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Cycling as a part of sustainable urban transport in Helsinki:
Assessing the influence of weather on cycling activity

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Analytical notice

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RÉSUMÉ	L'utilisation du vélo est en pleine extension dans les zones urbaines - développement d'infrastructures cyclables, mise en place des systèmes de vélo en libre-service. Cependant, certains inconvénients, comme la présence de fortes intempéries, mettent un frein à son développement. Le but de ce rapport est d'étudier l'influence des différentes conditions météorologiques sur l'utilisation du vélo (aux niveaux journaliers, heures, saisons,..). L'étude se porte sur Helsinki en 2016 et prend en compte deux sources de données : le système de vélo en libre-service et le comptage automatique de vélo. Ce rapport présente divers résultats permettant une meilleure compréhension de l'influence des conditions météorologiques sur l'utilisation du vélo et suggère des améliorations possibles pour les plans de déplacement urbain.		
ABSTRACT	Cycling, as a zero emission vehicle, is a relevant transport mode concerning sustainable development. Bicycle use is increasing as development of cycling infrastructures and introduction of bicycle sharing system are made through cities. However, cycling still has many restriction such as being dependent of the weather conditions. The aim of this study is to assess how weather influences bicycle use from different perspective (e.g. depending on time periods and weather attributes). Empirical research is conducted in Helsinki in 2016 with two different data sources - the bicycle sharing system and the automatic bicycle counter systems. The report presents main findings, which are further discussed and reasoned; and practical implications in improving planning cycling infrastructure and promoting bicycle use are made.		

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Contents

Figure list

Table list

Introduction

The concept of sustainable development was put forward in the Brundtland Commission report in 1987 by defining sustainable development as "Satisfying the needs of the current generation without compromising the ability to satisfy the needs of future generations" (Brundtland 1988). What appears in this definition is the desire to be able to take care of the present demand (e.g. economic and social development, environmental, health) without endangering the future generation and preventing it from taking care of their own future demand.

The aim of sustainable development is complex, since it combines and takes into consideration many aspects such as economy, environment and the consequences of today's actions on the world of tomorrow. Because of this complexity, depending on the culture and the economic theory used, different models are proposed when talking about sustainable development (Sanches Pereira 2007). In concordance with sustainable development, several concepts appeared, such as "smart cities" , established to take into account several aspects of the construction of a city (e.g. urban technology, urban governance and organization or other critical problems) (Batty et al. 2012; Caragliu, Bo, and Nijkamp 2017).

The concept of sustainable development is established in all kind of sectors, from energy to housing, and in particular in transport and mobility. Sustainable transport have various definitions depending on the discipline where it is used, be it engineering, planning or geography (Black, Paez, and Suthanaya 2002; Kayal, Singh, and Kumar 2014). At large, sustainable transport is mainly seen from two different aspects " those that envision sustainable transport as a pathway, and those that envision it as an end-state" (Goldman and Gorham 2006).

Sustainable transport, when seen as a pathway, does not have clear indicators. There are some linked to sustainable mobility (e.g. polluting CO^2 and Nitrogen Oxides (NOx) emissions), but they are seen as giving a direction to improve sustainability. For example, the Center for Sustainable Transportation (CST, 2002) considers sustainable transport based on three factors:

- "Allows the basic access and development needs of individuals, […] in a manner consistent with human and ecosystem health, and promises equity within and between successive generations.
- Is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy […]
- Limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation […] while minimizing the impact on land and the generation of noise."

With the above definition, it appears that no precise goal can be defined in order to have a sustainable transport; even so, one should always have as a goal to create a more sustainable transport.

The second definition, "sustainable transport is seen as an end-state", seems to define more clearly what sustainable mobility is and the goals to reach it. The Organisation for Economic Co-operation and Development (OECD) , in 1996, gives a different definition than CST. With its definition, precise indicators are given to measure sustainable mobility (e.g. reduce the emission of NOx, reduce volatile organic compounds (VOCs) to a non-excessive level). However, these indicators vary a lot depending on the organizations. The World Business Council for Sustainable Development's (WBCSD) takes into account 12 indicators for sustainable transport, from access to mobility, safety (World Business Council for Sustainable Development 2010), and seems less focused on the environmental aspect than the OECD.

Reaching towards sustainable transport and promoting sustainable mobility of people is closely connected with the promotion of cycling, and in urban context in particularly. Several world institutions and guidelines have acknowledge cycling as one potential transport mode to achieve sustainable mobility (Organisation for Economic Co-operation and Development 1996). As a zero emission vehicle, working without any engine (except for electric bicycles), the environmental impact of the bicycle is already extremely low as it doesn't release any fine particles or polluting gas (Litman 2010).

Cycling is also both space efficient in densely built-up areas as well as flexible for individual mobility. The space requests for parking bicycle is rather marginal compared to other types of vehicles. Bicycle would require only about 8% of parking space needed for a car (Kurt 2008). Cycling is also a flexible mean of transport since it can be integrated with other public transportation modes, and it can be used for an individual mobility need the same way as for private cars, as each person may have its own (or rented) bike. The development of popular bike sharing systems (BSS) is bringing even more affordable way to use bicycle in cities which also contributing to the spatial equity of people (e.g. annual BSS membership cost 25 euros in Lyon or Helsinki for example and the first half hour is free of charge[1]).

Not the least, using bicycle makes people practice more physical activity and thus has predominantly positive impacts on public health in case of reduction of risk of obesity or of developing hypertension, improvement of mobility - strength and endurance- (Bassett et al. 2008; Praznoczy 2012).

[1] Source
Lyon: https://velov.grandlyon.com/en/offers-and-rates.html
Helsinki: https://www.hsl.fi/en/citybikes

Therefore, sustainability transport has become a relevant subject nowadays in all fields from economics to politics (Rupprecht, Urbanczyk, and Laubenheimer 2010; OECD 1996; Brundtland 1988). The development of bicycle use in urban areas has regularly increased and contributed directly to the increase of scientific research on cycling. Different aspect and advantages of bicycle in urban areas are thus examined, such as predicting bicycle movement patterns (Rybarczyk 2014), the positive impact of building cycling infrastructure on bicycle (Moudon et al. 2005) or the use of bicycle to go to work (Heinen, Maat, and Van Wee 2011; Wardman, Tight, and Page 2007) .

The development of bicycle use in urban planning is reflected through the development in bicycle sharing system (BSS). As it is cheaper and easily accessible, its use increases in a spectacular way and often thousands of people use the BSS where it is implemented. In addition, this system is providing a new type of data, which did not exist before and is now available to researchers – information about the bike usage of people. Travel time, speed, locations of the trips are available and correspond exactly to what happened, in comparison to survey data where people may give an approximation concerning these information's. Not the least, new BSS systems may be also preferred instead of owning a bicycle, as the risk of theft is non-existent and it is easy to change transport mode by leaving the bicycle to a station (Bachand-marleau, H.Y.Lee, and M.El-Geneidy 2012; Fishman et al. 2014).

However, as bicycle has advantages it also has some restrictions as a transport mode. Many scholars, when thinking about developing cycling, push forward the need of cycling infrastructure (Hull and O'Holleran 2014; Meng et al. 2014 ; Pucher, Dill, and Handy 2010). Cycling is also viewed as a rather dangerous way of travelling as people are more sensitive to the perception of risk in bicycle riding than in many other transportation mode (Noland 1995). Furthermore, the cultural image of cycling which varies from country to country (e.g. mainly regarded as sport or leisure activity) may also have a negative impact on bicycle use as a daily transport mode (Oosterhuis 2016). Other limits of cycling is topography, as a city with lots of hills make it difficult use bicycle (Parkin, Wardman, and Page 2007), and weather conditions.

Cycling is a mean of transport, which is heavily dependent on weather. When weather conditions are difficult (more extreme) – it is raining, winding, snowing or too hot – the only protection that one has is its own clothes. In comparison, in a car or public transport the vehicles protect the users. Moreover, the weather conditions affect also by making the cycling infrastructure less practical (freezing surface, snow which cover signboard). In a sunny day, most people do not consider weather affecting their use of bicycle. However, with snowfall, rainfall, strong wind, or too hot weather conditions, the use of bicycle is more complicated and thus people may reduce their use of bicycle (Thomas, Jaarsma, and Tutert 2009) or tend to turn to other transportation mode (Saneinejad, Roorda, and Kennedy 2012).

Weather influence may also depend of the geographical context (i.e. climate). In some cities, it may have slight influence, e.g. San Francisco in United states (Cervero and Duncan 2003), whereas in other places it may have an important influence, e.g. Helsinki, as the number of cyclist are divided by five during snowy period (Helsingin kaupunki Kaupunkisuunnitteluvirasto 2016).

Thus, *the influence of weather attributes on bicycle use is relevant and Helsinki, the capital of Finland provides an excellent case study setting to examine this thoroughly.* Helsinki is a city with weather conditions having significant change throughout the year, e.g. average daily temperature from -10 to 25, more than one third of the days being snowy days or half of the days being rainy days. It is also developing its use of bicycle by restructuring old bicycle infrastructure and implementing the BSS in 2015.

Objective and research question

Given the context above, the broad objective of this study is to obtain more comprehensive understanding on **how weather conditions influence bicycle use.** By conducting this study, the author aims to give a better understanding of the weather effects on bicycle use whereas in case of Helsinki to provide practical implications for better cycling, planning and promoting bicycle use.

Thus, this study has three aims, which will be answered through specific research questions.

<u>The first aim is to look at the influence of weather conditions depending of different time period</u>. Specific research questions are:

- To what extent weather influences varies depending on weekdays or weekends.
- How the impact of weather on cycling is influenced by hours of day?
- Which is the most suitable time period to analyze the influence of weather on bicycle use?

The second aim is to examine how different weather attributes influence cycling. Specific research questions are:

- Which weather attributes has the most effect on cycling?
- Are weather influencing bicycle use linearly ?

The third aim is to compare different cycling data sources and compare the pros and cons in studying weather impact on cycling. This study applies two types of bicycle dataset: the bicycle sharing system (BSS) dataset and the automatic bicycle counts (ABC) dataset. Specific research questions are:

- What are strength and weaknesses of the different data sources?
- How data types of weather variables influence the modelling of bicycle use?

This dissertation will first look at the theoretical background that is connected to the research question in section I. The development of urban cycling, the national and cities policies, and weather effect on human and bicycle behaviors will be studied. Section II will propose a broad overview of the case study, Finland and Helsinki, including geography, past and current state of cycling. Section III present the methodology including the introduction of applied data sources, methods and tools. In section IV empirical results are presented and reasoned. Discussion about obtained findings, used methodology and future steps are presented in the final section V. Finally, the conclusion will consist of a brief resume of this dissertation.

I- Theoretical background

Bicycle is a transportation mode, which use and aspect changed a lot between its creation and the present demand. As it is now, bicycles are taking an important place in the everyday trips of people and also in politics on the urban planning. It is thus important to have a better understanding of bicycle use.

I-1 Development of cycling and bicycles

I-1.1 The many roles of bicycles

Bicycles first entry was in the beginning of the 18th century. Composed of a wooden frame and two wheels, bicycles, in many European countries, were more seen as an original and trending vehicles for nobles than a useful way of transport (V. Herlihy 2004). Because bicycles were not practical and their cost were high, there were only a few of them. One of the most decisive development took place in the late 19th century when bicycles started to be equipped with pneumatic tires. Another important evolution appeared afterwards with the creation of mechanically propelled bicycle which permitted the use of bicycles to be more common (Oosterhuis 2016).

In each country, bicycle uses took different path and varied according to local culture. In France, for example, different steps for the use of the bicycle were observed. First the bourgeois era, where bicycle was a symbol of social distinction. Then the popular era, where bicycle was a way of traveling for the working class and finally the ecologic era (nowadays), where bicycle is seen as a activity of leisure (Carré 1998) and a way to reduce pollution. Bicycle in France has also always had a strong image as a tool for competitions ("Le Tour de France" is an international competition widely popular). In comparison in Netherlands, bicycling is usually not considered as a sport game but as a practical tool for travelling (Oosterhuis 2016).

In the late 20th century, due to the acceleration of industrial development in Europe, cars were the priority vehicle for urban people, leaving the other way of transport in a bench (e.g. bicycle but also public transport) (Rupprecht et al. 2010). As a consequence, most people who now live in urban area consider cars as being the easiest way to travel (Gilbert et al. 1996). However, the inconveniences of cars becoming more and more visible and growing (e.g. air pollution, traffic noise), people started adopting a different view concerning vehicles and thoughts about reducing the use of cars appeared.

A global political trend in western countries is now to consider bicycle as a sustainable transport and a mean to reduce the utilization of cars (refer to Introduction). In 1991, 73% of European people questioned through a survey believed that the emphasis should be on the promotion of bicycle rather than on cars (Commision European 1999).

I-1.2 The promotion of bicycles and bicycle sharing systems

The desire in European countries to increase sustainable development gave the bicycle a momentum to be an alternative to the use of car. The European Commision, in 1999, and the Organization for Economic Co-operation and Development, in 2004, produced books which promote the use of bicycle. Projects at an European level were elaborated in order to encourage cycling like the “Promoting Cycling for Everyone as a Daily Transport Mode” (PRESTO) project (Rupprecht et al. 2010) or the “Eurovelo” project, that aims to build bicycle lanes connecting countries of the European continent and which is expected to be achieved in 2020[2].

Among the different advantages displayed to promote the use of bicycles (and other sustainable transports), there is, for example, the space needed for using a car compared to the space needed for using public transport, bicycle or walking. In one hour, 2 000 people can cross a 3.5 meter space in an urban environment using private cars against 14 000 people using bicycle (Kurt 2008). Another advantage is the speed, and thus the time needed, for average distance in urbanized areas. For travelling less than 5 kilometers in a rather large town, the bicycle appears faster than the car. In Europe, were more than 50% of the trips made by cars are less than 5 km, it is a significant information (Commision European 1999).

One interesting system developed to encourage cycling in urban areas in Europe (and in other parts of the world) is the Bicycle Sharing System (BSS). Bike sharing system appeared in Amsterdam in 1965 (Midgley 2011). Since then more than 460 BSS were created all over the world (Benoît 2007). The BSS is based on three functionalities. First one is an easy mobility: a BSS user can take his bike in a station and leave it in another one if there is space available. This allows using BSS without having to come back at the starting point. The second point is that it is an automatic system: most BSS systems around the world have bicycle posts where you need a card to rent a bicycle (in most cases it is the public transport card of the town). Thus, withdrawal and returning a bicycle is relatively simple. Finally, it has a specific pricing system: the first half an hour or the first hour is usually free of charge which encourage people to use BSS for short trips.

With the development of BSS, many people began to take an interest in this system. Studies were made in order to predict the availability of bikes in stations (Kaltenbrunner et al. 2010); to look at different activities linked to the use of bike sharing (Vogel et al, 2011) or to see the connections between BSS and public transport (Ting, Chao, and Sevgi 2015 ; Jäppinen et al, 2013). The use of BSS allows to suppress some problems related to the use of bicycle (e.g. price, theft) but some problems remain the same for both type of bicycle utilization, like the influence of weather attributes.

However, BSS systems permitted to develop the use of bicycle as an urban transport and it is more and more commonly part of Bicycle urban planning in middle to big size towns.

[2] Source : http://www.eurovelo.com/en

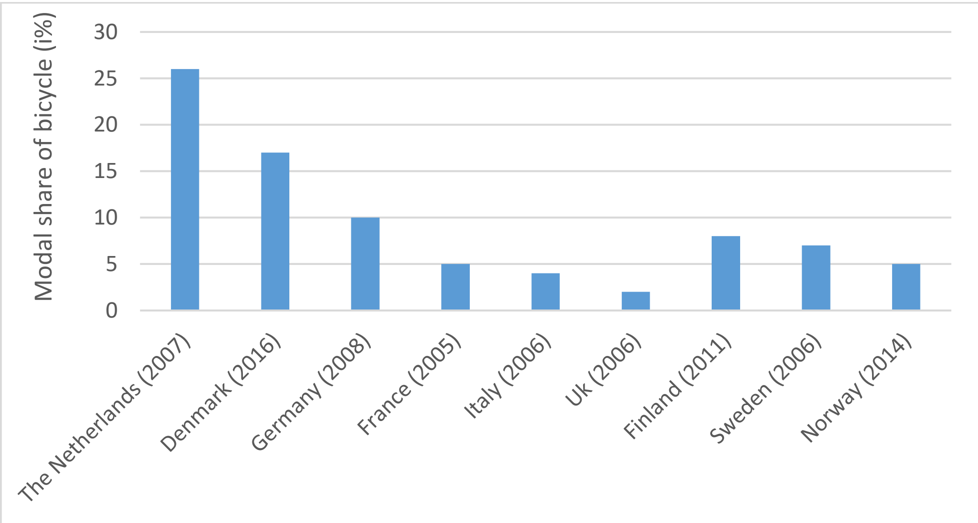
I-2 Bicycle in urban planning

I-2.1 Bicycles and urban planning in European countries

Regarding bicycle at a national level, Figure 1[3], shows that the modal share varies a lot depending of on the countries. Globally, the modal share of bicycle is around 5-8% in Europe (Kurt 2008). However, some countries, like Netherlands and Denmark, have a high share modal of bicycle, respectively 26 and 17%, whereas others, like the United Kingdom or Italy, have a relatively low bicycle modal share. One of the main reason of the high modal share of bicycle in Netherland and Denmark is that, along with the development of cycling facilities and policies, in many city center the use of cars was discretized (Pucher et al. 2017) (Pucher et al. 2010).

In most countries, bicycle planning at a national level began to develop in the end of the 20th century. It may be part of a national transport or environmental program, as in Finland (Finnish ministry of Transport and Communications 2008) and promotes cycling by encouraging local government to invest or increase the quality standard for bicycle routes.

Figure 1 : Modal share of bicycle in different European countries



The urban plan may also be more specific and specialize about plans against bicycle's theft or increase bicycle's safety like in Norway (Espeland and Amundsen 2012).

[3] Source: National Norway Travel Survey 2014 https://www.toi.no/publications/2013-14-national-travel-survey-key-results-article32972-29.html
Finland national travel survey http://www.liikennevirasto.fi/web/en/statistics/national-travel-survey/results#.WRRigoVOJQA
German National travel survey http://daten.clearingstelle-verkehr.de/223/12/MiD2008_Ergebnisbericht.pdf
Denmark national travel survey cycling in the Netherlands
http://www.modelcenter.transport.dtu.dk/english/tu/hovedresultater
modal share of Italy, Netherland, France : Policy department Structural and cohesion policies, 2010
modal share of UK and Sweden : Bassett et al. 2008

National policy guidelines were adopted in order to promote cycling at a national level by organization like the OECD (Organization for Economic Co-operation and Development 2004) or by countries with well-developed cycling policy like Netherlands (Pettinga et al. 2009). The cycling urban plan may also be drafted at the regional levels as in France with regional/department plan (Anon 2015).

Concerning the benefits and disadvantages of bicycle use, there are many such as reduction of traffic, better health for the public, space saving, cost of infrastructure, dependent of the topography and weather, fear of danger, etc… In addition, these observations on bicycle are valid when looking at bicycle in local scale also.

I-2.2 Bicycle and urban planning in local scale

Cycling is mostly used for short distance, a few kilometers: it is therefore natural that the responsibility to develop cycling lays mainly within the hands of the local authorities. Moreover, given the local context (e.g. landscape, heavy snow) and preferences of people (e.g. cultural trend), the local policy makers ,with help of other relevant interest groups, are the main initiators to develop cycling at local scale.

The variation in the modal share of bicycles is very important depending on the cities, even within the same country (Table 1)[4]. Copenhagen, Denmark, has a modal share of bicycle of almost 30%. The bicycle was long ago largely promoted in Copenhagen, which explains this high percentage. Oulu and Helsinki, in Finland, have different bicycle modal share, from to 11% in Helsinki to 21% in Oulu. The difference can be partly explained because Oulu highly promotes the use of bicycle even in cold months.

Berlin, Germany, has developed cycle route network whereas Odense, Denmark, organizes regular events and campaigns to promote cycling (OECD 2004). Strasbourg, France, has opened some lanes only for buses and bicycles in order to simplify their use in town (Commision European 1999).

High modal shares of bicycles in certain cities are partly due to the municipal policies of restraining the use of cars and encouraging the use of bicycle (Rietveld and Daniel 2004; Tomlinson 2003). An example of a variation in the modal share of bicycles in two cities of a same country is Strasbourg and Saint-Etienne in France. Strasbourg has a modal share of bicycle of 8% and Saint-Etienne has a modal share of bicycle of less than 1%[5]. Those values however do not only depend on the fact that cities promoted or not the use of bicycle but also on their natural landscape as Saint-Etienne has many hills, which makes the ridding of bicycles quite difficult.

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[4] Source : http://www.epomm.eu/tems/
Source : http://www.fub.fr/velo-ville/villes-qui-aiment-velo/velo-france-etat-lieux.

Other aspects influence bicycle use such as the size of the town, the culture, the geographic context and so the explanation beforehand just explain partly the variations of bicycle depending on the town. While doing these comparisons, it is to be noted also that the years for the data available were not the same thus the results may defer nowadays. However, promoting bicycle use seems always to have a positive impact in the different cities where it is done.

Table 1 : Modal share of bicycle in different European cities

Cities	Modal Share of bicycle
Copenhagen (Denmark)	30% (2014)
Odense (Denmark)	27% (2008)
Strasbourg (France)	8% (2009)
Saint-Etienne (France)	1% (2008)
Helsinki (Finland)	11% (2016)
Oulu (Finland)	21% (2009)
Berlin (Germany)	13% (2008)
Munster (Germany)	38% (2007)
Amsterdam (Netherlands)	22% (2008)
Oslo (Norway)	5% (2014)

In number of towns, documentation about cycling is published and available. For example Helsinki Bicycle account (City of Helsinki 2015a), provides information about the number of bicycle users' in town, their satisfaction about the bicycle's infrastructure, etc... In Lyon, the plan for sustainable mobility, "plan modes doux" (Le Grand Lyon 2009), presented the new objectives of the municipality about sustainable mobility, including bicycle transport mode, and explained the importance of bicycles infrastructures. These documents are aimed to reach the public and promote bicycle by showing all its benefits.

Bicycle sharing system is also a method to develop cycling in urban areas. There are some differences between BSS depending on the municipalities. In Berlin, a special code by phone is given in order to take out a bicycle; in Helsinki, you only have to register through the web and you can leave your bicycle in a station even if it is full due to a system, which permit the bicycle to lock by itself. The number of bicycle dock's and vehicles also differ from one city to another according to their size (Quay Communication Inc 2008) (Table 2)[6].

[6] Source : Helsinki : https://www.hsl.fi/en/citybikes
Lyon : http://www.stationvelo.fr/lyon-velov.html
Paris : http://www.parisavelo.net/stats.php

Table 2 : Bike sharing system in different towns showing different number of bicycles and bicycle's docks, 2017

Town	Number of bikes	Number of Stations
Helsinki	1 400	140
Lyon	4 000	348
Paris	13 990	1 263

In general, the use of BSS differs a lot. In Berlin only 3% of BSS users take a bicycle every day and just 10% once every week. In Oslo, 42% of BSS users use the system 4 to 5 times a week (Benoît 2007). The objectives of the BSS (e.g. to complement other transportation mode, to promote sustainable transport), and their physical aspects are changed in order to appeal to local actors (citizens but more precisely pedestrian or drivers or those who will be impacted by the BSS) (Huré 2014)**.** Links are even made about the influence of BSS in bicycle uses in places where there are not any BSS (Ravalet and Bussière 2012).

I-2.3 What influence cycling and cyclist

Previous studies have revealed who are currently the main population groups to use bicycle. Bicycle users tend to have higher education(Fu and Farber 2017). They also tend to be young adults, mostly males and into physical activities (Moudon et al. 2005). People are mainly separated into two groups while looking at cyclists: people using bicycle to go to work (Heinen et al. 2011 ; Wardman et al. 2007) and people using bicycle for recreational activities (Heesch, Giles-Corti, and Turrell 2015).

Research also exposed the reasons why and how specific countries or towns would have a high modal share of bicycle users. In a specific country, the cultural image of bicycling (a sport activity, a trending way to move…) has obviously a major impact on encouraging and developing bicycle use (Oosterhuis 2016). The importance of infrastructures is often being put forward. Like many transportation systems, bicycle developments depend on the built infrastructures (Hull and O'Holleran 2014; Meng et al. 2014; Pucher et al. 2010). The use of bicycle by people is also due to a more convenient and time-saving transport mode (Fu and Farber 2017).

However bicycle can also be viewed as a transportation mode with high risk level and people are more sensitive to the perception of risk in bicycling than in many other transportation mode (Noland 1995; Hull and O'Holleran 2014). This potential risk concerning one's own safety is one of the main reasons that limit the use of bicycle. Another restriction on bicycle use is weather attributes.

Weather plays an important role in influencing bicycle use for individuals. In Northern countries, some BSS systems are closed in winter due to low temperature and heavy snow: Copenhagen's BSS system is closed between December and April and Helsinki's BSS program is closed between October and April.

I-3 Weather

I-3.1 Weather influence on human behavior

Weather, defined as a the atmospheric conditions[7], is part of our everyday life. It is delimited as representing the sky attributes (e.g. wind, rain, snow, air temperature). Weather is defined for a short period: between minutes, hours, days or months. When weather is observed for a longer period, like analyzing the evolution of temperature over the last 40 years, then it is defined as climate.

The importance of weather influence can be seen by how many ways there are to get the weather data in the city you are living in. Most likely, there is in each country a TV channel proposing a weather forecast informing about the variation of temperature, wind and rain for the coming days. Almost every newspaper has a column for weather; phones applications about weather are widely available and in some building, TV or other screens indicate the weather in the town.

Whether sun is shining or rain is falling, everyone will be aware of it and it will have an impact in a subconscious level. The effect of weather on people's behavior was studied in psychology research and it has been shown that high level of humidity increased sleepiness whereas rising temperature lowered anxiety but increase aggressiveness (Keller et al. 2005; Howarth and Hoffman 1984).

Weather conditions do not just affect our behavior but also our activity patterns. Scholars have revealed that international tourists seems to plan their travels depending on the weather (Järv et al. 2007) and, on a more local scale, activities may change depending on the weather forecast (Cools and Creemers 2013). These studies showed that weather conditions affect human spatial behavior at different spatial scales.

Furthermore, cold or rainy days tend to diversify people's everyday activity patterns (Horanont et al. 2013). During sunny weekends, people tend to spend their day outside whereas in rainy weather people most likely conduct activities indoor (e.g. cinema, bowling). The duration of the travel, the travel demand or the mode choice are also dependent of the weather conditions (Tsapakis, Cheng, and Bolbol 2012; Liu, Susilo, and Karlström 2014).

[7] Source : https://www.vocabulary.com/dictionary/weather

I-3.2 Weather influence on bicycle use

Existing literature show clear influence of winter condition on cycling. Researchers decided to divide the cyclists into two groups while analyzing the impact of weather: the winter cyclists and the summer cyclists (Bergström and Magnusson 2003). The reason was that so many cyclists were affected by the winter period that it seemed more interesting to look at them in two different groups. In addition, when comparing the factors that determine bicycle use between these two groups, the difference was obvious: temperature and precipitation were ranked in the first three most important conditions for summer cyclists whereas for winter cyclists (who also cycle in summer) they went in seventh and eighth in rank of importance. This article also showed that average distance cycled fell a lot during winter, from a maximum distance of 20 km in summer to a maximum distance of 10 km in winter.

Existing research have showed that one inch of snow reduced the use of bicycle by almost 10% (Flynn et al. 2012) and a thesis on cycling in Finland also confirmed that winter cycling, due to cold temperature and snow, was less popular than summer cycling (Birling 2014). However, snow is not the only weather attributes to influence bicycle use.

Studies presented that rainfall reduced a lot the use of bicycle while increase of the air temperature affects positively bicycle (Parkin et al. 2007; Helbich, Böcker, and Dijst 2014). Just the threat of rain sometimes may bring to lesser cycling rates as the author observed the number of parked bikes which were reduced with appearance of clouds (Nankervis 1999).

Another weather attribute, sometimes taken into account, is wind speed (Saneinejad et al. 2012) which is proven to reduce also the use of bicycle significantly. Research about BSS and weather pointed that warmer temperature had a positive effect on the use of BSS (El-Assi, Salah Mahmoud, and Nurul Habib 2015a). Other works related partly to weather showed a decrease in the use of BSS during different weather conditions (Faghih-Imani et al. 2014; Corcoran et al. 2014a). The effect of fog and thunder on BSS use was also conducted (Gebhart and Noland 2013a) but no correlation was found.

However some studies also revealed that rainfall had little impact in cycling (Cervero and Duncan 2003) or that weather attributes in general did not have an impact as important as expected (Nankervis 1999) on bicycle use. The fact that studies have different conclusion, shows that weather influence depend on the places where these studies took place.

(Cervero and Duncan 2003) and (Nankervis 1999) did their studies in San Francisco, in the United stated, and Melbourne in Australia respectively. If we look at their average temperature or rainfall[8], we see that the climate seems rather even, with minimum between 13 and 22 degrees for San Francisco and 6 to 25 degrees in Melbourne. In consequence, there is also no snow in these towns during winter. The number of days with precipitation is also very small in San Francisco for example and rainfall during these days is not heavy.

While for (Parkin et al. 2007) and (Helbich et al. 2014) , the studies concerned the weather influence in England and Wales and in Rotterdam in Netherland respectively. As England and Wales are known to have many rainy, cloudy and windy days[9], Rotterdam as a city of the Netherland, has temperatures that goes under zero degrees and snowy days. The average precipitation by month is also significant with rainfall between 60 and 80 millimeters.[10]

Even if it appears mostly that weather conditions may reduce the use of cycling, this is not the case in all cities. The various results concerning the effect of weather attributes may be due to the place but also the people, the culture and the variations of weather. It also may rely on the different indicators that were considered while analyzing the influence of weather attributes.

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[8] Source : http://www.australia.com/en/facts/weather/melbourne-weather.html
http://www.usclimatedata.com/climate/san-francisco/california/united-states/usca0987

[9] Source : http://www.metoffice.gov.uk/climate/uk/regional-climates/wl
http://www.metoffice.gov.uk/climate/uk/regional-climates

[10] Source : https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Rotterdam,Netherlands

I-3.3 How to analyze weather influence on bicycle use

One of the difficulties concerning analyzing the influence of weather attributes on bicycles use is that there are many ways to choose indicators for weather attributes. A day could be considered rainy if it just rained once during the said day (Flynn et al. 2012) or if at least one millimeter of rain fell (Branderburg, Matzakaris, and Arnberger 2006). One can also observe the average rainfall of the day (Helbich et al. 2014) or classify different degree of precipitation (Nankervis 1999). Likewise the temperature can either be taken as the average temperature of the day (Thomas et al. 2009), divided into different categories (Saneinejad et al. 2012) or as the perceived temperature and not the real one (Branderburg et al. 2006).

Research also exposed that winter had more influence on bicycle use that summer (Nankervis 1999). Bicycle articles, when analyzing the influence of weather attributes about commuting activities (mostly work and school traveling), showed that rainfall, cold temperature or snowing had a negative effect on bicycle use for this activity (Flynn et al. 2012; Parkin et al. 2007).

The difference between weekday and weekend revealed that recreational cyclists are a lot more sensitive to weather than commuting ones (but each group is influenced by weather attributes) (Thomas et al. 2009; Branderburg et al. 2006).

The influence of spatial locations combined with weather conditions was also conducted and showed that temperature, rain and wind had less effect on a dense urban location than a remote area (Helbich et al. 2014). This implicates that the same weather attributes could have different impact on bicycle use depending on the urban infrastructure.

Concerning BSS data and weather, dummy variables can be used when comparing on an hourly basis for rainfall (Gebhart and Noland 2013a; Faghih-Imani and Eluru). On daily basis, however, it seems that the average rainfall is used (El-Assi, Salah Mahmoud, and Nurul Habib 2015b; Corcoran et al. 2014b). Weather seems to have the same type of influence for BSS users as for personal bicycle users (e.g. increase of temperature provokes an increase of BSS trips, weekends users are more influenced then weekdays users by temperature) but the difference in the degree of influence of weather attributes between BSS use and personal bike use is unknown.

Few scholars made comparison between BSS data and personal bike data (Castillo-Manzano, López-Valpuesta, and Sánchez-Braza 2016). And studies concerning personal bicycle data that were not survey data are also limited, as (Nankervis 1999) who looked at parked bike or (Branderburg et al. 2006) who had video recording.

II- Presentation of the case study area

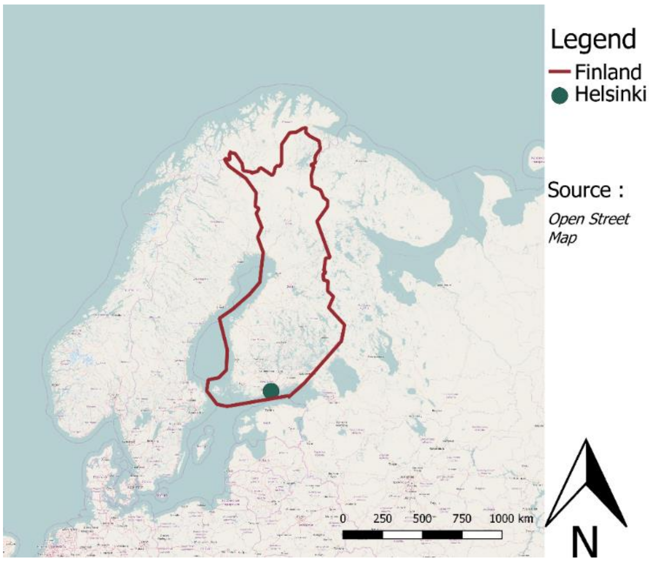
As studies regarding cycling and weather were shown to depend on the geographic and cultural context, it is important to understand the place where the study was undertaken. As many places, Finland and its capital Helsinki have their own specific features.

II-1 Geographical context

II-1.1 Finland

Finland is located in the northern part of Europe, bordered in the east by Russia, in the west by Sweden and in the north by Norway. Helsinki, capital of Finland, is located at the far South of Finland (Figure 2).

Figure 2 : Geographic position of Finland and Helsinki



Finland, which became an independent country in 1917, is this year celebrating its century of independence. Finland has two national languages, Finnish and Swedish, the latter being only spoken by about 5% of the total population (5 493 000 inhabitants). Finland is one of the few countries in Europe with limited urbanized areas and with a rather low density of only 18 persons per km^2. Its area is 338 144 km^2 with 70% representing forest area and 10% lakes area. Finland is also known as “the country with a thousand lakes”. However, the number of lakes is far higher as the total is over 180 000. While looking at temperatures, average daily values were between -14°C and +17°C through the year 2016.

Regarding Finland’s growth and development, services which are at the peak in an international level for Finland are postal, telecommunications, financial and insurance services (Finland chamber of commerce) . Concerning wellbeing and education, Finland is above most European countries and is known to have a very good school system. The employment rate, 69%, is however behind the other northern countries like in Denmark where it reaches 72.5%, and Sweden and Norway with 75% (OECD Finland 2016).

One interesting fact about Finland, at is a northern country, is the amount of daylight, which varies a lot throughout the year. If you look at its northern region, like Lapland, then during summer the sun will not set for seventy days. On the contrary, during wintertime, the sun may not show up for more than a month. Even in the most southern cities, like Helsinki, during winter, darkness represents more or less 80% of the time with only three hours of sunlight. And in summer, the sun may get down around one or two am and go up at five am[11].

II-1.2 Helsinki

Helsinki was founded in 1 550 by the king of Sweden and became the capital of Finland in 1812 (City of Helsinki 2015b). 11.4% of the finish population, which represent 628 208 habitants, lives in the capital. The official languages are Finnish and Swedish, the latter being spoken by 5.7% of the population. The density is a lot higher then Finland with 2 945 person/km^2. Helsinki area represent 719 km^2 however, over one quarter of the land surface is made of islands as Helsinki includes 315 islands (City of Helsinki 2016). The temperature, which varies a lot, can reach -23 °C during the coldest period of the year and the warmest day in 2016 was 25 degrees in May.

Public transport in Helsinki is well developed, with 13 different trams lines, 1 metro line and more than 100 bus lines. Metro and tram usually close before midnight whereas bus services are still operating until 2 am[12]. The number of vehicles running in the city is about 235 000. Helsinki, as a city, is very concerned by transport, which can be observed by looking at the main transport projects being realized[13]. The strategy program for 2013-2016 elaborated by Helsinki municipality (Helsinki City Council 2013) is divided into 4 categories:

- "Promotion of well-being resident": improving health care, taking care of elder and young people…
- "Helsinki full of like": development of firms and competitiveness.
- "Functional Helsinki": development of an urban structure with better accessibility and a more sustainable approach.
- "Well balanced economy and management": aim to stabilize the economy and to increase productivity.

In the category "Functional Helsinki", the development of cycling appears as the main topic in the strategy to reach sustainable transport.

[11] Source : http://www.visitfinland.com/article/land-of-the-midnight-sun/
[12] Source : https://www.hel.fi/helsinki/en/
[13] Source : http://kartta.hel.fi/?setlanguage=en&e=25496825&n=6673044&r=4&w=&l=Karttasarja&o=100&swtab=kaikki

II-2 Cycling

II-2.1 Finland

It can be observed, Figure 1, that Norway and Sweden have a bicycle modal share similar to Finland, respectively 5% and 7%. However, when comparing it to the modal share of bicycle of some other northern countries, like Denmark or Netherland, respectively 17% and 26%, the modal share of bicycle in Finland can be considered relatively low. The difference is not only due to climate and topography. As Finland, Denmark and The Netherlands encounter very cold weather, which also affects the use of bicycle. Furthermore, Finland is a rather flat country like the Netherlands.

The difference in the modal share with other countries can partly be explained by the fact that cycling was viewed as a common tool to travel and actively promoted in Denmark and the Netherlands (Tomlinson 2003). Various associations linked to the promotion of bicycling as a practical way of transportation are actives in these countries, like the National Dutch Wheelers' in The Netherlands. This single voice allowed them to show bicycle as a way to become independent, courageous and in control of oneself.

In the above mentioned countries, municipalities have taken measures to develop and promote cycling (bicycle infrastructure) and cyclist's rights and safety (Jensen Andresen et al, 2012; Pettinga et al. 2009), while limiting the development of cars compared to other European countries (Oosterhuis 2016). The policy of "carrot and sticks" has been widely used in these countries (promoting the use of bicycle and constraining the use of cars) and thus it can explain the important modal share of bicycle in these countries.

However, concerning Finland, as in many other European countries, the use of cars is well developed. Nowadays cars are used for short trips: one out every four cars trips in Finland rides less than 4 km in average[14]. Concerning the average number of vehicles in Finnish households, in 2012, 76% of households had at least one car, which represents an increase of 5% compared to 2006[15]. Finland appears as one of the countries that did not promote cycling as a unique entity and where the increase of cars out waved other transports as the government was principally preoccupied by these matters in the 20th century.

Indeed, policy concerning cycling appeared in the late 90s. In 1992 the Finnish ministry of transport decided to set up a working group in order to develop and promote cycling (Birling 2014).

Since then, different policies and programs were drafted. One of them is the Jaloin Program: it was elaborated between 1997 and 2005, by the ministry of Transport and Communication. Its objective was to promote and develop cycling.

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[14] Source : http://yle.fi/uutiset/osasto/news/municipalities_promote_cycling_in_a_bid_to_save_millions/8915800

[15] Source :https://tilastokeskus.fi/til/ktutk/2012/ktutk_2012_2012-11-05_tie_001_fi.html)

Another aim of this plan was to reduce car dependency and promote a healthy and environmentally friendly way of transportation. In the transport policy guidelines of 2008 (Finnish ministry of Transport and Communications 2008) the key to improve long-term sustainability in transport policy is said to be, chapter 4 “Promoting public transport and pedestrians and bicycle traffic as attractive alternative”.

Another process for promoting the development of cycling was conducted by the Finnish transport agency with the objective to have a centralized and comprehensive traffic for cyclist and pedestrians by 2020. The aim is to make 20% more journey by bikes by 2020 compared to 2005 (Ministry of Environment 2012). The main objective of these different programs is to create a centralized and comprehensive traffic for cyclist and pedestrians.

It has been mentioned that the promotion of cycling varies a lot depending on the municipality, even in a specific country. It can be applied in Finland where the modal share of walking and cycling varies between 15-40% depending on the cities concerned (Birling 2014). The Finnish city with the greatest score is Oulu which had a modal share of bicycles of 22% (Studies and Plan 2016) in 2009, and increased it to 27% in 2017[16]. There, the decision makers were keen to develop the use of bicycles since the 80s, building an average of 17 km bicycle lanes per year. In addition, winter maintenance in Oulu is very high as already mentioned. However, other cities are trying to improve the use of bicycle. The aim of Hyvinkäa city for example is to be recognized as a capital-cycling city[17] in the near future. In order to develop the use of cycling, this city allows its citizen to borrow electric and folding bikes. Moreover, Helsinki aim to develop the use of bicycle.

[16] Source : http://torontoist.com/2017/02/what-toronto-can-learn-about-winter-cycling-from-oulu/
[17] Source : http://yle.fi/uutiset/osasto/news/municipalities_promote_cycling_in_a_bid_to_save_millions/8915800

II-2.2 Helsinki

Comparing the modal share different European cities, Table 1, Helsinki, with a modal share of bicycle of 11%, seems under the average compared with other European cities. However, the ones taken in account were mostly capitals where bicycle use is well developed. As the average modal share of bicycle for cities through Europe is not known, it is difficult to know which value represent the average modal share of bicycle. However as it is, the aim of every cities should be to increase the modal share of bicycle.

Nowadays, cycling is included in the different urban plans drafted for Helsinki, which fall under the responsibility of the urban planning department of Helsinki[18]. Four major policies for promoting cycling are pushed ahead:

- Bicycle must not be associated with pedestrian walk anymore but must clearly be seen as a moving vehicle. For this reason, cycling routes must not necessary be side by side with pedestrian roads.

- Raise the modal share of bicycle to 15% by 2020.

- Make the bicycle a safe mode of transport.

- Upgrade the winter maintenance in order to create an annual bicycle cycle.

With 1 200 km of cycle paths (2 600 km in the urban area)(Helsinki Public Transport 2008), Helsinki has quite an important cycling path. In addition, development of bicycles infrastructures are going on and plannded until 2025 (see annexe A). Compared to other European cities, even places with high modal share of bicycle like Copenhagen, the cycle path and lanes are more developed in Helsinki (European Parliament 2010) (Table 3). So, the cycling infrastructure is already there and Helsinki seems to be easily accessible by bicycle [19]. However, some of the bicycle paths are not of good quality.

One of the main plan of Helsinki concerning bicycle path is the Baana lane. Fist opened in 2012, with 1.3 km, the Baana lane is meant to be a high-quality cycle path running all over Helsinki with a length of 130 kilometers by mostly restoring older cycling paths, but also creating new high-quality cycle paths. Baana network is expected to be accessible during snowfall with the development of winter maintenance.

[18] Source : http://www.hel.fi/www/Helsinki/en/maps-and-transport/cycling/planning/

[19] Source : http://www.ulkoilukartta.fi/

Table 3 : Cycling and lane paths in different European cities

Cities	Cycle and lanes paths (km per km^2)
Barcelona	1,2
Berlin	0,7
Copenhagen	4
Helsinki	8,9
Munich	2,5
Stockholm	4
Wien	2,7

In order to facilitate biking, Helsinki city allows to carry bicycles in the metro (Helsinki Public Transport 2008). It is also possible to carry bicycles in trains (free of charge for trains travelling in Helsinki area) and ferries (there is a fee cost). To develop and promote cycling, Helsinki bicycle account (City of Helsinki 2015) is published every two years, since 2015, with the idea of presenting biking development, citizen's opinion and cycling service. The objective is to put the emphasis on the positive effects of cycling and thus increase the interest of the public for cycling. However, some of the information is a bit twisted (the spots where cycling decrease are not presented for example).

The budget for developing urban cycling amounts between 5-7 million euros per year[20] . Another promotion of bicycle emerged with the bicycle center opened that opened in Kampii in 2012, under the supervision of the city of Helsinki and with the support of some private firms. This center offers emergency repair, facilities for people to repair their bike, information about bicycles and a parking area. Assistance with punctured tires and misplaced chains are provided and a free pumping station is available.

Figure 3 : A bicycle sharing station in Helsinki

Helsinki also developed in 2016 a city bike service. Like most BSS in Europe, the first 30 minutes are free of charge and afterwards it costs 1 euro every 30 minutes. For regular users, the cost is 5 euros per day or 25 euros for a seasonal membership. After 5 hours of renting, 80 euros is deduced from the user's bank account if the bike is not returned. The Bicycle Sharing System (BSS) in Helsinki is only available during the warm season, i.e. between May

[20] Source : https://www.hel.fi/helsinki/en/maps-and-transport/cycling/promotion/

and October.

50 stations and 500 bicycles were set up. In May 2017, 90 more stations and 900 bikes were added[21]. A webpage allows the user to see in which stations bikes are available.[22]

Each day, bicycle users travel about 406 000 kilometers in Helsinki (City Of Helsinki 2015). A comprehensive survey the Pyöräily-barometri (Helsingin kaupunki Kaupunkisuunnitteluvirasto 2016) is carried out every two years in Helsinki to examine cycling related issues in Helsinki. The latest survey revealed among other findings that :

- For those biking, 37% do it almost every day, 28% do it from 2-3 times a week, 15% once a week and 19% sometimes.
- The most important reason for bicycle trips is commuting to work or educational institution (48%).
- The most important reason for choosing cycling is convenience purpose (40%), health care (35%), and leisure (36%).
- 87% of the cycling residents are satisfied with Helsinki as a cycling city.
- Problems, which limit the use of cycling, are said to be: disrupted cycling routes resulting from construction, efficiency, safety cycling.
- Concerning BSS, 76% of citizens are satisfied with the service and 88% of those using BSS are satisfied with the service.
- 96% of the people support the idea of promoting the use of bicycle in Helsinki.

This information corroborates the results found in some articles, as convenience and health care were cited as main reason to use bicycle and that bad infrastructures or safeties were showed of having a negative impact on the use of bicycle.

Another barometer used to study cycling is Pyöräliikenteen laskennat Helsingissä (Helsingin kaupunki 2016) which is looking at the traffic cycling based on manual counts in June and automatic city counts throughout the year. However, as it is automatic, no information is available concerning the bikers, only the number of bicycle counts are listed.

[21] Source : https://www.hsl.fi/en/citybikes
[22] Source : https://kaupunkifillarit.fi/

II-3 Weather conditions and biking

II-3.1 Finland's cities

It can be observed that Finland climate sets its own challenge for commuting by bicycle. Some plans, at a local level, were made in order to increase the use of bicycle during winter period however very few of them were found by the author. The difficulty of searching in a unknown language (Finnish) may be one of the reason for the lack of findings.

The Jaloin program in Finland considered the effect of weather and more precisely winter traffic. A study conducted in 4 towns (Oulu, Jväskylåa, Rovaniemi and Helsinki) showed that 28% of people mainly cycling in summer would be prepared to cycle in winter if there was a better maintenance (Ministry of Finland 2005). Main reason that people do not cycle during wintertime is the cold weather and the slippery path, which make the use of bicycle less convenient.

However, a city as Oulu showed that it was not impossible to have a high modal share of cycling even during wintertime. In Oulu, which has the biggest modal share of bicycle in the country with 22%, the modal share of bicycle goes to 12% during wintertime (Studies and Plan 2016). This large difference shows the important effect of weather on cycling. Nevertheless, it is interesting to notice that the modal share in Oulu in winter season (very cold with a lot of snow) is still above 10%. It can be explained by the fact that the culture of biking is quite different but also by the fact that bicycle network is maintained during winter. By investing in winter maintenance, the number of winter cyclists is said to have increased by 25% in Oulu. Oulu is moreover part of the winter cycling association[23]. Therefore, development of winter maintenance may change the attitude towards climate.

II-3.2 Helsinki

There are some plans to promote winter cycling in Helsinki (Helsingin kaunpunki 2016). During the winter of 2016, two roads were maintained to make biking easier: the baana road, which is now 3.1 km, and the Helsinki Oulunkylä road, which is 5.6 km[24]. The biggest problems that were observed during winter were:

- Discontinuity of winter care due to temperature and snowfall that vary each day.
- Coordination of plowing of the road that must be done in hours limiting the impact on bikers using these roads.
- Snowshoes and other objects that are lost on bicycle path, which may endanger cyclists who do not see them in bad weather.
- Dirt (combination of snow and earth) which can slide under the wheel tire and damage it.

[23] Source : http://www.wintercycling.org/

[24] Source : https://kerrokantasi.hel.fi/hearing/talvipyoraily?fullscreen=true

Different methods for winter maintenance are used. The Helsinki methods are one used by most European countries, which are brushing and sanding. These methods are used in countries with high modal share of bicycle like Sweden, Denmark or Netherlands.

The method used in Helsinki was with brush salting and not sand because it is said to be less painful when cyclist fall and it reduces the risk of puncturing tires. Plowing is also used if snowfall has fallen by at least 5 cm and just after the snowfall in order for the road to be cleared the next morning. Plowing is also used if snowfall has fallen by at least 5 cm and just after the snowfall in order for the road to be available the next morning.

Some feedbacks have been collected from bikers about these roads and winter maintenance. Most praised the quality of the road and the level of winter maintenance was deemed better than before. Still, there were also negative feedback with using salt, which is said to hurt dog paws and that the corrosion effect of salt was not good. The number of cyclists during wintertime is said to have increased by 18% in 2016 compared to 2014-2015.

Another interesting study about weather and cycling in Helsinki is done in the 2016 Pyöräily-barometri (Helsingin kaupunki Kaupunkisuunnitteluvirasto 2016). In this survey, a cyclist is a person who uses a bicycle at least once a week during snowless time. This type of definition was made because if you look at the number of people cycling all year round, they represent 11% of the people of the survey, whereas when taking people cycling during snowless time then it represents 57% of the people in the survey. Therefore, even if people say that weather do not influence their use of bicycle, when looking at the period of time they used it, it certainly has an effect.

In addition, looking at other information, it can be seen that 28% of the people only cycle between May and September. Therefore, these people do not consider just the snow while riding but also the winter season that is partly linked to cold temperature. Obviously, the influence of wintertime is very important on cyclists. Here are some of the results:

- 57% of the citizens which answered the survey use bicycle once a week during snowless time.
- 28% of the people are satisfied of bicycle during wintertime (compared to 93% in other seasons).
- 44% (53% of cyclist and 32% of non-cyclists) mentioned that better winter maintenance would make them bicycle for the first time in winter or use more bicycle more frequently.

However, the influence of weather conditions on cycling in a more detailed level is not examined in Helsinki, to the knowledge of the author. Thus, it is currently unknown how different weather conditions such as rainfall, wind, humidity affect cycling.

III- Methodology

To answer the research question, an hypothetical-deductive and falsifiability approach was undertaken, based on its definition in “la démarche d’une recherche en sciences humaines” of François Dépelteau (DEPELTEAU 2010) This approach could be summarized in three main points:

- Choice of the subject : the problematic
- Theoretical conjectures: presented part I
- Empirical test and communication of the data : presented part IV

We talk of hypothetical-deductive method because it is based on observation, analyze of documents and analyzing empirical results to corroborate, or not, the research question. The ad of the falsifiability approach, invented by Karl Popper (Soler 2007), take into account the problem of induction and the impossibility of verification.

Problem of induction because it is important to know that what we see is never always true. If the theory is proved right now, it may change in a few years from now. Impossibility of verification because in a scientific approach it is necessary to see if the refutation of the hypothesis is possible. Here the refutation would be that weather attributes do not affect in any way bicycle use. It would be verified if weather attributes were not found significant to the use of bicycle.

The method used for this approach was analyzing the contents and making statistical analysis. Analyzing contents as we aimed to understand documents related to the research theme and statistical analysis as statistical data from other were used in order to obtain empirical results. This section will in this way focus on the statistical analysis.

III-1 Presentation of the data

III-1.1 Data sources

We will be focusing on three different data sources shown (Table 4): The automatic bicycle counter data (ABC data), the bicycle sharing data (BSS data) and the weather data. The ABC comes from an automatic system, which counts the number of bicycle coming through sixteen different locations of Helsinki.

The weather data comes from the Finnish meteorological institute, which gives the different weather attributes from different weather stations placed in Helsinki. However, in order to simplify the work, only one location, which was the Kumpula weather station, was chosen to analyze the weather variations, as it was geographically located in the middle of Helsinki and thus being the most suitable station to represent Helsinki. Given that had marginal recording problems (no records), thus a total of about 20 hours in year 2016 were excluded from the analysis. Its location, with the ABC locations and BSS stations are represented Figure 4

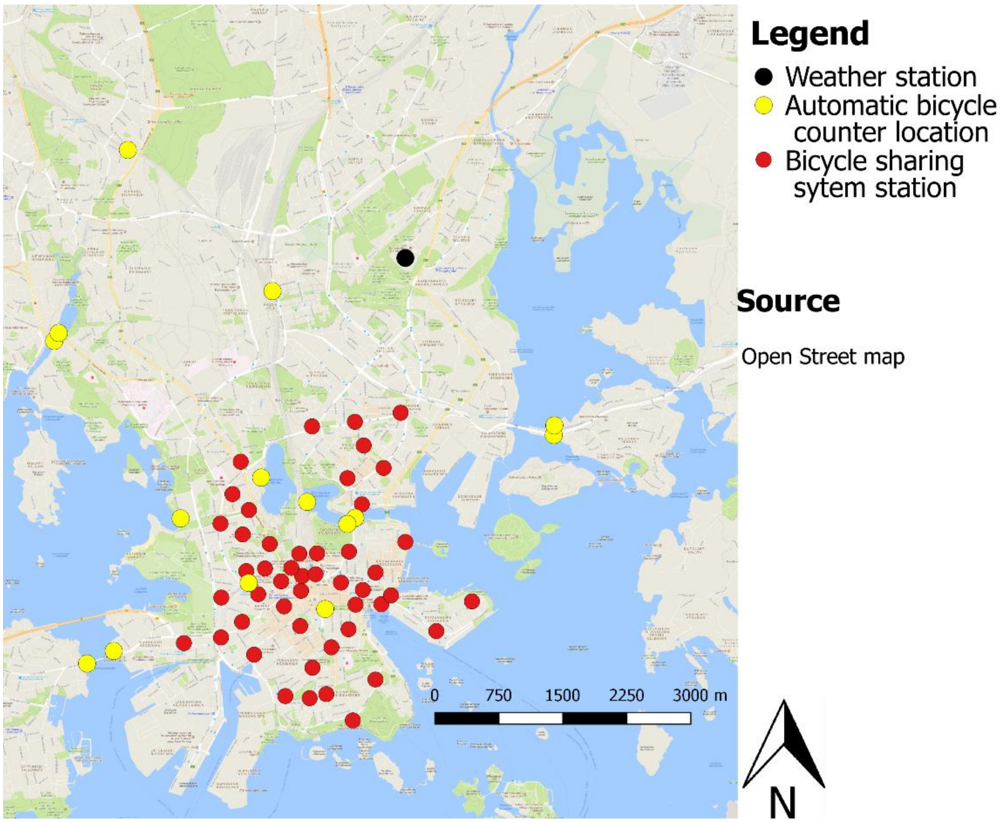
Table 4 : Presentation of the three-different dataset

Data	Location/ scale	Time table	Time precision	Information given
Automatic Bike counter data[25]	16 different points in Helsinki	January 2014 - March 2017	Hours	Number of bicycle who pass in each location
BSS data[26]	50 bikes stations in 2016	May 2016-October 2016	Minutes	Number of trips, duration of the location, Origin and destination of the travel, social data (sexe and age)
Weather data[27]	Helsinki	2016	Every 10 minutes	Average weather attributes values (rainfall, snowfall, temperature, humidity…)

The BSS data and Count data were each aggregated into trips and bicycle counts respectively in an hourly or daily level, putting together all the trips and bicycle counts together, independently of the location. The weather was aggregated also in hourly and daily level, looking at the average value except for rain and snow where the values were summed up (on a daily and hourly level).

[25] Source : Provided publicly by Helsinki region : http://www.hri.fi/fi/dataset/helsingin-pyorailijamaarat
[26] Source : Helsinki city transport public company
[27] Source : Finnish Meteorological university institute

Figure 4 : Locations of the different dataset sources in Helsinki in 2016



IIII-1.2 Weather data

The different weather attributes that were given are: temperature (temp), wind, snow, precipitation (precip), humidity (hum), clouds, dew-point temperature, gust, visibility, pressure, direction, WDCode and darkness.

Clouds are indicated in a subjective way, with a nomenclature going from 0 to 8, 0 being no clouds at all in the sky, and 8 would be a sky totally covered by clouds. Darkness is the number of hours in a day which were dark (no sunlight coming by). Gust is a sudden increase of wind which does not last longer than 20 seconds, and dew-point temperature is the temperature at which the air can no longer contain all of the water vapor in it. WDCode is the average weather of the day, combining the different weathers attributes. And snow is not the amount of snow that fell but the snow that covers the ground (even if it wasn't snowing on a day but the day before, if the temperature is cold enough, then the amount of snow on the ground will be the same and thus the value of snow attributes will remain the same)

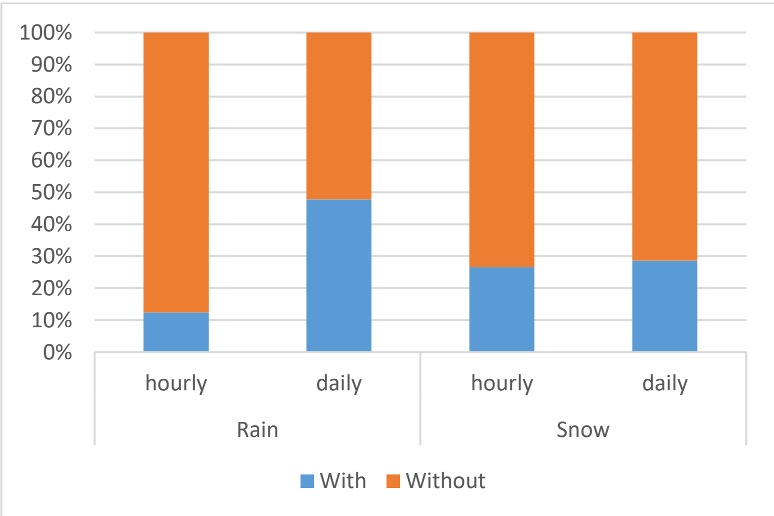
As to be seen section III-3 for darkness, gust, dew-point, visibility , pressure, direction and WDCode , these weather attributes will not be used in this essay so their variations will not be looked at in this part. Table 5 describes the variance of weather during the study period, year 2016, regarding selected weather attributes. The variation for a weather attributes, be it on a daily or hourly level, is very important.

Table 5 : Daily and Hourly Variations of the weather attributes

	temp (in C. °)	wind (in km/h)	snow (in cm)	cloud (n_man)	precip (mm)	hum (%)
hour_mean	6,5	4,3	2,9	4,7	0,5	78,7
hour_min	-25,1	0,3	0,0	0,0	0,0	20,5
hour_max	26,2	11,3	35,0	8,0	84,8	100,0
day_mean	6,5	4,3	2,9	4,7	11	79,0
day_min	-23,6	1,4	0,0	0,0	0,0	35,3
day_max	21,1	8,7	31,6	8,0	310,0	100,0

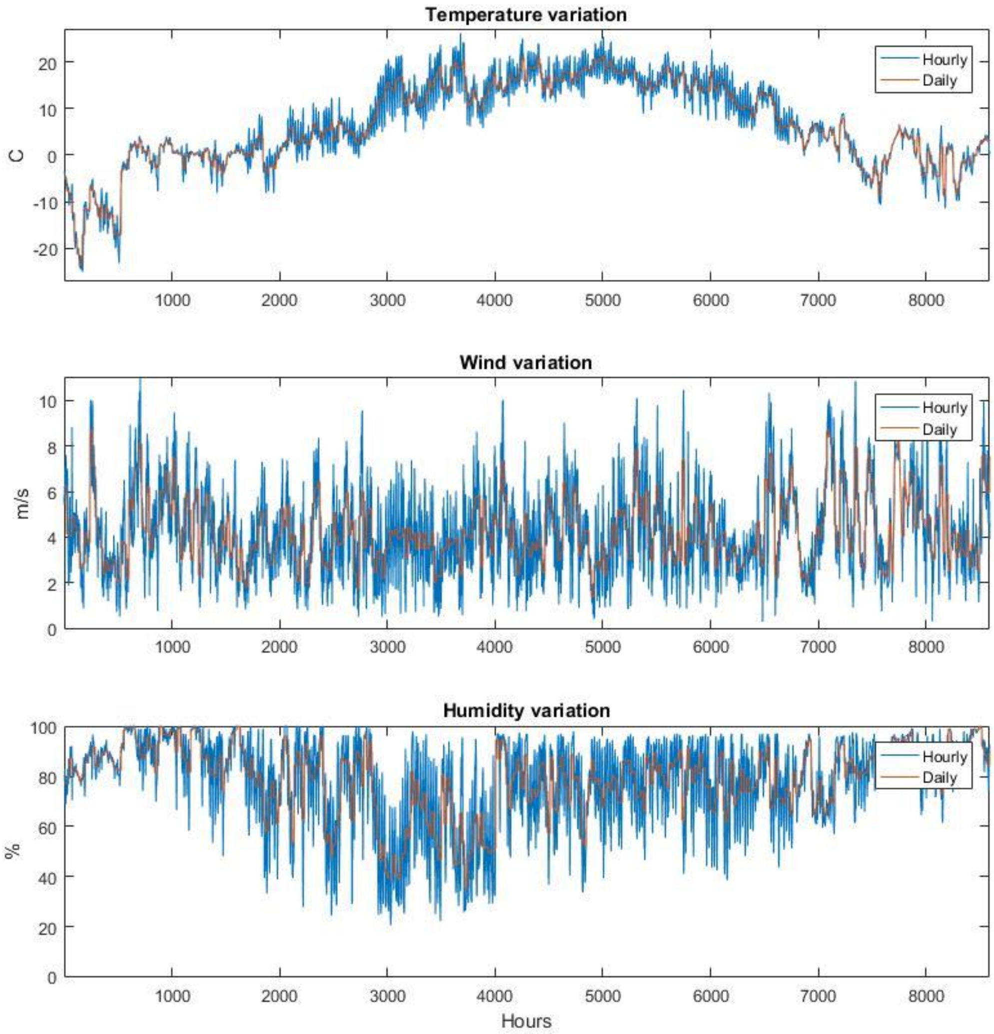
Another important information is to see how snow and rain vary on hourly and daily level (Figure 5). The average snow presence does not vary a lot between hourly or daily basis as observation were being on snow coverage and not snowfall. If temperature is under zero, then the snow coverage will stay the same throughout the day. However, the rain presence is varying a lot when looking at it in a daily basis or in an hourly basis. For example, it rained once every two days in Helsinki during the year 2016. However, it rained only 12% of the hours of 2016.

Figure 5: Presence of snow and rain in Helsinki on a daily and hourly basis



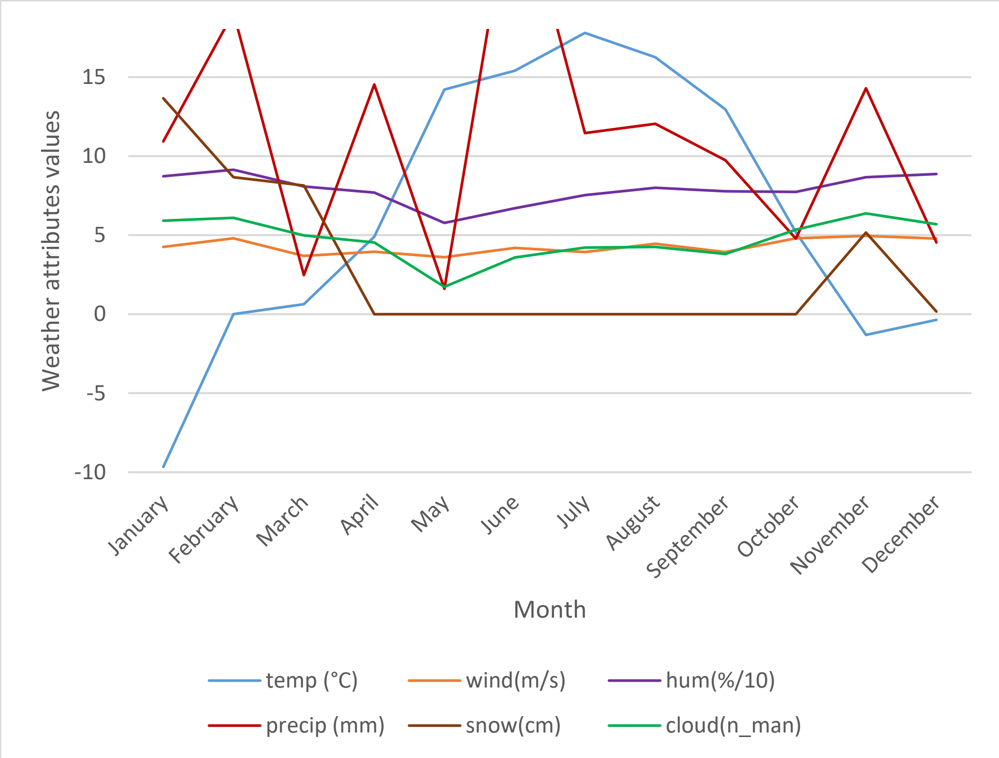
Therefore, hours and days give very different information. Moreover, the difference in variations for the temperature, wind and humidity between hours and days through the year 2016 is also very important (Figure 6). The variations between hours are very significant but when looking at it daily these variations are not seen. As the rain, the effect of some weather attributes may be over or under estimated while doing daily observations. It brings again the use of looking at influence of weather in an hourly level, as the precision will be higher.

Figure 6 : Variations of weather attributes through 2016 on a daily and hourly basis



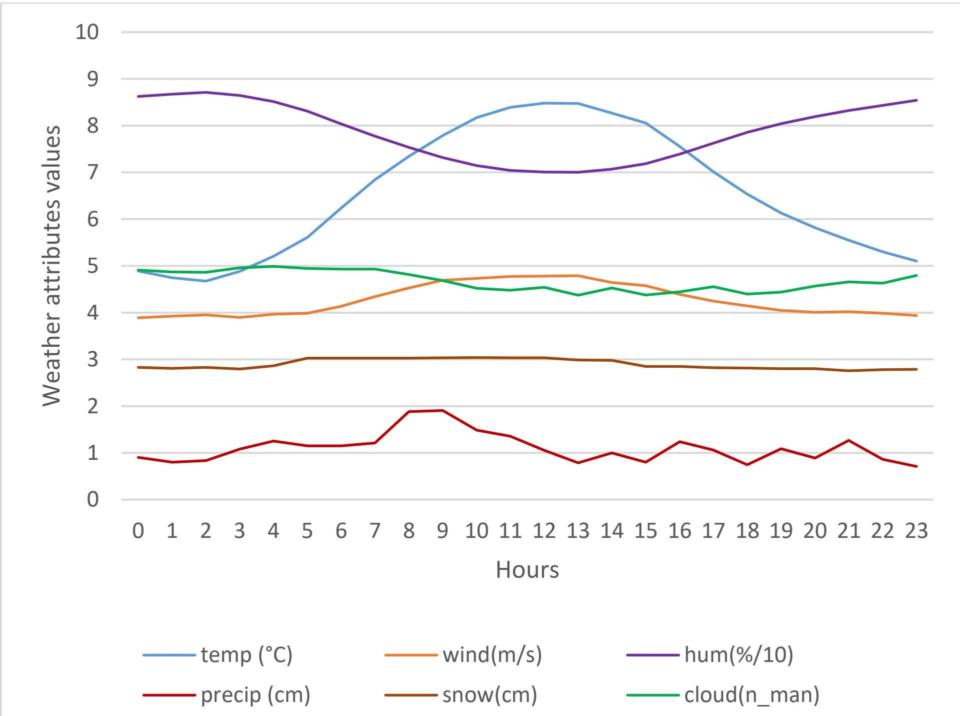
As we showed, weather attributes vary through hours and each day. The average daily weather attributes per month, Figure 7, shows also how much depending on the month the values change. Temperature change as its value is at -10 degrees was the average daily value in January compared to 18 degrees in July. Snow only appears in cold month as expected. However, humidity also varies a lot, between a 57% daily average in May to 91% in February. In addition, precipitation change a lot, the amount of rainfall moving through every month.

Figure 7 : Weather attributes values depending on the month



Moreover, the average weather attributes value depending on the hours shows also some significant variations sometimes (Figure 8).

Figure 8 : Weather attributes values depending on the hours

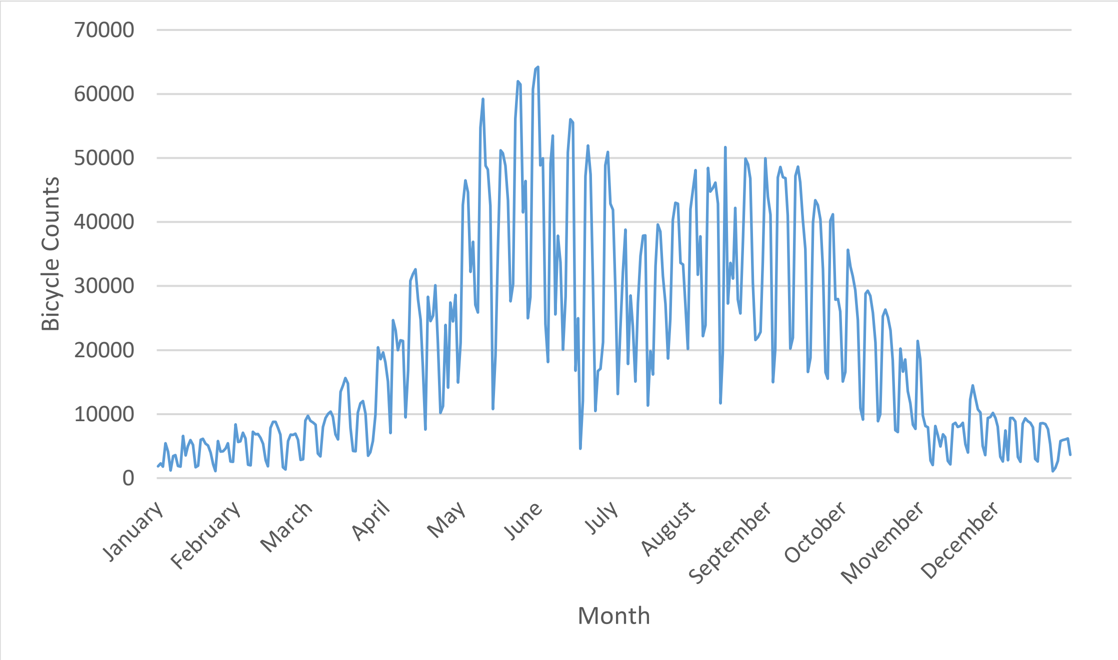


III-1.3 Automatic Bicycle Counter data

The ABC data had a total of 7 662 596 bicycle counts for the year between the 1st of January 2016 and the 31st of December 2016.

Now if we look at the daily variations of bicycle counts during all the year, Figure 9, some clear patterns can be observed. The winter season seems to greatly affect biking as it was indeed presented with the bicycle barometer. We can also see a decrease important of bicycle counts during summer, which correspond to the month of July. This is most certainly due to holidays as people leave Helsinki and thus the number of people biking is reduced.

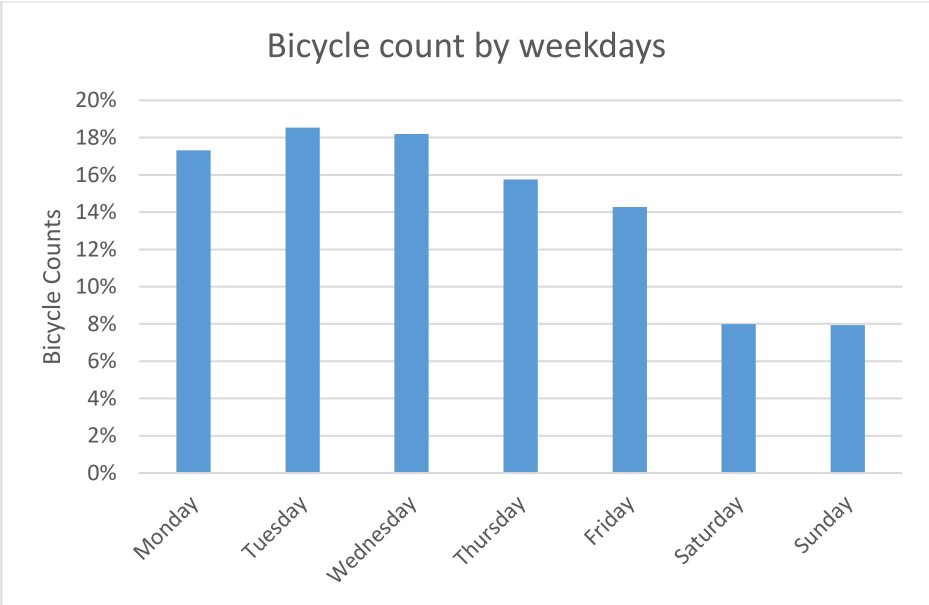
Figure 9 : Automatic Bicycle Counter Data by days through 2016



This variation may bring some problems while studying the variations of bicycle counts due to weather attributes. Of course during winter, we saw that the ABC decreased and that it is most likely due to the cold temperature of these days and the presence of snow. However, in July the decrease of bicycle counts is most likely due to the holidays as temperature is at its highest during this month. The impact of high temperature may thus be under estimated, as it will be linked with decrease of bicycle counts.

In case of weekdays, a clear difference can be seen between working days and weekdays (Figure 10). The bicycle counts during weekends represent 16% of the total bicycle counts. Every weekday has nearly twice as much bicycle counts as in Saturday or Sunday's. These difference between weekdays and weekends are most likely due to the two types of cycling that were identified part I: recreational cycling and commuter cycling (people using bicycle to work or to go to school).

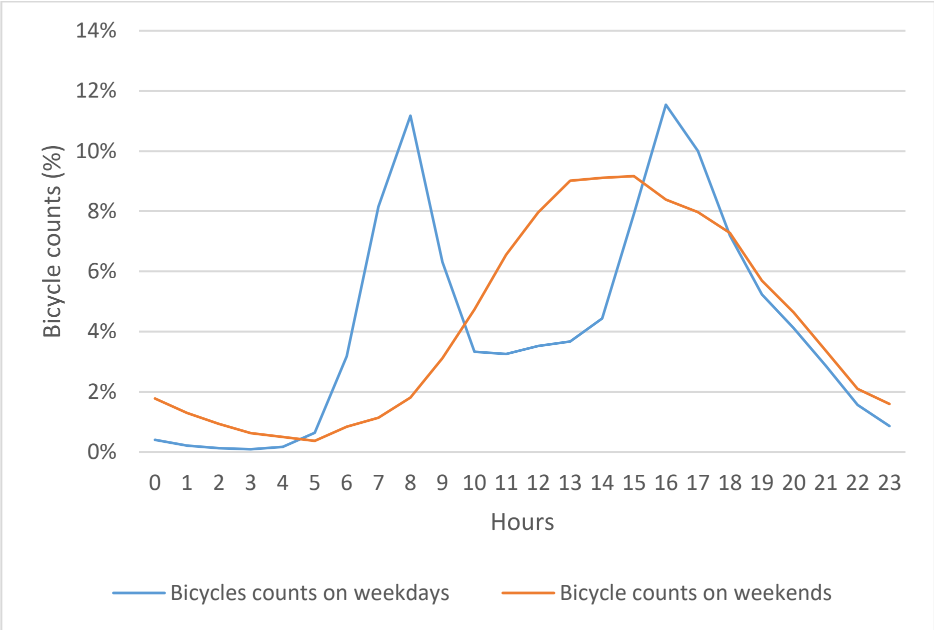
Figure 10 : Automatic Bicycle Counter data depending on the days of the week



To have a better understanding of the variations of ABC, the bicycle counts depending on the hours and by separating the weekends from the weekdays is observed (Figure 11). We see that some group hours can be made. During the weekdays, the 2-big increase are most likely related work/school departure and returns (similar to the commuting cycling in the daily analysis). We also see that during night time the use of bicycle drops considerably. Hours in between these two groups have also a significant use of bicycle. The weekend ABC data seems to have a group hour in the middle of the days, between 11 and 18, where the Automatic Bicycle Counts variations between hours is low (similar to the recreational cycling in the daily analysis).

What is observed is that by looking at bicycle counts in an hourly level, the variations between hours is too important and there is a need to separate them if we want to look objectively at the influence of weather attributes on bicycle counts.

Figure 11 : Automatic Bicycle Counter data depending on the hours, weekends and weekdays

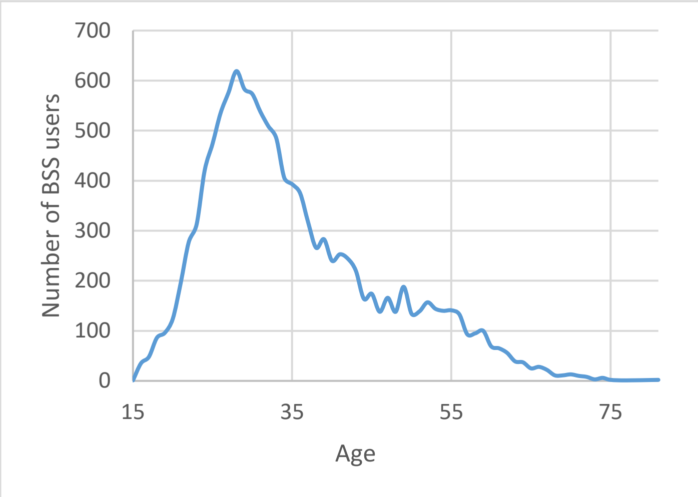


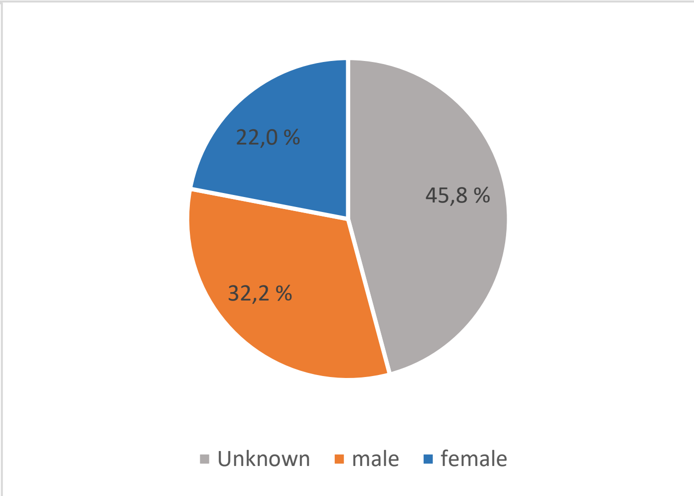
III-1.4 Bicycle Sharing System

To analyze the BSS data, cleaning had to be done. In the data that was received, the trips under 60 seconds or under 200 meters were not taken for example as this time or duration is not enough to go from one station to another. These trips were thought to be a change of heart of the bicycle user, who put back the bicycle, or misinformation from the system. Trips going to or from stations that were not the 50 original stations (station numbered after 900 were maintenance stations, which were used by the BSS worker's) were taken out also. Finally, all trips who had user with a formula different from day, week or year were deleted, as they are not bicycle users but people working for the BSS. In the end, the BSS data had 354 251 trips counts and 13 189 users.

Concerning the social information on BSS users, they seem to be in accordance with the information published in various articles about bicycle users. The average age is young adults and people using BSS seem most likely to be males (Figure 11). However, because 40% of the users who did not put their gender and some information concerning the age (above 100) were false, representing almost 10% of the information, the result may vary.

Figure 12 : Age and gender of bicycle sharing system users



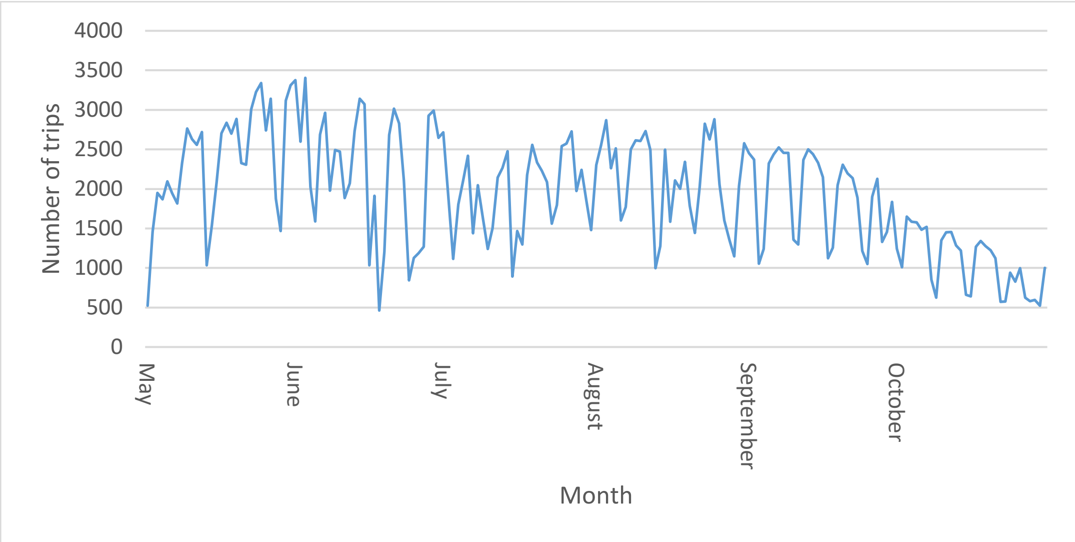


To resume other information concerning the users of BSS, it was surprising to find that even though 79% of BSS user had a year formula (14% daily formula and 7% a week formula), near 40% of BSS users used the system for only four days (20% for just one day). Moreover, 60% of the users took the BSS for less than 20 trips (9% just for one trip) (see annex B). It seems that while most of BSS user's registered for a season account, their use of the BSS system was limited.

Now we will look at the variations of BSS trips and compare it to the variations of the ABC data. The time during which the BSS is opened in Helsinki will be called the "summer" period even if it is not exactly the summer time. As we look at the bicycle counts during the "summer" period, the number of bicycle counts is reduced to 6 0199 228 bicycle counts which represent 78% of the total number of counts. As this period is lasting 5 months, it shows how much people reduce or stop their use of bicycle during colder month.

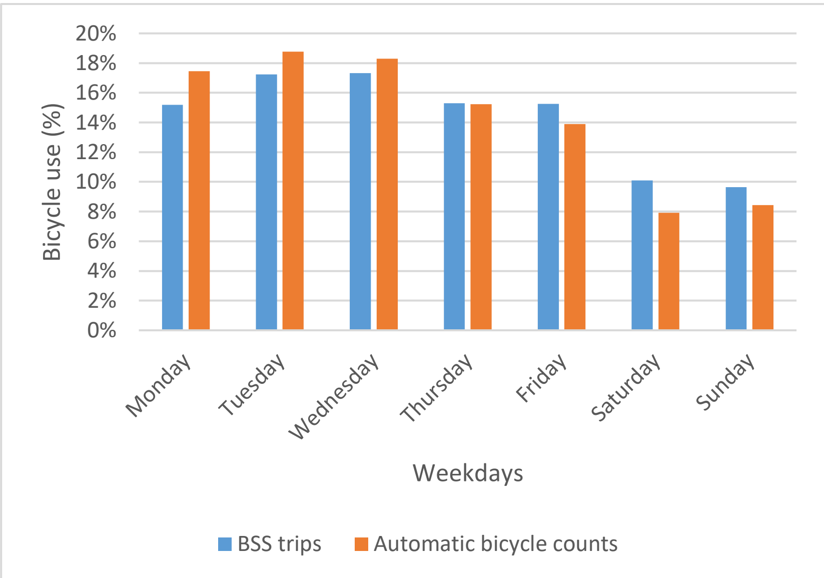
Now if we look at the daily variations of bicycle trips through the days, Figure 13 , the variation of BSS data regarding trip counts by day is somewhat similar to ABC despite different spatial locations. The difference between weekdays and weekends are obvious. There is a decrease of the use of the BSS between June and July and afterwards, between July and August, a small increase. Then, as the winter season approach, the numbers of trips are reduced significantly.

Figure 13 : Bicycle sharing system data through by days through season 2016



If we look at the variations depending on the days of the week, we can see that BSS trips are less influenced by weekdays then ABC (Figure 14). The number of BSS trip's during the weekends correpsond to approximatively 20% of the total number of trips. The variations of trips between weekdays is also less significant then for the ABC data. Thus there seem to be, for the BSS user's, a more equal use of bicycle between recreational and commuting activities even if difference between these two types are still important.

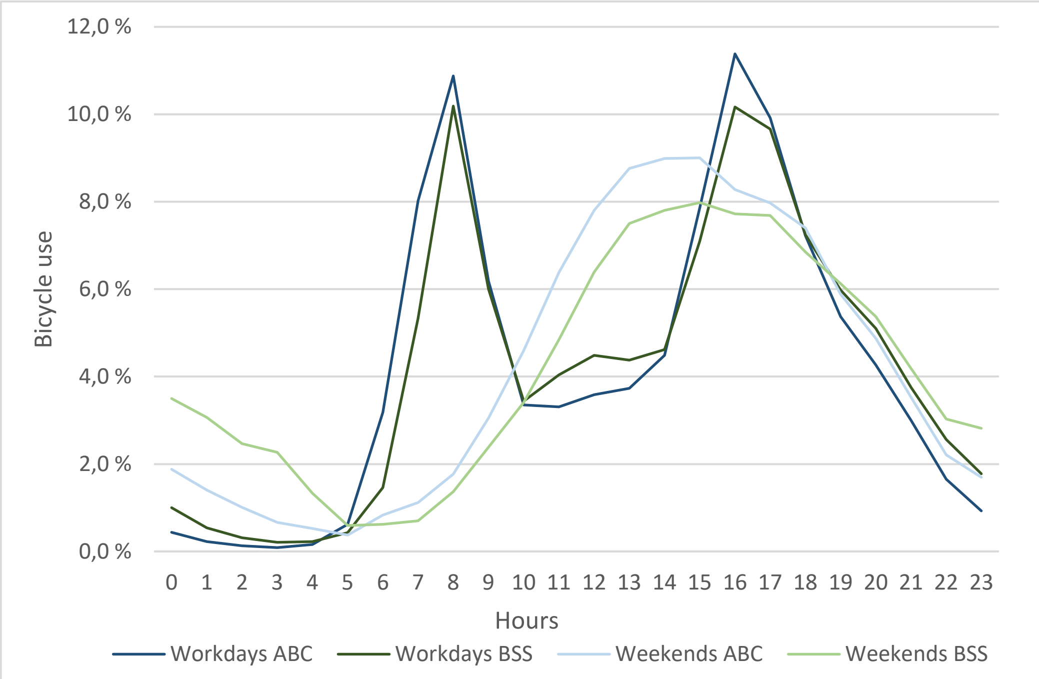
Figure 14 :Bicycle use in "summer" period for the two datasets depending on the weekdays



Concerning the variations of bicycle use depending on the hours, weekdays and weekends, (Figure 15) we see that variations of ABC and BSS are mostly the same. The observations for the 2 datsets during the ”summer” period” are the same as the ones for the all year for the ABC dataset : different group hours can be seen such as rush/peak hours, night hours and recreational hours.

When comparing the two dataset, during workdays and weekdays, the variations between hours is almost the same for the two dataset. BSS however have less variations between hours.

Figure 15 : Bicycle use in "summer" period for the two datasets depending on the hours, weekdays and weekends



III-2 Analyzing the data

III-2.1 From linear analysis to GLMs model: the negative binomial model

In order to analyze our data, it was decided to use the negative binomial regression. To explain the choice of the method it seems necessary first to explain briefly the concept of General linear models and Generalized linear models.

The general linear model describes the relationship between dependent variables, the ones we wish to analyze (e.g. the use of bicycle), and independent variables (e.g. temperature), the ones that we assume explain the variations, as a linear relationship. The equation that could explain this model could be defined as:

$Y = X * \beta + \alpha * r$ with:

- $Y = (y_1, y_2 \ldots y_i)$, y_i representing the i-y dependent variable, also called the predicted variable
- $X = (x_1, x_2 \ldots x_i)$ x_i representing the i-x independent variable, also called the predictor variable
- $\beta = (\beta_1, \beta_2 \ldots \beta_i)$, β_i representing the i-β coefficient related to i-x
- $\alpha = (\alpha_1, \alpha_2 \ldots \alpha_i)$ α_i the i-constant, representing the value of Y when x is null
- $r = (r_1, r_2 \ldots r_i))$, r_i the i-error of the predicted value

So if a linear relation between Y and X was made, an increase of X by one would have for consequence an increase of Y by β. First important thing to know is that β explain the variation of the dependent variables based on the units of the independent variables. Therefore, if the unit is modified (e.g. from cm to m) than the coefficient will change also. Another important information is that the independent variables X can be categorical (e.g. if it is a rainy day or a rainless day). In order to use the General linear model, different assumptions have to be made:

- There is a relation linear relationship between each dependent variable and each independent variable when all other variables are fixed.
- The residuals (or residuals) have a normal distribution
- There is a homodescaticity concerning the residuals, which means that the residuals should not be more important for a certain category of values then for another.
- The independent variables must be uncorrelated.

However, a general linear model is not appropriate when the range of Y is restricted or if the variance of Y depend on the mean. As we are looking at the bicycle counts of the ABC data or the number of trips of the BSS data, these observations are restricted, as they cannot go under zero. Thus, the model that will be use is an extension of the general linear model and will be one of the Generalized Linear Model (GLM).

One of the main difference is that, for the GLM, there is no need to have a linear relationship between the dependent variables and the independent variables. A function is thus added in the model, called the link function and named g, which transform the independent variables. The expected response variable, $\boldsymbol{\mu}$, (which is the mean of the response of all dependent variables with the same independent variables coefficient) of the distribution will then be

$$E(Y) = \mu = g^{-1}(X * \beta + \alpha)$$

With Y, X, β α defined as in the general linear model. If g were the identity function then we would find the general linear model again. In our case, we will just have one dependent variables (the bicycle counts or the trip counts) but we will have multiple independent variables (e.g. temperature, snow). The GLMs have fewer assumptions than the general linear model as the residuals do not have to be normally distributes and there is no need for homodescaticity of the residuals. However, the predicted variables must be uncorrelated to each other and the dependent variables must be independently distributed. (Mann, Larsen, and Brinkley 2014) .

Now in order to analyze counts data, two main models are suggested to be used mostly: the poisson model and the negative binomial model (Hara and Kotze 2010; Fox 2008). The two models have the log as a link function. However, to use the poisson regression the response variable needs to have a poisson distribution, which implicate that the mean and the variance must be the same. If we look at the distribution of the bicycle counts through the year, we have a mean of 20 936 and a variance of $2.63*10^8$. Therefore, the poisson model cannot be used.

The negative binomial regression is a sort of generalization of the poisson model. Hence, the over-dispersion of the data is assumed, which mean that the variance of the dependent variable can exceed the mean without any problem. In consequence, the negative binomial model can be chosen to analyze the variations of bicycle counts depending on the weather attributes. The link function of the negative binomial model is the log function.

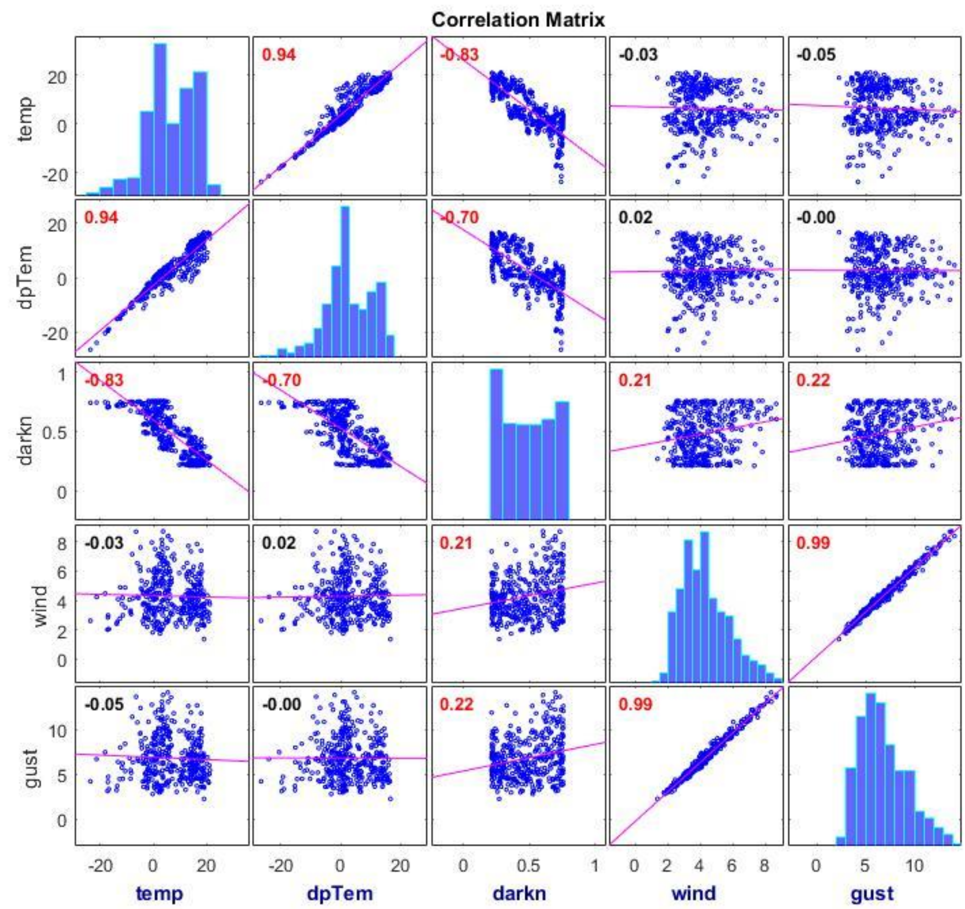
While modeling the data, the β coefficient, the t-value, p-value and R-squared value will be given. The p-value indicates whether the variables are significant. There is no absolute values but articles and scientist in general choose either a p-value of 0.05 or a p-value of 0.1 (if the p-value is under these numbers, then the variable is said to be significant). The t-value is the estimated coefficient divided by its own standard error. It is used to test if the true value of the coefficient is not zero. Normally a t-value above two is considered enough. In addition, the R-squared value inform how much does the model fit the data: a R^2 of 1 means that all variations on the model are explained by the dependent variables and their coefficient.

III-2.2 Verification of the model

Now to apply the negative binomial model, all variables need to be uncorrelated to each other. The hypothesis was to leave out variables that had correlation above 0.7 (the value 1 meaning that the two variables are identical). The value 0.7 was chosen in an arbitrary way while looking at the plots between weather attributes. The variables, which had correlation above 0.7 are: temperature with dew-point temperature and darkness, wind with gust (Figure 16). The choice here was to take the temperature and the winds as variables over dew point temperature and gust as their evolution are easier to understand. In addition, temperature gives more information than darkness so the variable darkness was left out. All other correlations between the different variables were under 0.7 (see annex C).

Concerning the independency of the predicted values between them, we assume that it is the case even if it is not perfect for the ABC data and the BSS data. Indeed, as said before, the ABC data represent the bicycle counts in 15 different locations of Helsinki. Therefore, it is possible that one-bicycle trips represent multiple bicycle counts in different places. Equally, for BSS and ABC data, it is likely that people are not just having one trips but also the return trips, especially concerning the workdays.

Figure 16 : Highest correlations found between weather attributes



While applying GLM, one needs also to assure that the model does not overfit the data(Fox 2008). It is possible that the model explains perfectly the variations of the dependent variable. However, some results may be just fitted for these observations and when trying to use the same model, for the same place but a different time, then the results would be very different. As we said in the beginning of section III, the results will always differ given a certain time. However, it is still expected to see some similar results in a small-time period (few year) otherwise there is no point in observing a model which can change every day. One solution to avoid the overfit problem is to divide studied dataset into two datasets: training and testing datasets.

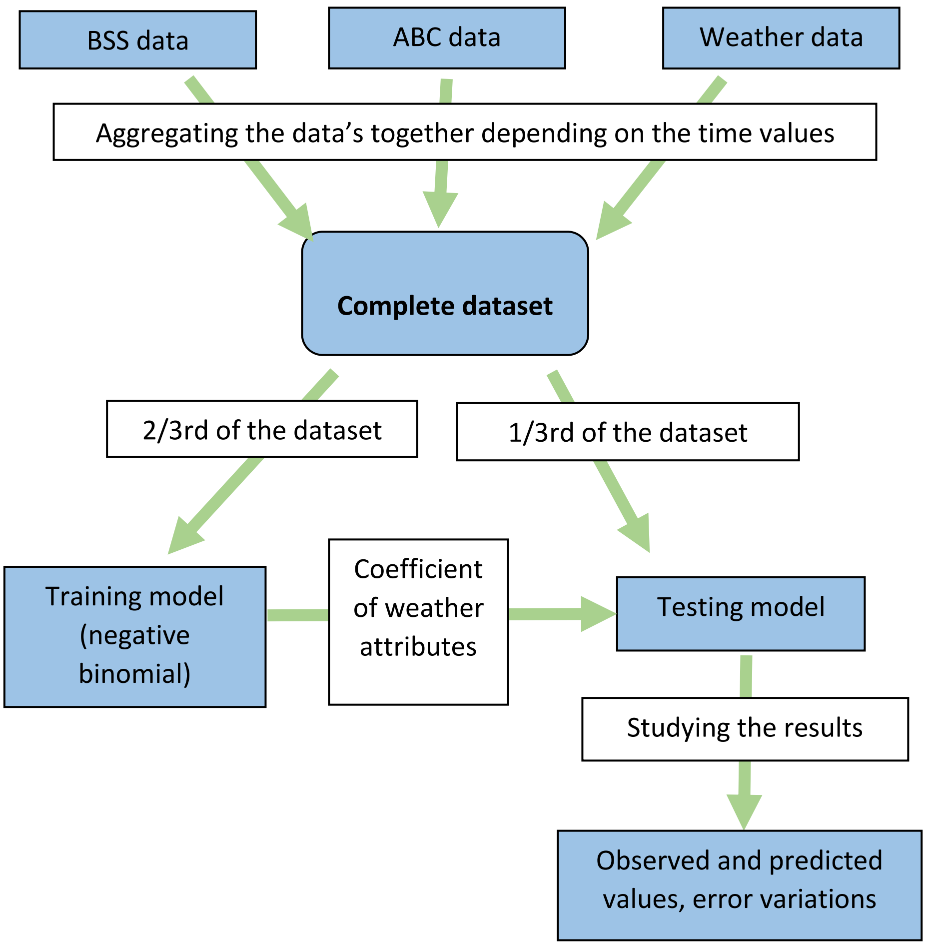
For one of this group, the training dataset, the negative binomial model will be used and the result will give the training model. Then, with the coefficient of the variables given by the training model, we will try to predict the values for the dataset that was not used. The result of the prediction of the values will be called the testing model. Afterwards we will compare these predicted values to the observed values.

To compare the predicted values to the observed values, we calculate the variance of the error for each observation and see how close the predicted values are to the observed values. The variance of the error here will be calculated as:

$$Error\ Variance = \left(\frac{Predicted\ Value - Observed\ value}{Observed\ value}\right) * 100$$

In order to have a minimum of data to run the negative binomial model, two third of the dataset will be used for the training model and one third of the data will be used on the testing model. The flow chart presents the approach which is applied in this study (Figure 17).

Figure 17 : flowchat picture of the methodology to analyze the influence of weather attributes on bicycle use



III-2.3 Statistical analysis

One of the aim of this essay is to propose a different point of view to the study of weather attributes and bicycle use by analyzing the effect of weather attributes with a new type of data, the novel data. BSS data is already used but still recent and the ABC data, collected in an automatic way all over Helsinki is also very recent and has only been studied in Helsinki by a group of students[28] and on the official barometer of Helsinki to the knowledge of the author. These types of data are rarely used when analyzing bicycle attributes.

These new data sources are very interesting as they consider a lot more bicycle trips than the survey data, which give information about a few hundred or thousands of people. The information may be considered as more accurate also as that we directly see if the number of bicycle trips are reduced during rainfall, whereas in a survey the person may declare that weather don't affect his use of bicycle while it may unconsciously.

The effect of those weather attributes will be analyzed on a daily level, separating weekdays and weekends, but also on an hourly level, whereas most studies concerning weather and bicycle are done on a daily one.

Though, as we saw, bicycle's use dependence on the hour is very important. So, in order to limit its influence while modeling the data, different group hours will be made, putting together the hours who seem to have the same activities and the same share of bicycle trips or counts. These group hours were made based on the interpretations of the observed data, the articles analyzed and on personal observation through the time living in Helsinki.

The hours were divided into 3 groups during the weekdays: the rush or peak hours, between 7 and 9am and between 4 and 6am the recreational hours, between 10am and 3am and between 7 and 9pm, and the night hours between 10pm and 6am. The hour 8am, with 11.2 % of bicycle counts though the weekdays (10% for the BSS data), which had one of the highest bicycle counts, was also analyzed in a separate model.

Now for the weekends, the hours were separated into three groups also: the leisure hours, between 11am and 7pm, the late and morning hours, between 7am and 11am and between 7pm and 1am, and finally the night hours between 2am and 6am. The hour, which has the most bicycle counts (and BSS trips), is also analyzed separately. It was the hour 3pm and had 8 %, respectively 9%, for the ABC counts, respectively for the BSS trip counts.

For each of these studies, the negative binomial model was found to be the best model to use. A comparison will be made between the uses of bicycle to see how much bicycle's use on weekdays are involved in a different way by weather attributes than bicycle use on weekends (daily and hourly level).

[28] Source : http://www.kaupunkifillari.fi/blog/2015/03/04/pyoraily-on-arkista-touhua/

The objective of the hourly level, is to see if having a more detailed precision on the data will give better results that are more interesting or, on the contrary, if the precision of the data brings more variations and thus more errors. This hour analyses will permit to look at other theories (e.g. bicycle uses during peak hours, the difference between leisure hours). Articles showed that weather conditions had less influence on people during peak hours (sometimes called working hours) than on leisure hours (sometimes called recreational hours) (see section I-3). By looking at the variation of bicycle use during these group hours, we could make uphold this assumption.

Concerning the timetable, the ABC data will be analyzed for the year 2016. However, while comparing BSS and ABC data, the time table will be the length of the BSS, called the “summer” period as it was said before. The number of bicycle counts and the number of trips by BSS will be looked in daily and hourly time period. Some social data for the BSS system are available but will not be useful as we aggregate the trips together in an hourly or daily based for the model in order to compare with the ABC data. The other reason is that the knowledge to add these social data while aggregating trips by hours and days is not known by the author of the essay.

Weather attributes will also be transformed into categorical variables. The aim is to observe the impact of weather attributes depending on its value: do snow coverage on the ground reduce the use of bicycle counts for each cm of snow going or is there a limit afterwards the number of cyclists are not reduced anymore? In short, do every weather attribute have a linear impact on bicycle use.

While running the models, different weather attributes were found to be insignificant for all models such as Pressure, Visibility, direction and WDCode. In consequence, these variables will not be shown on the next section as the models were run again without considering them. The attribute Clouds was found to be significant also but only when humidity was used as a variable also. Therefore, the correlation between humidity and clouds, even if under 0.7, created some problems and these two variables could not be put into the same model. As humidity had real units, whereas clouds had subjective values, humidity was kept instead of clouds for daily and hourly analysis. However, clouds will be looked at when making categorical models to see its influence.

Finally, the negative binomial uses a log transformation on the variables. So, the impact of each variables is shown not by the Beta coefficient directly, but by the exponential of the coefficient and deducing one from its value. This value will be called the **Ecoefficient** and will be the value used when comparing the weather attributes between them from different model or for different categories of a weather attribute in the same model.

For example, an increase of one degree will have for effect an increase on bicycle use of 6.3% : $e^{0.061} - 1 = 1.063 - 1 = 0.063$.

IV- Empirical results

Based on the methodology explained section III, the performance of different models will be analyzed. Afterward, a comparison between time period (e.g. weekdays/weekends, group hours) and data sources (Bicycle Sharing System (BSS) and Automatic Bicycle counts (ABC)) will be made.

IV-1 Weather influence on cycling at daily level

IV-1.1 Weather influence on cycling at daily level all year period

Table 6 represents the ABC model for the weekday analysis. Now as was said in section III-3, the negative binomial uses a log transformation on the variables. Therefore, to look at the influence of each weather attributes, the value called Ecoefficient will be looked at.

In this model, an increase of the speed of wind by 1 km/h has for consequence a decrease of the use of bicycle by 8%. The increase of snow on the ground by 1 cm reduce the use of bicycle count by 2.4% and an increase in humidity by 1% decrease the use of bicycle counts by 1.3%.

Table 6 : Automatic bicycle counter daily training models all year

	Weekday training model		**Weekend training model**	
Parameter	*B*	*t-value*	*B*	*t-value*
(Intercept)	10,933*	60,0	10,372*	35,3
temp	0,061*	17,5	0,080*	16,3
wind	-0,083*	-4,9	-0,141*	-6,0
snow	-0,024*	-5,0	-0,025*	-3,5
hum	-0,013*	-6,0	-0,014*	-4,5
precip	-0,002*	-3,0	-0,010*	-3,8
R^2	0.84		0.91	
Observations	172 days (4 285 722 biycle counts)		69 days (751 648 bicycle counts)	

- : p-value under 0.05

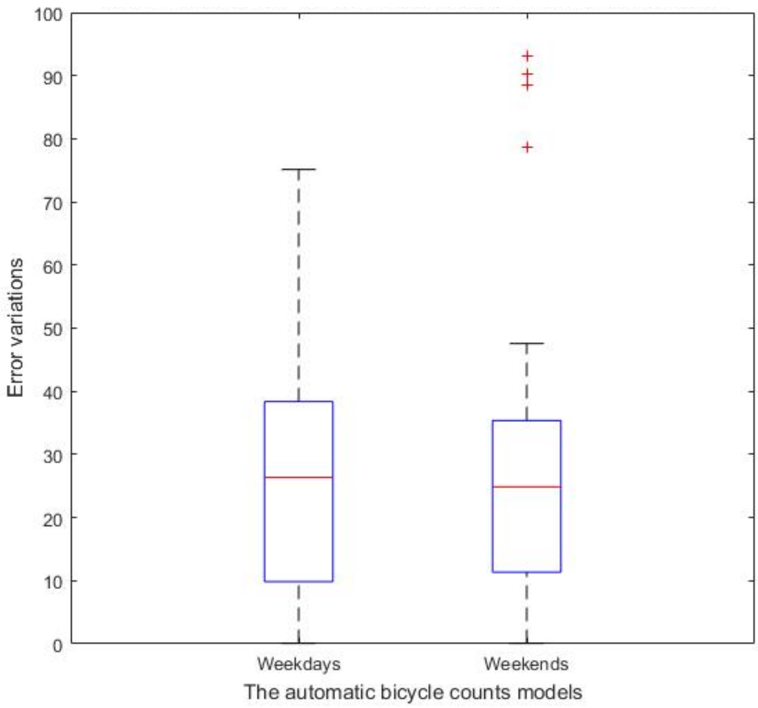
Now these values must be analyzed very carefully as their representation are not the same. Indeed, just by looking at these values, it may seem that that wind is the weather attribute with the most important impact on bicycle use. However, wind varies from one to 9km/hours whether temperature varies from -10 to 25 degrees. Now If 20 degrees was taken as the reference, by looking at the variations with a day where the temperature was -5 degrees, it would mean a decrease of 78% of the number of bicycle counts.

For the wind, a day with a wind speed of 1km/h compared to a day with a wind speed of 9km/h (maximum of daily wind value, see section III-1) represents a decrease of 53% on bicycle counts, which is significant but less than temperature's influence. Regarding the rainfall, knowing the average precipitation on a rainy day is 23.08 mm, it would have for consequences an average decrease of the number of cyclist by 5.4%. Of course, this result is a less significant than the one resulting from temperature or wind variations, but as it rains once every 2 days in Helsinki, it is still noteworthy. And in the weekend training model the precipitation impact is a lot higher which bring the average rainfall days in weekends to reduce the use of bicycle counts by 19,7%.

Concerning the humidity level, as its value goes from 35 to 100%, the number of bicycle use would be reduced by 57% between these two daily extreme values. Knowing that humidity value is high may have for consequence that rain will fall and high humidity is also correlated with clouds. In consequence, if there are lots of clouds or if the probability of raining is high, the use the of bicycles will be reduced compared to a sunny day.

The boxplots of the error variations for the testing models, (the high valued outliers are not shown as they are would make the figure non-readable) show that for the weekdays testing model, half of the errors are under 25% and ¾ of the error are under 40%, Figure 18. The boxplots for the error variations of the testing weekend model is even better with the 3rd quartile near 35% and the higher whiskey under 50%. However, this difference in precision may be due to the high outliers that were observed in the weekday's model.

Figure 18: Error variations of automatic bicycle counter daily testing models all year



Indeed, looking at the weekdays predicted values and comparing it to the observed values, Figure 19, the testing weekdays model appears to follow the variations of the observed Automatic Bicycle Counts. Nonetheless, some important errors (above 300% sometimes) happen.

These outliers occur mostly during the cold month, between December and March. All these outliers happen during either National holidays (6th of December is the independence day, 25th and 28th of march are public holidays as the 5th of May) or winter holidays (between the 28th of December and the 1st of January) .[29]

Between the end of August and mid-October is seems also that the testing model is underestimating the number of cyclist by more or less the same error. Therefore, it may be that the training model gave to one of the variable to much impact.

Now between March and August the errors variations are around, in absolute value, 10 to 30% except for July where it is around 50%. The fact that July has higher errors were expected, as July was a month with good weather attributes but a decline in the use of bicycle counts. As explained part III, the decrease of bicycle counts in July is most likely due to the holidays; finish people leaving the capital to go to their summerhouses or elsewhere.

By comparing the weekends predicted values to the observed values, Figure 20, the ABC testing model seems to follow the observations with few important mistakes. Six significant error were observed, which are above 80% in absolute value. Compared to the weekday training model, the predicted values of the weekend testing model can also be a lot less important than the one observed (in the weekdays model the important variations error were always positive).

These important error variations for the weekend testing model are not due to holidays for most of them (except 31st of December). There were some events on these days, which may explain the variation of bicycle counts, like the carnival food festival in January 31, or the coffee festival for April 24. However, must weekends have always some sort of event and it is difficult to see whether this event should reduce, increase or not affect the use of bicycle. These important errors are not explained as easily as those in the weekday's testing model are.

[29] Source : http://www.officeholidays.com/countries/finland/2016.php

Figure 19 : Comparison of automatic bicycle counts predicted and observed values on weekdays daily all year period (with error variations between the two models)

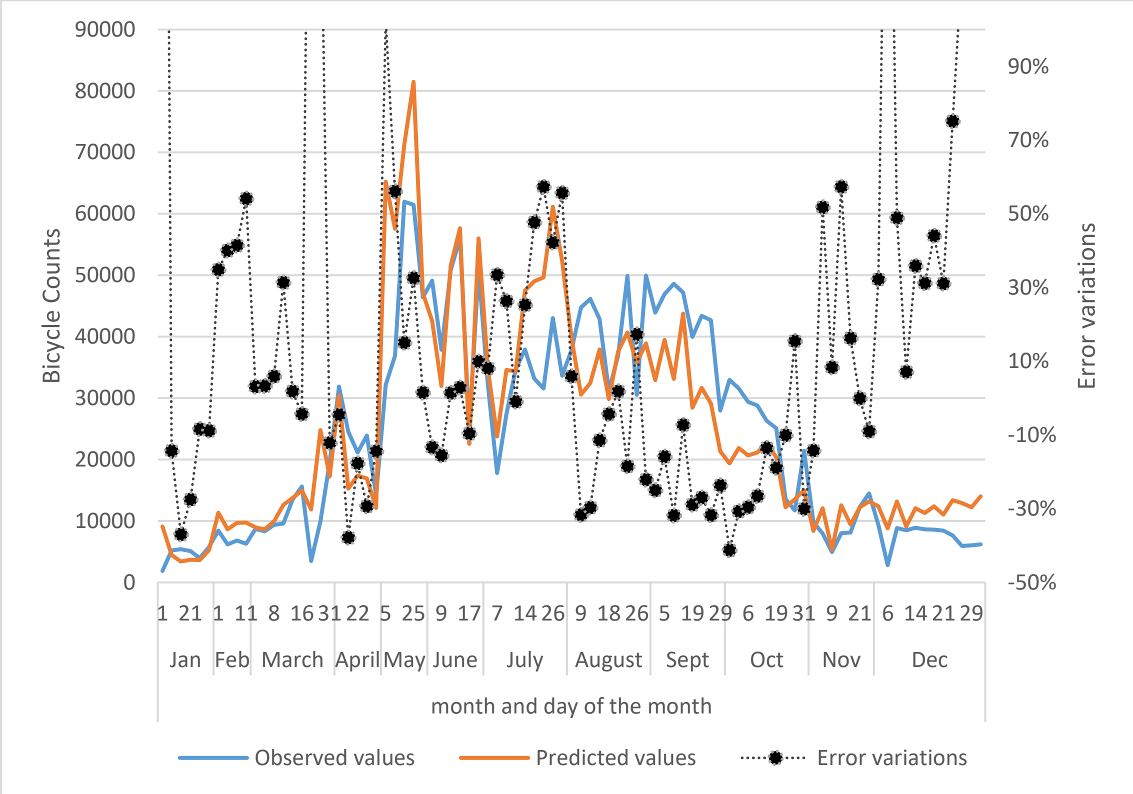
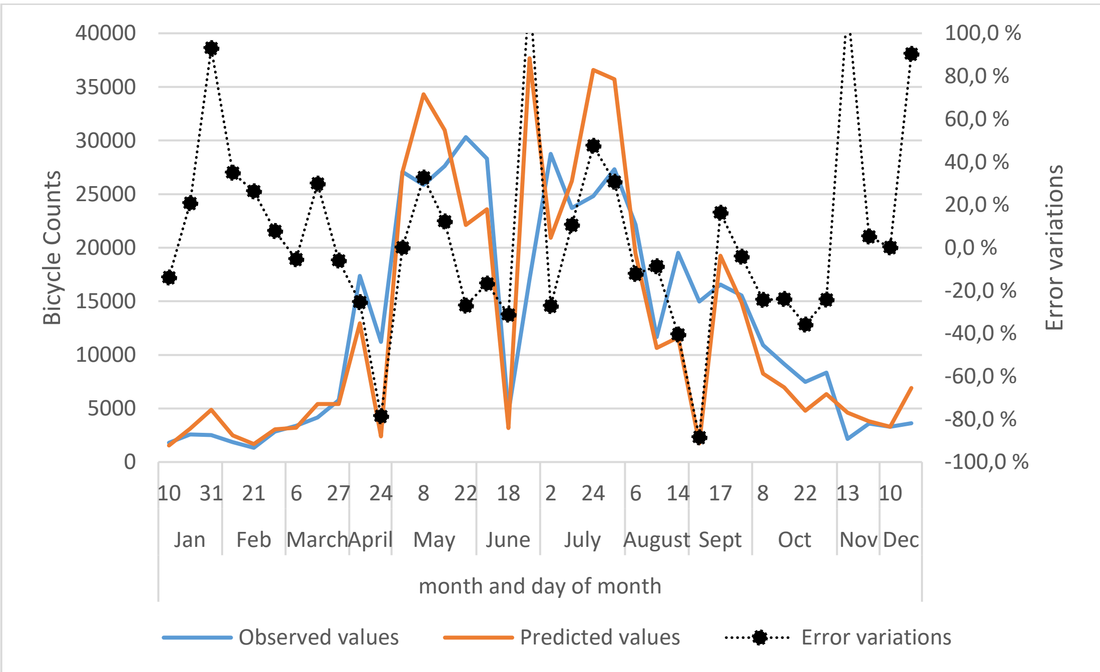


Figure 20 : Comparison of automatic bicycle counts predicted and observed values on weekends daily all year period (with error variations between the two models)



IV-1.2 Weather influence on cycling at daily level on “summer” period

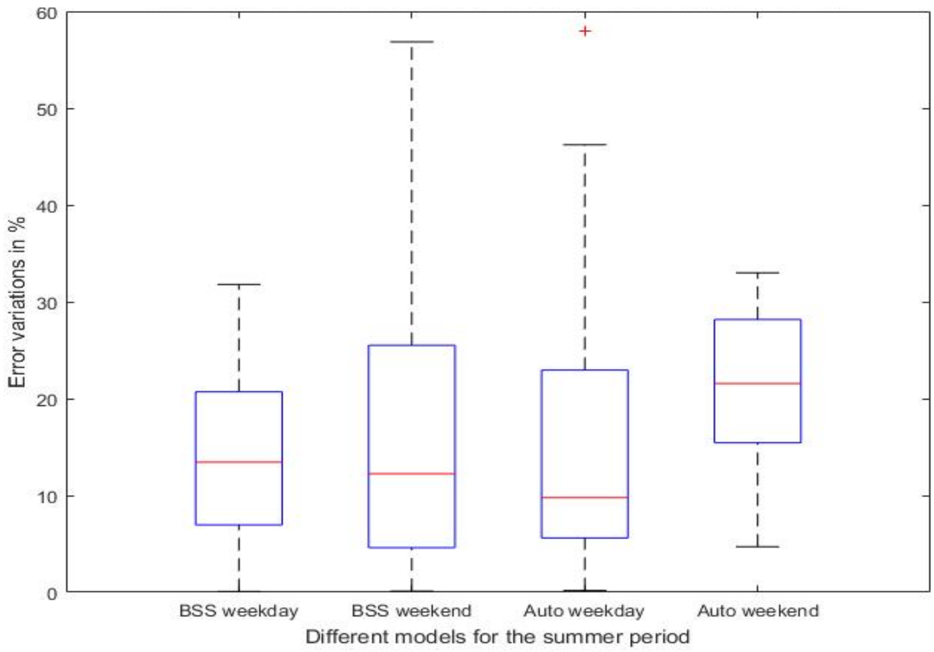
This section analyzes weather influence only during “summer” period. As said in methodology section III-3, “summer” period refer here to the time between May and October 2016, which is the time when the BSS was working. The training models for the BSS and ABC weekdays and weekend trips counts are Table 7. One of the surprising results when running the model was that the wind was not found significant for the BSS weekdays model. It seems that people using BSS during weekdays are almost not influenced by wind.

Table 7 : Daily training models for "summer" period

	BSS Weekday model		**BSS Weekend model**		**ABC Weekday model**		**ABC Weekend model**	
	B	t-value	B	t-value	B	t-value	B	t-value
(Intercept)	7,369*	36,3	7,712*	26,7	10,897*	53,0	10,393*	33,9
temp	0,047*	7,1	0,056*	7,2	0,034*	5,5	0,057*	7,1
wind	not significant		-0,063*	-2,9	-0,044*	-2,0	-0,087*	-3,9
hum	-0,005*	-2,0	-0,014*	-5,0	-0,009*	-4,1	-0,013*	-4,5
precip	-0,003*	-4,1	-0,004*	-2,1	-0,003*	-5,0	-0,006*	-3,0
R^2	0.47		0.775		0.546		0.778	
Observations	86 days (184 019 Bicycle trips)		35 days (47 366 Bicycle trips)		86 days (3 312 978 Bicycle trips)		35 days (648 159 Bicycle trips)	

The boxplots of error variations display that the weekend testing models are less precise than the weekdays models for the two data sources ABC and BSS (Figure 21). For the ABC weekday testing model, we see significant results with half of the errors variations under 10%. The fact that the error variations are more important for weekends model than weekdays may be due to the lack of data for the weekend models as just 17 days are used in the testing model.

Figure 21: Error variations of daily testing models for "summer" period



Now comparing the observed values to the predicted values, results seem indeed close to the observed values (Figure 22). There are not any huge error variations data except for the BSS weekday model on October 27, which has an error variance of 80%. When looking at the data it was the only day, in the testing model, where the wind has a speed above 7km/h. Therefore, it may be because the BSS weekday model does not consider the wind and in this particular day, due to very strong wind, the use of BSS is not as high as expected. We can see that most errors have a negative value (under estimating the number of BSS trips) except in July and in October. The error in July may again be due to the fact that it is the holiday month in Finland. However, the errors are not as important as the ABC data, Figure 23, as tourist may also come to Helsinki and use the BSS (few of them are likely to bring their own bicycles).

Concerning the automatic counts during summer period, the error variances are mostly the same as the whole year data when looking between May and October with even less errors. No important error variations are observed as they are all between -20% and 60%. The 27th of October does not have a high error variance (34%) compared to the BSS data so the lack of the wind as a variable may have been indeed the reason for the important error in the weekdays BSS model. The undervalued estimation of bicycle counts between end of September and October is not observed for the ABC summer testing model compared to the all year model.

Figure 22: Comparison of Bicycle Sharing System trips predicted and observed values on weekdays daily "summer"period (with error variaitons between these two models)

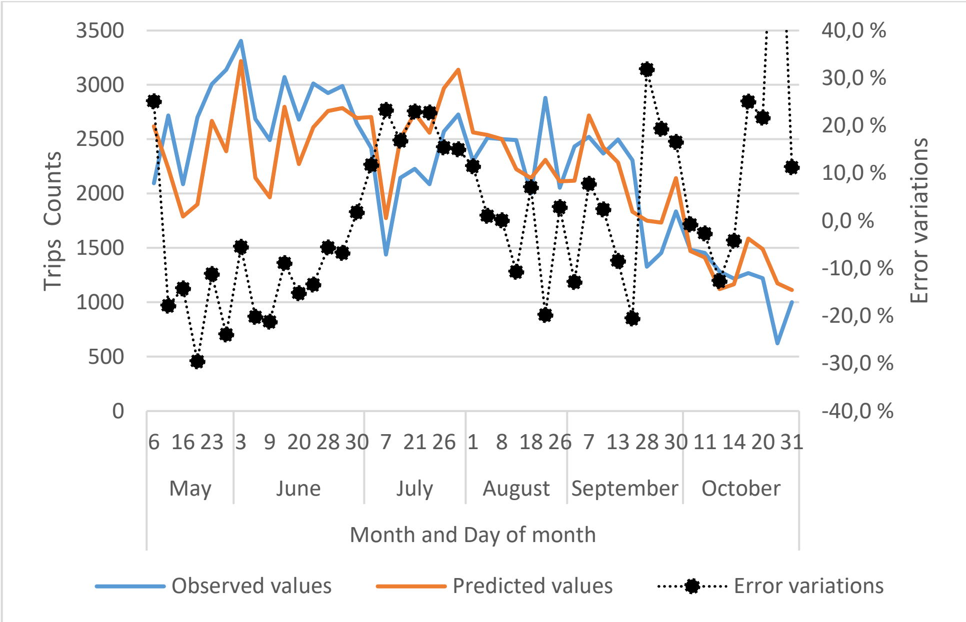
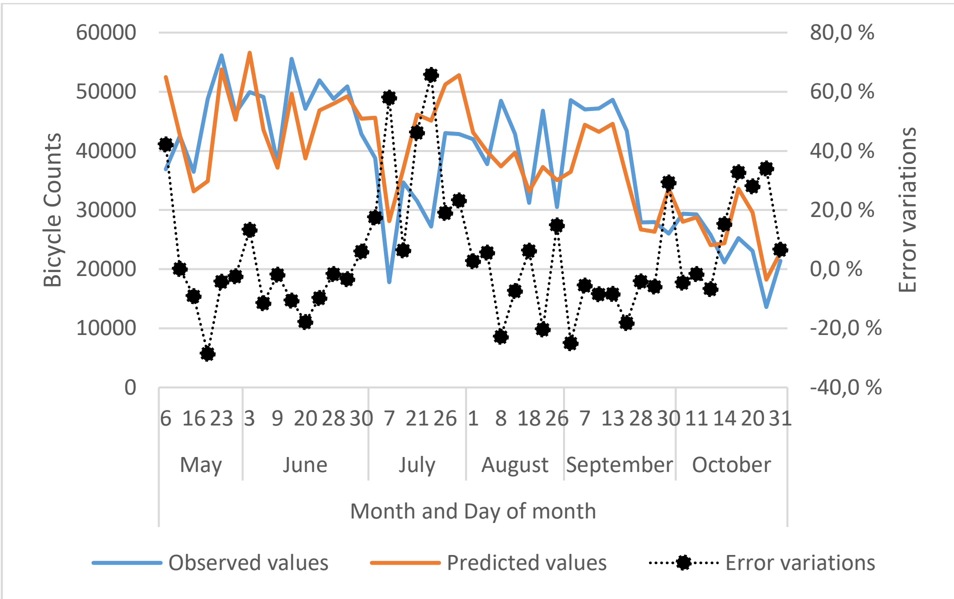


Figure 23: Comparison of Automatic Bicycle Counter data predicted and observed values on weekends daily "summer" period



Finally, the weekend testing models do not seem to have any pattern but they resemble each other (see annex D). Analyzing the errors of the different models do not give directly an answer about how weather influence bicycle counts. However, knowing that these models have low error variations mean that the weather attributes have a significant influence on the variations of bicycle counts. Knowing for the weekdays that half of the time the prediction will have errors under 26% (16% if you take just the summer time) is significant. Therefore, the results given by the model can be trusted.

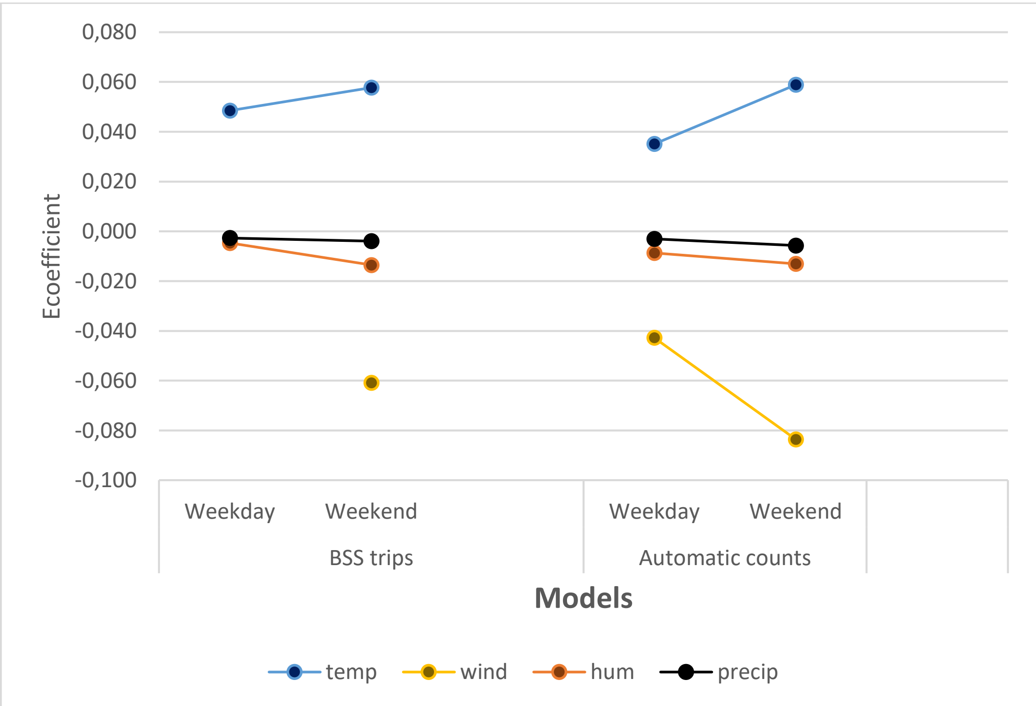
IV-1.3 Comparison of weather impacts on cycling at a daily level

The Figure 24 shows the influence of each weather attributes for ABC and BSS trips depending on the weekdays or weekends. The values are the Ecoefficient (refer to section III for explanation about Ecoefficient) Table 7. While observing these data's, we can see that during weekends, weather attributes have more influence than during weekdays. People using bicycle during peak hours on weekdays are less likely to be influenced by weather conditions as people using bicycle on leisure hours on weekends ('recreational' use). However, the variations are not the same depending on the weather variable.

For the BSS data, the wind does not have any influence during weekdays, as observed before, whereas its impact on weekend is still important with an Ecoefficient of -0.06. Another high variation is the Ecoefficient of humidity that goes from -0.005 to -0,014, which represent an increase of 190%. The precipitation's Ecoefficient have an increase of 30% while the temperature is the variable which influence does not have a significant change between weekends and weekdays with a small increase of 19% (0.048 from 0.058). Most likely, before using the BSS on weekends, people will check the weather conditions for the day.

For the ABC data, the wind and precipitation variable influence nearly doubles between weekdays and weekends with an increase of 95% and 87% respectively. Temperature and humidity have smaller variations as their Ecoefficient increase by 67% and 51% respectively. The difference in variations between weather attributes for weekdays and weekends are less important with the ABC data than with the BSS data.

Figure 24 : Comparison of weather influence on daily bicycle use on "summer" period



Finally, depending on the data set, the influence of weather is not always the same. On weekends, the variations of the weather attributes Ecoefficients between BSS and ABC are not very important. The highest variation between these two models is the precipitation's coefficient with an increase of its Ecoefficient by 50% for the automatic bicycle counts compared to the BSS trips counts (-0.004 from -0.006).

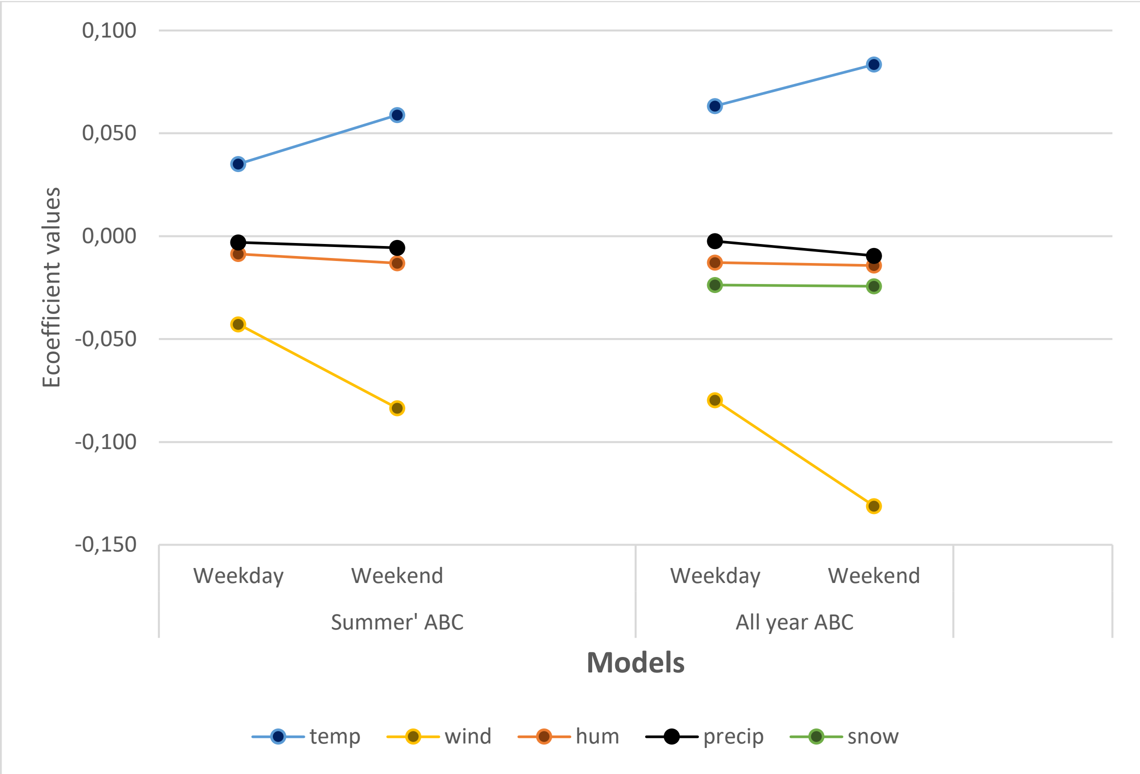
During the weekdays, the variations of weather attributes between models are more significant. The wind is not significant for BSS trips during weekdays for example but have an impact on automatic bicycle counts. The influence of the humidity is more important for automatic counts than for BSS trips and its coefficient nearly doubles (from -0.05 to -0.09).

To continue, let us observe the influence of weather attributes for the same dataset but different period, Figure 25. For the all year period, the influence of weather, like the summer period, is more important in weekdays then in weekends.

However, it is interesting to see also that most variations between weekends and weekdays are less important when considering the all year counts than just the summer year except precipitation, which coefficient triples between weekdays and weekends for the all year count (-0.02 from -0.09). As precipitation seems to effect less the bicycle users during winter time in weekdays, people who are still willing to use their bicycles during weekends in winter time may, on the contrary, be a lot more effected by rain then during summer time, when if it is warm enough then a little rain have less effect. All the other variations of weather attributes, between weekends and weekdays, during all year period are between 2% (which is the snow cover of the ground) and 65% (which is the wind).

However, the weather conditions have more influence in the all year counts than in the summer counts as their Ecoefficient are higher for all variables in weekdays and weekends except precipitation which influences decrease by 20% (-0.03 from -0.02). During weekdays, temperature and wind influence doubles on bicycle counts when looking at the ABC all year compared to the ABC summer and humidity influence increases by 50%. By comparing the weather attributes of these two models during weekends, precipitation, wind and temperature Ecoefficient increase by 50% for the ABC all year compared to the ABC summer whereas humidity coefficient stays nearly the same.

Figure 25 : Comparison of weather influence on daily bicycle use for automatic bicycle counter data on different period



It seems that during winter, weekdays and weekends are affected in a more similar way by weather conditions then during summer but weather attributes have a higher effect on bicycle counts than in summer, except precipitation. The difference between winter and summer is most likely the snow and the cold temperature. So one hypothesis may be that under a certain temperature, and/or with snowfall, the recreational and working cycling are affected in a similar way by weather conditions.

IV-2 Weather influence on cycling at hourly level

The weather attributes are now analyzed in an hourly level. As there are many different models, only the table of the models, the boxplots of error variance and the variations of the weather attributes influence between different models are observed.

IV.2.1 Weather influence on cycling on hours of weekdays

All year models

While modeling these group hours, some interesting results are found (Table 8). Humidity and temperature are significant for all models however, wind is not found significant for the model with just the hour 8am. As wind was not found significant for the BSS model already before, it seems indeed that wind influence on bicycle use during peak hours is not high.

The other interesting observation is that precipitation is not found significant for the recreational hour model and the night hour model. As it may be easily explained for the night hour model that precipitation do not have any influence due to small use of bicycle counts, the results for the recreational hour's model is surprising. As humidity and precipitations have some correlation, the model was tested without the variable humidity and precipitation was then found to be significant.

Different reasons may therefore be presented to explain the lack of precipitations influence. One reason may be that there is a lack of data concerning precipitation in hourly level (section III-1). Another reason may be that the relationship between precipitation and humidity make it impossible for the model to take those two variables into account at the same time. Another explanation is that during the recreational hours, people tend to look a lot more at the possibility of raining and at the clouds in the sky (which represent the humidity level) before using bikes then the rain in itself. It would explain that bicycle counts would reduce in the same way during high humidity, whether it would rain or not. Finally, it may also be possible that rain does not have an important impact during these time period.

In conclusion, the decision was to take the humidity as a variable and not precipitation. The reason is that by comparing the testing model with and without humidity compared to with and without precipitation, the humidity model had less error variations. Most likely that humidity considers not only the influence of rain (when humidity is higher than 90%, it is most likely to rain) but also the sky conditions. And as said, the variations of the variable humidity are more important than precipitation (which most of the time have a value of 0).

Table 8: automatic bicycle counter weekdays hourly training models all year

	Peak hours training model		Recreational hours training model		Night hours training model		hour 8 training model	
Parameter	*B*	*t-value*	*B*	*t-value*	*B*	*t-value*	*B*	*t-value*
(Intercept)	8,103*	87,4	7,258*	100,7	6,498*	30,5	8,097*	38,8
temp	0,052*	23,5	0,065*	37,6	0,075*	20,1	0,047*	8,8
wind	-0,042*	-5,2	-0,076*	-11,2	-0,044*	-2,8	not significant	
hum	-0,009*	-9,0	-0,009*	-11,4	-0,020*	-3,6	-0,008*	-3,3
snow	-0,024*	-8,1	-0,027*	-10,9	-0,011*	-4,8	-0,023*	-2,7
precipitation	-0,008**	-1,8	not significant		not significant		-0,044*	-1,8
R^2	0.66		0.685		0.279		0.592	
Observations	1 040 hours (2 341 212 Bicycle Counts)		1 533 hours (1 627 704 Bicycle Counts		1 510 hours (306 918 Bicycle Counts)		178 hours (492 274 Bicycle Counts)	

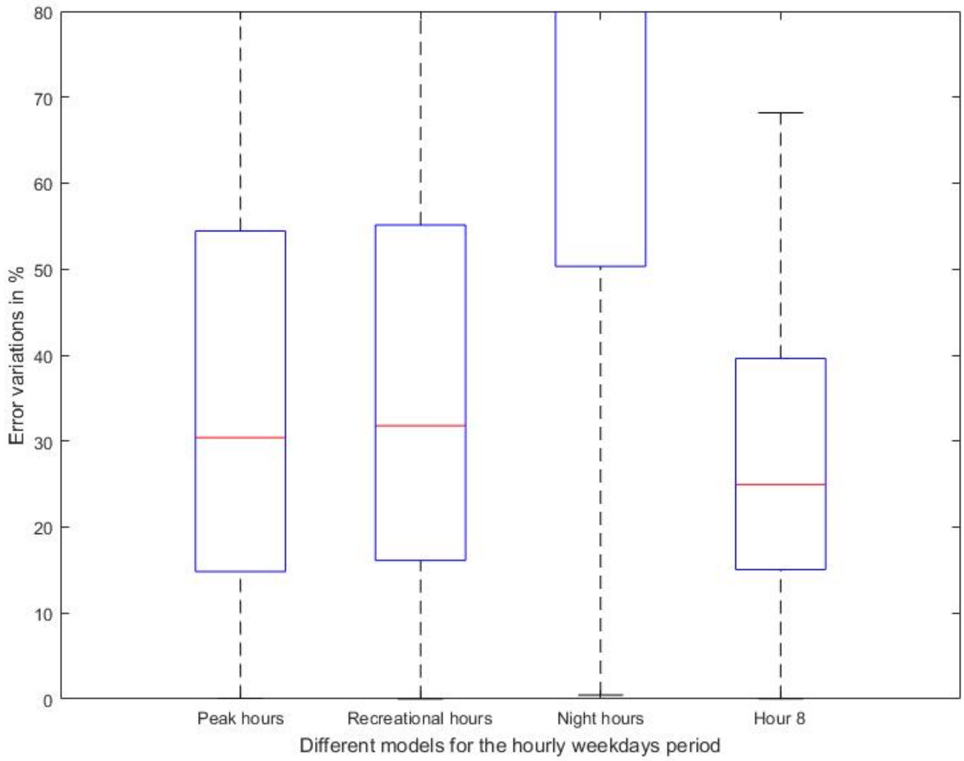
*: p-value under 0.05

**: p-value under 0.1

The error variations are a lot more important during night then during peak hours or recreational hours as the first quartile begins near 50 % and the third quartile ends near 500% (Figure 26**Erreur ! Source du renvoi introuvable.**). So, the people riding during the night are a lot less influenced by weather then other group hour. As the error variations are so high, the current testing model for the night hours must be missing some crucial variables. As the errors are globally so important, no analyze of the night weekday model will be done. The recreational hours model and the peak hours model seem to have apparently the same exactness. We see also that the error is more important with the working group than the hour 8am.

This is most likely due to the use of bicycle depending on the hours. It seems that even if these hours have more or less the same number of bicycle counts, there is still too much difference between the hours for them to be affected the same way by weather attributes. The outliers are not all shown on the figure as their values are a lot higher, going even up to 3000%. However, these high values again are due to national holidays and their mistake can be considered “natural”. Still some outliers, between 100 and 500% are not due to holidays so it seems that modeling by hours bring more mistake sometimes.

Figure 26: Error variations for all year hourly weekdays testing models



BSS and automatic models

The same groups hours for the summer period and for the two dataset, ABC and BSS data were then analyzed Table 10 and Table 9. As the night hours models error variations were as important as the all year period model, its values will not be analyzed. However, it does not mean that the results in itself are not interesting as it shows that weather attributes do not explain well the variations of bicycle use during night hours.

As the all year models, the precipitation and humidity are too highly correlated to be used together for the recreational model so the humidity is kept as a variable. The precipitation is not significant for the BSS hour 8AM model also. Finally, the wind is not found significant for the hour 8 models and the BSS peak hours model. The reason for precipitation being not significant may be due to a lack of effect on bicycle use but it can also be linked to the lack of values for precipitations or people being more influenced by the probability that it will rain (humidity) then the rain in itself.

Table 9 : Bicycle sharing system hourly "summer" training models

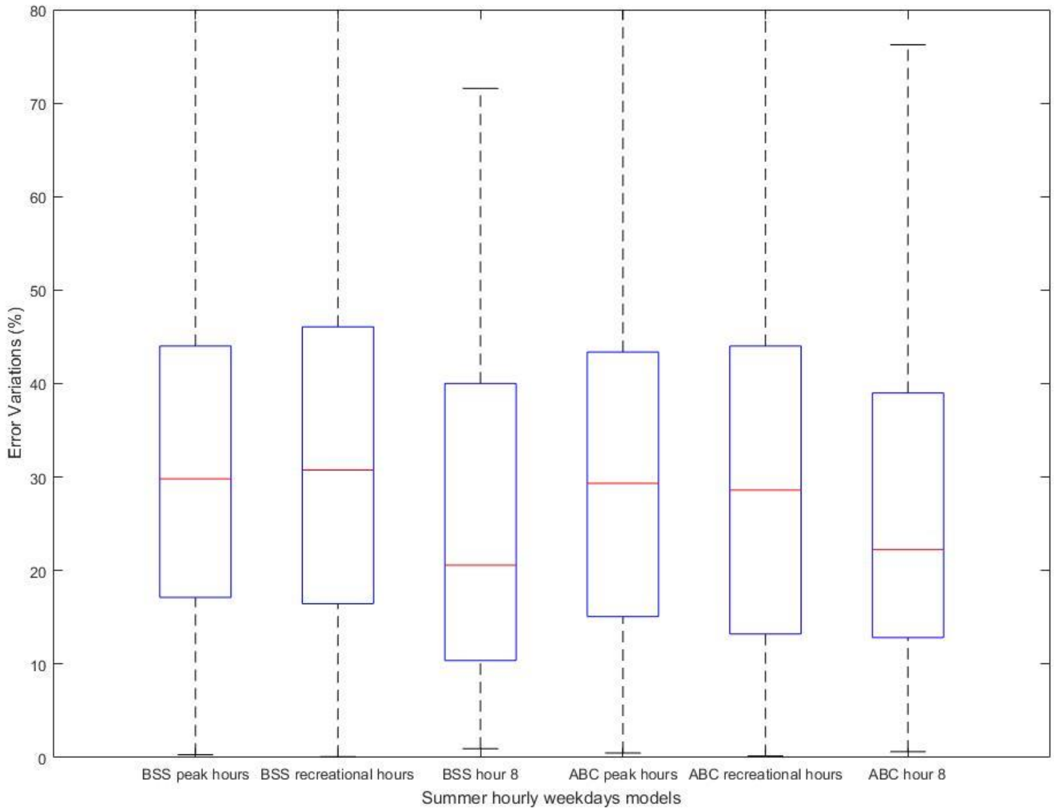
	BSS peak hours model		**BSS recreational hours model**		**BSS hour 8**	
Parameter	B	t-value	B	t-value	B	t-value
(Intercept)	5,253*	48,3	4,740*	54,2	5,460*	28,0
temp	0,025*	6,7	0,042*	15,1	0,015*	2,3
hum	-0,007*	-6,1	-0,007*	-9,3	-0,004**	-1,9
precip	-0,007**	-1,9	not significant		not significant	
wind	not significant		-0,062*	-8,4	not significant	
R^2	0.198		0.292		0.134	
Observations	517 hours (91 986 Bicycle Trips)		985 hours (100 281 Bicycle Trips)		79 hours (18 104 Bicycle Trips)	

Table 10 : Automatic bicycle counts hourly "summer" weekdays training models

	ABC peak hours model		**ABC recreational hours model**		**ABC hour 8**	
Parameter	B	t-value	B	t-value	B	t-value
(Intercept)	8,510*	80,6	7,631*	87,5	8,519*	41,7
temp	0,017*	5,3	0,039*	14,3	0,014*	2,1
hum	-0,008*	-8,0	-0,009*	-10,7	-0,006*	-2,6
precip	-0,012*	-3,8	not significant		-0,063*	-2,9
wind	-0,024*	-2,5	-0,061*	-8,3	not significant	
R^2	0.244		0.311		0.264	
Observations	517 hours (1 792 770 Bicycle Counts)		985 hours (1 603 079 Bicycle Counts)		79 hours (337 145 Bicycle Counts)	

The error variations for these models are lower than the all year models as all their 3rd quartile are under 50 % (without taking the night hour model into account),Figure 27. There is some small difference between recreational and working models, as for BSS data recreational model is more accurate and for the ABC model, it is the working model which is more accurate. We realize again that the testing models, which take just the hour 8 into account, give better prediction but the difference is not as high as observed in the all year testing models. This could mean that for summer period, weather attributes influence peak hours in more or less the same way compared to winter period.

Figure 27: Error variations for hourly "summer" weekdays testing models



IV.2.2 Weather influence on cycling on hours of weekends

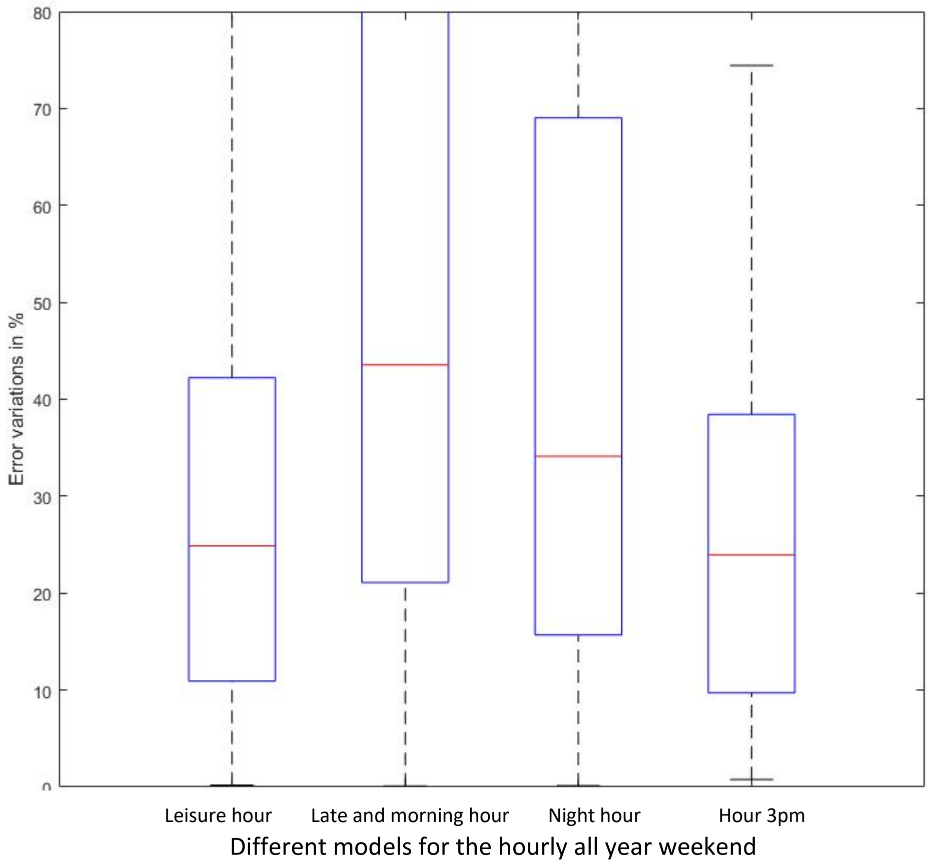
All year models

All variables for the all year hourly weekend models are found significant (see Table 11). However, when looking at the error variations, Figure 28, the night hour model and the late and morning hour model have significant errors. Either it may be that during these times, weather have less influence or that each hour have too much influence on bicycle counts to be put together. In any case, given the low performance of the testing models, these two group hours will not be looked at. The hour 3pm weekend testing model is better than the leisure hours weekend testing model. However, their differences are not as important as observed for the weekdays all year period. This is most certainly due to the fact that for leisure hours on weekends, the use of bicycle is very similar between hours compared to peak hours, which has significant difference in bicycle use depending on the hours (see section III-1.3).

Table 11 : Automatic bicycle counts all year weekend training models

	Leisure hours model		**Late and morning hours model**		**Night hours model**		**Hour 3pm model**	
Parameter	B	t-value	B	t-value	B	t-value	B	t-value
(Intercept)	7,526*	67,9	6,853*	40,3	5,401*	25,2	7,614*	23,6
temp	0,069*	28,0	0,077*	22,4	0,072*	18,7	0,066*	2,4
wind	-0,094*	-9,9	-0,107*	-8,3	-0,090*	-5,9	-0,078*	-23,5
hum	-0,014*	-12,0	-0,017*	-9,9	-0,014*	-6,5	-0,014*	-2,1
snow	-0,037*	-9,9	-0,028*	-5,2	-0,027*	-4,4	-0,036*	-3,7
R^2	0.78		0.648		0.641		0.78	
Observations	614 hours (563 998 Bicycle Counts)		627 hours (203 775 Bicycle Counts)		421 hours (36 909 Bicycle Counts)		72 hours (74 392 Bicycle Counts)	

Figure 28: Error variations for hourly all year weekend testing models



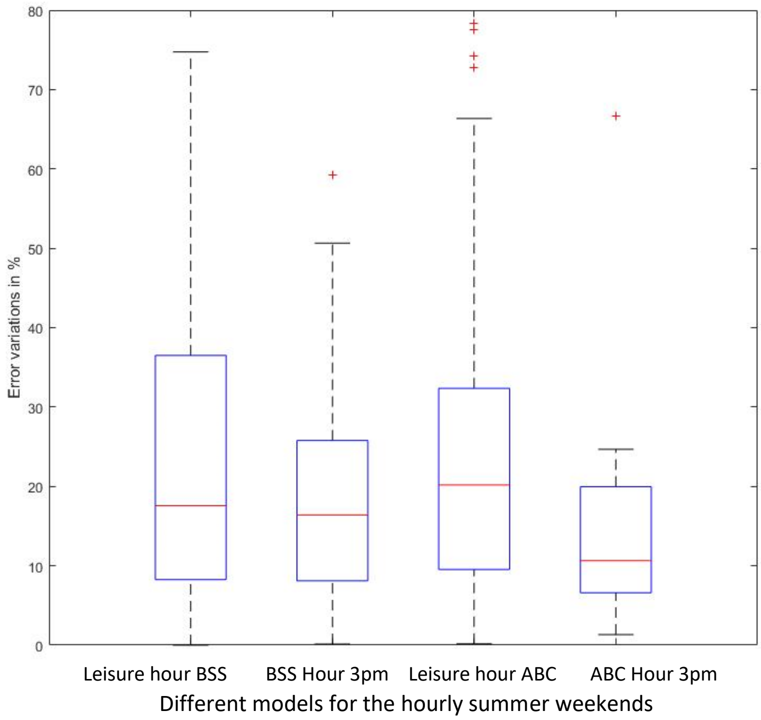
BSS and ABC during summer period

The same models are then analyzed for the summer period and for the two dataset (table 12) .As the night testing models and late and morning testing models, error variations are as important as the all year period, its values are not shown. Again, it shows that weather attributes are not sufficient to explain bicycle variations for these group hours. The difference between the all year models is that for the hour 15 model the wind is not found significant. It seems that during weekends, in the most influential hour for bicycle use, wind does not have any influence. The error variations show that a specific hour model is better than a group hour model. The ABC models this time give a better accuracy than the BSS models (Figure 29).

Table 12 : Hourly "summer" weekend training models

	BSS leisure hours		**BSS hour 3PM**		**ABC leisure hours**		**ABC hour 3PM**	
Parameter	B	t-value	B	t-value	B	t-value	B	t-value
(Intercept)	5,052*	33,1	4,764*	14,9	7,661*	55,4	7,129*	23,6
temp	0,043*	9,8	0,042*	3,3	0,048*	12,9	0,047*	4,1
hum	-0,013*	-9,8	-0,012*	-3,8	-0,012*	-1,2	-0,007*	-2,4
wind	-0,067*	-5,8	not significant		-0,073*	-60,8	not significant	
R^2	0.451		0.472		0.528		0.406	
Observations	315 hours (29 345 Bicycle Trips)		36 hours (4 120 Bicycle Trips)		315 hours (449 653 Bicycle Counts)		36 hours (64 198 Bicycle Counts)	

Figure 29: Error variations for houly "summer" weekend testing models



IV.2.3 Comparison of weather impact on cycling at an hourly level

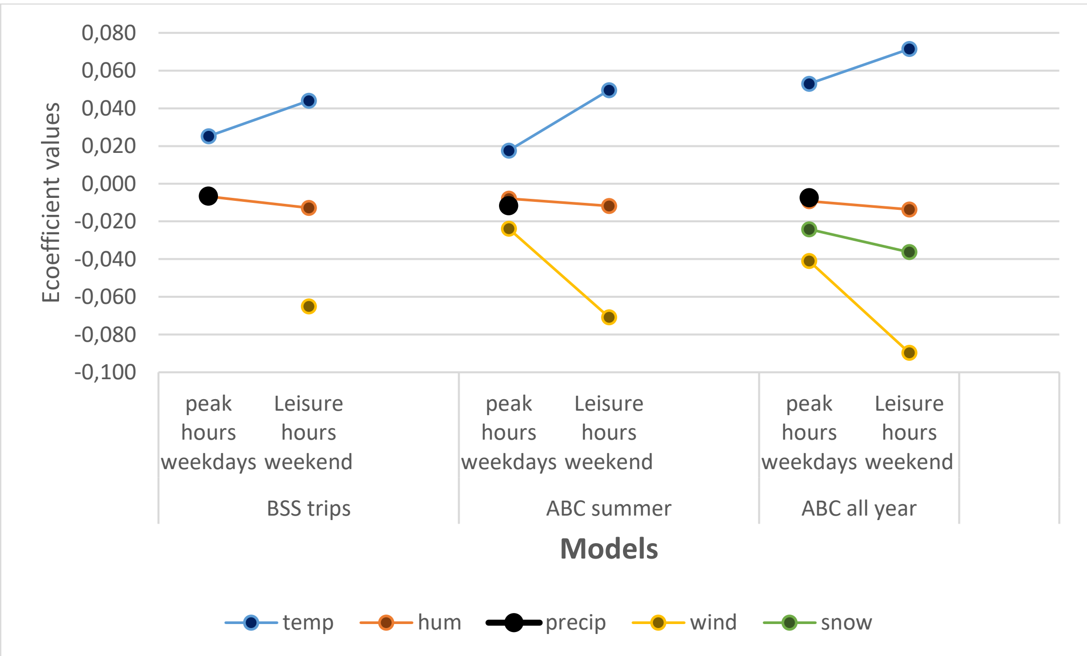
Leisure hours on weekends and peak hours on weekdays

Figure 30 shows the Ecoefficient values of the different weather attributes for the peak hours on weekdays and leisure hours on weekends training models.

As we look at the values of the weather attributes coefficient of the peak weekdays hours and leisure weekend hours models, we observe that weather attributes Ecoefficient increase for the leisure hours. What is interesting is that the variations for humidity between peak hours and leisure hours models is very similar between for the dataset and time period: an increase of 50% of its Ecoefficient between the peak hour model and the leisure hours models. When comparing the variations of temperature between peak hours on weekdays and leisure hours on weekends in the summer period, the Ecoefficient variation is more important between the ABC "summer" model, with an increase of 177% (0.018 to 0.050), compared to the BSS models, which has an increase of 76% of the Ecoefficient (0.025 to 0.044).

However, the values of weather attributes Ecoefficient between BSS and ABC dataset in summer period do not change a lot for leisure hours, with a maximum difference of 15% between for the temperature Ecoefficient. Comparing the peak hours model indicates more variations as precipitation Ecoefficient increase by 50% from BSS to ABC "summer" (-0.007 to -0.012) whereas temperature Ecoefficient increase by 40% from ABC to BSS models. The influence of wind is also present in the ABC peak hours model whereas it was not found significant for the BSS model. Therefore, it seems, that for the BSS data, during peak hours, weather have few influence on bicycle use and people are less affected than cyclist of the ABC dataset whereas during leisure hours the influence of weather attributes is the same.

Figure 30 : Comparison of weather influence on bicycle use for peak hours weekdays and leisure hours weekends



Now, for the comparison between the ABC “summer” data and the ABC all year data, the wind influences triples for the ABC summer data between the peak hours model and the leisure hours weekend model whereas it doubles for the all year period. The variation of temperature Ecoefficient is also a lot less important during the all year period with an increase of its influence by 34% between the peak hour’s weekday model and the leisure hour’s weekend model (177% for the summer period). Therefore, the variations of weather attributes between the weekday peak hour’s model and weekend leisure hour’s model are more important during the summer period then the all year period.

While comparing the values of the weather attributes however, most of them are higher in the ABC all year model with precipitation as an exception (-0.07 for the all year period and -0.012 for the “summer” period). The most important variation is between the Ecoefficient of the temperature. When comparing the leisure hour’s weekend models, the temperature influences increase by 42% between the summer period and the all year period. When looking at the weekday peak hour’s model, its influence in the all year peak hour’s weekday model is multiplied by four compared to its value on the summer peak hour’s weekday model. The variations of the Ecoefficient of other weather attributes between the all year and summer period then go between 12% (humidity) and 70% (wind).

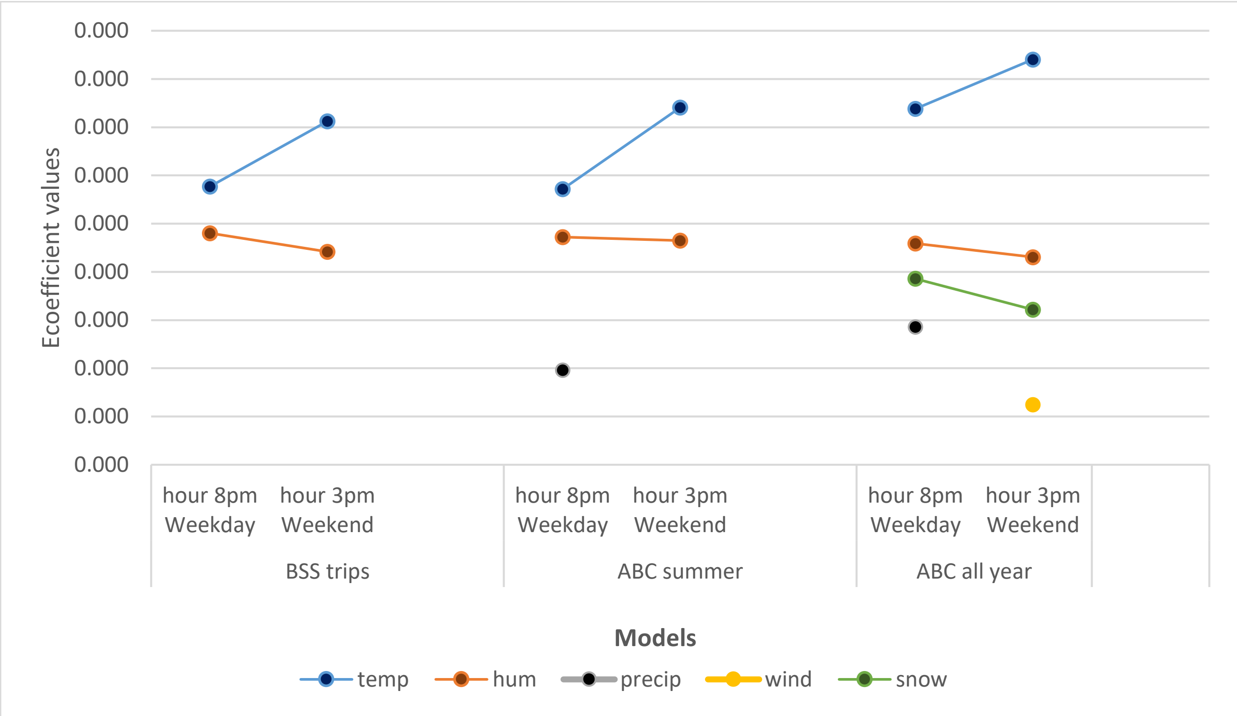
Therefore, between the all year and summer period, whether it is the variations between the leisure hour’s weekend and the peak hour’s weekdays or comparing the Ecoefficient between the different models, the values are different between the models.

Comparison between the hour 8 AM of weekdays and hour 3PM of weekends

Now the observation will be on the hour with the highest amount of bicycle counts (or trips counts) in weekend and weekdays, Figure 31. First, the influence of wind disappeared from all models except for the hour 3pm ABC all year weekend model. Therefore, it seems that wind, during the most important influential hours, is not important for bicycle use. The effect of precipitation also could not be grasped for mostly all data. For humidity, temperature and snow, weekend is more affected by these weather attributes then weekdays.

Comparing the summer models, between the hour 8am weekday model and the hour 3pm weekend model, the variations of humidity depend a lot on the dataset as its influence triples for the BSS data (-0.004 from -0.012) and stay nearly the same for the ABC summer data (-0.006 to -0.007). However, the variations of temperature between the hour 8am in weekdays and the hour 3pm in weekends is nearly the same for the BSS models or the ABC summer models with an increase that nearly triples.

Figure 31 : Comparison of weather influence on bicycle use for hour 8am weekday and hour 3pm weekend



Even more, ABC "summer" and BSS data seem influenced in the same way during the hour 8am on weekdays as temperature (0,015 and 0,014) and humidity (0,004 and 0,006) have resembling Ecoefficient. For the hour 3pm weekend models however, the influence of humidity is a lot more important for the BSS model then for the ABC summer model.

The models of BSS and ABC during summer period seem to resemble but some difference are observed such as the variations of humidity or the value of precipitation.

Now comparing ABC "summer" and ABC all year, all weather attributes except precipitation have more influence when taking the all year dataset then just the summer period (for precipitations the values are -0.061 for the "summer" period and -0.043 for the all year period). The most important variations of weather attributes between these 2 models is the temperature which Ecoefficient triples for the hour 8am in weekdays between the summer period and the all year period (0.014 to 0.048). All other variations between summer and all year ABC, be it on weekdays or weekend, is under 50%.

Moreover, if we compare the variations of the influence of temperature and humidity for the hour 8am on weekday and hour 3pm on weekend, temperature vary less for the summer period. However, the humidity has more effect for the ABC all year with an increase of 75% between the model of hour 8am weekdays and hour 3pm weekend.

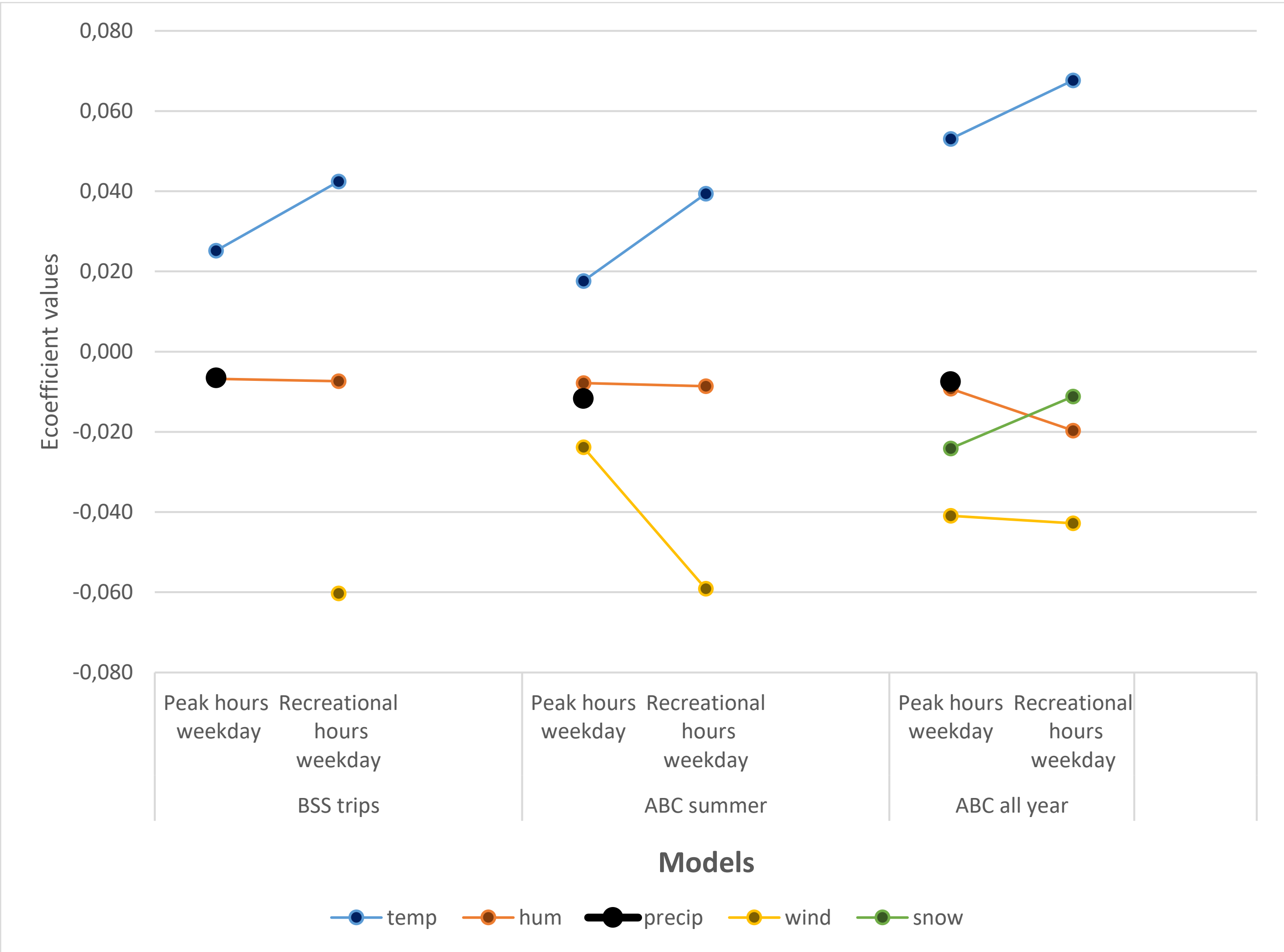
So, the all year period and summer period have very different weather attributes values which mean that the influence of weather change a lot depending on the period.

Peak hours in weekdays and recreational hours in weekdays

Finally, by concentrating only on weekdays and comparing the peak hour's models and recreational hour's model, we can see that variations between these two groups are less important than the one's before Figure 32. Between BSS and ABC summer, the values are very similar for the temperature and humidity. The wind has also similar influence between Recreational hour's weekday models.

However, comparing ABC during summer period and all year period, the weather attributes are a lot different. Temperature and humidity have fewer variations between peak hours and recreational hour in weekdays during the all year period than during the summer period. However, it is the opposite for humidity. One surprising result is that the snow has more effect on bicycle counts during peak hours than during recreational hours: its Ecoefficient is reduced by half during peak hours (-0.024 to -0.011).

Figure 32 : Comparison of weather influence on bicycle use for hourly working weekdays and hourly recreational weekdays



IV-3 Comparing the influence of a weather attribute depending on its values

One way to have a better idea of the impact of the weather variables is to change them into categories. Thus, the continuous daily weekday model is the "primary model" and just one variable will be changed into a categorical one to see what effect it has.

These categories were chosen as they were significant and presented the most differences in their coefficient but also for them to have a certain amount of data. These categories are subjective and several were tried. Only those seemed interesting will be shown and talked about. As them being categorical values, the coefficient analyzed, which represent the variations of the weather attributes influence, will be the exponential value of the beta coefficient. This value will also be called the Ecoefficient even if it is not calculated the same way as before.

IV-3.1 Influence of temperature

Now to see the influence of temperature 6 categories were first made which varied from 5 degrees to 5 degrees with -5 as limit minimum and 15 as limit maximum. However, the category of temperature between 10 and 15 is not significant (the p-value was 0.508). This information in itself is very significant as it indicates, considering a certain value of temperature, that bicycle counts does not change. This may explain why in the weekday's daily model, the decrease between end of August and mid-October is more important compared to the observed data. Indeed, most of these temperatures are between 10 and 15 degrees.

In consequence, the category between 10 and 15 is removed and we can see, in Table 13, that each categories of temperature are significant in this model and have significant difference between their Ecoefficient values. Each time the temperature decreases the number of cyclist decrease also. An example is the variations between temperature above 10 and temperature under -5 which implicates a decrease of 79% of the number of bicycle counts.

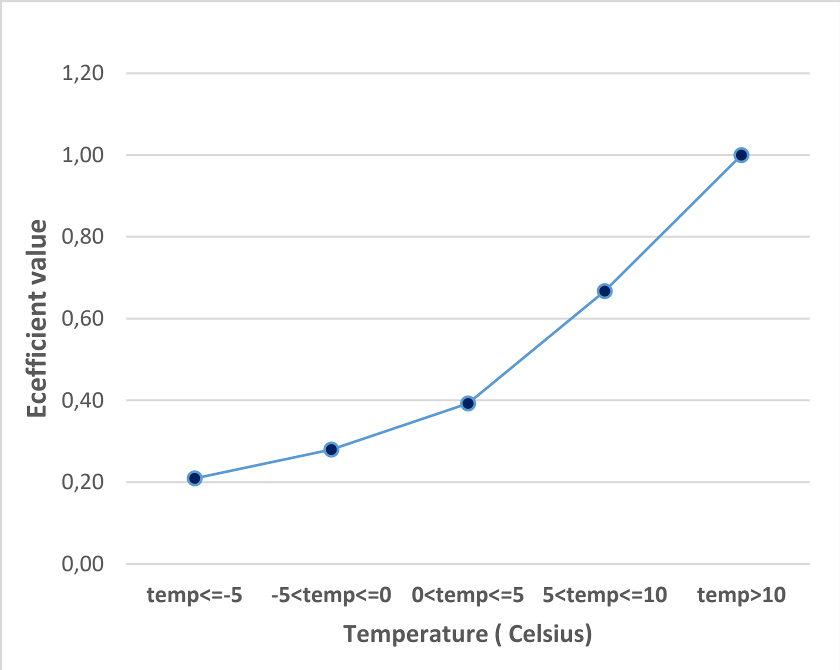
We can also see that the variations between different categories are not the same Figure 33. The decrease of bicycle counts between the first 3 categories (0-5, 5-10 and above 10) seems to be likely the same. However, afterwards we can see that the bicycle counts do not decrease as much: the variation of the temperature Ecoefficient slows down between temperatures under -5 and temperature between -5 and 0.

One of the reason may be that these temperatures are" winter" temperature. People using bicycles with temperature being under 0 are most likely winter cyclists and decide to cycle all year, independently of the temperature.

Table 13 : Training model with temperature

Parameter	**B**	**t-value**
(Intercept)	11,804*	70,92
wind	-0,0784*	-4,32
hum	-0,012*	-5,52
precip	-0,003*	-3,45
snow	-0,022*	-4,03
temp<=-5	-1,564*	-12,60
-5<temp<=0	-1,273*	-14,39
0<temp<=5	-0,935*	-13,85
5<temp<=10	-0,405*	-5,00
temp>10	0	
R^2	0.841	

Figure 33: Temperature's Ecoefficient as a categorical variable values depending on its category



Thus, temperature has a lot of influence on the number of cyclist as it can decrease its number by 79%. However, given a certain low temperature and a certain high temperature, its effect will be a lot less important. And in Helsinki it seems that the variation in temperature which can have an important effect on cyclist is between -5 and 10.

IV-3.2 Influence of snow and rain

Now in order to see the impact of the snow on bicycle count, snow was first converted into a binary variable **Erreur ! Source du renvoi introuvable.**. As shown on table, it seems that when there is snow, the number of bicycle counts is reduced by 39%. Even if the results seem less important than temperature, snow has lots of impact. In Helsinki, as it was said section III-1.2, 1/3rd of the days in all year there was snow on the ground. Therefore, 1/3rd of the time, the number of bicycle counts are reduced by 39%.

Another type of category is used in order to see the effect of snow coverage of the ground and four groups were made depending on the number of centimeters the snow fell on the ground: no snow, between 0.01 and 5 cm of snow, 5 and 15cm of snow and above 15 cm of snow **Erreur ! Source du renvoi introuvable.**. Each category is shown to be significant. Figure 34 presents the variation of snow on the grounds and it does not seem to have high influence on bicycle use.

Table 14: Training model with snow as a binary variable

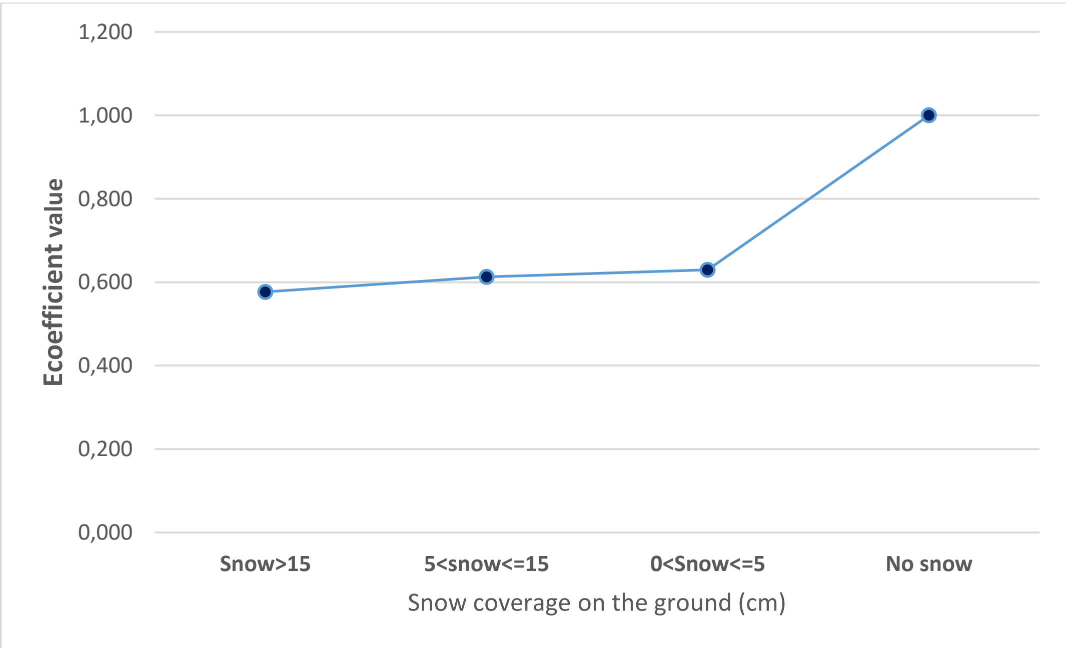
Parameter	**B**	**t-value**
(Intercept)	11,006*	63,63
wind	-0,075*	-4,64
hum	-0,013*	-6,24
temp	0,053*	14,14
precip	-0,003*	-3,49
Snow	-0,493*	-6,75
No snow	0	
R^2	0.857	

Table 15: Training model with snow as a categorical variable

Parameter	**B**	**t-value**
(Intercept)	11,006*	63,43
wind	-0,077*	-4,69
precip	-0,003*	-3,44
hum	-0,013*	-6,20
temp	0,053*	13,69
snow>15cm	-0,550*	-4,92
5<snow<=15cm	-0,489*	-6,28
0<Snow<=5cm	-0,462*	-4,32
No snow	0	
R^2	0.858	

When looking at the types of snow coverage and its coefficient the number of bicycle counts decrease between each category. However, the difference between each coefficient is small, and goes from 0.63 to 0.58, which indicate a decrease between 37 and 42% compared to snowless days. This result seems to imply that the variation of snow coverage does not affect in a significant way the use of bicycle and it is the presence of snow itself that have high influence. In addition, as the snow coverage went from 1 cm to 31cm in Helsinki in 2016, the continuous snow variable may have important variations depending on the snow coverage and therefore does not seem adequate to analyze the influence of snow.

Figure 34 : snow's Ecoefficient value depending on its category



As the snow, the variable precipitation is changed into a binary variable. The first model showed that binary-rain is not significant (the p-value was 0.144 **).** However, knowing the problem accoutered before with rain and humidity, the model was run again without considering the variable humidity. The binary-rain is then found to be significant Table 16.

Rainy days seem to reduce the use of bicycle by 18%. Knowing that it rains once every 2 days, 18% is still very important. In addition, this value is more important compared to the continuous precipitation variable who seemed to show that rainfall reduced the use of bicycle counts by 5%.

Then precipitation is afterwards divided into 5 groups to see how rainfall impacted the use of bicycle: no rainfall, between 0 and 1mm, between 1 and 10mm, between 10 and 40mm and above 40mm. However, the influence of small rainfall did not have enough impact to be found significant. As consequence, other groups are made (variable Table 17). For days when rainfall was above 40 mm, the use of bicycle counts reduces by 38%.

Table 16 : Training model with rain as a binary variable

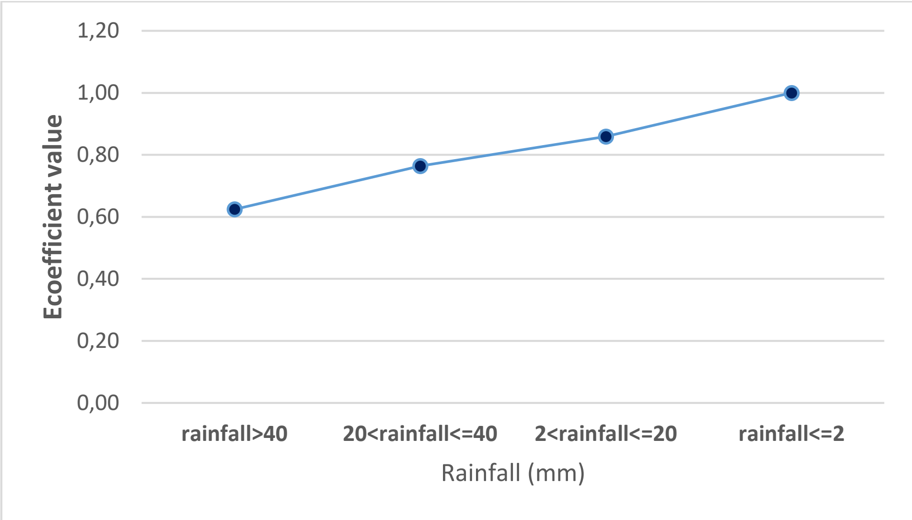
Parameter	**B**	**t-value**
Intercept	9,980*	105,70
Rainy days	-0,196*	-3,27
No rain	0,000	
wind	-0,078*	-3,70
temp	0,066*	18,02
snow	-0,028*	-5,25
R^2	0.798	

Table 17 : Training model with rain as a categorical variable

Parameter	**B**	**t-value**
(Intercept)	9,956*	105,96
wind	-0,078*	-3,86
temp	0,067*	18,44
snow	-0,026*	-4,86
rainfall>40mm	-0,471*	-4,43
20<rainfall<=40	-0,269*	-2,41
2<rainfall<=20mm	-0,152*	-2,37
rainfall<=2mm	0	
R^2	0.811	

If we look at the variation of ABC depending on the rainfall we can see that it is almost linear, Figure 35. The more rain there is, the less bicycle counts there are. Compared to snow or temperature, a continuous variable seems to be a god fit for the variable precipitation. As we could see for the rain, when looking at its influence by putting the variable into different categories, the variable humidity has to be removed because it is too strongly correlated to the rain. However, by removing the variable humidity the model changes a lot and does not explain as well the variations of bicycle count than before as we compare the R^2.

Figure 35: precipitation's Ecoefficient value depending on its category



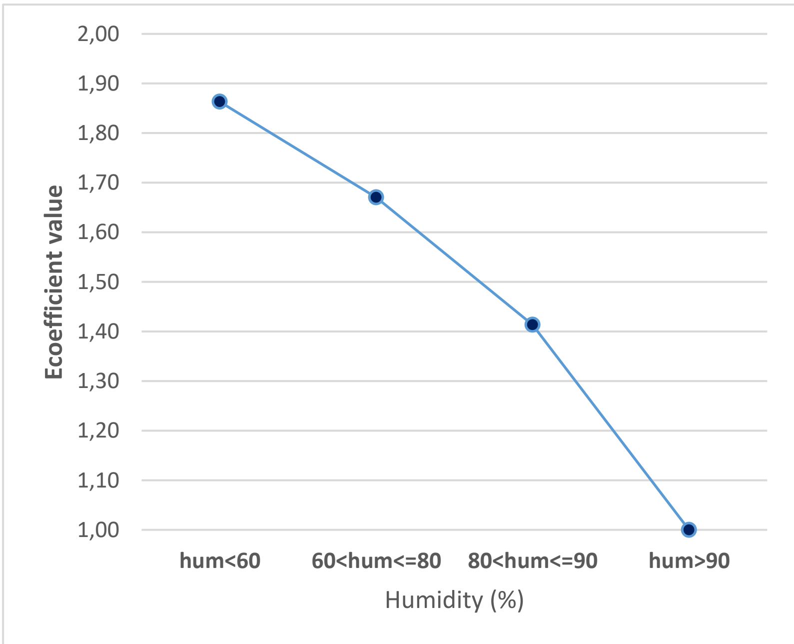
IV-3.3 Influence of clouds, humidity and wind

Now concerning humidity, four groups were made that were significant: under 60%, between 60 and 80%, between 80 and 90% and above 90%Table 18. We can observe that the less humidity there is, the more bicycle counts there are. Between a day with more than 90% of humidity and a day with less than 60% of humidity we can see an increase in 86% of the bicycle counts, Figure 36.

Table 18 : Training model with humidity as a categorical variable

Parameter	**B**	**t-value**
(Intercept)	9,539	91,70
wind	-0,082	-4,91
temp	0,062	17,60
snow	-0,024	-5,10
hum<60	0,622	6,14
60<hum<=80	0,513	6,42
80<hum<=90	0,346	4,79
hum>90	0	
precip	-0,002	-2,030
R^2	0.845	

Figure 36: Humidity's Ecoefficient value depending on its category



This influence of humidity shows that people look at the prediction of weather or look outside to see how the weather is before deciding to take a bicycle. You see also that when humidity is high then a decrease of 10% in humidity have a higher impact on bicycle counts than a decrease of 20%.

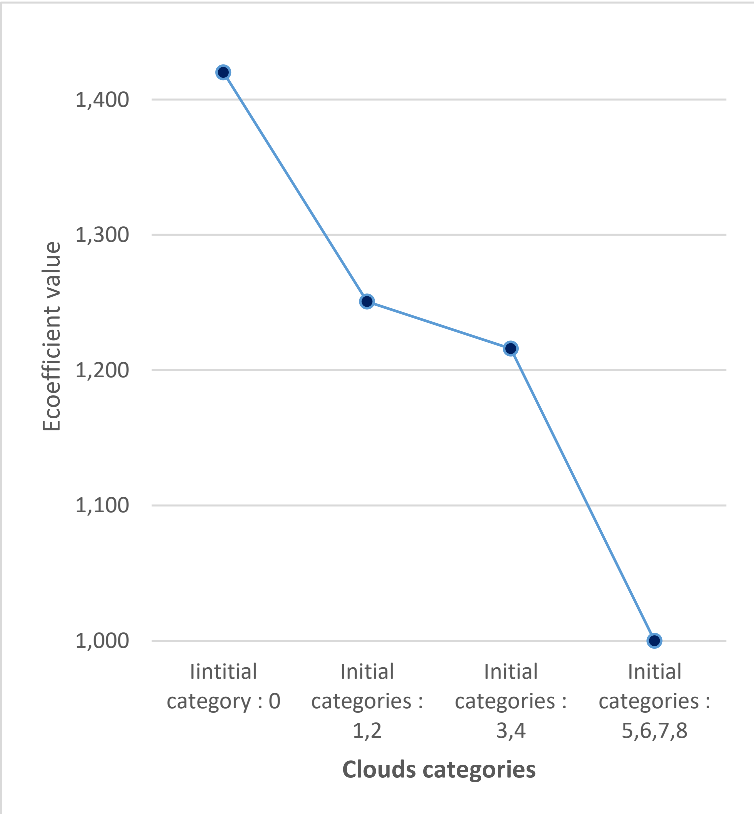
the influence of clouds are also looked at. However as we said the correlation between humidity and clouds is too important so the variable humidity had to be removed. Small humidity is linked to less clouds and a sunny day whereas high humidity is linked to cloudy sky and possible rain. Nevertheless, some categories of clouds still were not significant, most likely because they had the same effects on bicycle counts. Therefore, categories were put together until each one of them were significant Table 19.

Due to the first data on clouds being subjective, putting some clouds categories together make this variable even more subjective. However, some few observations can still be made, Figure 37. When there are no clouds at all (category 0), then the use of bicycle increase to 42% compared to days when the sky is cloudy or totally covered by clouds (initial categories from 5 to 8). And a sky with few clouds compared to a sky with some clouds (which would be categories between 1 to 4) do not seem to have different impact on bicycle counts whereas a day with no clouds have a lot more impact on bicycle counts. Finally, as the categories between 5 to 8 had to be put together, it seems that with a certain amount of clouds in the sky, then their impact on ABC do not vary. So the presence of clouds have an influence even if it is difficult to predict its exact influence as their presence are signaled as observations and categorized in a subjective way.

Table 19 : Training model with clouds as a categorical variable

Parameter	**B**	**t-value**
(Intercept)	9,814	105,23
temp	0,063	17,18
wind	-0,077	-4,18
snow	-0,028	-5,71
precip	-0,003	-3,88
Cloud Initial category : 0	0,351	3,77
Cloud Initial categories : 1,2	0,224	3,12
Cloud Initial categories : 3,4	0,195	2,88
Cloud Iinitial categories :: 5,6,7,8	0	
R^2	0.827	

Figure 37: Cloud's Ecoefficient value depending on its category



Concerning the wind, it was first divided into 3 categories: under 3km/h, between 3km/h and 6km/h and above 6 km/h. However, the variations were not enough between each categories to find them significant. So the wind was then changed in 2 categories: under 5km/h and above 5km/h Table 20 (see annexe). The increase of wind seemed to decrease the use of bicycle counts by almost 20%.

Table 20 : Training model with wind as a categorical variable

Parameter	**B**	**t-value**
(Intercept)	10,622	60,3
hum	-0,013	-5,8
temp	0,062	17,3
precip	-0,003	-3,2
snow	-0,024	-4,9
Wind >5	-0,215	-4,0
Wind <=5	0,000	
R^2	0.833	

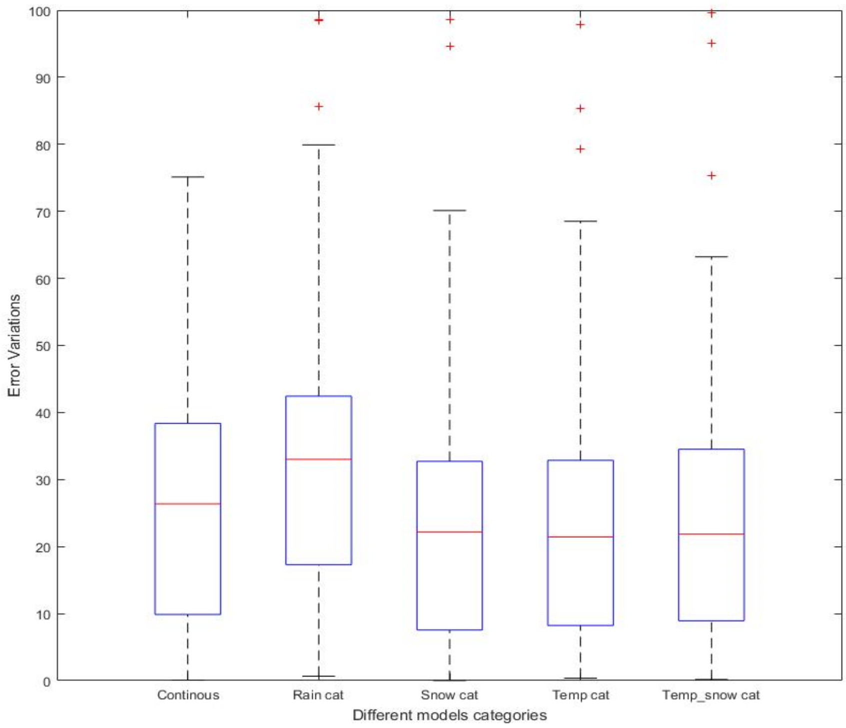
IV-3.4 Which model best describe the influence of weather attributes on bicycle use.

To know the model that best represent the influence of weather conditions, the error variations of the testing models are compared. A model with snow and temperature as categorized variables was added to see if putting 2 categories variables in the same model made some difference.

By looking at the testing models and their error variations, the average number of outliers for the models are between 7 to 8 outliers, and correspond to the same dates (as expected because there were holidays). The only days that sometimes are not outliers are the 5th of May and the 22nd of December (which are the lowest outlier for the continuous model). What is observed, when looking at the test models for each different category that was made, is that the errors variations are more important for the models without the variable humidity taken into account.

For these figures to be visible, only five models are shown Figure 38. The two models that have the least error variations represent the models with temperature as a category and snow as a category (the 10 boxplots corresponding to each model are shown in annex E).

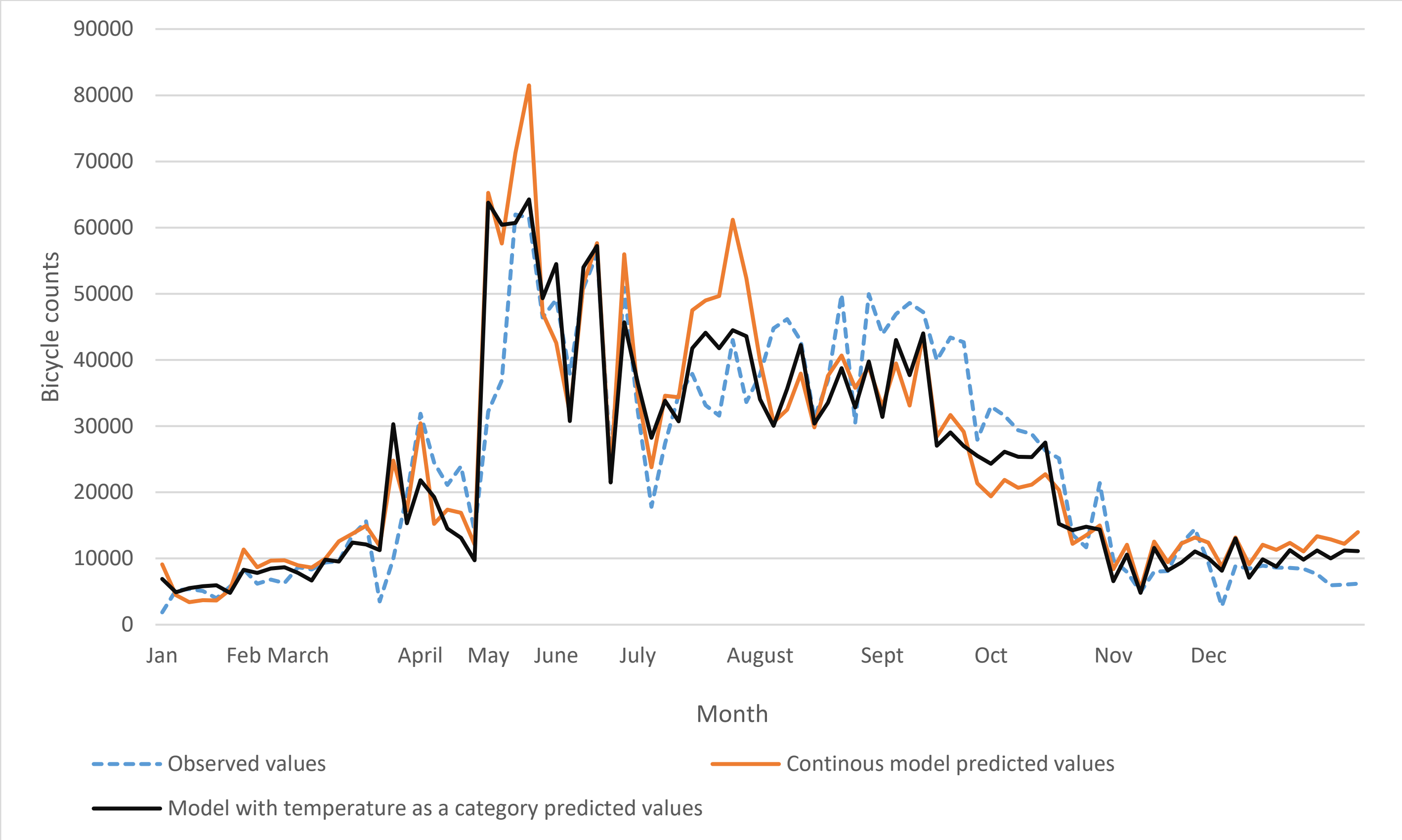
Figure 38: Error variations of weekday's testing model all year with variables as categories



Now the difference of error variance between each model is not very important (except for the model without humidity): the maximum variations between each model is between 3-5% between each quartile. Each of these models have their 3rd quartiles under the continuous and have a mean error between 37 and 38% model, except the model without humidity which have higher errors and the model with just temperature as a category who has a mean error of 31%. So, the model with temperature as a category seem to be the most fitted one to evaluate the impact of weather attributes on bicycle counts.

Indeed, the model with temperature and snow put as categories is not as good as the model with just temperature as a category. It is possible that by putting these two variables as categories, some errors are magnified as snow and temperature have some correlations. Now let's compare the predicted values of the continuous model, the predicted values of the model temperature as a category and the observed results, Figure 39.

Figure 39 : Comparison of predicted values for the testing continuous model and temperature as categories with the observed values



The values between end of August and mid-October are more correctly evaluated with the model with temperature as a category then the continuous model. The high temperature in may is also more correctly estimated as variations in winter season. Therefore, to conclude categories variables can give interesting results and a more comprehensive explanation about the weather attributes than the continuous variable.

V- Discussion

The testing models gave different results which have been observed through section IV. The empirical findings are now further discussed given the aims and research questions of this study.

V-1 Influence of weather conditions depending of the period

In general, this study exposed how weather influence on cycling depends on different time period. The overall observations found were consonant with what was found in the existing literature.

Indeed, the results showed that “winter” period - from November to April- had more influence on bicycle use than “summer” period - from May to October- result in line with some articles (Bergström and Magnusson 2003; Birling 2014). These results also confirmed what was observed in the 2016 Pyöräily-barometri (Helsingin kaupunki Kaupunkisuunnitteluvirasto 2016) as bicycle use was found to be reduced in a significant way while it was snowing, which correspond more or less to the “winter” period (see section II-3).

As different articles showed influence of weather on bicycle use was more important during recreational activities than commuting activities (Thomas et al. 2009; Branderburg et al. 2006), this study showed the use of bicycle was more influenced by weather on weekends than on weekdays (weekday use of bicycle is most likely related to commuting activities whereas on weekend bicycle use is linked to recreational activities). Certainly, the variations were different depending on weather conditions. However, the influence of weather was increased by half at least, and for some attributes its influence could triple between weekdays and weekends.

In a more detailed observation, during the working day peak hours (7AM- 9AM and between 4PM-6PM), the use of bicycle was found less influenced by weather than on weekend during the leisure hours (11AM-7PM) or on weekdays during the recreational hours (10AM-3PM and between 7PM-9PM). Most of the time, influence of weather was increased by half or doubled between the peak hours on weekdays and the other group hours. This indicates that the use of bicycle on peak hours is most likely a routine activity (e.g. going to work or school), which is more difficult to reschedule than a temporally and spatially flexible leisure-related activity during weekends.

Now as this study made different models in daily and hourly level, it showed the importance of the time period in the analyze of weather influence on bicycle use. The comparison between hourly and daily models, by observing the errors of the different models, shows that daily models make fewer mistakes (see section IV-1.3 and IV-2.3). However, the daily models underestimate or overestimate some weather conditions.

Precipitation value can have four times as much influence in the peak hours model than in the daily weekdays model. It is interesting to see this significant difference as peak hours in average represent the global use of bicycle on weekdays. This difference of influence for precipitation is connected to how a rainy day is represented. Daily precipitation concerns half of the day of 2016 in Helsinki. However, a rainy day can be a day when it rained in the night between one and two a.m. As the use of bicycle during the day will not be affected by the precipitation that occurred at night, its influence is then under estimated in the daily models.

The other weather attribute which influence changed a lot between daily and hourly models, is wind. Looking at daily models, wind influence is significant. However, when looking at the different group hour's models, the wind influences decrease or cease to be significant. It shows that most people who ride are not influenced as much by wind as we may suspect. The fact that wind has significant values in the daily models and few in the hour models may be since wind speed varies a lot through the day, looking at its average daily value bring some mistakes when estimating its influence (see section III-1.2).

However, at hourly level a difficulty was added to observe the models, as the use of bicycle depends on the hours. Even when group hours were made trying to regroup some hours with similar use of bicycle (e.g. peak hours), in case of some time period of the day (e.g. night hours between 9 pm to 7am for the weekdays) the variations of bicycle use could not be explained just with the models. One explanation to these high errors could be the low number of trips during night hours in weekdays, which incorporates high error level to the analysis. Furthermore, it shows that weather conditions are not as an important factor during night hours as social factors are (e.g. hours where people sleep, hours which are not standard for people to go out). Another limit concerning hour modeling is that some results are more difficult to understand (e.g. precipitation being not significant during leisure hours on weekends).

To have the most accurate information, without creating more errors, models analyzing only specific hour would be best. In future steps, research should focus more on hourly modeling. Now depending on which reason the influence of weather conditions on bicycle use is looked at, different models could be used. If it were to have a global idea on its impact then daily models would be enough. The influence of snow or temperature is clearly shown in these models and indicates that promoting cycling on winter season would be a good idea to develop bicycle use.

If there is a desire to have more precise information and to know which type of activities are influenced by weather attributes, then there is a need to look at hourly models. For example, people using bicycle sharing system (BSS) were influenced in a different way by weather conditions depending on the hours.

V-2 Different weather conditions influencing cycling

Comparison between weather attributes is a complicated task, as some weather attributes are difficult to analyze, such as precipitation as its influence varies a lot through different models. The fact that humidity is more or less correlated with precipitation, or that it is a weather attribute which influence on bicycle use is rarely direct, makes it even harder to compare.

As the wind is a weather condition which is not significant in many models, its influence is less important. It is one of the results which differs the most from most existing literature (Saneinejad et al. 2012; Helbich et al. 2014; Corcoran et al. 2014b) but one (Flynn et al. 2012).

One of the difference observed with the articles that found wind significant was that weather was taken as a daily value whereas Flynn et al. 2012 looked at the weather values in an hourly level. Of course, the different locations where the studies were done may also have a strong impact of the difference concerning the influence of wind (Toronto in Canada, Rotterdam in Netherland or the state of Vermont in the United states)

Looking at snow, this weather attribute that may be one of the easiest to understand. The snow depth on the ground does not seem to have an important effect but the presence of snow does. During snowy days, the number of cyclist is decreased by nearly 40% compared to snowless days.

Finally, if we would compare by using the values of the categorical models, then the temperature would be the most influential weather attributes. Between a daily temperature above ten degrees and a daily temperature under minus five degrees, the use of bicycle decreases by more than 70%. As it is, this study showed that the most important weather conditions to take into account in urban planning would be temperature and snow.

Some weather attributes however were too highly correlated between each other to be analyzed, as temperature and darkness or wind and gust, see section III-2.3. The decision was to take the weather conditions that was the less subjective. Highly correlated attributes need to be further studied in order to decide which weather attribute is more proper to be included in modeling.

The only comparison made was between clouds and humidity, section IV-3.3. Even though the clouds showed better prediction values than humidity as a continuous variable, see annex E, it is defined in a subjective way with human nomenclature, and its categories had to be changed again for it to be significant for the model. In consequence, it seems to be less suitable to analyze weather impact on cycling as the categories are more difficult to explain.

Sunlight, as it was being correlated to temperature, could not be analyzed here. However, research showed that sunlight had effect on bicycle use (Gebhart and Noland 2013a). And as sunlight has significant variations in Helsinki (see section II-1.2), further studies should try to take into account this variable. To analyze sunlight with temperature, one idea would be to look at interaction between the different weather attributes.

Finally, by putting some weather attributes as categories, this study showed that some weather attributes did not influence the bicycle use in a linear way (section IV-3) and that the use of categorical variables may be more interesting instead of continuous variables.

As we said, for snow, the ground coverage does not have a significant impact on the use of bicycle. It is the presence of the snow that influences the use of bicycle. The temperature also was found to have its influence decreased when temperature had attained ten degrees, as the use of bicycle did not increase as much afterwards, or when it was under minus five degrees, as the use of bicycle did not decrease as much afterwards. And humidity had more influence when its category was high than when it had a low value.

V-3 Pros and cons of the applied data sources

One of the specificity of this study was that it was applied to two datasets about cycling in Helsinki: the bicycle sharing system (BSS) and the automatic bicycle count (ABC). The only comparison made, to the knowledge of the author is between the speed of cyclist between BSS users and personal users (Castillo-Manzano, López-Valpuesta, and Sánchez-Braza 2016).

Concerning the datasets, one of ABC data sources strength is that it is undergoing during the whole year. Moreover, all bicycle users are counted in the ABC data. Concerning its drawbacks, one is that it counts the number of bicycle and not the number of trips. It does not represent exactly the number of trips made throughout Helsinki as it is not possible to know how much trips are represented by bicycle counts. Which bring to the lack of data concerning the users. The only data available were the number of counts and locations through the hours on 2016. As here only bicycle counts were used in the model, the problem was eluded. However, it will bring limitation to further studies on ABC data as social data (e.g. age, gender) gave important information on bicycle use.

Another limit of the ABC data are the few locations, 16, throughout Helsinki which are used. As these data set are about bicycle counts, having few locations permit to limit the number of times a same trip is counted. However, some trips may not be counted at all if they do not pass by the counter station. Moreover, some locations are very close to each other (entrance and exit of three bridges have ABC stations) and thus may give data that repeats itself. Finally, even as ABC data seems to look at the general bicycle users of Helsinki, it may be possible that, due to its locations, some users are not taken into account.

Now one strength of the BSS dataset is that it does not only give information about the number of trips made by users but it potentially allows to understand cycling more thoroughly: trip lengths, trip duration and average speed. Social information such as age, gender and postal code of the BSS users are available. Although not included to this study, further research should include these information's to have a better understanding of bicycle use.

Concerning BSS, one limit is that it only counts the users of the BSS, which does not correspond to all the bicycle users of Helsinki. The system also works during five months and not through all year. If the study is concentrating on the summer period, then it is not an issue, however, it cannot be used for an all year analysis. Finally concerning BSS, one limit of this data is that the location of the stations predefined the use of the bicycle. To use the BSS, there has to be a bicycle available at the station first and afterwards, you have to place you bicycle in a particular place.

Interestingly, both data sources provided similar outcome although some difference emerged, especially between daily models. For example, on daily models, the influence of some weather attributes was sometimes more important on the BSS data then on the ABC data (e.g. temperature), and sometimes weather attributes had more influence on the ABC data than on the BSS one (e.g. wind and precipitation).

One reason to explain these differences would be that BSS users do not represent the global bicycle users in Helsinki and thus, the influence of weather attributes would be different on the two data sources.

However, when looking at the hourly models for the summer period, the influence of the weather attributes between ABC and BSS datasets were close, especially between leisure hours on weekends and recreational hours on weekdays (lunch times and after work hours), see section IV-2.3. This may imply that the BSS users represent the average global population of bicycle users during certain time period such as afternoon on weekends or during recreational hours on weekdays.

The difference then observed on the daily models may be due more specifically to the people using bicycle during the peak hours on weekdays. As using bicycle for this type of activity is most likely a routine for the average cyclist user, BSS users using bicycle during these hours may be fickler and depend on other context (e.g. parent who have sometimes to take their children to school) for the use of bicycle.

As was expected given previous research (Fu and Farber 2017; Moudon et al. 2005), the social data analyzed on the BSS were in accordance with what was implied for the general population of bicycle user's (e.g. the average people using bicycle's being young adult or students, mostly male). Although not the scope of given study, it would be possible to generalize results from BSS to the whole population of Helsinki and make some hypothesis concerning the global use of bicycles in Helsinki as the origin of the users of BSS is also available. Furthermore, in future studies the incorporation of social background information of BSS users (e.g. income, household) would allow to assess how internal (e.g. users' background) and external (e.g. weather) attributes affect cycling.

Certainly, there is a need to be careful while doing comparisons between BSS and ABC data regarding the difference in recording methodology and defining trips and bicycle users, and making too general conclusions about the whole population of bicycle users.

V-4 Critical assessment on obtained results

Most important errors in the weekday's models were due to cultural factors (e.g. national holidays, summer holidays). To improve the model, it would be possible to remove these days and gain less error variations. However, these errors show that the models do not consider every possibility. Concerning the weekend models, we saw that errors variations were not only due to cultural factors. Other factors that the study did not take into account have thus important influence on bicycle use on weekend. One of these factors may be a more societal context (e.g. the locations of the bicycle counts station). Concerning the hourly models, as the hours also influence bicycle use, it is again another factor that should be considered.

In future studies thus, cultural and societal factors should be taken into account (as categorical variables) while assessing the weather influence on cycling, as it is already done by some researchers, (Thomas et al. 2009; Bergström and Magnusson 2003). Indeed, no data should be taken out, as the information given, even as false prediction concerning the use of bicycle, are significant and show where the problem lies.

Finally, when looking at the difference in error variations between the summer period and the all year period, the analysis revealed that the error variations were less important for the summer period than the all year period (see section IV-1.1 and IV-1.2). The errors for the same days were also different depending on the data taken: ABC data of the "summer" period or the ABC data of the all year period.

To explain this difference in error one reason could be that the influence of weather conditions is different whether it is summer or winter (temperature decrease a lot, snow appears). Thus as the year 2016 takes winter and summer period into account, its weather influence is not similar to the weather influence of the summer period. It would have been interesting to make a clear comparison between the "summer" period and the "winter" period to know exactly the difference of weather influence. Another reason could be that the "summer" period represents more than 70% of the bicycle use during the year. Thus, with fewer trips during the cold month, the error level may have increased, as it was observed during the night hours.

By putting weather into categories, it was shown for some weather attributes (e.g. temperature and humidity) that they did not have a linear influence on bicycle use. However, what was surprising is that the values of bicycle count during the month of July were also better predicted. Or the decrease in the number of bicycle counts in July was most probably due to holidays. In consequence, by setting the temperature into a categorical variable, some errors were suspected to be due to the temperature, as July was the hottest month but there was no increase in bicycle counts. Therefore, this study showed that putting weather attributes into categories gave some significant information and sometimes better models; however, it must be handled carefully. To use the original data (e.g. continuous data) compared to transformed data (e.g. categorical data) is less delicate as their errors can be more easily explained when there is an over estimation or under estimation of the values.

V-5 Taking weather dependency on biking into account in urban planning

This study showed the significant effect of weather conditions on bicycle use. Moreover, other articles showed that with snowfall, rainfall, or strong wind, the use of bicycle is more complicated and thus, people reduce their use of bicycle and tend to utilize other transportation mode (Saneinejad et al. 2012). A study looking at the weather effect on Bike Sharing System (BSS) showed that during rainfall people tend to take more often the metro, if there is a station near their place, and to reduce their use of BSS (Gebhart and Noland 2013b). In consequence, it is important to look at weather influence on bicycle use while preparing urban bicycle policies.

We have seen that in urban planning, cycling was taken into account in many different forms (see section I-3.2 and I-3.3). Weather influence in bicycle use however, when promoting bicycle, is not often seemed as significant. Some national bicycle policy guidelines (Rupprecht et al. 2010) and some books about bicycle planning (Jensen et al, P 2012; Pettinga et al. 2009), recognize that weather attributes can be a problem for bicycle use. Different solutions are proposed to limit their influence on bicycle use (e.g. Winter maintenance by doing de-icing treatments and snow removal, planting trees in order to provide shades to cyclist and reduce warm weather effect, covering and secure parking bikes to limit rainfall effect).

However, weather is mostly seen as a barrier that can easily be overcome as cities in different European countries have an important modal share even with harsh weather conditions. Indeed, the United Kingdom, a country which encounters a lot of rainy days, has a town like Cambridge where more than 27% of travels are made by bikes even during important precipitations (Commision European 1999). In Oulu, Finland, approximatively one third of trips are made by bike (Kurt 2008). In consequence, weather influence is seemed not important and few applications concretely are done.

Nonetheless, these cities are an example to follow but this doesn’t mean that all users of bicycle react the same way over weather impact in every city. Because weather is often a barrier to the development of bicycle use in many cities, it seems important to conduct research on it to have a better understanding of its effect and to consider it in urban planning. We saw in our study that weather influence has a key role in bicycle use in Helsinki and that it should be considered in urban planning in order to develop cycling.

V-6 Implication for developing cycling in Helsinki

The prediction of bicycle use depending on the weather will also enhance implications for policy making concerning transport planning, in general, and urban bicycle planning, in particular. This study clearly indicates that not only climatic conditions, but also continuously changing weather conditions, affect cycling in Helsinki. Three implications can be observed to contribute in promoting cycling in Helsinki: 1) to develop the use of bicycles as a proper transport mode alternative to private cars; 2) to change social attitudes towards cycling; and 3) to improve BSS system in Helsinki.

The promotion of bicycle in urban planning could be improved by integrating cycling more with public transport whereas improving cycling infrastructure and the use of bicycle to become less weather-dependent. As it was shown that winter season had an important influence, the improvement of infrastructure and maintenance (e.g. snow clearance) is essential to try to increase its modal share during winter.

As for snow influence, maintenance of the roads is the biggest improvement needed to develop its use. The use of winter tires permits an easier use of bicycle during snow times. As it seems that two roads had important maintenance during winter 2016 in Helsinki (Helsingin kaupunki 2016), it would be very interesting to see the variation of bicycle use between these two roads and the other bicycle path to observe how well did it work.

Concerning temperature influence, more advertisement about protecting one about the cold may work. For peak hours, there could be development of protected parking bicycle places against rain, or maybe some tools available to repair or to maintain one's bicycle at workplace or at school. It may be interesting also to accept flexible departure and arrival depending on the weather (e.g. presence of heavy clouds).

For the leisure hours on weekend or for the recreational hours on weekdays, to integrate more the use of bicycle with other public transport would decrease weather-dependence of cycling. The fact that the metro enables the cyclist to bring their bicycle in is for example a good way to develop the use of bicycle (see section II-2.2). The possibilities of allowing it on trams could be analyzed. Parking locations of bikes under roof could also, as a more weather-resilient biking infrastructure, reduce the influence of weather conditions.

And as we saw that humidity had a lot of impact, the promotion of bicycle during cloudy days should also be put forward. With a good equipment (raincoat, boots), weather conditions will have less effect on users. To make raincoat available near public transport system (e.g. from train, bus and railway stations) could be a way to increase the integration of bicycle with the public transport.

Concerning BSS, the possibility to take a cheap raincoat at the stations could also reduce the fear of coming rainfall. Of course, there is the issue of waste and recycling which should be taken into account. The stations could also be in protected areas or have a protection above their station to avoid wet saddles. An electric saddle heating may also be another solution.

As we saw that for temperature between 5 and 10 degrees people still used bicycle a lot, for the year 2016, the BSS could have started two weeks earlier in mid-April. The BSS season could also be flexible depending on the weather conditions, opening it earlier if snows stop falling earlier for example or if temperature is higher. Afterwards, depending on the results, the extension of BSS period could be improved further.

A solution for the BSS to develop its period of availability would be to put winter tires on its bicycle during wintertime. However, winter cycling may be difficult to improve as risk of accident are more important and some questions, such as who is covering insurance issues, will have to be answered.

Finally, one restriction was concerning the cultural context. During July, if people of Helsinki leave their house to go elsewhere, in the same time tourist from other countries or other towns of Finland will come in Helsinki. The BSS could then try to attract more these kinds of users, as July is a month with good temperature and not extreme weather conditions. Marketing for tourist and making the use of BSS more convenient for them would be useful. One way would be to put an electric terminal, like in Lyon, which allow people to rent a bicycle from the station. As tourist may not be aware of the existence of the BSS website, it would be a way to facilitate the first contact with BSS. Special stations during this month could also be implemented next to places where tourists arrive such (e.g. harbors, bus stations).

Conclusion

Cycling, as a zero-emission vehicle, is a relevant transport mode concerning sustainable development. Bicycle use in urban setting and planning is gaining popularity with development of cycling infrastructures, integration with public transport systems and introduction of the bicycle sharing system all over the world. However, as it is, cycling is still under many restrictions such as being dependent of the landscape of the place or of cultural and societal factors. Moreover, it is also influenced by climate and weather conditions.

Helsinki (Finland), with a significantly varying weather throughout the year, is one of the best case study setting to analyze the influence of weather condition on bicycle use - with hourly temperature variations from -28 to 25 Celsius degrees, snow being present in more than 30% of the days during 2016. In order to examine its influence, two dataset were used: the bicycle sharing system dataset and the automatic bicycle counter dataset in addition to detailed weather measurement data. This study aim at assessing how weather influences bicycle use in general and to propose practical implications for better cycling, planning and promoting bicycle use.

As we saw, weather had a lot of effect on cycling. Certainly, weather influence depends on many aspects from a study period (e.g. whole year; summer and winter period), weekdays to time intervals used (by hours and days) and data types (Categorical vs continuous). The bicycle sharing system and automatic bicycle counter dataset showed similar outcomes (e.g. during leisure hours on weekend) but also some difference (e.g. on weekdays). The models showed also limits due to cultural and social factors having an important effect on cycling but being absent from the model (e.g. summer holidays in July).

As winter period have a bigger impact on bicycle use then summer period, with a significant reduction of the use of bicycle, the most important objective to increase the use of cycling in Helsinki would be to promote the use of cycling in winter by developing infrastructure and making them more practicable in winter.

To develop the study on bicycle it would be interesting to look at the influence of weather depending on the locations of the different places where bicycles were used. If there are some locations in Helsinki where weather has a greater influence in bicycle uses than others, than it could help new urban planning in focusing on these area to develop infrastructure to reduce the impact of weather. The locations may give also more information concerning the use of the BSS data (e.g. as a complementary type of transport).

In conclusion, this study clearly indicates that weather conditions in using bicycles matter. However, empirical study revealed several new research avenues and several methodological suggestions were born out for obtaining more accurate assessments of weather influence on cycling. Not the least, this study did not consider the geographical perspective of an urban setting (e.g. land use), but would be one promising future research direction for improving modelling of weather influence on bicycle use.

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Annex

Annex A : Construction of Baana network in the center of Helsinki

blue lines : one way bicycle roads

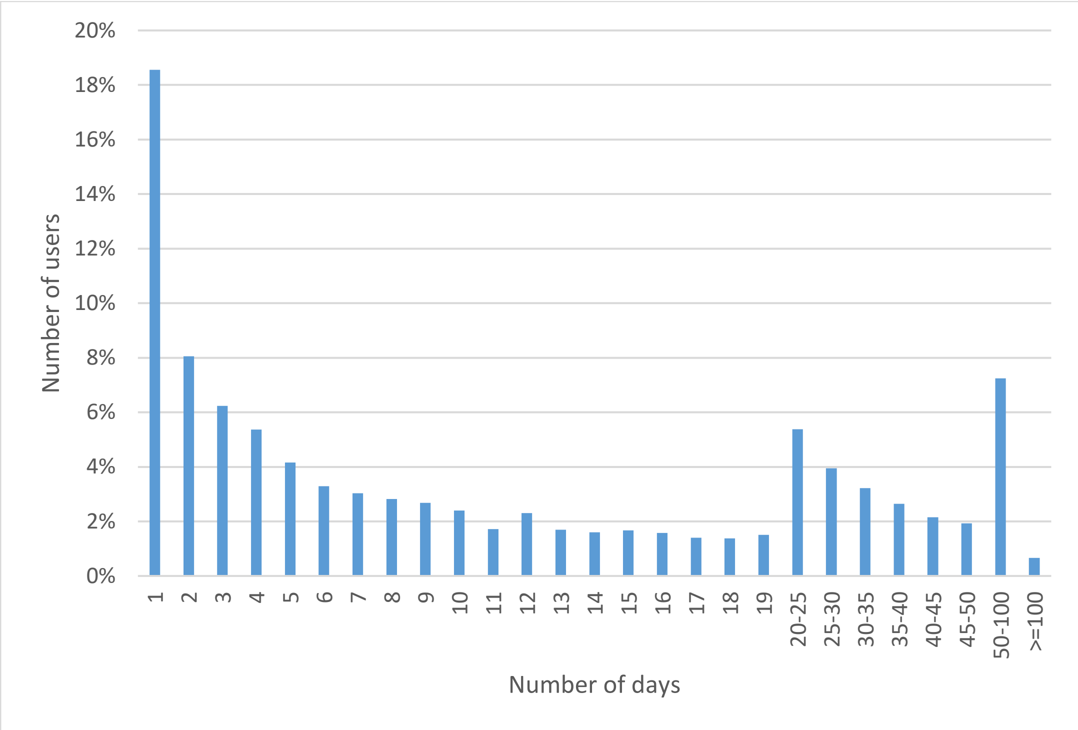
red lines : two way bicycle roads

blue and red highlights : estimated completion time between 2016-2020 for one way and two ways bicycle roads

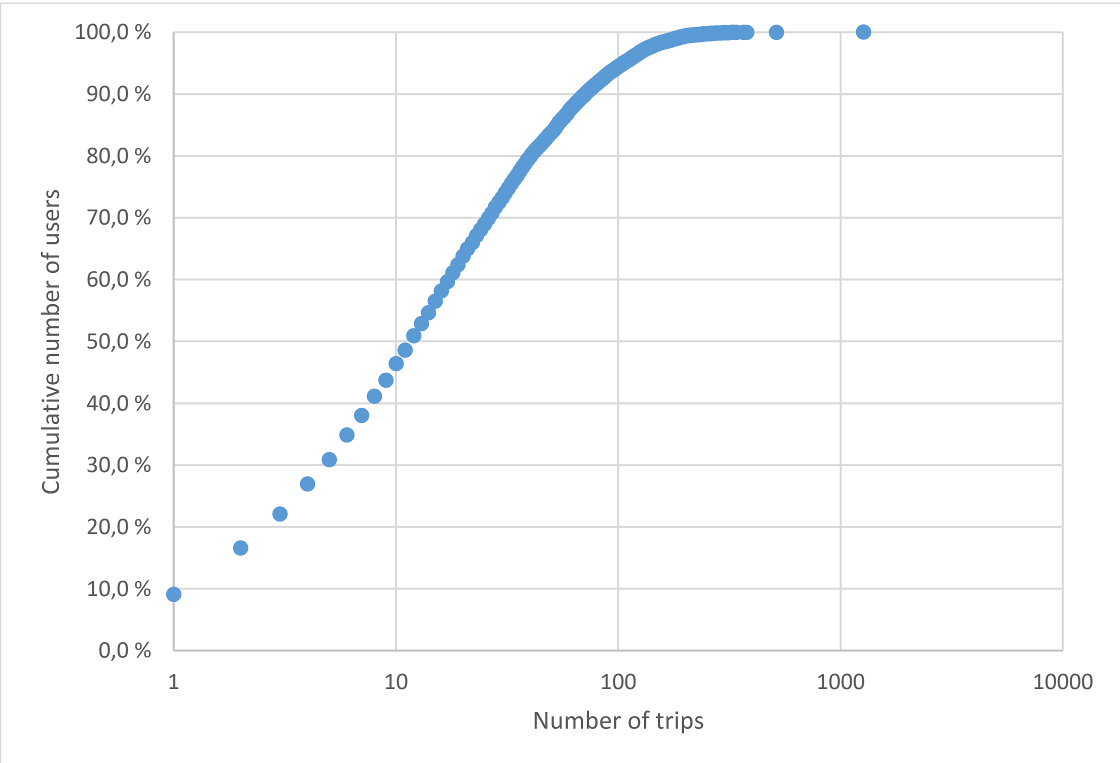
blue and red dots : estimated completion time between 2020-2025 for one way and two ways bicycle roads

Annex B: Information concerning BSS users.

B.1 Number of days the BSS was used per users



B.2 Number of trips per user

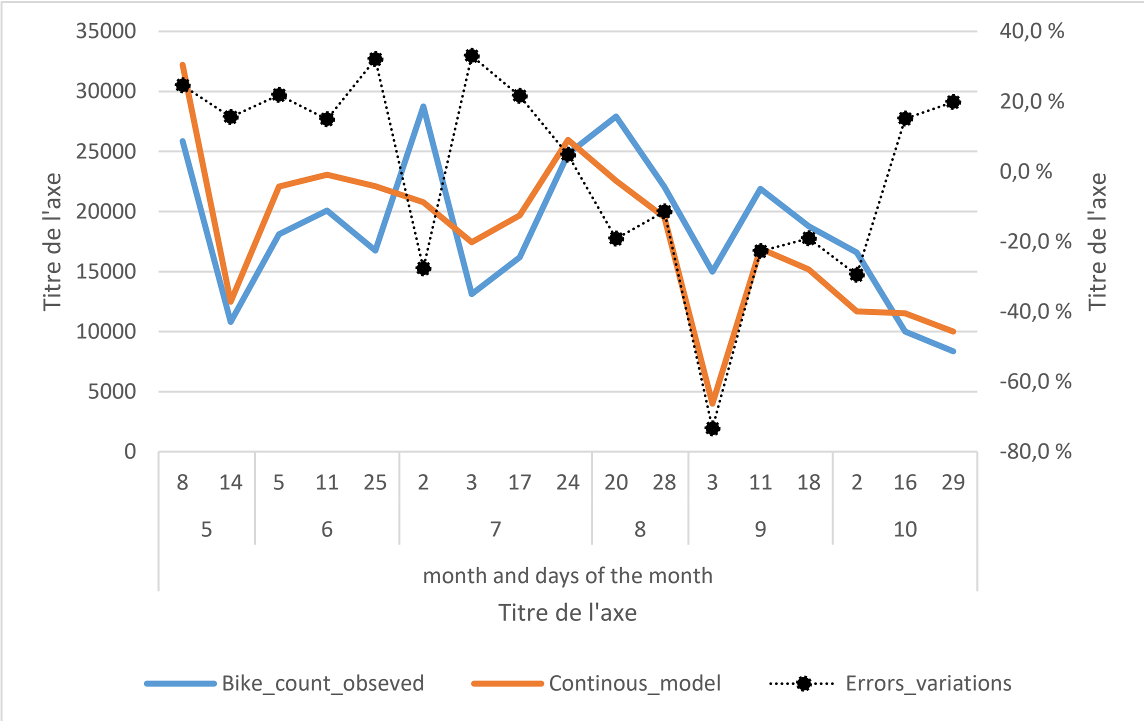


Annex C: Correlations between the different weather attributes

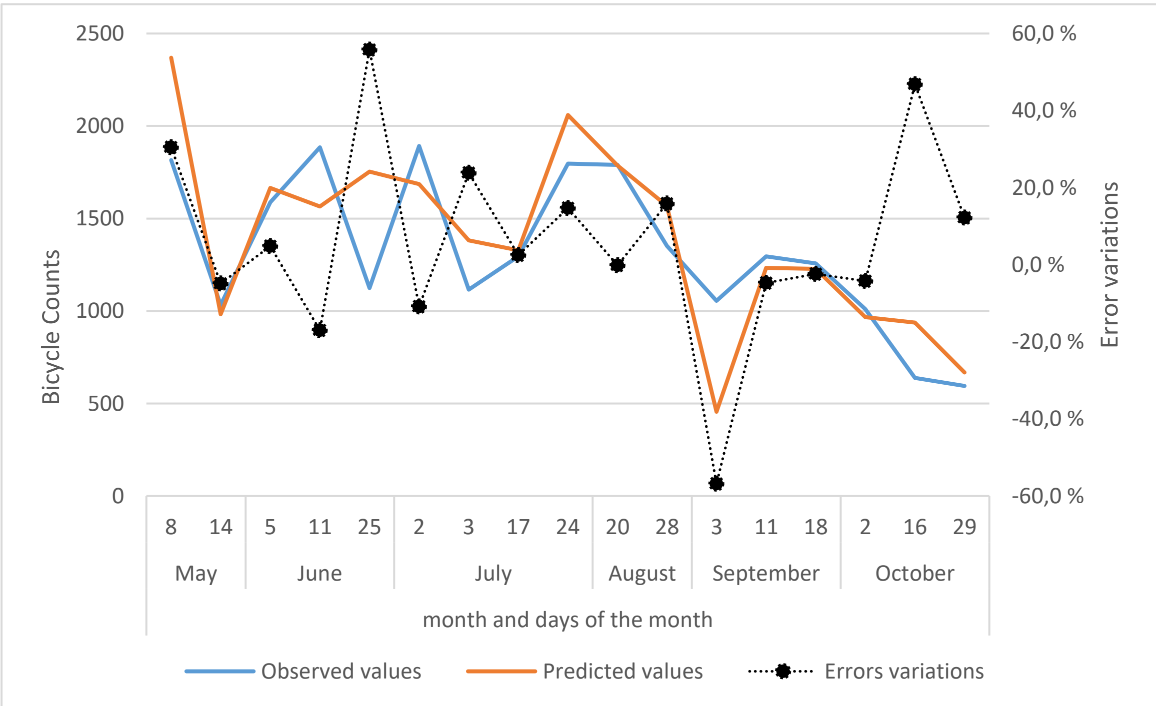
	temp	wind	gust	direct	hum	dp_temp	precip	snow	pressure	vis	cloud	darkness
temp	1,00	0,03	0,05	0,02	0,43	0,94	0,06	0,57	0,04	0,27	0,36	0,83
wind	0,03	1,00	0,99	0,15	0,12	0,02	0,17	0,08	0,32	0,11	0,25	0,21
gust	0,05	0,99	1,00	0,12	0,12	0,00	0,17	0,08	0,33	0,11	0,28	0,22
direct	0,02	0,15	0,12	1,00	0,09	0,02	0,19	0,07	0,12	0,27	0,20	0,02
hum	0,43	0,12	0,12	0,09	1,00	0,09	0,30	0,34	0,26	0,67	0,68	0,55
dp_temp	0,94	0,02	0,00	0,02	0,09	1,00	0,17	0,51	0,05	0,06	0,13	0,70
precip	0,06	0,17	0,17	0,19	0,30	0,17	1,00	0,02	0,27	0,35	0,28	0,07
snow	0,57	0,08	0,08	0,07	0,34	0,51	0,02	1,00	0,14	0,32	0,27	0,42
pressure	0,04	0,32	0,33	0,12	0,26	0,05	0,27	0,14	1,00	0,22	0,21	0,03
vis	0,27	0,11	0,11	0,27	0,67	0,06	0,35	0,32	0,22	1,00	0,55	0,30
cloud	0,36	0,25	0,28	0,20	0,68	0,13	0,28	0,27	0,21	0,55	1,00	0,44
darkness	0,83	0,21	0,22	0,02	0,55	0,70	0,07	0,42	0,03	0,30	0,44	1,00

Annex D: Testing models

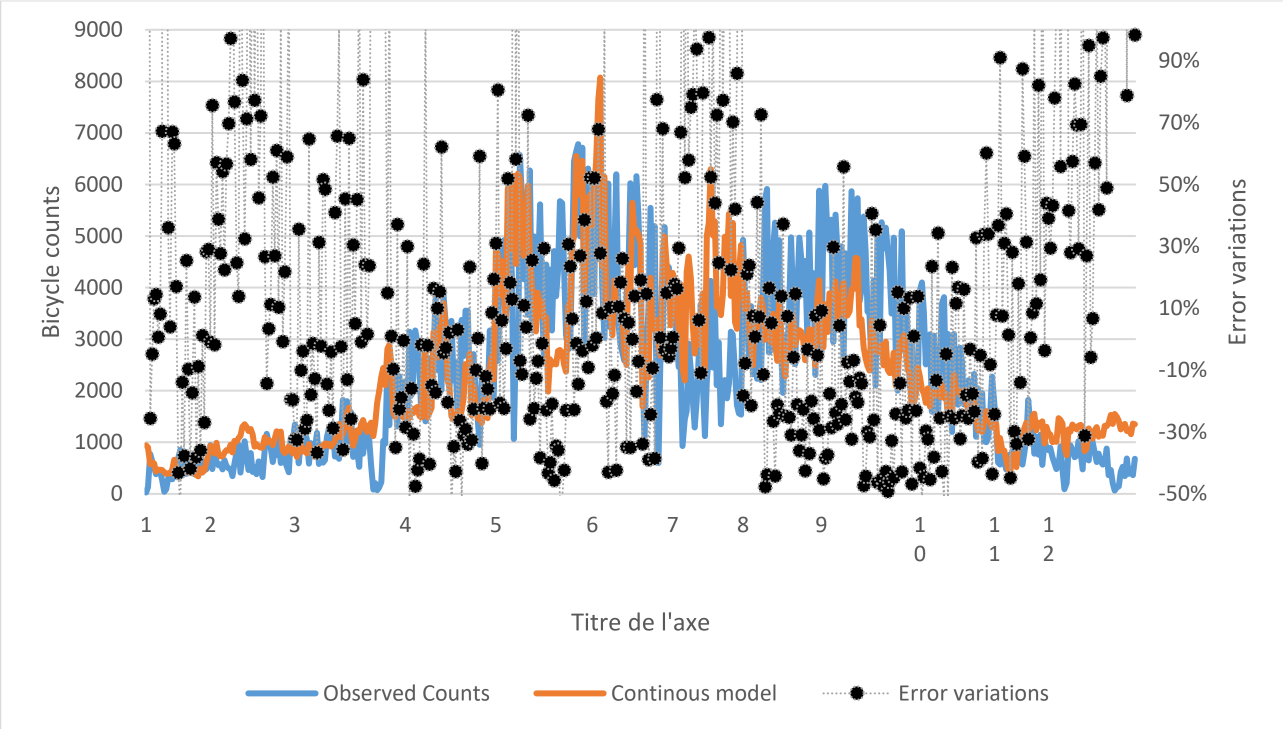
D-1 Testing weekend “summer” model for automatic bicycle counts



D-2 Testing weekend “summer” model for bicycle sharing system



D-3 Testing working hours model all year



Annex E- Error variations of all year weekdays testing model with weather variables put into categorical variables