voluntary forgot by JCDECAUX because the profile of the local inhabitant doesn't correspond to the target group researched by the company. This last reason may partially explain why in Brussels and in Vienna, the bicycle station network seems to be unbalanced. Indeed on the map 31 in the appendix. One can notice that the bicycle station network, is much more developed in the North East than in the South West of Brussels. The same phenomenon is less visible in Vienna. Nevertheless, one can observe that 40% of the bicycle station s are located a long side the Gürtel or the Ringstraße (see map 32 in the Appendix).

To avoid those kind of issues, a partnership between public authorities and the local public transport company would have been more suitable. Indeed, local authorities and public authorities share the same goal: in prove the mobility. Further, public transport companies can consider a bicycle sharing company has an extra offer provided to their client. Then it is also a non expensive way to extend the public transport network or provided an extra public service twenty-four seven. Finally, it makes the accessibility to the bicycle sharing system more easy, because this last one can be include in the public transport subscription.

This last argument let us conclude that the Viennese and the Brussels bicycle sharing system have the main advantage to make the bicycle more visible on the road. It is therefore a strong signal in order to promote it use. Moreover, both models are economically viable because they are financed by the customers or the publicity. Nevertheless, this last source of revenue inducted social inequalities if a company like JCDECAUX is involved in the project. Therefore, the bicycle sharing system of Brussels or Vienna are environmentally and economically acceptable but not really sustainable.

6 The bikeabilty index of Brussels, Copenhagen and Vienna

The different topic of this practical case studies are not directly linked to each other and not easily comparable. Therefore, in order to conclude the present work with one single quantitative measure. We created a “bikeability” index. To calculate this index, we selected in each chapter some quantitative variables representative of the main results. Then those last one were standardized so as that their absolute value could not influence the final result. The standardization was done through the following formula:

$$X'=(X\text{-Average})/\text{standard deviation}$$

Here X represent the absolute value of the variable considered.

We also took in account that the different variable considered played a more or less an importance role on the propensity to cycle. Therefore we asked to 7 different bicycle experts to rank from the less important to most important one, the 9 variables took in account in the calculation of the bikeability index. Then, the balance of each variable was obtained by ordering the score given by each expert to each variable. Finally, we added up each standardized and ballanced variable to obtain the bikeability index of each city. The results can be seen in the figures 30 and 31 p86 and p87.

6.1 Results

The results obtained through the bikeability index confirm our previous outcome. The weighting made by the bicycle experts even increase those last one.

With a bikeability index of 123, Copenhagen has the best result. This outcome is mainly obtained through the variables *Extend of the discontinuous Dense Urban Fabric,the price of a VW GOLF and the price of a parking spot in the city centre during 1h€.* For the same variable, the two other cities got negative results.

On the opposite, Brussels has the worse bikeability index, with a negative score of -132,1. Six out nine variable have a negative outcome. But the variables *Average slope by km² and The length of the bicycle network* explain 75% of this bad result.

In between, Copenhagen and Brussels, the bikeability of Vienna rises 24,4. Most of the Viennese variable obtained a positive result. Nevertheless one can be noticed that all the variable link to a price are negative in the Viennese case.

Variables	Average for the 3 cities	Standard deviation	Brussels	Copenhagen	Vienna
Average slope by km²[43]	2,54	1,83	-1,15	0,65	0,55
Average crossroad/Km²	73,9	11,63	-0,03	-0,99	1,01
Extend of the Continuous Urban Fabric	24,68	4,23	0,32	-1,12	0,8
Extend of the discontinuous Dense Urban Fabric	44,5	28,61	-0,86	1,1	-0,24
The price of a VW GOLF in €	19622,33	5893,36	-0,43	1,32	-0,39
The fuel price in €	1,39	0,14	0,51	0,65	-1,15
The length of the bicycle network in km	823,33	508,05	-1,15	0,51	0,64
The extend of the bicycle sharing system around the city centre in km²	3	1,32	0,76	-1,13	0,38
The price of a parking spot in the city centre during 1h in €	1,57	0,82	-0,69	1,15	-0,45
Bikeability index			-2,73	2,13	-1,1

Figure 30: The bikeability index of Brussels Copenhagen and Vienna

Source: own calculation

43 The topographical variable is the only variable that has a negative influence on the bicycle use. Therefore the score obtained by this last one, was multiplied by -1

Variables	weighting factor of the experts	Brussels	Copenhagen	Vienna
Average slope by km²	37	-42,61	24,09	18,51
Average crossroad/Km²	20	-0,56	-19,71	20,29
Extend of the Continuous Urban Fabric	20	6,43	-22,43	15,99
Extend of the discontinuous Dense Urban Fabric	32	-27,38	35,18	-7,8
The price of a VW GOLF in €	30	-12,83	39,72	-11,62
The fuel price	28	14,19	18,06	-32,25
The length of the bicycle network	49	-56,45	24,95	31,51
The extend of the bicycle sharing system around the city centre	17	12,85	-19,28	6,43
The price of a parking spot in the city centre during 1h	37	-25,71	42,41	-16,69
Bikeability index		-132,1	123	24,4

Figure 31: The bikeability index of Brussels Copenhagen and Vienna balanced by bicycle experts

Main Conclusions

The development of the utilitarian bicycle is one sustainable solution to reduce the impact of our cities on the environment.

The development of the bicycle use in an urban context largely depend on different factors more or less depend of each other. The state of the art showed that the number of factors influencing the propensity to cycle are numerous. A complete study of their influence on the propensity to cycle would be the topic of a PHD thesis. Therefore, the present work was limited to the comparison in three urban context of four different elements that might act upon the bicycle use: The topography, the urban fabric influence, the economical accessibility to different transport mode and the development of bicycle infrastructure.

Those four last factors were studied according to different methodologies according to their specificity. But the aim of each study was to make a comparison possible in between the three cities considered : Brussels, Copenhagen and Vienna.

The results obtained in this master thesis put the following points in evidence:

- The topography clearly disadvantages the bicycle use in Brussels. But is highly favourable in Copenhagen and in Vienna
- The urban structure of Copenhagen through an original hand model, asset the use of the bicycle in addition to the public transports Moreover the high density of the volar region of this hand model potentially decrease the journey distance. From a large point of view, the Viennese and the Brussels radio concentric models might discourage the bicycle use. Nevertheless their dense historical centre present a mix that could advantage the bicycle use
- The tax system might play an important role. The Copenhagen car tax system obviously make cars expensive. On the opposite the Belgian taxation system privileged an easy accessibility to corporate car.
- The bicycle networks of Copenhagen and Vienna are similar and well developed. On the other hand, the Brussels one still need to be improved but shows original solution to integrate cyclists into the rest of the traffic.
- Even if the bicycle sharing system of Copenhagen participate to the reputation of the city as a bicycle friendly town, some design flaw made the system collapsing. On the opposite the bicycle systems of Brussels and Vienna seems to work, although they may be

objectionable from a social perspective

But we have to regognize that the elements took in account in this repport are too limitated and it would be presumptuous to make any definitive conclusion. Indeed psycho-cultural behaviour factors were not directly studied. Those last one could therefore be the topic of a next study Nevertheless, in our oppinion, any bicycle policy should be plan according to potential offered by the physical environment as well as the structure of the urban fabric of a city. The developement of the bicycle as one major mode of transport in Copenhagen started already one century ago and is therefore a product of history. So we thing that what is done in Copenahgen should not be apply else where without being re-contextualize in the local context. Vienna might have a good potential to develop a similar bicycle developement model as Copenhagen, but this last one is not sufficiently exploited. In the framework of this repport we didn't find any evidence explaining this phenomenon. We saw that the municipality of Vienna provided important technical solutions to develop the bicycle use. But from prelimary research it seems that the promotion of the bicycle is only limitated to a bicycle exhibition. On the opposite through active bicycle association (like provelo), the bicycle seems to be more promoted. A comparative study focusing on the strategies deloped by cities to promote the bicycle usage could be a good topic for a furtur reasearch.

Appendix

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