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POSSIBILITY AND FEASIBILITY OF INSTALLING A BICYCLE SHARING SYSTEM IN TALLINN

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1. Introduction

Tallinn is the largest and capital city of Estonia. The population is about 425.249 inhabitants occupying an area of 159.2 km^2. It is situated in a strategic place on the northern coast of the country, on the shore of the Gulf of Finland, 80 km south of Helsinki, east of Stockholm and west of Saint Petersburg.

Fig1. Map of Estonia and the countries around it.

More and more vehicles, urbanization and higher population density are increasingly causing congestion in Tallinn. Traffic jams constrain public transport infrastructure, slow down travel time, increase fuel consumption and air pollution. At present, Tallinn cannot monitor traffic. There is no operative information on the situation at central intersections and traffic managers have no way to detect emerging traffic jams and identify their causes. The lack of information makes impossible to effectively manage traffic flows.

Studying all these problems that the city has with traffic, they want to promote, creating a bicycle sharing system, the use of bicycles as a mode of transport. This reduces the number of vehicles circulating in the city, and consequently the pollution will be reduced, among other issues.

By this way is how they try to increase the number of people moving inside the town by bicycle, currently 0% of the modal split. Also try to integrate the system with other ways of transport that the city has.

Basically, the system has to be integrated with the public transport that in Tallinn consists in bus, tram, trolleybus, train and ferry.

1.1 The problematic

For establish the bike sharing system, we have to focus on this people that are tourists or are people that are living in Tallinn but is not a citizen of Tallinn, because for the citizens of Tallinn the public transport is free. The fares of the system must be cheaper than the trips with public transport for attract more people. Also we have to think about how we can adapt the entire city to be ready for the bike invasion.

The big problem that the city has is the weather; at the same time for establish the system this will be one of the main aspects to be considered. As the service is only available one part of the year, during this period it must be ensured the perfect functioning of the system and as well as the perfect all the surrounding cyclist infrastructure.

And during the period in which the system is unavailable all bikes must be removed and also the computer systems must be protected as well as the stops due to weather.

1.2 The aims

The main aim of this thesis is try to establish a bike sharing system in Tallinn. Also, learn about the whole process for seeing if it is possible to do it or not. Moreover, is learning about all kind of bicycle indicators, the meaning, what they express, and the influence that these indicators have in each different city. The knowledge gained by using the simulation program is also an interesting thing.

1.3 The range

This thesis covers a small comparison of some bicycle sharing systems, and using the bicycle indicators among other things it is going to be decided if the system is available for Tallinn. Afterwards, this thesis will explain where the stations of the system should be and the process about how it has been done. This thesis will not focus on the mechanical aspects of the stations and neither the economics aspects like the economical viability of the project.

1.4 The methodology

The methodology used to develop and respond to the thesis it has been explained below. First there will be an investigation of bicycle sharing systems that are currently in Europe. It will be studied how the various systems are and as well a series of data will be collected that will help us more forward.

Subsequently, the systems will be compared and conclusions it will be found, and evaluate the best option for the city of Tallinn.

Next, with the data collected a series of indicators will be calculated that will help us to know numerically what to do to succeed in the desire to establish a system in the city.

As for the second part of the project, regardless of whether or not is feasible to install the system, it will be calculated with an innovative way that nobody has done before where the stations should be located for make this system in the most optimal way.

Obviously, before we have knowledge of the criteria employed by various European cities. As they serve as a starting point for some calculations.

Finally, with mathematical models the location of the stations is calculated. With the results obtained will reach conclusions.

2. Theory of the operating of bicycle sharing systems

2.1 The bicycle sharing systems

First of fall it have to be explained what means a bicycle sharing system. A **bicycle sharing** system, or bike share scheme, is a service in which bicycles are made available for shared use to individuals on a very short term basis. Bicycle sharing systems can be divided into two general categories: "Community Bike programmes" organised mostly by local community groups or non-profit organisations; and "Smart Bike programmes" implemented by government agencies, sometimes in a public-private partnership. The central concept of these systems is to provide free or affordable access to bicycles for short-distance trips in an urban area as an alternative to motorised public transport or private vehicles, thereby reducing traffic congestion, noise, and air pollution. Bicycle sharing systems have also been cited as a way to solve the "last mile" problem and connect users to public transit networks.

Public bike sharing programmes address some of the primary disadvantages to bicycle ownership, including loss from theft or vandalism, lack of parking or storage, and maintenance requirements. However, by limiting the number of places where bicycles can be rented or returned, the service itself essentially becomes a form of public transit, and has therefore been criticised as less convenient than a privately owned bicycle capable of point-to-point transport. Government-run bicycle sharing programmes can also prove costly to the public unless subsidised by commercial interests, typically in the form of advertising on stations or the bicycles themselves.

Moreover all the features that the systems have have to be explained. The **description** of the system explains how the users make the registration to the system, how they do to pick up the bike and also to return the bike, and also how use the main electronic menu in the station in case is need it. The feature **registration** explains if the user has to pay anything for make the registration, like the cost of the paperwork.

The **timetable** is when the system is available to be used, in a lot of cases is during all the day but others close at one hour and since this hour the user can't pick a bike but the user can return the bike when ever.

The **subscription** is a business model where a customer must pay a subscription price to have access to a service, in our case the bike sharing system. The subscription allows to the user to have access to the service. This subscription could be annual, seasonally, monthly, or daily. However, the users, a part of paying the subscription they have also to pay the travelling costs. The **travelling costs** consist in the cost that the user has to pay in each trip, in other words, every time that the user takes a bike when this one will begin to pay.

For example, the first 30 minutes of each trip are free and after that ones the user has to pay 0.5 € every 30 minutes more. With this feature the system guarantees that the users make short trips and the bicycles are not relocated.

The **deposit** is the amount of money that the user has to pay when it makes the registration and ensures that the client takes the bike and returns within the time allowed. If the client doesn't return the bike, it is considered as stolen bike and it will take your deposit automatically and invalidate the registration. The deposit is a fraction of the bike's cost; this does little to deter theft. Other bike sharing programmes have implemented rules requiring the user to provide a valid credit card, along with substantial security deposits for bicycles and mandatory security locks.

As respects the **fine** is closely linked to the deposit, if you exceeds a given travel time or you stole the bike, you will lose the deposit or it will take out of your bank account the amount of money that has been agreed in the time of registration, is usually the price of a bicycle, about 150 €.

Another important concept to consider is the **modal split**, the modal split also called mode mode-share is the percentage of travellers using a particular type of transportation or number of trips using said type. In our case is the modal split referred to bicycles.

Modal share is an important component in developing sustainable transport within a city or region. In recent years, many cities have set modal share targets for balanced and sustainable transport modes, particularly 30% of non-motorized (cycling and walking) and 30% of public transport. This goal reflects a desire for a modal shift, or a change between modes, and usually encompasses an increase in the proportion of trips made using sustainable modes.

2.2 Parameters

The **parameters** are all data taken into account for making the comparison and the analysis between the systems. The following section it will explain the meaning of each one. Among many types of parameters, some of them were chosen because these ones are considered to be more representative and easier access to finding the data.

The main parameters that have been considered for the analysis are:

The **population** of a country is all the people that live in that country. But only it has been considered the population of the city, not of the province that includes the city, because there are cities that there are also provinces.

The **area** means, the surface of the land occupied by the city, is measured in square kilometres.

The **density of population** is a parameter that indicates the people that live per a square kilometre.

$$Density\ of\ population = \frac{Population\ (inhabitants)}{Area\ (km^2)} = {inhabitants}/{km^2}$$

Cities with high population densities are, by some, considered to be overpopulated, though the extent to which this is the case depends on factors like quality of housing and infrastructure and access to resources

Regarding the infrastructure of the city and of the bike sharing system were considered the following parameters:

The **bike lanes**, the bike lanes are the lanes only allowed for the bicycles, is measured with kilometres and don't include the pedestrian streets.

The **roads**, the roads are all the city streets that are just for cars, motorbikes or vans. Is measured with kilometres

The **station,** the station is the place where the users have to park or have to pick up the bicycles. Usually the stations are for 15 to 20 bikes so a lot of place is needed. For example, in Barcelona the station occupies 3 car parking places. The station is not a standard bike rack, also contains an electronic device for indentify the users (with a lector), prints a receipt after every trip, says to the user which bike have to pick up and with leds or with sounds notice to the user if the bike has returned well.

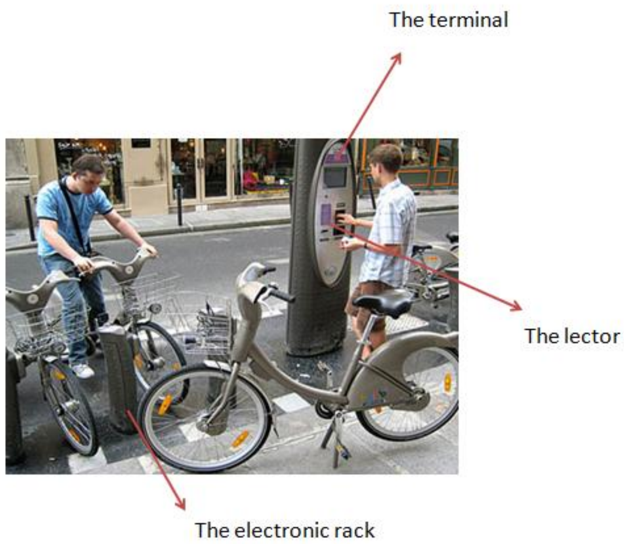

Fig2. The parts of the station

Something that is closely related to the stations is the **density of the stations**, is the number of stations that are per square kilometre. This parameter it will help because maybe for increase the modal split is not necessary a high number of stations per square kilometres.

$$Density\ of\ stations = \frac{Stations\ (number\ of\ stations)}{Area\ (km^2)} = {}^{stations}/_{km^2}$$

One of the most important concepts is the **users**, for users it refers to those users registered in the system. That is all those people who used the system during the last year.

Finally, this section ends by defining the concept of **change in the modal split**. The change in the modal split is the difference between the modal split in the year of the installation of the system and 4 years after.

$$Change\ in\ modal\ split = Modal\ split_{year\ of\ the\ installation} - Modal\ split_{4\ years\ after\ the\ insallation}$$

2.3 Relations between parameters and indicators

In this section, the meaning of the indicators, why this indicators and the relation with the parameters it will be explained.

First of all the meaning **indicator** should be explained. The indicators are, in the first place, a tool to understand the current mobility situation and allow comparing the state of bicycle circulation between bicycle partners. By comparing cycling indicators between partners (and best-practice cities), it is possible to identify weak points and to deliver numerical evidence for actions to be taken.

Among many indicators it has been considered to calculate the following ones:

The fist one is the **cycling index**; that indicates how many km of cycling tracks are per citizen in the city. This indicator is an infrastructure one, because as higher is that index higher is the infrastructure for the bikes that every citizen can use. It is calculated as follows:

$$Cycling\ Index\ (C.I) = \frac{Cyclcing\ tracks\ (km)}{Citizens} = {}^{km}/_{\text{citizen}}$$

The next one is the **network coverage index**; this one indicates the similarity between the kilometres of roads and the kilometres of bicycle lanes. As closer is to the value of 1 more similarity exists between these two networks, and means that the city has the same infrastructure for the cars as for the bicycles. This one is also an infrastructure index and it is calculated like that:

$$Network\ Coverage\ Index\ (N.C.I) = \frac{Roads(km)}{Bicycle\ tracks\ (km)}$$

Another important infrastructure index is the **network density index**, as the same says is the density of cycling tracks. Shows how many km of tracks are per square kilometer, is like how many kilometers there are in the whole area of the city. Is calculated in that way:

$$Network\ Denity\ Index\ (N.C.I) = \frac{Bicycle\ tracks(km)}{Area\ (km^2)} = \mathrm{km}^{-1}$$

To sum up, it's important to explain what means and how is calculated the correction of the modal split. The correction of modal split is a correction that is has made for show which part of the modal split represents the users of the system. In the graphs that appears after in the thesis is represented as *'modal split *'*. And this is how is calculated:

$$Modal\ Split^{*} = \frac{Users}{\mathrm{Population}} * \mathrm{Modal\ Split}_{\mathrm{the\ modal\ split\ after\ 4\ years\ of\ the\ insallation}}$$

Worth mentioning that this choice has been made and no indicators were calculated as:

The **End-point index** is an infrastructure index that is not considered in that thesis because it was impossible to find the necessary data for being developed. Is calculated in that way:

$$End - point\ index^{*} = \frac{Number\ of\ bicycle\ parkings}{\mathrm{Number\ of\ public\ car\ parks}}$$

Where a bicycle parking is considered a place with a sufficient number of racks where bicycles can be locked safely. A car-park is an indicated public parking (on-ground or multiple floors) plus street parking. Metro or light rail stations count always as a car-park (even if they are without car-park). Street parking is suggested to be calculated as total length of urban road network divided by 600m.

This indicator it has been explained because maybe somebody wants to continue with the research.

3. Bicycle sharing systems

3.1 Barcelona

Barcelona is a city with a high demographic density with more than 1.620.000 inhabitants within an area of 101 square kilometres, this means 15.963 habitants/km^2 of density of population. The existence of a cycle lane network provided a basis for introducing the system in 2006, and since then the network of cycling roads has been increased a lot, now a days the network consists in more than 180 km.

The bicycle sharing system that Barcelona's has is called as '*Bicing'*; the registration is free but is only available for the citizens. The system consist in that all the users have a card, putting this card on the station's lector the system unlock a bike. For return the bike the users have to put the bike in the station and if you have put well the bike a Led changes the colour from green to red, for be sure that you have returned well the bike you can put the card to the lector and if you have done it well a message will appear on the screen: well returned bike.

The users can use the system during the week from 5 am to 2 am and during the weekend doesn't close. The only option for being a member is the annual subscription, this subscription began with a price of 25 € per year but now costs 45.46 €, which annoyed a lot the users and caused many casualties. A part of the subscription each trip could cost some money, because, the first 30 minutes are free but after that ones you have to pay 0.73 € every half an hour, the maximum of the trip is 2 hours, after this 2 hours every extra hour cost 4,43 €. If the member looses the bike or doesn't return well the bike and someone steels the bike, it has to pay a fine of 150 €.

All this information is summarized in the following table:

City	**Barcelona**
System	Bicing
Description	All the members have a card, and with this card you have to put it on the lector in each station, and then the lector unlocks a bike. For return the bike, you park the bike in the station and if you have parked well the bike a LED changes the colour from green to red, also you can check it if you put again the card in the lector and there appears a message : well returned bike.
Registration	Free
Timetable	Mon-Friday: 5:00 am - 2:00 am Sat-Sunday: All day
Subscriptions	1 year = 46,46 €
Travelling costs	1rst 30 min--> free + every 30 min --> 0,73 € (Maximum 2h) After 2 h Every hour--> 4,43€
Deposit	NO
Fine	150 €
Modal Split *	0,90%

* Of the year of the system installation

Fig3. Table of the bicycle sharing system in Barcelona

The system purpose is to cover the small and medium daily routes within the city in a climate friendly way (17 degrees and 74 rainy days per year), almost without pollution, roadway noise, traffic congestion and to reclaim the urban streets with non-polluting vehicles.

First of all began with 96 stops that covered less than 40 % of the city and currently the network consist of more than 400 stations to lend and return over 6.000 bicycles distributed throughout the system, covering approximately 70% of the city area, except areas with slopes of more than 4%. After three years of its installation the modal split of bicycles in the city has increased 1.3 % thanks to the 123.000 users of '*bicing'* and also to the cycling network.

Fig4. Example of a 'bicing' station

3.2 Seville

Seville is another large city with an important bike sharing system. The city comprises an area of 141 square kilometres with more than 700.000 inhabitants. This represents a population density of 4.988 habitants/km2. Due to the 30.000 service users along with more than 160 kilometres of cycle lanes the modal split has increased by 2.4 %.

As for the city of Seville, the system is called 'Sevici' and the operation is similar to the 'bicing' in Barcelona with the only difference that when a user return a bike instead of see a led you will heard 2 bips (sound) if you have returned well the bike, if not you will heard 1 bip.

The registration is free and also the tourists can use the system, because exist the possibility of be a user for 7 days with a cost of 11,28 € or annual user with a cost of 28,20 €. A part of the subscription, the short term users have to pay an extra cost after the first half an hour that is free , 1,03 € every 30 minutes after the first ones. In the other hand the long term users have to pay 0,51 € every 30 minutes after the first ones. The system is available during the 24 h each day of the week. The long term users have to pay a deposit of 150 € just in case the user loses the bike. The short term users don't pay a deposit but also they have to pay a fine in case they lose the bike.

All this information is summarized in the following table:

City	**Seville**
System	Sevici
Description	It's the same system as Bicing but when you have returned the bike, instead of see a LED you will heard 2 BIPS if you have returned well the bike if not you will listen 1 BIP.
Registration	Free
Timetable	24h/7days
Subscriptions	7 days-->11,28 € 1 year-->28,20 €
Travelling costs	Short Term: 1rst 30 min--> free + 30 min --> 1,03 € +every hour-->2,04€ Long Term: 1rst 30 min--> free + 30 min --> 0,51 € +every hour-->1,03 €
Deposit	Short Term: 150€ Long Term: NO
Fine	150 €
Modal Split *	3,20%

* Of the year of the system installation

Fig5. Table of the bicycle sharing system in Seville

The system consist in a network of 250 station with at least of 2000 bicycles, this stations are situated with a distance of around 200 meters between each one, the majority of them located next to public transport stops to make easier the intermodal use.

Fig 6. Example of 'sevici' station

3.3 Saragossa

The city of Saragossa is the capital city of the Saragossa province and of the autonomous community of Aragon, Spain. Currently the population of the city of Zaragoza is 701.090, within its administrative limits on a land area of 1.062,64 km² (therefore a density of population of 659 habitants/km^2), ranking fifth in Spain. Moreover Saragossa is the 35th most populous municipality in the European Union. As an important city in Spain, Saragossa has also an important bicycle sharing system called as '*bizi*'. After some years of the installation the modal split in the city has increased 2 % thanks to the 30.000 users of '*bizi'* and also to the cycling network with more than 106 km of cycling lanes.

The operation is the same as in Barcelona but with one difference. In Zaragoza exists the possibility of be a 3 days user, this users when they pay for the service, they receive a code for unlock the bikes in the stations, putting this code in the screen of any station allows you to unlock the bike. The fare that the 3 days users have to pay is 5,13 € plus the travelling costs, the annual users have to pay 35,83 € also plus the travelling costs. This travelling costs consist in, after the first 30 minutes that are free, paying 0,51 € every half an hour till a maximum of 2 hours, after the 2 hours the users have to pay 3,07 € every hour. Obviously exists a fine of 200€ in case the user loses a bike, it is the same amount of money that the short term users have to pay for a deposit.

All this information and also the timetable is summarized in the following table:

City	Zaragoza
System	Bizi Zaragoza
Description	The same as bicing, but the 3 day users for take a bike they have to put a code that they have received when they have paid for the service, on the screen of the station.
Registration	Free
Timetable	Mon-Thru: 6:00 am - 0:00 am Friday: 6:00 am -1:00 am Saturday: 8:00 am -1:00 am Sunday: 8:00 am -0:00 am
Subscriptions	3 days-->5,13 € 1 year-->35,89 €
Travelling costs	1rst 30 min--> free + every 30 min --> 0,51 € (Maximum 2h) After 2 h Every hour--> 3,07€
Deposit	Short Term: 200 € Long Term: NO
Fine	200 €
Modal Split *	1,00%

* Of the year of the system installation

Fig7. Table of the bicycle sharing system in Zaragoza

Currently the network consist of 130 stations to lend and return over 1.000 bicycles distributed throughout the system, covering approximately all the center of the city area.

Fig8. Example of 'bizi' station

3.4 Burgos

Burgos is a city located in the north of Spain, historic capital of Castile. Currently it has about 180.000 inhabitants in the city, within its administrative limits on a land area of 107 km², consequently a density of population of 1.680 habitants/km^2, and another 20.000 in the metropolitan area. Also it is the capital of the province of Burgos, in the autonomous community of Castile and León.

The city has its own public bicycle sharing system, called as '*bicibur*'. A local company has developed the system with more than 16 stations and at least 85 bicycles. A network of over 100 km of bicycle lanes makes Burgos the first city in Spain in kilometres of bicycle lanes per resident. This system it works exactly in the same way as Barcelona's system, the users don't have to pay a deposit, exists a fine in case you lose the bike, but the big difference is that you only pay the annual subscription, 15 €, and it is all, you don't have to pay the travelling costs. Another difference is that the members can use the system 24 h during the 7 days that has the week. All the people and also the tourists can use the system. The huge difference in the operating is that after you put your annual card in the lector you have to put your pin code. You can see all this information summarized in the following table:

City	Burgos
System	BiciBur
Description	The same as bicing.
Registration	Free
Timetable	24h/7days
Subscriptions	1 year = 15 €
Travelling costs	[]
Deposit	NO
Fine	150 €
Modal Split *	0%

* Of the year of the system installation

Fig9. Table of the bicycle sharing system in Burgos

So in this case the system with 2.500 users and the network of bike lanes has caused the increase of 3.8% in the modal split during the following 3 years since its introduction.

Fig10. Example of 'bicibur' station

3.5 Lyon

Lyon is a city situated in the east-central part of France, between Paris and Marseille. Lyon has the second largest population in France behind Paris with 1.300.000 inhabitants but only 608.000 in the city of Lyon. The city of Lyon embraces an area of 67 km^2 thus giving to the city a density of population of 9053 habitants/km^2. Lyon has a pleasant climate influenced by Mediterranean, continental and oceanic.

As the cycling was very low (2%) it was boosted a bicycle sharing system that could take advantage of the existing good cycling network with more than 270 km of bike lanes.

This system triggered that the modal split increased up to the 5 % that nowadays the city has. The system reached the 60.000 users with 340 stations throughout the city and more than 4000 bicycles in circulation.

The bike sharing system that Lyon has is called as '*vello'v'*, the operating is mixture between the Barcelona's system and the Seville's system. It is a mixture because when the users return a bike well they will heard 2 successive beeps and also a green light will confirm that the bike is locked. If your bike is correctly locked, you will be able to print a receipt; on the contrary, the following message will be indicated: you currently have a bike out on hire.

The operation is similar to Burgos, after putting your card or you ticket number for the short term users you have to put your PIN code for unlock the bike.

The registration is free and available for the tourists also because exist the possibility of three different fares, 1 day ticket for 1,50 €, 7 days ticket for 5 € or 1 year ticket for 25 € or 15 € in case you are young (between 14-25 years old) . The deposit that the annual users have to pay is 150 € and it's this amount of money the fine you have to pay in case you lose the bike. The users can have the system 24 hours a day for 7 days a week.

All this information and also the travelling costs is summarized in the following table:

City	Lyon
System	Vello'V
Description	Once you have completed your journey, return your bike to any velo'v station. Wait a few seconds, two successive beeps and the green light will confirm that the bike is locked correctly. If not, push the bike clip as far as possible into the bike post. If necessary, lift the bike up into the saddle at the same time to facilitate parking. Any doubt on the restitution of your bike? Identify yourself at the station. If your bike is correctly locked, you will be able to print a receipt. On the contrary, the following message will be indicated: « you currently have a bike out on hire ».
Registration	Free
Timetable	24h/7days
Subscriptions	1 day-->1,50 € 7 days-->5 € 1 year-->25 € or 15 € (people between 14-25 years old)
Travelling costs	Short Term: 1rst 30 min--> free + 30 min --> 1 € + every 30 min --> 2 € Long Term: 1rst 30 min--> free + 30 min --> 0,75 € + every 30 min --> 1,50 € (max 24 hours)
Deposit	150 €
Fine	150 €
Modal Split *	2%

* Of the year of the system installation

Fig11. Table of the bicycle sharing system in Lyon

Fig12. Example of 'vello'v' station

3.6 Brussels

Brussels with 163.210 inhabitants and in an area of 326 km^2 is the administrative and economic capital of Belgium. It is also considered the capital of the European Union. It is the most populated city in Belgium with a density of population of 7025 habitants/km^2. Brussels has a powerful cycle network with 200 km of different types of cycling lanes. But is it told that the structure of the roads is not auspicious for cycling, however, the city has a high modal split (5%) in comparing with other cities in Europe.

As the main city of Europe, Brussels has also a bicycle sharing system called as 'v*illo!'* With a network of 180 stations and 27.000 users that can take one of the 25.000 available bicycles. Today the modal split of the city is about 6,5 % so the objective of the system has fulfilled the expectations.

The operating is exactly the same as in Lyon. Also the registration is free and available for the tourists. Exist the possibility of three different fares, 1 day ticket for 1,50 € or 7 days ticket for 7 € or 1 year ticket for 30 €. The deposit that the annual users have to pay is 150 € and it's this amount of money the fine you have to pay in case you lose the bike. The users can have the system 24 hours a day for 7 days a week.

All this information and also the travelling costs is summarized in the following table:

City	Brussels
System	Villo!
Description	Pick up a bike in one station and drop it off at the other. To hire a bike, make sure you have your subscriber card or your 1 Day or 7 Day ticket. Identify yourself at the terminal by using your card or ticket and type your PIN. Select a bike by using the menu. Push the button to release the bike from the bike stands. Attach the bike to a stand and wait for the beeps and the indicator light to confirm that the bike is properly locked in place.
Registration	Free
Timetable	24h/7days
Subscriptions	1 day-->1,50 € 7 days-->7 € 1 year-->30 €
Travelling costs	1rst 30 min--> free + 30 min --> 0,50 € + 30 min --> 1 € + 30 min --> 2 € Every 30 min--> 2 €
Deposit	150 €
Fine	150 €
Modal Split *	5%

* Of the year of the system installation

Fig13. Table of the bicycle sharing system in Brussels

Fig14. Example of 'villo' station

3.7 Krakow

Krakow is the second largest and one of the oldest cities in Poland. The city is situated on the Vistula River in the Lesser Poland region, with 756.267 inhabitants living in an extended area of 327 km^2, and with 2315 habitants/km^2 of density of population. Most of the city is flat since it lies on the area located along the Vistula. The historical centre retains, as Tallinn does, its medieval character with a lot of streets closed for cars and promoting the non motorized vehicles. Nevertheless the modal split in Krakow it is insignificant (0%), for this reason the government busted a bicycle sharing system with 13 stations and reaching the peak of users in 2012 with more than 4.500. This jointly with the 70 km of bike lanes provoked the increasing of the modal split, currently 2%.

The bike sharing system in Krakow is called as *'bike one'* and the operation consist in register and make initial payments on the website (www.bikeone.pl). During registration he/she obtains personal customer number and defines his own PIN code. Only these two numbers are needed to use the system later on. The extra costs are charged in the user bank account. Also the users have to pay a deposit of 26 €. The members can have the system 24 hours a day for 7 days a week. The registration is free and available for the tourists also exist the possibility of four different fares, 7 days ticket for 7 € or 30 days ticket for 5,34 € or 90 days ticket for 10,68 € or a year ticket for 21,37 € plus the travelling costs explained in the following summary table:

City	Krakow
System	Bike One
Description	A potential client has to register and make initial payments on the website (www.bikeone.pl). During registration he/she obtains personal customer number and defines his own PIN code. Only these two numbers are needed to use the system later on. No credit card is needed. After that client's customer account is charged depending on rental time. When the registration process is over, process of bike's renting is a simple operation: Switch on the bike rental station. Check if the selected bike is operational. Enter the number of the selected slot and your Bike One customer number. Confirm the operation with your PIN number. The system checks availability of the bike and your status in the Bike One system. The system signals authorization and releases the port. You have 15 seconds to plug the bike out. Upon return of the bike, plug it in an empty port.
Registration	Free
Timetable	24h/7days
Subscriptions	7 day-->2,56 € 30 days-->5,34 € 90 days-->10,68 € 1 year-->21,37 €
Travelling costs	1rst 30 min--> free + 40 min --> 0,20 € + 60 min --> 0,38 € Every 60 min--> 0,85 €
Deposit	26 €
Fine	▯
Modal Split *	0%

* Of the year of the system installation

Fig15. Table of the bicycle sharing system in Krakow

Fig16. Example of 'bike one' station

3.8 Vienna

Vienna is the most populated city in Austria with more than 1.680.000 inhabitants within its administrative limits on a land area of 415 km^2, consequently a density of population of 4050 habitants/km^2. In spite of the west part of Wien is situated on a hilly area, the other part of the city is flat since it lies on the Danube plain. Astonishingly with this situation the city has an extensive cycle network, which today consists of 1090 km of bicycle lanes. This reason made that the modal share was 3 % before the installation of the bicycle sharing system. The objective of the last Transport plan is to reach the 8% of cycling share by 2020, and is in a good way because today the modal share is 5%.

Among, one of the factors that has influenced was the creation of a bicycle sharing system with a network of more than 100 stations with 1.200 bikes that all the 160.000 users have at their disposal.

The bike sharing system is called as '*city bike'* and it is different as all the systems that have been explained before. In this case, the members have to put their credit card, maestro card or the city bike card in the terminal of the stations. After putting your pin code you are allowed to pick your bike. The registration fee is 1 euro, and in that system you don't have a subscription you pay for every trip you do. The first hour is free, for the next one you pay 1 €, for the third one you pay 2 € more and since the 4 hour to the next hours you have to pay 4 € for each extra hour. If the users exceed 120 hours they are punished with a fine of 600 €. The members can have the system 24 hours a day for 7 days a week.

The system is also for tourists, and as the system it can be used with a credit card it is easy to use.

Fig17. Example of 'city bike' station

All this information is summarized in the following table:

City	Vienna
System	City Bike
Description	After your registration and payment of the registration fee you can hire a bike from any bike station. Go to the terminal of your choice, then insert your credit card, Maestro Card or City bike Card in the card reader, which is located directly below the screen. The system is checking your user data and initiating the subsequent steps, remove your credit card, Maestro Card or City bike Card from the card reader and after Select one of the available bikes on the screen by entering a bike box number, enter your password by using the soft keyboard and confirm your entry by pushing "CONTINUE", to confirm your selection, your selected bike box number will appear on the screen. Please make sure you remember this number, and then go to the bike box of your choice. Push the green illuminated knob to release your city bike. After that a faint 'click' is heard and the green light will start blinking. Now you can easily pull your bike backwards out of the bike box. For returning the bike, simply push your City bike into a vacant bike box and wait for the green light. As soon as the light is on, the hiring process is completed and you can be assured that the bicycle has been properly accepted by the system. At the point, the hiring period will end and no more fees must be paid.
Registration	1 €
Timetable	24h/7days
Subscriptions	[]
Travelling costs	1rst 1h--> free + 1h --> 1 € + 1 h --> 2 € + 1 h --> 4 € Every + 1h--> 4 € (Maximum 120 h)
Deposit	NO
Fine	600 €
Modal Split *	3%

* Of the year of the system installation

Fig18. Table of the bicycle sharing system in Vienna

3.9 Montpellier

Montpellier is a city located in southern France with 255.000 inhabitants. It is the capital of the Languedoc-Roussillon region, and is built on two hills thus some of its streets have big differences in height. Montpellier is the 8th largest city of France, and is also the fastest growing city in the country over the past 25 years, nowadays is disposed on an area of 57 km2. It is the third-largest French city on the Mediterranean, for this has a typical Mediterranean climate.

Observing the conditions of the city is normal to understand the why of poor cycling network, with 100 km of bike lanes, and thus the poor percentage in modal share of cycling, 2%. But thanks to the implementation of the bicycle sharing system, called as '*velomagg*', the modal share has been increased up to the 4 %. And the merit of this achievement is for the more of 50 stations that the system has and the 9.000 users can take part of it.

The operating of this system is exactly the same as in Barcelona but with one difference, the users can buy three different cards. The global card that allows you to use the service during 3 months (40 €) or during the whole year (80 €), the free time card that is like a cash card, you pay for 20 trips (5 €) or 50 trips (10 €). The last card is called as ticket explorer, you can pay for use the system during 4 hours (1 €) or for use the system during all the day (4 €). A part of all this fares the global ticket user has to pay the travelling costs, which the first hour is free of charge but after that one the user has to pay 0,50 € every half an hour. The deposit that the annual users have to pay is 150 € and it's this amount of money the fine you have to pay in case you lose the bike. All this information is summarized in the following table:

City	**Montpelier**
System	Velomagg
Description	The same system as Bicing. But with 3 kind of different cards.
Registration	Free
Timetable	24h/7days
Subscriptions	Ticket explorer--> 4 hours= 1 € 1 day= 4 € (You have to return the bike at the same station) Free Time--> 20 credits= 5 € 50 credits= 10 € Global--> 3 months= 40 € 1 year= 80 € (<=26 years 25 €)
Travelling costs	Global Ticket--> 1rst 1h-->Free +every hour -->0,50 € Maximum of 12h
Deposit	150 €
Fine	150 €
Modal Split *	2%

* Of the year of the system installation

Fig19. Table of the bicycle sharing system in Montpelier

Fig20. Example of 'velomagg' station

3.10 Paris

Paris is the capital and largest city of France. It is situated on the river Seine, in the north of the country, and has a moderate oceanic climate. Within its administrative limits (105 km^2), Paris has a population of about 2,230,000, the most populated city in France. Paris has an extensive cycling network with more than 371 km of bicycle lanes, but the modal split is not as big as they want, 2 %. It's for that the city has developed a bicycle sharing system some years ago. With this system the modal split has increased but not as they have expected, 1% more. The system consists in 1451 stations distributed along the entire city. The more than 85 800 users can have a bike very quickly because at least every 200 meters it can be found one of these stations.

This system is called as '*velib'*, the operating it is similar to the other ones. Both tourists and citizens can use the service. The annual users can use the system with the long term card (29 €), and also exists the possibility to buy in all the stations a ticket for one day (1,70 €) or for 7 days (8 €). These users when they pay in their first trip they will receive a code that allows them to use the system as long as they have paid for. Moreover the long term users have to pay the travelling costs, the first hour is free, for the next one you pay 1 €, for the third one you pay 2 € more and since the 4 hour to the next hours you have to pay 4 € for each extra hour. If the users exceed 120 hours they are punished with a fine of 150 €.

The members can have the system 24 hours a day for 7 days a week. All this information is summarized in the following table:

City	**Paris**
System	Velib
Description	**For pick the bike**: Short-term users: Go to terminal at a Vélib' station, follow on-screen instructions, select a bike and enter bike number, Wait for the green light and signal and take your bike. Long-term subscribers: Select a bike, swipe your long-term subscriber card over the card reader and wait for the green light and signal to release your bike. **For return the bike**: Push the bike clip as far as possible into the bike post. If necessary, lift the bike up into the saddle at the same time to facilitate parking. An orange, then green light, followed by two successive beeps, confirm that the bike is locked correctly. To make sure your bike has been locked correctly, print a receipt at the station or try to hire another bike.
Registration	Free
Timetable	24h/7days
Subscriptions	1 day-->1,70 € 7 days-->8 € 1 year-->29 €
Travelling costs	1rst 1h--> free + 1h --> 1 € + 1 h --> 2 € + 1 h --> 4 € Every + 1h--> 4 € (Maximum 120 h)
Deposit	150 €
Fine	150 €
Modal Split *	2%

* Of the year of the system installation

Fig21. Table of the bicycle sharing system in Paris

Fig22. Example of 'velib' station

3.11 Orleans

Orleans is a city located in the north-central part of France, about 130 kilometers southwest of Paris. The city comprises an area of 28 square kilometres with more than 107.000 inhabitants. Orleans has a dynamic cycle network with the help of 60 km of bicycle lanes and also with a bicycle sharing system that has been established some years ago. The system called as '*Velo* +' has contributed with 33 stations and 400 users to increase the modal split by 1 %, 5 % to 6%.

The city of Orleans has the exactly same operating system as Paris has. The only think that changes is the fares, the annual users can use the system with the long term card (15 €), and also exists the possibility to buy in all the stations a ticket for one day (1 €) or for 7 days (3 €).

Also the annual users have to pay an extra cost for the registration (10€), plus the travelling costs that for them are: the first hour is free, the first hour is 1€ and every hour after the first one is for 2€ each one. For the short term users the travelling costs are the half of the other ones.

The deposit that the annual users have to pay is 150 € and it's this amount of money the fine you have to pay in case you lose the bike or in case the user exceeds the 24 hours using the bike. The service is available during 24 hours a day for 7 days a week. And also the tourists can use the system. All this information is summarized in the following table:

City	Orleans
System	Velo +
Description	The same as Paris. The short term users pay by credit card.
Registration	Card--> 10€ for annual subscriptions
TimeTable	24h/7days
Subscriptions	1 day-->1 € 7 days-->3 € 1 year-->15 €
Travelling costs	Short Term: 1rst 30 min--> free + 30 min --> 0,50 € + 30 min --> 1 € + every 30 min --> 2 € Long Term: 1rst 1hour--> free + 1hour --> 1 € + every every hour --> 2 € (max 24 hours)
Deposit	150 €
Fine	150 €
Modal Split *	5%

* Of the year of the system installation

Fig23. Table of the bicycle sharing system in Orleans

Fig24. Example of 'velo+' station

3.12 Berlin

Berlin is the capital, the largest city of Germany and one of the 16 states of Germany. Populated with almost 3.5 million people, Berlin is the second most populous city in Germany and the ninth most populous urban area (with 3813 habitants/km^2) in the European Union. Is located in north-eastern Germany, Berlin is influenced by a temperate seasonal climate.

The cycling network is well developed at least with 1.115 km of bike lanes. The modal share has been increasing a lot in the last few years, since the government implanted a bicycle sharing system the modal share increased from 13% to 17%.

The system as Berlin all the German cities that are analyzed here have is called '*call a bike'*, the system is totally different in comparison with all the systems that have been analyzed before. The system is a mobile phone based scheme. The customers register via website or by phone. To rent a bike the user calls the individual number on the bike lock and gets a 4-digit code. After entering this code on the touch screen of the electronic lock releases the bike. To return the bike, the user locks the bike, presses return on the touch screen and receives a 4-digit code. The user calls the number of the bike again, inserts the code via phone and leaves a voice message with the bike location.

Exist two kind of subscriptions, the basic tariff that consists in the user pays like a phone call, 0,08 cents per minute or 9 € per day if you are student or you have the Bahn card if not you have to pay 15 € per day. The other tariff is the annual one, the user pays 48 € (if the user doesn't have the Bahn Card) or 36 € (if the user has the card) or 24 € for students. For the annual users also they have to pay the travelling costs, for them the first 30 minutes are free but after they have to pay 0,08 cents per minute or 9 € per day. The system is available for the tourist but previously you have to make a registration that is free. In this system you don't have to pay a deposit however you have to pay a fine of 80 € in case you lose the bike.

All this information in the following table:

City	Berlin
System	Call a Bike
Description	CaB is a mobile phone based scheme. Customers register via website or by phone. To rent a bike the user calls the individual number on the bike lock and gets a 4-digit code. After entering this code on the touch screen of the electronic lock releases the bike. To return the bike, the user locks the bike, presses return on the touch screen and receives a 4-digit code. The user calls the number of the bike again, inserts the code via phone and leaves a voice message with the bike location.
Registration	Free
Timetable	24h/7days
Subscriptions	1 year--> 48 € (if you don't have Bahn Card) 36 € (with) 24 € for students
Travelling costs	1rst 30 min--> free 0,08 €/minute 9 €/day
Deposit	NO
Fine	80 €
Modal Split *	13%

* Of the year of the system installation

Fig25. Table of the bicycle sharing system in Berlin

This system consists in a network of 1.715 bicycles spread around the entire city; currently the system has more than 50.000 year users.

Fig26. Example of 'call a bike' station

3.13 Munich

Munich is the capital of the federal state of Bavaria. The city is located on the River Isar in north of the Bavarian Alps. Munich is the third largest city in Germany, behind Berlin and Hamburg. Nearly about 1.42 million people live there within an area of 310 km^2.

The network of the city is well developed; this is demonstrated by over 1.200 km of bicycle lanes and by a very high modal split 14 %. But nowadays after a bicycle sharing system was implanted in Munich the modal split has increased till the 17%. The system has helped with more than 1.400 bicycles and 42.200 year members.

In this case as Berlin, the system is exactly the same, is the same company that has developed the system so all the features are the same. As you can see in the following table:

City	Munich
System	Call a Bike
Description	The same as Berlin.
Registration	Free
Timetable	24h/7days
Subscriptions	1 year--> 48 € (if you don't have Bahn Card) 36 € (with) 24 € for students
Travelling costs	1rst 30 min--> free 0,08 €/minute or 9 €/day
Deposit	NO
Fine	80 €
Modal Split *	14%

* Of the year of the system installation

Fig27. Table of the bicycle sharing system in Munich

3.14 Stuttgart

Stuttgart is the capital of the state of Baden-Württemberg and is located in southern of Germany. The sixth-largest city in Germany, Stuttgart has a population around the 600.000 inhabitants and a density of population around the 2.880 habitants/km^2. The city lies at the centre of a densely populated area, surrounded by a ring of smaller towns located on the steps slopes. The whole of this area is called as Stuttgart Region and has a population of 2.7 million.

Although the cycling is not very popular in this city because of the hills, the cycling network consists in 140 km of bike lanes and also the city has a bicycle sharing system with more than 4.200 users and 50 stations along the entire city. With the help of the system the modal split in the city has increased from 5 % to 9 %.

As the both German cities that have been explained before, Stuttgart has the same system as them. The system is also call a bike and the operating is the same. As it can be seen in the following table:

City	**Stuttgart**
System	Call a Bike
Description	The same as Berlin.
Registration	Free
Timetable	24h/7days
Subscriptions	1 year--> 48 € (if you don't have Bahn Card) 36 € (with) 24 € for students
Travelling costs	1rst 30 min--> free 0,08 €/minute 9 €/day
Deposit	NO
Fine	80 €
Modal Split *	6%

* Of the year of the system installation

Fig28. Table of the bicycle sharing system in Stuttgart

Fig29. Example of 'call a bike' station

3.15 Modena

Modena is a university city located in the south side of the Po Valley, in the Province of Modena in the Emilia-Romagna region of Italy. The city lies on the Pianura Padana, and is bounded by the two rivers Secchia and Panaro, both are affluents of the Po River. With 200.000 inhabitants, the city of Modena embraces an area of 183 km^2 thus giving to the city a density of population of 1092 habitants/km^2.

Even though Modena has a continental climate featured by fog and heavy rain, the city has a budget of 71.000€ per year for improve and repair the cycling infrastructure, this with the fact that the city has more than 130 km of bike lanes makes to the city a modal split of 9 %.

And after a couple of years of the sharing bicycle system was installed, the modal split has increased to the 10 %. The system attracts 2.000 users with a network of 32 stations.

In that case, this city has another different system since it has been shown till now. When you pay the deposit (20 €), they give to you one key that unlocks one bike. So you have to return the bike where you have taken before. In this system the users don't have to pay travelling costs, and neither a subscription. The system is available for the citizens of Modena and also the tourists. They can use the system between 7:00 in the morning and the midnight. All this information is in the following table:

City	Modena
System	C'entro in bici
Description	When you pay the deposit, they give to you one key that unlocks one bike. So you have to return the bike where you have taken before.
Registration	Free
Timetable	7:00 am - 00:00 am
Subscriptions	Free
Travelling costs	Free
Deposit	20 €
Fine	20 € + 2€/day
Modal Split *	9%

* Of the year of the system installation

Fig30. Table of the bicycle sharing system in Modena

Fig31. Example of 'c'entro in bici' station

3.16 Parma

Parma is also a university town, is the home of the University of Parma, one of the oldest universities in the world. The city is divided into two parts by the little stream with the same name. Currently the population of the city is 196.864 inhabitants, within its administrative limits on a land area of 206,7 km². Following the little infrastructure that the city has in regard to bike lanes (83 km) is surprising the modal split that the city has (5%). Moreover the council of the city has implanted a bicycle sharing system, which nowadays is reflected on the modal split (6%).

The system consists in a network of 11 stations that the 700 users have at their disposal.

The system that Parma has is called as '*punto bici'* and the operation is exactly the same as in Barcelona. But the main difference is that in parma stations every bike has a lector for unlock the bike. Also exists only the annual tariff for 25 €, and the travelling costs are: the first 30 minutes are free and after that one's every 30 minutes more the user has to pay 0,8 cents, after 3 hours the tariff increase to 1 € each hour. In that case you don't have to pay a deposit, and the system is available for tourists. All this information and the timetable is summarized below:

City	**Parma**
System	Punto Bici
Description	The same as bicing but every bike has a lector for unlock the bike.
Registration	Free
Timetable	7:00 am - 00:00 am
Subscriptions	1 year--> 25 €
Travelling costs	1rst 30 min--> free + every 30 min --> 0,8 € After 3 h Every hour--> 1 €
Deposit	NO
Fine	▯
Modal Split *	5%

* Of the year of the system installation

Fig32. Table of the bicycle sharing system in Parma

Fig33. Example of 'punto bici' station

3.17 Milan

Milan is the capital of Lombardy. The city has a population of about 1.35 million, within an area of 182 square kilometres, this means 7.119 habitants/km^2 of density of population. Even having 144 km of bike lanes and a bike sharing system, the city has not experienced any growth in terms of modal share of cycling, despite the passing years the modal reminds stuck at 4%.And is not because the system is not valid, because it has more than 103 stations covering most of the city. But one has attracted 16.500 users.

In the Milan system, '*bike mi'*, the operation is the same as in Barcelona but as there is the possibility of be a short term user something is different. For the short term users (1 day for 2,50 € or 7 days for 6 €) the operation is that they have to sign up for a subscription occasional (weekly or daily), they will receive, via sms or e-mail, a user code, which, together with the password they chose during registration, they will have to type on the keyboard of the column of any service station '*bike mi'*. But all the users, also the annual users (36 €) they have to pay the travelling costs, as every city the first 30 minutes are free of charge but every next ones cost 0,50 € each ones, with a maximum of 2 hours. If you exceed the 2 hours you have to pay a fine of 150 €. The same fine if you lose the bike. All is explained in the following table:

City	Milano
System	Bike mi
Description	The same as bicing but for If you sign up for a subscription occasional (weekly or daily), you will receive, via sms or e-mail, a user code, which, together with the password you chose during registration, you will have to type on the keyboard of the column of any service station Bike Mi. Press the "Conv" to every post. The display of the column of the station, once you have entered your information, we will indicate the number of the engagement from which to take your bike. Please note that your subscription will start from the occasional time when you will receive codes.
Registration	Free
Timetable	7:00 am- 23:00
Subscriptions	1 day-->2,50 € 7 days-->6 € 1 year-->36 €
Travelling costs	1rst 30 min--> free + every 30 min --> 0,50 € (max 2 hours)
Deposit	NO
Fine	150 €
Modal Split *	4%

* Of the year of the system installation

Fig34. Table of the bicycle sharing system in Milan

Fig35. Example of 'bike mi' station

3.18 Stockholm

Stockholm is the capital of Sweden and is the most populous city in Sweden, with a population of 810.120 in the municipality , nowadays is disposed on an area of 188 km^2. The topography of the city is flat, even though the city has a lot of hills and ridges the city is provided by a bicycle network of 1.964 km including the only three bicycle links crossing the water between the north and the south of the city. This fact and also the boost of a bike sharing system have contributed to the increase of 2% (from 5% to 7%) in the modal split. And the merit of this achievement is for the 73 stations that the system has and the 5.200 users that can take part of it.

The operating of this city is exactly the same as Barcelona but as a lot of cities has a short term fare for 20 € (3 days) and the season fare for 35 €. This city has a season fare (April-October) because during the winter season it's impossible to use the bikes because the low temperatures and is always snowing. The system is available for the tourists and the fine that the users have to pay if they lose the bike is 95 €. In this case the users don't have to pay the travelling costs but if they exceed 2 hours of using the bike they have to pay the fine. All this information and the timetable are explained below:

City	Stockholm
System	Stockholm City Bikes
Description	The same as bicing.
Registration	Free
Timetable	6:00 am- 22:00 (Till 1 am you can return the bike)
Subscriptions	3 days-->20 € 1 Season (April-October)-->35 €
Travelling costs	Max. 2hours
Deposit	NO
Fine	95 €
Modal Split *	5%

* Of the year of the system installation

Fig36. Table of the bicycle sharing system in Stockholm

Fig37. Example of 'Stockholm city bikes' station

3.19 The more suitable system for Tallinn

Before starting with the choice of operating system that it will be decided by Tallinn, it is worth mentioning that Tallinn is a very touristy town, receives more than 2.72 million tourists in 2011 and it has increased 3% compared to 2008. It is a city that is fully oriented to the tourism so also is very important to consider it in choosing the most suitable option for this city.

Firstly, two main groups of systems it will be distinguished: the Germans and the rest, because the Germans have a totally different system to the rest. As can be appreciated it before in the explanations of systems.

In order to choose a system to Tallinn it will be elected the system that the rest of Europe has, because the German is harder to use and involves phone calls and if the target for the system are the tourists also is not thought to be the appropriate one. Because if the tourists don't have a german phone card, the service it will cost a lot, moreover each call it will be extremely expensive and not the price set by the server.

Once there, in terms of subscriptions, as Tallinn is a very tourist oriented city and the system has to be orientated to most of them. For that there will be such as the cities of Milan, Orleans, Paris, Montpellier, Krakow, Brussels or Lyon reduced rates. Obviously there will be one day fare and the rate will be cheaper than going to a destination and back by public transport.

Currently this fee is 1.60 € each way, so the rate of one day will be cheaper than 3.2 € to be competitive and attract tourists who apart from making tourism in a healthy way they can move around the centre by bicycle in a cheaper way.

Then, as the target system is mostly the tourists, the system will also have a fee of 3 days. Because according to statistics provided by the tourist office in the city, tourists visit the city an average of 2.9 days per person in 2011.

Therefore, the price of this rate must be more considered, the city centre is relatively small and they can walk if they wish, then if they use public transport at least one time the cost is 3.2 € the same as it has been before mentioned, bearing in mind that they are staying an average of 3 nights it is probable that they want to visit a couple of emblematic sites in the city, so they will go at least once more with public transport. Summing up in these three days they would be spent at least 6.4 €, taking as examples of Stockholm and Zaragoza, worth 20 € and 5.13 € for the 3 days ticket respectively. For Tallinn the appropriate price would be about 4,5 €. So tourists would save at least 2 € and it is attractive. With a good advertising in the hotels, at airports, port and in tourist guides it will be a very successful system.

In addition, considering the bicycle culture of the foreign visitors of the city will guarantee success, the Finns (42%) who visit the city have a modal split where 6% of the trips are with bike, the Russians (24%) have a modal split of 24% of its capital in Moscow and in St. Petersburg a 6% and finally to highlight the Swedes (10%) with a 10 % in modal split.

This city does not make sense to talk of a fare for 7 days, as tourists are on average 2.9 nights and also the city is small and is not worth being there most days. People who have more nights they dedicate the time to travel around cities like Riga, Helsinki or St. Petersburg.

Finally, this analysis will determine the tariff rates of the season due to the cold and the bad weather will be like in Stockholm from April to October. So, with this rate must attract students not residing in Tallinn and people that are living and working in Tallinn but don’t have their residence here, because for them the public transport is not free. Students have to pay 8.5 € for 30 days and the not resident people in Tallinn that are not students have to pay 23 €. So 6 months of public transport cost 51 € and 138 € respectively. So, the fee that fits more and is attractive compared with the conditions and prices of other cities is believed to be the appropriate price between 25 and 30 €.

Obviously, for defining the costs for travelling, if you want to be competitive don’t have to entail any additional cost to the user, so, it will be free, because the trips in average are short and many rarely exceed 30 minutes. For example, a student who lives in the centre of Tallinn and wanted to go to college that is farther from the centre, TUT (Tallinna University of Technology), take an average of 33 minutes. And in all the cities in Europe the first 30 minutes or the first hour is free so is a good option.

The schedule for the system would be used 24 hours a day every day of the week and win adherents to public transport that ends at midnight each day.

Finally, establishing a fine in case of lost or broken bicycles, the fine will be 300 € based on other European systems and on the prices of bicycles in Tallinn.

Lastly the name of the system it should be defined, the task is in charge for the marketing department of the city council but a hint for this could be: ‘*Tallinnonbike*’.

4. Comparison and analysis between the systems

This section of the thesis, using the parameters found for each system together with the calculation of the indicators, it going to try to find a relationship between parameters and indicators. If the relationships between parameters it have been found, this will serve us to determine, using existing data from the city of Tallinn, if it is feasible to implement a system in that city.

4.1 The bicycle indicators

Common performance indicators are, in the first place, a tool to understand the current mobility situation and allow comparing the state of bicycle circulation between bicycle partners. By comparing cycling indicators between partners (and best-practice cities), it is possible to identify weak points and to deliver numerical evidence for actions to be taken within bicycle as well as for future EU projects. This is why WP3 has been placed temporarily before the implementation phase. The usage of the indicators as a measure of the overall success of actions taken within this project is important, but is not the main emphasis. It is usual to make site interviews to demonstrate the effect of local infrastructure changes on users. These interviews will not be inside the range of this thesis.

This section describes briefly the indicators that should be calculated, based on the collected data: Firstly, some widely used standard indicators for cycling infrastructure and usage need to be determined in any case. This is necessary to be able to compare the results with the outcome of other projects and best practice cities. However, some alternative, more significant indicators will be proposed or identified during this work package. Both, the standard indicators and a proposition for alternative indicators are described below.

The following standard indicators shall be calculated for each partner (if not already available):

- *Cycling index* (km of cycle track per citizen)
- *Network coverage index* (road km per km of cycle track)
- *Network density index* (cycle track km / area in km^2)

4.1.1 Cycling Index

This indicator is only a division between the citizens living in the city and the kilometers of bicycle lanes that the city has.

City	Km of bike lanes	Inhabitants	Cycling index (km bike lanes/inhabitant)
Barcelona	180	1615448	0,000111424
Seville	160	702355	0,000227805
Zaragoza	106	701090	0,000151193
Burgos	100	179906	0,000555846
Lyon	300	608000	0,000493421
Brussels	200	163210	0,001225415
Krakow	70	756267	9,25599E-05
Wien	1090	1680266	0,000648707
Montpelier	120	255000	0,000470588
Paris	371	2168000	0,000171125
Orleans	60	107841	0,000556375
Berlin	1115	3416255	0,000326381
Munich	1200	1302376	0,000921393
Stuttgart	140	597176	0,000234437
Modena	130	200000	0,00065
Parma	83	196864	0,000421611
Milano	144	1295705	0,000111136
Stockholm	1964	810120	0,002424332

The highest ones

Fig38. Table of the cycling index in all the analyzed cities

As it can be seen the cities with the cycling index indicator higher are Stockholm (because is a city with a lot of bike lanes instead of the people that lives there) Brussels (although the bike lane kilometers are not many, comparing them with the people who live there yes they are) and Munich (big population but a lot of bicycle lanes).

4.1.2 *Network coverage index*

This indicator is only a division between the kilometers of roads that there are in the city and the kilometers of bicycle lanes that the city has.

City	Km of roads	Km of bike lanes	N.C.I(km roads/km bike lanes)
Barcelona	1287	180	7,15
Seville	1100	160	6,875
Zaragoza	1794	106	16,9245283
Burgos	279	100	2,79
Lyon	2548	300	8,493333333
Brussels	2794	200	13,97
Krakow	1263	70	18,04285714
Wien	2794	1090	2,563302752
Montpelier	340	120	2,833333333
Paris	1700	371	4,582210243
Orleans	250	60	4,166666667
Berlin	5366	1115	4,812556054
Munich	2000	1200	1,666666667
Stuttgart	1400	140	10
Modena	850	130	6,538461538
Parma	855	83	10,30120482
Milano	1347	144	9,354166667
Stockholm	1758	1964	0,895112016

The highest ones

Fig39. Table of the network coverage index in all the analyzed cities

As is indicated by the indicator, here we see that higher values indicate the difference between the network dedicated to cars and dedicated to bicycles. The values next to 1 indicate the equality between cars and bicycles. And with that we can say that the city has a good network to travel by bicycle.

Thus it is seen that Stockholm, Munich and also Wien have an excellent cycle network that covers the city just as well as if you want to move away with car. So it's a way to attract citizens to use bicycle transportation, as they can go to everywhere with safe and comfort with such transportation.

On the other hand, we can distinguish two very different cases. The first is that of the cities of Parma and Milan that even having a little cycling network they have high modal shares, 4 % and 5% respectively. While Zaragoza and Krakow his poor cycling network is reflected in its modal split, 3% and 2% in their respective cases.

4.1.3 Network density index

This indicator is a division between the kilometers of bicycle lanes that the city has and the area of the city.

City	Km of bike lanes	Area (km^2)	Network density index (km bike lanes/km^2)
Barcelona	180	101	1,782178218
Seville	160	140,8	1,136363636
Zaragoza	106	1063	0,09971778
Burgos	100	107,06	0,93405567
Lyon	300	67,16	4,46694461
Brussels	200	326	0,613496933
Krakow	70	326,8	0,214198286
Wien	1090	414,88	2,627265715
Montpelier	120	56,88	2,109704641
Paris	371	105	3,533333333
Orleans	60	27,48	2,183406114
Berlin	1115	891,67	1,250462615
Munich	1200	310,4	3,865979381
Stuttgart	140	207,36	0,675154321
Modena	130	183,23	0,709490804
Parma	83	260,67	0,318410251
Milano	144	182	0,791208791
Stockholm	1964	187,84	10,45570698

The highest ones

Fig40. Table of the network density index in all the analyzed cities

In this indicator it can be seen that how much bigger the value is the area of the city is well covered with a large cycling network. This is the case of Stockholm, Lyon and also Munich and Paris, small areas and a lot of km of bike lanes.

4.2 Relations between parameters and indicators

In this section of the thesis, it will be show some of the graphs done, at the end of this section a comparative table it have been shown.

First of all, the parameter of the change in the modal split, between the year of the installation of the system and a few years after, it is going to be the main parameter for our study. It will be interesting to find a relationship between this parameter and another one because it will explain what feature have to has the city for has succeed in the task of increment the modal split. And compare the situation with Tallinn.

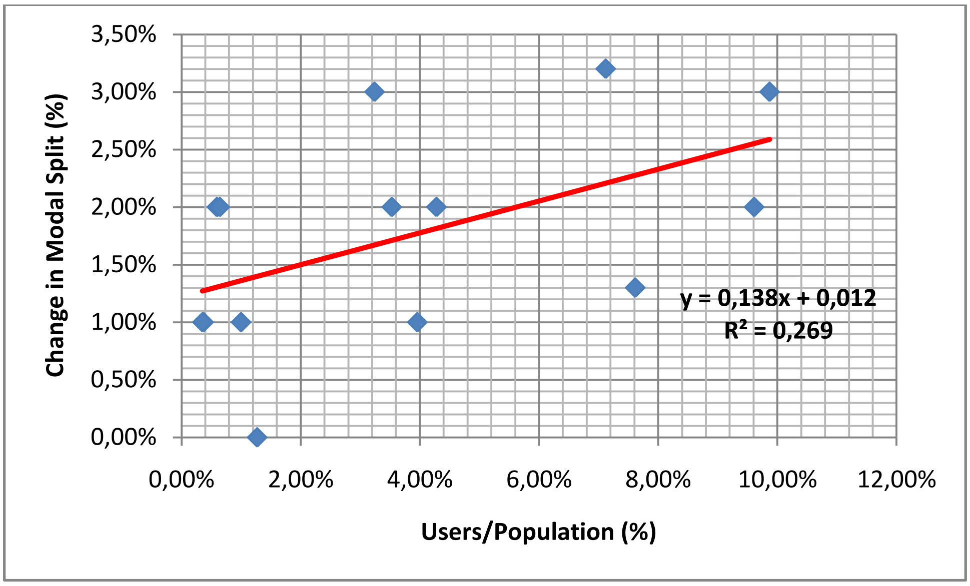

Fig41. Graph between the change in modal split and the users/population

In this graph it is shown that a relationship exists between these two parameters. It is normal that how many users the system has the change in the modal split increases. But extract something for Tallinn here it is difficult because they would have to foresee how many users will be and that we would see as how increase the modal split. Or only guess how many users the system must have to have an increase in the modal split that the customer wants.

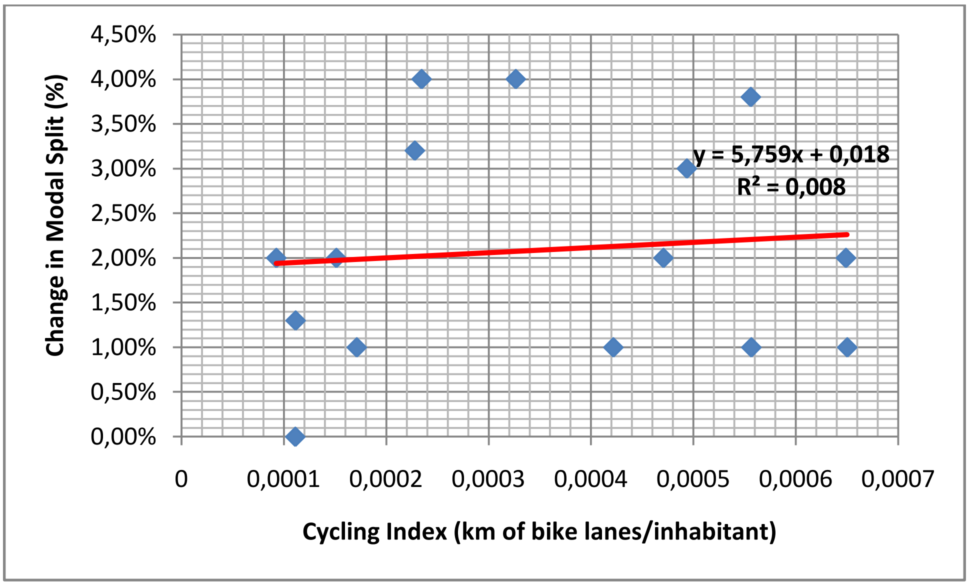

Fig42. Graph between the change in modal split and the cycling index

In this graph any relationship between the parameter and the indicator is it possible to appreciate it.

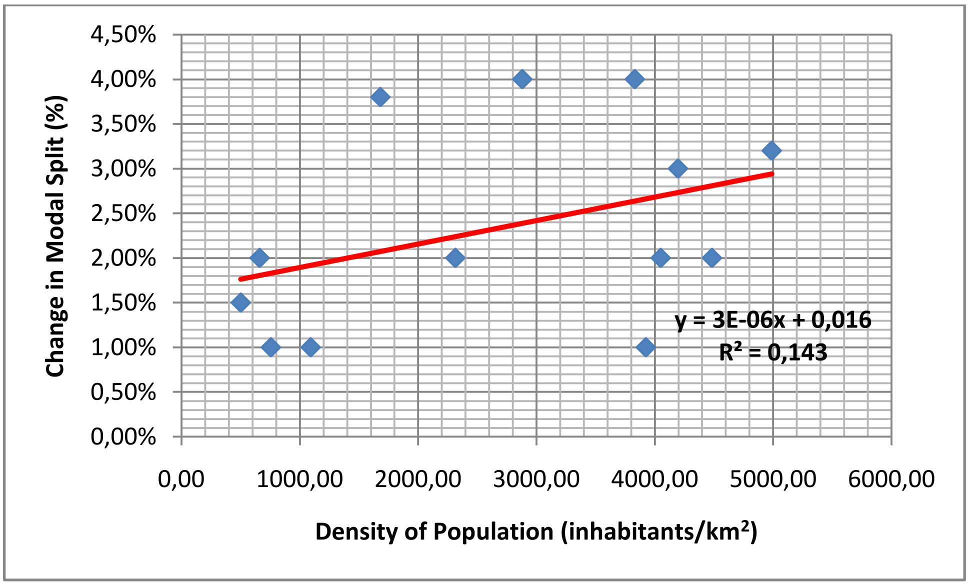

Fig43. Graph between the change in modal split and the density of population

In that one, a little relationship it can be appreciate on it. As it was expected how more people are living in the area more increase the modal split, it is because it is for probability, if there are more people is it possible that more people will be attracted to use the system.

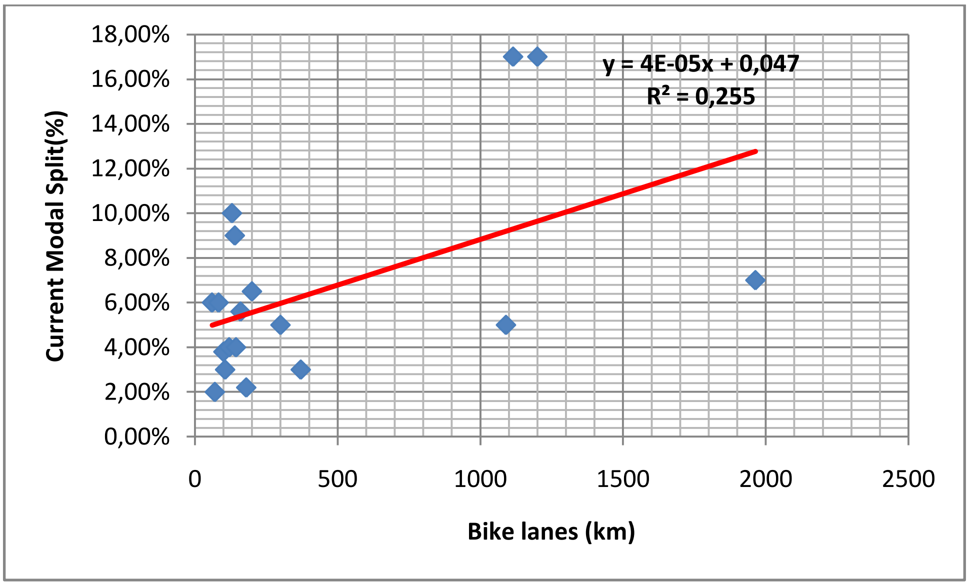

Fig44. Graph between the current modal split and kilometres of bike lanes

In this graph it is possible to appreciate that how more extended is the bicycle network more modal split the city has.

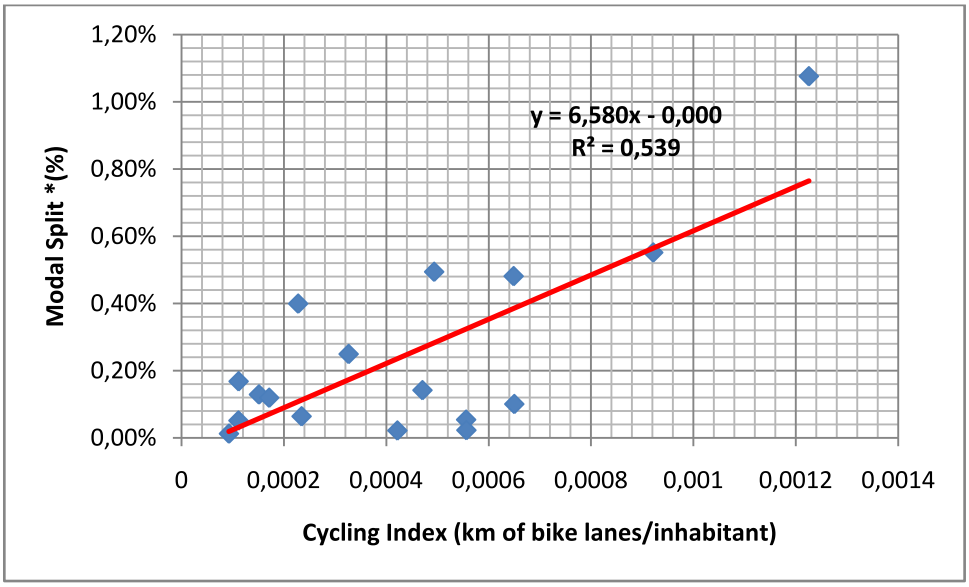

Fig45. Graph between the correction of modal split and cycling index

As it can be seen in the graph, a strong relationship exists between the cycling index and the modal split correction. As it was expected, how higher the cycling index is the modal split increases. Therefore maybe the index is a good parameter to consider for gets a good modal split.

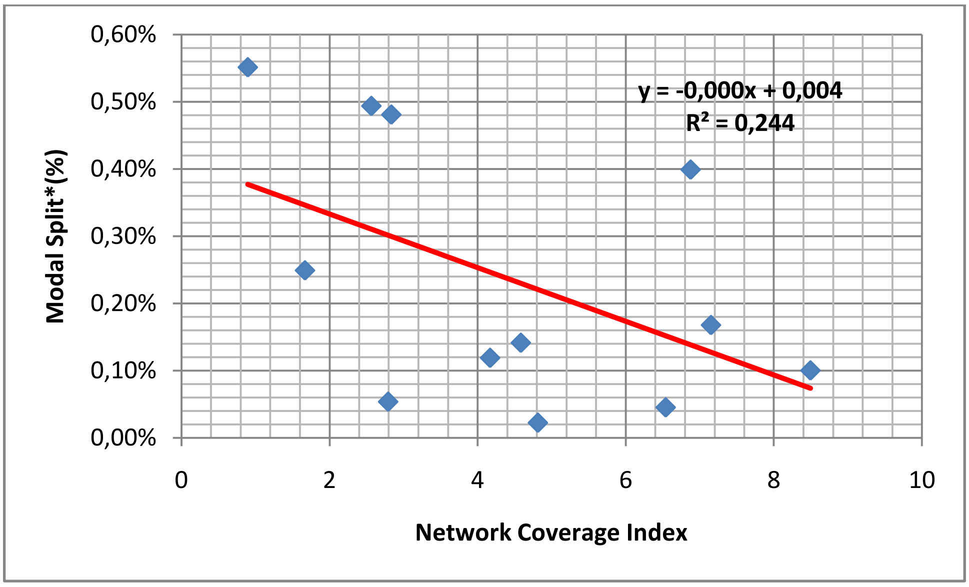

Fig46. Graph between the correction of modal split and the network coverage index

In this graph it can be seen the high relationship between the network coverage index and the modal split correction. As it has been explained before, the network coverage index is the kilometres of roads that have the city divided per the kilometres of bicycle lanes. So when the index it's close to 1 indicates that the bicycles and cars network are very similar. How it is normal how bigger is the modal split, the coverage index it is closer to 1. Therefore to grantee a high modal split it is necessary to try to have the same kilometres of roads for the bicycle lanes.

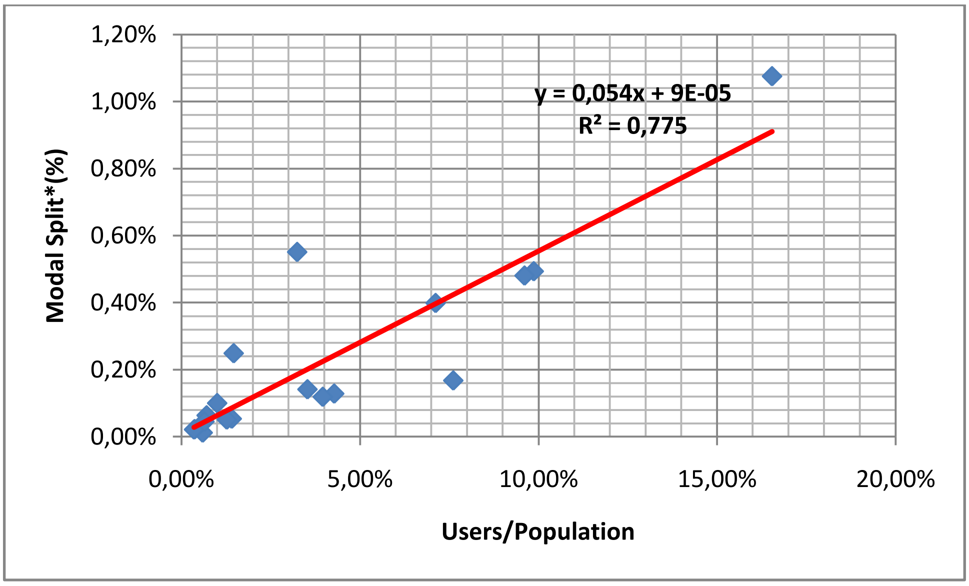

Fig47. Graph between the correction of modal split and users/population

Here there is an obvious relationship as the two are directly proportional.

4.3 Conclusions of the analysis

First of all it will be shown the result of all comparisons made not shown above because it was not considered as important. Afterwards will display a table where you can see the R2 of each graph done and with this it will be known or not to the strong relationship between certain parameters.

	Cycling Index	N.C.Index	Density of Population	Users/Population	Bike Lanes
Current Modal Split	0,006	0,122	0,024	0,091	0,255
Modal Split *	0,539	0,244	0,239	0,775	0,149
Diference in Modal Split	0,009	0,026	0,143	0,269	0,171

	MAX
	MIN

Fig47. Table with all the R^2 of all the possible comparisons

As it can be shown exists a strong relation between the correction of modal split and the percentage of users in front of the population, 0,775. Also a high relation between the correction of the modal split and the cycling index it can be appreciated (0,539).

Therefore, considering these two relations, together with the role of others play, it can be said that having a good network of bike lanes ensures an increase in the modal split. So the city has to have a bicycle network as similar as possible to the total vehicle roads. Obviously if the system achieves a high number of users is guaranteed an increase in the modal split. But the fact that Tallinn has the free public transport means that it will never predict how many people will decide to use this system because it will cost some money per season. It has been appreciated the option, because the city of Tallinn during the summer receives a large number of tourists, guide system for them.

The first step is to carry out the city improve and adapt the bike to the city, creating a good network of bike lanes, as currently consists of 160 km of these, however many of these kilometers are between Tallinn and villages around, not within the city.

The second step is to decide to who focuses the system and thus make certain advertising to attract as maximum people as possible. Once is decided to who direct the system, It will be established the rates and what part of town you want to start implementing the system.

Finally, having determined the area has to decide where the stations of the system it will be located to improve and optimize the system as much as it can be.

As a conclusion in response to the thesis, considering the advantages of bike sharing system such as: reduce car use, promote public transport, promoting cycling, reduce pollution, improve the health of citizens, improve road safety and encourage the local economy among other things. And considering all the results that have been calculated previously, it’s a good risk to install a bike sharing system. But firstly the system it has to be installed in one part of the city and after according to how many people is using the system and how is working it can be extended.

As in Tallinn the modal split is 1% if it exists a good advertisement is not difficult that a lot of people will use the system. It’s easier in this city than in a city where the modal split is it high.

5. The models of location theory

5.1 Location criteria

Firstly, the concept of location criteria has to be explained. The **location criteria** is the strategy that the cities with the bike sharing system has adopted for located the stations of the system. It is a very important fact because if it is done without thinking anything problems will appear after and faster.

As in the case of Barcelona, all the bikes are in the same stations and some of the stations are full in the peak hours and others are empty. And also in the first years didn't calculate well how many people will use the bike and during the first years a lot of users complained about the insufficient number of bicycles.

For this important fact, in this thesis a new method of location it will be suggested and verified. The location models for other application are going to be adapted for be used in this case. Any city has done this before and maybe it's going to be a new tendency.

5.2 The location models

5.2.1 The P-Center model

The *P*-center model minimizes the coverage distance such that each demand node is covered by one of the facilities, within that minimized distance. This is in fact a minimax problem, since the model minimizes the maximum distance between a node and its nearest facility. Noticed that this minimum distance is determined endogenously (Daskin, 1995). The model is described below:

$$[MIN][MAX]Z = D \qquad (1)$$

$$Subject\ to:$$

$$\sum_i Y_{ij} = 1, \quad \forall j \qquad (2)$$

$$\sum_i X_i = p \qquad (3)$$

$$Y_{ij} - X_i \leq 0, \quad \forall\ i, j \qquad (4)$$

$$D \geq \sum_i d_{ij} \cdot Y_{ij}, \quad \forall j \qquad (5)$$

$$Y_{ij} \in \{0,1\} \quad \forall\ i, j \qquad (6)$$

$$X_i \in \{0,1\} \quad \forall\ i \qquad (7)$$

$$where:$$

$$d_{ij} = distance\ from\ node\ j\ to\ facility\ i\ ;$$

$$Y_{ij} = \begin{cases} 1\ if\ demand\ node\ j\ is\ assigned\ to\ facility\ i \\ 0\ otherwise \end{cases}$$

$$X_i = \begin{cases} 1\ if\ a\ facility\ is\ located\ at\ candidate\ site\ i \\ 0\ otherwise \end{cases}$$

The objective function (1) minimizes the maximum distance between a demand node and its closest facility. Constraints (2) require each node to be served by only one facility. Constraint (3) defines a number p of facilities to be located. Constraints (4) assure that nodes are assigned only to activate facilities. Constraints (5) state that the distance between any demand node and the facility which will serve it must be less than the maximum distance between a demand node and its nearest facility. Finally, constraints (6) and (7) are standard integrality conditions.

5.2.2 The P-Median model

One of the most popular models used to solve the location problem is known as the *P*-median. This model is related to a network problem, and has been extensively applied to facility location (Daskin, 1995). This problem, first presented by Hakimi (1964, 1965), deals with decisions of locating p facilities (medians) in a network, minimizing the weighted sum of all distances from each node to its nearest facility. The complete model is described below:

$$[MIN]Z = \sum_i \sum_j D_j \cdot d_{ij} \cdot Y_{ij} \quad (1)$$

$$Subject\ to:$$

$$\sum_i Y_{ij} = 1, \quad \forall\, j \qquad (2)$$

$$\sum_i X_i = p \qquad (3)$$

$$Y_{ij} - X_i \leq 0, \quad \forall\ i,j \qquad (4)$$

$$Y_{ij} \in \{0,1\} \quad \forall\, i,j \qquad (5)$$

$$X_i \in \{0,1\} \qquad \forall\, i \qquad (6)$$

$$where:$$

$$D_j = demand\ at\ node\ j\ ;$$

$$d_{ij} = distance\ from\ node\ j\ to\ facility\ i\ ;$$

$$Y_{ij} = \begin{cases} 1\ if\ demand\ node\ j\ is\ assigned\ to\ facility\ i \\ 0\ otherwise \end{cases}$$

$$X_i = \begin{cases} 1\ if\ a\ facility\ is\ located\ at\ candidate\ site\ i \\ 0\ otherwise \end{cases}$$

The objective function (1) minimizes a demand-weighted sum of distances between nodes and nearest facilities. Constraints (2) require each node to be served by only one facility. Constraint (3) defines a number p of facilities to be located. Constraints (4) assure that nodes are assigned only to activate facilities. Finally, constraints (5) and (6) are standard integrality conditions.

5.2.3 Maximal covering

The aim of this model is locating p facilities to maximize the covered demand. This model defines a maximum number p of facilities, what means that it allows some nodes to be uncovered, if the number of facilities needed to cover all nodes exceeds this number p. Therefore, the model is sensible to the demand level at each node. It will favour the nodes with higher demands. The model can be formulated as follows:

$$[MAX]Z = \sum_j D_j * T_j \qquad (1)$$

$$T_j \leq \sum_{i \in N_j} X_i \qquad , \forall\, j \qquad (2)$$

$$\sum_i X_i \leq p \qquad (3)$$

$$X_i \in \{0,1\} \qquad , \forall\, i \qquad (4)$$

$$T_j \in \{0,1\} \qquad , \forall\, j \qquad (5)$$

$$where:$$

$$D_j = demand\ at\ node\ j\ ;$$

$$T_j = \begin{cases} 1\ if\ \ node\ j\ is\ covered \\ 0\ otherwise \end{cases}$$

$$X_i = \begin{cases} 1\ if\ a\ facility\ is\ activated\ at\ candidate\ site\ i \\ 0\ otherwise \end{cases}$$

$$N_j = set\ of\ all\ candidate\ sites\ which\ can\ cover\ demand\ node\ j (N_j = \{i | d_{ij} \leq S\})$$

The objective function (10) maximizes the total covered demand. Constraints (11) link the location and coverage variables, Constraint (12) states that at most p facilities are to be located. Constraints (13) and (14) are integrality constraints.

6. The location of the stations

The second part of this thesis is focused on this aspect of the system because it is the most interesting area as is the area where transport planning and transport problems have more influence and can help us to fix the location of the stops in the most optimal way. Once located stops can also be expanded thinking on the problem where would be a store for repair bikes or where the vans should be parked expecting to redistribute the bikes. How many of these vans are needed for don't have never an empty station. From there many problems can arise quite interesting to consider.

6.1 The location criteria in other cities

The criteria for location of the stations are also an extremely important not to waste money and making it the most optimum possible ensures the perfect operation for the citizens and not lose money badly.

As is known, for example the case of Barcelona, and is currently a deficit and one of the facts could be his criteria for location. Like it was an election promise the system was implemented very quickly and is now suffering the consequences. So that now is considering closing the system.

In Barcelona the location criteria is divided in some points:

- The use of bicycles would be based on:

    1. *As the main phase of the journey. for example: by foot + bicycle + by foot.-→ 63 %*
    2. *As another phase of the journey. for example: by foot + public transport + bicycle + by foot.-→ 37 %*

- Firstly, the system should ensure that citizens can access on foot to the bicycle transportation system within no more than 300 meters in the first option and between 150-200 meters in the second option.

- In the second option, which would enhance intermodal transport, underground and bicycle, the distance routes should be made over 500 meters, because if not, the stage would be surely done by foot.
- Therefore, all the public transport stations that are inside our action area should have a bicycle station.

- Afterwards, the network of bicycle stations should be completed, placing new stations in those areas that are not covered by the public transport network. Moreover, this new stations, should be matched to points of generation-attraction journeys (shopping centres, universities, parks, government buildings, touristic places)

In other hand, in Seville like in Paris the stations are situated with a distance of around 200 meters between each one, the majority of them located next to public transport stops to make easier the intermodal use.

Looking at all this criteria it is need it a new methodology for locate the stations. Because is not worthy to install a bicycle sharing system without thinking in this aspect, and in a few years after the system should be closed.

6.2 The application of the models in Tallinn

Study the location of the stops on a 2 km radius around the centre of Tallinn, from there it will be decided the potential points. Once established the potential points, with the help of mathematical programming models it will be fond the optimal solution of where these stops should be located.

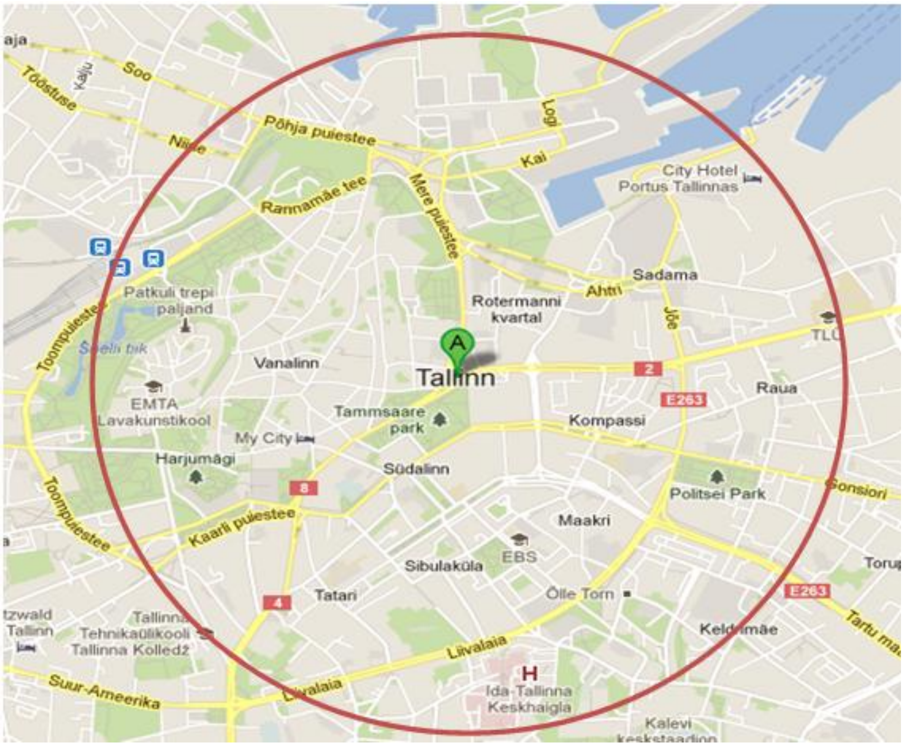

Fig49. Studied area for implement the system

The first step is to establish the potential points in this area. For establish this points, the criteria that is has been followed is to locate this points in: the main public transport stations, shopping centres, important buildings, hotels, universities, schools, ports and hospitals.

Obviously the system is focused in tourists but also the local people have to be attracted. It is for that the locations in the universities, schools and hospitals.

The good aspect of this system is that can be in continuous improving. Always exist the possibility of putting more stops, more bikes and more bike lanes. For example setting stations in the beach, near the areas where a high density of population exists.

The potentials points that have been chosen are these ones:

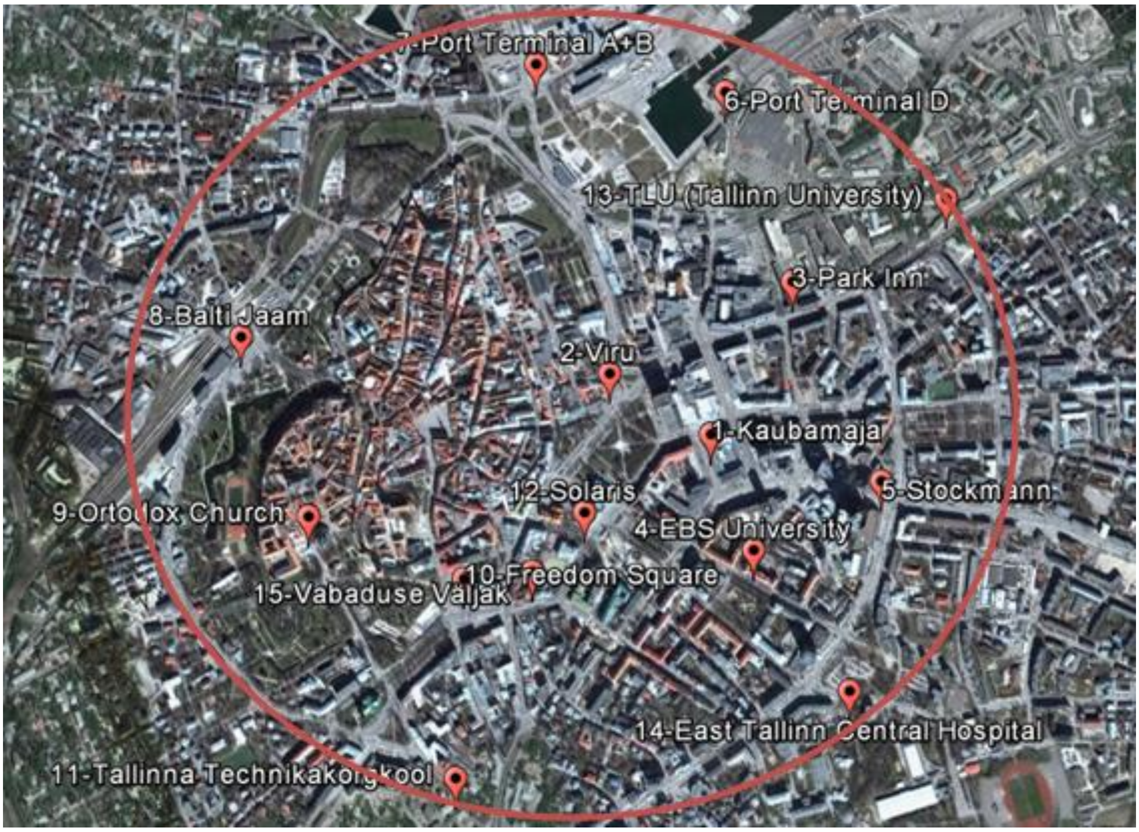

Fig50. The potential places in the studied area

6.2.1 *The data for the models*

For develop all the models, as you can see in the theory of the models (pages *48-51*) some variables are needed. First of all, the variable that is needed in all the models is dij, the matrix of distances. The matrix of distances includes all the distances between all the potential points. The distances have been calculated with the *Google earth*.

Matrix of Distances (m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1- Kaubamaja	0	350	600	400	550	1200	1500	1400	1200	850	1300	400	1000	1000	700
2- Hotel Viru	350	0	450	800	950	1100	850	1100	1000	700	1300	550	900	1200	650
3- Narva maantee (Hotel Park Inn)	500	500	0	800	700	800	1100	1500	1500	1200	1700	950	450	1200	1200
4- EBS University	400	800	800	0	550	1500	1600	1600	1400	850	1300	550	1100	550	700
5- Stockmann	550	950	700	550	0	1200	1600	1900	1700	1300	1500	950	800	600	1100
6- Port of Tallinn(d) + Rimi	1200	1100	800	1500	1200	0	1200	2000	2200	1800	2400	1600	850	1800	1800
7- Port of Tallinn(a,b)	1500	850	1100	1600	1600	1200	0	1000	1400	1500	2000	1400	1300	2100	1500
8- Balti Jaam (train Station)	1400	1100	1500	1600	1900	2000	1000	0	800	1000	1500	1200	2000	2000	1200
9- Toompea with Falgie tee	1200	1000	1500	1400	1700	2200	1400	800	0	500	700	850	1900	1600	650
10- Freedom Square	850	700	1200	850	1300	1800	1500	1000	500	0	600	350	1600	1100	170
11- Tallinna Technikakörgkool	1300	1300	1700	1300	1500	2400	2000	1500	700	600	0	900	2100	1200	700
12-Solaris, Opera	400	550	950	550	950	1600	1400	1200	850	350	900	0	1300	900	210
13- TLU (Tallinn University)	1000	900	450	1100	800	850	1300	2000	1900	1600	2100	1300	0	1400	1500
14-Central Hospital	1000	1200	1200	550	600	1800	2100	2000	1600	1100	1200	900	1400	0	1000
15- Vadabuse Väjak	700	650	1200	700	1100	1800	1500	1200	650	170	700	210	1500	1000	0

Fig51. The matrix of distances (m)

6.2.2 *The p-Center Model*

For this model, using the formulation of the model explained in the theory of this section in the pages 48 and 49 the solution have been found.

Firstly, the problem it has been solved with the program AMPL (Modelling Language for Mathematical Programming). The steps that have been followed are the next ones:

The first step for resolve the problem is that with a text editor called as G-Edit three files have been created. The first one is a file with a *.dat* extension. Is the file where all the known data, in this case is the matrix of distances and the variable p. This variable is the one that it is going to be changed for knowing the all possibilities that the system will have in case the number of stations that the system wants. The formulation used it is shown in the next image:

```
set J:= LOC1    LOC2    LOC3    LOC4    LOC5    LOC6    LOC7    LOC8    LOC9    LOC10   LOC11   LOC12   LOC13   LOC14   LOC15;


param p:=5;

param   distance:       LOC1    LOC2    LOC3    LOC4    LOC5    LOC6    LOC7    LOC8    LOC9    LOC10   LOC11   LOC12   LOC13   LOC14   LOC15   :=
        LOC1    0       350     600     400     550     1200    1500    1400    1200    850     1300    400     1000    1000    700
        LOC2    350     0       450     800     950     1100    850     1100    1000    700     1300    550     900     1200    650
        LOC3    500     500     0       800     700     800     1100    1500    1500    1200    1700    950     450     1200    1200
        LOC4    400     800     800     0       550     1500    1600    1600    1400    850     1300    550     1100    550     700
        LOC5    550     950     700     550     0       1200    1600    1900    1700    1300    1500    950     800     600     1100
        LOC6    1200    1100    800     1500    1200    0       1200    2000    2200    1800    2400    1600    850     1800    1800
        LOC7    1500    850     1100    1600    1600    1200    0       1000    1400    1500    2000    1400    1300    2100    1500
        LOC8    1400    1100    1500    1600    1900    2000    1000    0       800     1000    1500    1200    2000    2000    1200
        LOC9    1200    1000    1500    1400    1700    2200    1400    800     0       500     700     850     1900    1600    650
        LOC10   850     700     1200    850     1300    1800    1500    1000    500     0       600     350     1600    1100    170
        LOC11   1300    1300    1700    1300    1500    2400    2000    1500    700     600     0       900     2100    1200    700
        LOC12   400     550     950     550     950     1600    1400    1200    850     350     900     0       1300    900     210
        LOC13   1000    900     450     1100    800     850     1300    2000    1900    1600    2100    1300    0       1400    1500
        LOC14   1000    1200    1200    550     600     1800    2100    2000    1600    1100    1200    900     1400    0       1000
        LOC15   700     650     1200    700     1100    1800    1500    1200    650     170     700     210     1500    1000    0       ;
```

Fig52. Formulation used in the .data file

The second is a *.mod* file, where are defined the variables, the objective function and constrains. For the proper functioning of this model this is most important file. In this file all constrains and the objective function has to be perfectly programmed. In the image bellow it can be seen the programming language used:

```
set J ;

param distance {J,J};
param p >=0;



var D >=0;
var X{J} binary;
var Y{J,J} binary;



#------------------objective function---------------------------------------

minimize maxdistance:  D;


#--------------------------------------------------------------------------



subject to c1 {j in J}: sum{i in J} Y[i,j] =1;

subject to c2: sum { i in J} X[i]=p;

subject to c3 {i in J, j in J}: Y[i,j] - X[i] <=0;

subject to c4 {j in J}: D >= sum{i in J} distance[i,j]*Y[i,j];
```

Fig53. Formulation used in the .mod file

The third one is a *.run* file. This file that is it used for compile the other files and defines the rules that the program AMPL has to follow for solve the problem. In this file is it put which things of the solution do you want to see and where this solutions have to be written. For example in the following image, the solutions are written in the *cinquena.txt* file.

```
reset;
option solver cplex;
option presolve 1;
option omit_zero_cols 1;
option omit_zero_rows 1;
option display_1col 1;
option cplex_options "timing 1 mipdisplay 2";
#option cplex_options "cutsfactor 1";     # Play around with this parameter 1..10
#option cplex_options "cutpass -1";       # Try with and without this option
option show_stats 1;
option cplex_options 'timing 1';
option relax_integrality 0;
#option cplex_options 'iisfind 1';
option display_eps 1e-10;
option display_round 0;
option display_1col 0;
option print_separator ",";
option display_precision 1;
#option solution_precision 10;


model  cinquena.mod;
data   cinquena.dat;

solve;

display maxdistance, X, Y> cinquena.txt ;
exit;
```

Fig54. Formulation used in the .run file

As it can be seen, this file takes the model from the *cinquena.mod* file and takes the data from the *cinquena.data* file. And creates a *.txt* file where the solutions are written.

All the other orders are orders for solve the problem, this orders are put following the manual book for this program.

The second step is enter in the executable *sw* of the program, there the comand '*ampl'* has to be written, and after *include' nameofthefile.run'* has to be written. Then the program calculates everything and in the screen you can show:

```
sw: finished ampl = 0
File  Edit  Help
sw: ampl
ampl: include cinquena.run

241 variables:
        240 binary variables
        1 linear variable
256 constraints, all linear; 915 nonzeros
        16 equality constraints
        240 inequality constraints
1 linear objective; 1 nonzero.

CPLEX 12.5.0.1: timing 1

Times (seconds):
Input =  0.0156001
Solve =  0.124801
Output = 0
CPLEX 12.5.0.1: optimal integer solution; objective 800
185 MIP simplex iterations
0 branch-and-bound nodes
sw:
```

Fig55. The solution in the executable

Here it shows, the number of variables, the number of constraints, the time that the program has needed for solve the model, and also the optimal integer solution and the iterations done with the SIMPLEX.

Moreover, in the directory where is the program a *txt* file is created with all the parameters that have been determined in the *.run* file. For example:

```
maxdistance = 450

X [*] :=
 LOC1 1    LOC11 1    LOC3 1    LOC6 1    LOC8 1
LOC10 1    LOC14 1    LOC5 1    LOC7 1    LOC9 1
;

Y [*,*]
# $4 = LOC12
# $5 = LOC13
# $6 = LOC14
# $7 = LOC15
:      LOC1 LOC10 LOC11  $4  $5  $6  $7 LOC2 LOC3 LOC4 LOC5 LOC6 LOC7 LOC8 LOC9 :=
LOC1     1     0     0    0   0   0   0   1    0    1    0    0    0    0    0
LOC10    0     1     0    1   0   0   1   0    0    0    0    0    0    0    0
LOC11    0     0     1    0   0   0   0   0    0    0    0    0    0    0    0
LOC14    0     0     0    0   0   1   0   0    0    0    0    0    0    0    0
LOC3     0     0     0    0   1   0   0   0    1    0    0    0    0    0    0
LOC5     0     0     0    0   0   0   0   0    0    0    1    0    0    0    0
LOC6     0     0     0    0   0   0   0   0    0    0    0    1    0    0    0
LOC7     0     0     0    0   0   0   0   0    0    0    0    0    1    0    0
LOC8     0     0     0    0   0   0   0   0    0    0    0    0    0    1    0
LOC9     0     0     0    0   0   0   0   0    0    0    0    0    0    0    1
;
```

Fig56. The solution in the .txt file

This method it has been done ten times, changing the p parameter. For see what changes if the system has 6 stations or 10. In the following table it is summarized the obtained results:

	P=1	P=2	P=3	P=4	P=5	P=6	P=7	P=8	P=9	P=10
F.O=Min MaxDistance	1300	1100	1000	800	800	600	550	550	500	450
Chosen Nodes	2	12	12	3	10	10	10	10	1	1
		2	6	4	3	3	11	11	11	11
			8	7	4	4	3	3	14	3
				9	7	6	4	4	6	6
					8	7	6	6	8	8
						8	7	7	10	10
							8	8	13	14
								9	5	5
									7	7
										9

Fig57. Results of the model changing the parameter p

6.2.3 P-Median model

For this model, first of all, the demand it has to be defined. As the city don't have the demand required in each potential point, this is the method that is has been developed for find the demand.

The system of the city is focused in tourists, students that are not citizens of Tallinn and the people that live in Tallinn but is not a citizen. For calculate the demand, the potential points are divided in these three categories (students that are not citizens of Tallinn and the person that lives in Tallinn but is not a citizen). It has rated each potential point in each category (from 1 to 5) and multiplied the three categories. As it is shown in the next table:

Demand (Dj)	Tourists [1-5]	Students(not living in Tallinn) [1-5]	Inhabitants (not citizens of Tallinn)[1-5]	Demand[1-125]
1- Kaubamaja	3	4	4	48
2- Hotel Viru	5	2	3	30
3- Narva maantee (Hotel Park Inn)	5	1	2	10
4- EBS University	1	5	2	10
5- Stockmann	2	3	4	24
6- Port of Tallinn(d) + Rimi	5	3	1	15
7- Port of Tallinn(a,b)	5	3	1	15
8- Balti Jaam (train Station)	2	3	3	18
9- Toompea with Falgie tee	4	2	2	16
10- Freedom Square	4	3	4	48
11- Tallinna Technikakörgkool	1	3	3	9
12-Solaris, Opera	4	3	3	36
13- TLU (Tallinn University)	1	5	4	20
14-Central Hospital	3	3	3	27
15- Vadabuse Väjak	4	4	4	64

Fig58. The demand of each potential point

Once here, using the model explained in the pages 49-50 and with all the data defined before the model is calculated in the following way.

As all the two models before this one, the files have to be created. The first one is the file where all the known data, in this case is the demand and the variable p. This variable is the one that it is going to be changed for knowing the all possibilities that the system will have in case the number of stations that the system wants. The formulation used it is shown in the next image:

```
set J:= LOC1    LOC2    LOC3    LOC4    LOC5    LOC6    LOC7    LOC8    LOC9    LOC10   LOC11   LOC12   LOC13   LOC14   LOC15;

param p:=5;

param d:= LOC1 48
          LOC2 30
          LOC3 10
          LOC4 10
          LOC5 24
          LOC6 15
          LOC7 15
          LOC8 18
          LOC9 16
          LOC10 48
          LOC11 9
          LOC12 36
          LOC13 20
          LOC14 27
          LOC15 64 ;

param   distance:       LOC1    LOC2    LOC3    LOC4    LOC5    LOC6    LOC7    LOC8    LOC9    LOC10   LOC11   LOC12   LOC13   LOC14   LOC15   :=
        LOC1    0       350     600     400     550     1200    1500    1400    1200    850     1300    400     1000    1000    700
        LOC2    350     0       450     800     950     1100    850     1100    1000    700     1300    550     900     1200    650
        LOC3    500     500     0       800     700     800     1100    1500    1500    1200    1700    950     450     1200    1200
        LOC4    400     800     800     0       550     1500    1600    1600    1400    850     1300    550     1100    550     700
        LOC5    550     950     700     550     0       1200    1600    1900    1700    1300    1500    950     800     600     1100
        LOC6    1200    1100    800     1500    1200    0       1200    2000    2200    1800    2400    1600    850     1800    1800
        LOC7    1500    850     1100    1600    1600    1200    0       1000    1400    1500    2000    1400    1300    2100    1500
        LOC8    1400    1100    1500    1600    1900    2000    1000    0       800     1000    1500    1200    2000    2000    1200
        LOC9    1200    1000    1500    1400    1700    2200    1400    800     0       500     700     850     1900    1600    650
        LOC10   850     700     1200    850     1300    1800    1500    1000    500     0       600     350     1600    1100    170
        LOC11   1300    1300    1700    1300    1500    2400    2000    1500    700     600     0       900     2100    1200    700
        LOC12   400     550     950     550     950     1600    1400    1200    850     350     900     0       1300    900     210
        LOC13   1000    900     450     1100    800     850     1300    2000    1900    1600    2100    1300    0       1400    1500
        LOC14   1000    1200    1200    550     600     1800    2100    2000    1600    1100    1200    900     1400    0       1000
        LOC15   700     650     1200    700     1100    1800    1500    1200    650     170     700     210     1500    1000    0       ;
```

Fig59. Formulation used in the .data file

The second is the *.mod* file, where are defined the variables, the objective function and constrains. In the image bellow it can be seen the programming language used:

```
set J ;


param d {J};
param p >=0;

param distance {J,J};

var X{J} binary;
var Y{J,J} binary;

#------------------objective function---------------------------------------

minimize Median: sum{i in J}sum{j in J}Y[i,j]*d[j]*distance[i,j];

#---------------------------------------------------------------------------

subject to c1 {j in J}: sum{i in J} Y[i,j] =1;

subject to c2: sum { i in J} X[i]=p;

subject to c3 {i in J, j in J}: Y[i,j] - X[i] <=0;
```

Fig60. Formulation used in the .mod file

The third one is the same as in the other models, changing the data and the mod file that is it used. Afterwards, the model can be solved with the same method as the other ones, with the executable .sw.

The results obtained, changing the p parameter, are:

	P=1	P=2	P=3	P=4	P=5	P=6	P=7	P=8	P=9	P=10
F.O	242340	175220	140470	118120	92370	77370	64170	51420	39960	29460
Chosen Nodes	12	1	15	1	1	1	1	1	1	1
		15	2	15	13	13	13	13	13	13
			5	5	14	14	14	14	15	15
				8	15	15	15	15	6	5
					8	7	5	5	8	7
						8	7	6	10	10
							8	7	14	14
								8	5	2
									7	6
										8

Fig61. Results of the model changing the parameter p

6.2.4 Maximal Covering model

In this model, as it is explained in the theory of this section, the variable that has to be defined is Nj. That means the set of all candidate sites which can cover the demand of the node j. In this case, this parameter is defined depending on the distance between each one and thinking in the space that in each point is it available

```
N[LOC1]  := LOC1;
N[LOC2]  := LOC2 LOC3 LOC1;
N[LOC3]  := LOC1 LOC2 LOC3 LOC13;
N[LOC4]  := LOC4 LOC5;
N[LOC5]  := LOC1 LOC4 LOC5;
N[LOC6]  := LOC6;
N[LOC7]  := LOC7;
N[LOC8]  := LOC8;
N[LOC9]  := LOC9 LOC10;
N[LOC10]  := LOC10 LOC11 LOC15;
N[LOC11]  := LOC11 LOC10;
N[LOC12]  := LOC12 LOC15;
N[LOC13]  := LOC3 LOC13;
N[LOC14]  := LOC14;
N[LOC15]  := LOC10 LOC15;
```

Fig62. The variable Nj

In this table is it means that for example in the first row, the demand of the location 1 only can be covered by himself, or the second row means that the demand of the location 2 can be covered by himself or by the location 3 or the location 1.

Once here, using the model explained in the pages 50-51 and with all the data defined before the model is calculated in the following way.

As all the two models before this one, the files have to be created. The first one is the file where all the known data, in this case is the Nj, the demand and the variable p. This variable is the one that it is going to be changed for knowing the all possibilities that the system will have in case the number of stations that the system wants. The formulation used it is shown in the next image:

```
set J:= LOC1    LOC2    LOC3    LOC4    LOC5    LOC6    LOC7    LOC8    LOC9    LOC10   LOC11   LOC12   LOC13   LOC14   LOC15;
set facilities := LOC1  LOC2    LOC3    LOC4    LOC5    LOC6    LOC7    LOC8    LOC9    LOC10   LOC11   LOC12   LOC13   LOC14   LOC15;


set N[LOC1] := LOC1;
set N[LOC2] := LOC2 LOC3 LOC1;
set N[LOC3] := LOC1 LOC2 LOC3 LOC13;
set N[LOC4] := LOC4 LOC5;
set N[LOC5] := LOC1 LOC4 LOC5;
set N[LOC6] := LOC6;
set N[LOC7] := LOC7;
set N[LOC8] := LOC8;
set N[LOC9] := LOC9 LOC10;
set N[LOC10] := LOC10 LOC11 LOC15;
set N[LOC11] := LOC11 LOC10;
set N[LOC12] := LOC12 LOC15;
set N[LOC13] := LOC3 LOC13;
set N[LOC14] := LOC14;
set N[LOC15] := LOC10 LOC15;

param p:=10;

param d:= LOC1 48
          LOC2 30
          LOC3 10
          LOC4 10
          LOC5 24
          LOC6 15
          LOC7 15
          LOC8 18
          LOC9 16
          LOC10 48
          LOC11 9
          LOC12 36
          LOC13 20
          LOC14 27
          LOC15 64 ;
```

Fig63. The programming used in the file .data in

The second is the *.mod* file, where are defined the variables, the objective function and constrains. In the image bellow it can be seen the programming language used:

```
set J ;
set N{J};
set facilities;


param d {J};
param p >=0;


var X{J} binary;
var T{J} binary;


#------------------objective function---------------------------------------

maximize Demandcovering: sum{j in J} T[j]*d[j];

#--------------------------------------------------------------------------


subject to c1 {j in J}: T[j]<= sum {i in N[j]} X[i] ;

subject to c2 : sum { i in facilities} X[i]<=p;
```

Fig64. The programming used in the .mod file

It can be seen the model translated with programming language, defining the variables first, after the objective function and finally the constraints.

The third one is the same as in the other models, changing the data and the mod file that is it used. Afterwards, the model can be solved with the same method as the other ones, with the executable .sw.

The results obtained, changing the p parameter, are:

	P=1	P=2	P=3	P=4	P=5	P=6	P=7	P=8	P=9	P=10
F.O=MaxCovered Demand	148	260	287	312	332	350	365	380	390	390
Chosen Nodes	15	1	1	1	1	1	1	1	1	1
		15	14	10	10	10	10	10	10	10
			15	12	12	12	12	12	12	12
				14	13	13	14	14	14	13
					14	14	3	3	3	14
						8	7	6	4	4
							8	7	6	6
								8	7	7
									8	8
										9

Fig65. Results of the model changing the parameter p

6.3 Conclusions of the location criteria

Firstly, all the results of the models are going to be explained and after the whole comparison.

For explain the results of the p-center model is it good to remember in what consists. The *P*-center model minimizes the coverage distance such that each demand node is covered by one of the facilities, within that minimized distance. This is in fact a minmax problem, since the model minimizes the maximum distance between a node and its nearest facility.

This model is used when you are interested in minimizing the maximum distance between nodes selected as stations and nodes that are potential points of attraction and repulsion of people. Not takes into account the required demand for each node, as it means that all nodes have the same demand. This model can be very useful if we look at the skin of the citizen. Thus the potential points where the stations aren't located they will have a station as close as possible. The big problem arises not take into account demand, because if travellers are at a point where they have potential station and head for where it is and it is empty (due to strong demand) then have to walk more to the next. The great advantage of this model is that it has multiple applications, for example, if we try to talk instead of talking about bikes we talk about electric bikes with electric bike charging stations, if you have 15 stations, and we put seven charging stations so that cyclists pedal as little as possible because this would be the ideal model.

Observing the results obtained with this model, we can say that the first idea of where the stations should be placed according to how many stations want to locate the contracting company. Changing the parameter p (stations required) is observed that changes the minimum maximum distance travelled by users. It is interesting to note here that perhaps, to minimize the maximum distance 50 m is not worthy to spend more money to build another station. This model allows us to observe the gains or losses that involve installing or not a new station.

Suffice to say that this method does not take into account the demand is misleading. For this reason it has analyzed the next model defined previously as P-Median. This model is related to a network problem, and has been extensively applied to facility location. This problem deals with decisions of locating p facilities (medians) in a network, minimizing the weighted sum of all distances from each node to its nearest facility.

In this model it takes into account the demand. Therefore much closer to reality and therefore the conclusions that are removed are significant. Yet, I must say that the demand as we don't have had time or money for make surveys it was calculated as explained previously in the thesis. Therefore, if you have the necessary data using the same model it can be found the real optimal solution.

In this model is to minimize the total distance travelled by users between the stations and potential points. It is very interesting because it is where they have placed these stations minimizing this distance. The results are similar to the previous model but now considering the request. Observed that the more stations are located lower the total distance travelled, and therefore the observed change in the total distance that supports installing stations or not. As, for example, can go up to more economically install more bicycle parking at a station to cover more demand than installing a whole new station. Models help a lot in these last purely economic aspects.

As for the third and final model the demand is used, but not the distance matrix. It is maximum covered model and the aim of this model is locating p facilities to maximize the covered demand. This model defines a maximum number p of facilities, what means that it allows some nodes to be uncovered, if the number of facilities needed to cover all nodes exceeds this number p. Therefore, the model is sensible to the demand level at each node.

This model is very interesting because, you have to define the variable Nj it is to define the reasons for the hiring company wants to which of the potential nodes can include the demand of other nodes, ie, if a node is very close to another so that one can always cover their demand regarding there are sufficient number of bicycles, and, the space required to install the station is enough. Or if there are nodes that for conservation reasons of the old buildings they cannot cover their own demand, the program calculates what station it would be those close to that potential point. From the point of view where you want to cover the maximum possible demand this model is very important.

Looking at the results, it is seen that the demand increases with increasing stations installed. Obvious but nevertheless it is interesting because, looking at the demand deck you can see if it's worth installing another station or not. As an example, if you pass to set up 8 to 9 stations only the covered demand increases 10 and installing ten stations the demand does not vary respect to 9 installed, while extremely important to save money and time.

Finally, comparing the three models, it is clear that some are simply the evolution of the other or are complementary. Three models with different objectives but we used to see in three different ways and with different criteria which should be placed stops and profits or losses are obtained. The third model is very interesting because it can be fully adapted to the criteria that the customer wants. Both the first and the second only depend on the variables obtained or given by the client. So doing the three models has a vision from different points of view is always interesting and complete.

7. Conclusions

Once we explained the two distinct parts of the thesis which has been extracted and the respective conclusions shall make a final conclusion.

The thesis is divided into two parts, the first where we have analyzed a series of bicycle sharing systems and on through the experience of different cities and by the characteristics of the city of Tallinn, it has been determined the system that has to be installed in the city. (See page 36 and 37)

Also in this section has proceeded with collection of necessary data with the calculation of a series of indicators to determine whether the system will be successful if it will be installed. It's here where by graphics and regression lines was determined which parameters should be good for the city to ensure the success of this system. (See pages 46 and 47)

The second part of the thesis has been carried out to calculate the most suitable location for the system stops. It has been decided focussed on the location of the stops because this two factors: the first is the author's interest in the field of transport and logistics, and the second that has been found some deficiencies in other systems respect to the criteria used by other cities.

These deficiencies in other bicycle sharing systems are created budget problems at once and maintain this after a few years of installation. Therefore it has been attempted this calculation in a totally innovative and different way.

This calculation was based on the adaptation of location models into our case. We decided to perform the calculation with three different models, because we each bring different solutions. These models have been solved by programming them and finding the optimal solution with a powerful solver.

The results will be interesting depending on the objective of the customer that wants to contract the system.

In addition, the models may have already programmed for other purposes, i.e. with the same model could be calculated, for example, if they were electric bikes where the stops with the possibility of charging the battery should be placed so that the customers can avail the minimum distance.

End with conclusions that hopefully someday this wonderful project will be developed and realized in this charming city.

8. Summary

The main objective of this thesis is to establish a bicycle sharing system in the city of Tallinn, Estonia. Moreover, it will explain the whole process for establish the system, even though if finally the system is not worthy to be installed.

The first part of the thesis consists in analyze the different bicycle sharing systems in the world, since the city of Barcelona because it has been easier to get information till Stockholm because it has the same climatic conditions as Tallinn.

With all the data obtained of the cities, and also the experience, it is decided which is the suitable operating system for Tallinn.

This analysis is complemented with some calculations and graphs using some bicycle indicators, which they are going to be explained during the thesis. The indicators are used because will help us to understand the current mobility situation and allow comparing the state of bicycle circulation between bicycle partners, identify weak points and to deliver numerical evidence for actions to be taken within bicycle as well as for future. The usage of the indicators as a measure of the overall success of actions taken within this project is important. Also, It will be interesting to find a relationship between parameters and indicators. This relationships will explain what features must have the city for has succeed in the task of increment the modal split. And finally will help us to compare and foresee what will happen with the situation in Tallinn.

These calculations will help us to affirm or deny the thesis. And will help us to know which features have to has the city of Tallinn for has succeed in the development of the system. For example it has been found that Tallinn for has succeed in the system should develop the infrastructure necessities increasing the number of Km of bike lanes and make similar the km of bike lanes as the kilometres of roads. Also, improving the bike network other people that are not users will use the bike, so another way for see an increase in the modal split. In the other hand the city must promote the system, because without users the system doesn't exist.

After the analysis, in a studied area in Tallinn it has been chosen 15 potential points, this potential points will be possible candidates to be a station for the system. After this, with three different models an optimal solution it has been calculated. Depending on the target of the customer the model used for locate the station changes.

The results after solving the problem will show to the customer why and where they should locate the station, avoiding losing money in a silly way.

The different results of this analysis it will be studied according to the benefits for the city.

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