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A logistics analysis of Bicing

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Ajuntament de Barcelona

We are students from International Business Economics' bachelor at UPF university. We conducted this project about Bicing during the first term of our 3rd year, encouraged by our business logistics professor, Helena Ramalhinho, who supervised and supported us during the elaboration of the project. We are very thankful for the help and the opportunity she gave us to learn in a different way. We have learned a lot while creating a project that we expect others to find interesting and useful.

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1. INTRODUCTION

The bicycle sharing system of Barcelona, commonly known as Bicing, is a urban transport system based on the shared use of about 6,000 bicycles that can be picked up and returned in different stations located throughout the city. The system is being managed and maintained in partnership by the city council of Barcelona jointly with the Clear Channel Communications Corporation until the last quarter of 2018. After that, the city council has assigned the service to Cespa, that will start to manage it from 2019 on.

Bicing was born in 2007 to become a realistic alternative or complement to the traditional private and public transportation, which could offer a practical, healthy and environmentally friendly service, mainly oriented to cover small and medium daily routes within the city area. Its service usage schedule is the following: from Monday to Thursday Bicing operates the whole day except from 2am to 5am; on Friday it operates the whole day except from 3am to 5am, as well; and on Saturday, Sunday and holidays the service is available the 24h.

The annual subscription to the service costs € 47.16 and it includes the first 30 minutes of each usage for free, a reasonable time since the average usage time is between 13 and 14 minutes. Thereafter, the subsequent half hour intervals are charged at € 0.74 up to a maximum of 2 hours. In the case of exceeding the 2 hours limit, a penalty and a consequent charge for improper use of € 4.49 per hour is charged to the user. Finally, in the event that a bicycle is not returned after 24 hours, a fine of €150 is imposed.

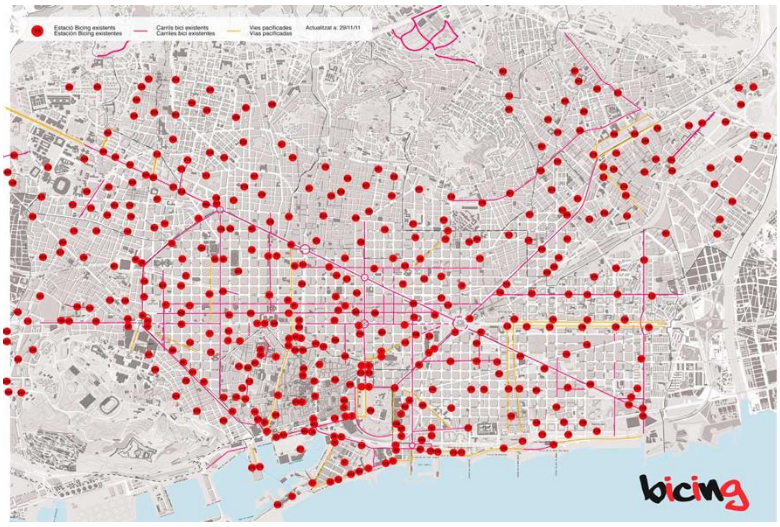


Figure 1. Location of Bicing stations. Source: bicing.cat

There are more than 400 stations distributed in Barcelona, each with a fixed number of slots that can be either empty or occupied. Users who want to use the service must find a station with occupied slots, travel to his destination station, and leave the bike there on a free slot. There is an app that informs users on the availability of bicycles and slots on every station. In the case in which there is no available spot to leave the bike, the user must identify himself in the station by using the membership card, and the system will tell him where the nearest station with available spots is, and it will give him extra 10 free minutes to arrive there. Since the system registers every time a user takes or leaves a bike, it is important that users are aware of the time elapsed.

Nonetheless, as it occurs with any other transportation system, it presents some problems that users have to deal with and that we will discuss throughout the project.

2. THE MAIN PROBLEM

Originally, when the system was first introduced in the city, it was thought that the flow of bicycles itself from one part of the city to another, would lead to an equilibrium in terms of the proper distribution of bicycles. But, as time went by, it was evident that there was the need for a bicycle replacement system to fix some logistics issues. However, this solution was only partial, and some problems are still alive today in Barcelona.

Since Barcelona is downward sloping, people tend to use the service only from the top to the bottom, so that at a certain time of the day, most of the bicycles are stationed in the lower part of the city, with very few people willing to use them to move upwards, while there are not enough of them at the top.

Consequently, as the day goes by, many stations in the lower part of the city have no empty spots, which becomes also an important problem for the users, who have to pay extra costs, both in money and time, due to this usual problem.

Another cause for a bad redistribution of bikes can be something as simple as weather. For instance, if in the morning there's good weather, many people will use the bikes to go to work, but if it starts raining, they will probably use public transport to go back home, leaving all the bikes concentrated in the most concurred places (where businesses usually are).

3. PROPOSALS

In order to solve the presented problem, we will try to analyze possible solutions with the data available in order to determine whether these proposals may be implemented or not, and which is the best way to do so.

3.1. Economic incentives

In order to improve the logistical management of the service while reducing costs, both for the provider of the service and the users, an economic incentive to use Bicing in ascending trips could be introduced, in the form of discounts in the annual user tariff, to foster the natural redistribution of bikes throughout the city.

The maximum discount rate the service could offer, is the amount they would save if the relocation of the bikes was made at no cost. We have not been able to find accurate accounting data of the service, but we have an estimation of the cost of relocating the bikes of 30% of the total budget of the service. This percentage has been obtained from “Gestión del Bicing BCN: Un algoritmo para un equilibrio sostenible”, but we cannot estimate the accuracy of the data since we have not been able to find the sources.

The total budget of the service for 2018 is of € 15,654,064, from which we can estimate a relocation cost of € 4,696,219 (30% of total). If we divide it by the current number of users (105,545), we get that we could offer to each user a discount of € 44.50, almost equivalent to the annual tariff of € 47.

From the project mentioned above, we have an estimation of the number of bikes relocated of 3,710,069. We will assume that all this relocations are made upwards, since, as previously stated, users tend to use Bicing only for downward-sloping trips, so that the cost of each relocation is of (€4,696,219/3,710,069) € 1.26.

To sum up, the incentive proposed would be of € 1.26 of discount for each ascending trip, up to a maximum annual discount of € 30. The problem we see with this incentive is that it is too high: by doing not even 30 ascending trips, the user would have reached the maximum discount and would no longer be interested in the incentive for the rest of the year. Thus, we have to calculate a lower incentive per trip.

As mentioned above, it would be quite easy for users to surpass the annual subscription fee if the discount offered was too high. Nonetheless, it could be done the other way around, by implementing a fixed lower incentive per trip (for example € 0.05 per ascending trip) and see how users react to this measure. If this incentive happened to be ineffective in solving the problem of optimally redistributing the bikes, this fixed amount could be easily changed at any time, since each station has a screen connected to the central network, that would allow users to know the discount offered for each ascending trip.

Another possible solution we came up with, and which is similar to the one above, is making the discount for each ascending trip variable. The company could calculate the costs they would incur at a particular time for the reallocation of the bikes as a function of the number of bikes that are needed on the upper side of the city and the number of extra bikes in the lower side, something similar to a stock market system. The discount calculated could be shown in real time in the screens each station has, and the user could decide at the moment whether to use the service or not.

Our proposal would be to start testing the incentive system by offering a maximum annual discount per user of € 30, to see how the system works. Depending on the results of the first year, this quantity could be easily adjusted, just the way they change the annual tariff each year.

Another variable when calculating the incentive discount, we came up with is the moment of the day. For instance, at nine o'clock in the morning on Mondays, many Bicing users come to the university, so it would be interesting to incentivize during that time the trips in the opposite way, to rapidly reallocate the excess of bikes at the Bicing station near the university. But to implement this idea we find two problems.

The first one is that we would need a lot of data about the usage of the service by zones and by the time of the day, that we cannot access. Another possible problem is that users could be incentivized to delay their trips, in order to obtain a discount or another, which would lead to an inefficient usage of the service. So, in order to evaluate this proposal, we would need much more data than we have, so we cannot give any conclusions about it.

To sum up, the most interesting discount systems to implement are the two that apply a variable discount rate: the one starting with a low discount and varying it depending on how it works; and the variable discount system depending on the ratio of bikes that are badly allocated.

3.2. Electrical bicycles

Another solution would be the substitution of the current bicycles for electric ones, given the fact that an engine makes it easier to climb slopes by riding a bike with no effort. This way, it may be the case that the reallocation was efficient, or at least more efficient than it currently is.

It must be taken into account, though, that Bicing currently offers the service of electrical bicycles. At the time when the service was launched, the objective was not to substitute the existing Bicing, but to complement it. The goal was to improve the service, target a wider range of consumers, and facilitate longer and upward sloping journeys while helping Barcelona become more sustainable. However, in 2018, three years after the launch, the service has proved to be unsuccessful.

In order to be able to use this service, people must be a user of mechanical Bicing and in addition, pay a tariff of € 14 per year. Unlike in the mechanical bike service the first half hour is not included: it costs 45 cents. Every extra half hour is charged by 80 cents, up to two hours.

In addition to the high cost, the service is not very popular because there are not many stations, some of them are in indoor parkings, and an electrical bike can only be parked in a parking destined to this type of vehicle. Therefore, if someone wants to go from one place to another and do so by electrical bike, but the destination place does not dispose of a slot to park it, it is not convenient to use the service.

In addition, some Bicing users state that they decided not to enroll to the service because they thought that the additional price would not compensate if they were not allowed to do long journeys.

For the better understanding of the problem, the calculation of the annual price of the service assuming an average usage of half an hour journey per day is useful. The fixed costs are composed of the mechanical and the electrical Bicing fees, amounting to € 61.16 yearly. Regarding the variable costs, they would amount to € 164.25 (€ 0.45 per journey * 365 journeys). Thus, the total annual cost of using electrical Bicing for the assumed usage rate would sum € 225.40, which may be seen as a high cost, bearing in mind all the restrictions that this service still presents.

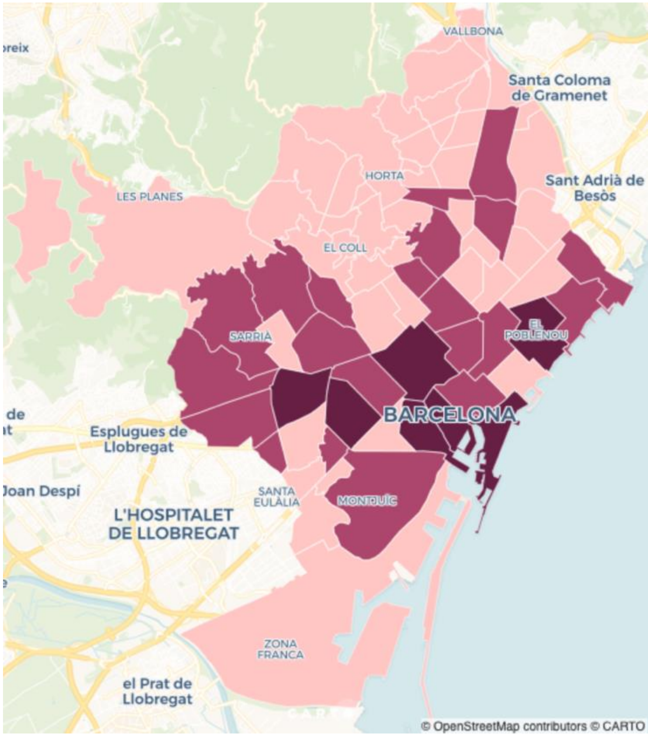


Figure 2. Map of electric Bicing stations.
Source: own source.

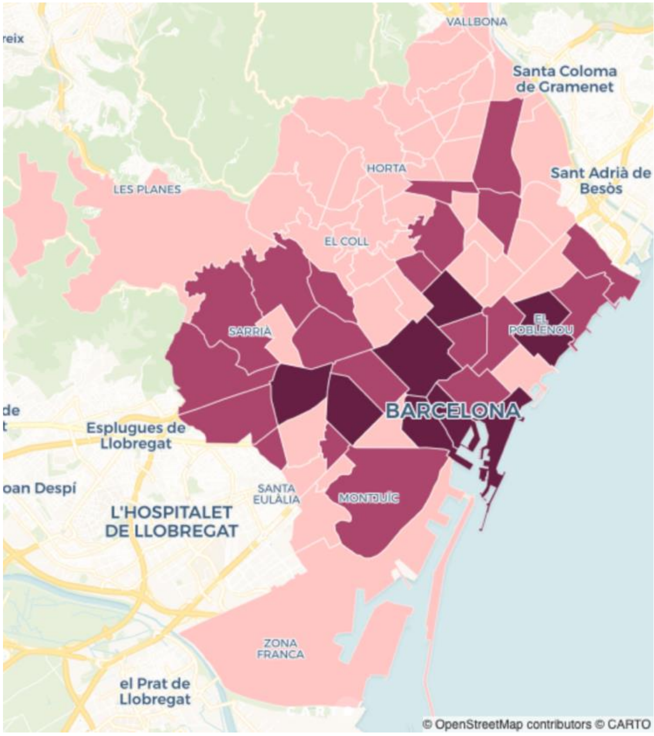


Figure 3. Map of electric Bicing spots.
Source: own source.

These maps show the neighborhoods in which electrical Bicing is more present by precising the location and distribution of electrical Bicing stations and slots. The neighborhoods that show a more intense color are the ones that enjoy a higher number of them, unlike the ones colored with a lighter color, which possess a low number.

It can be noticed that both maps are exactly the same, meaning that there is perfect correlation between the number of stations and the number of slots, which makes perfect sense: the more stations, the more slots there will be.

Another thing that comes to sight when observing these two maps is the fact that the majority of neighborhoods do not enjoy this service, coinciding with the fact that they are precisely the neighborhoods the streets of which have a greater slope.

The proposal consists of both the ampliation of the service and the lowering of prices, which we consider to be the right way to increase the usage rate of the service since, as previously mentioned, the fact that electrical Bicing is not an extended service around Barcelona and its excessive price are the two key problems it presents.

In fact, one of these two problems will be solved at least partially, since in January 2019, the council of Barcelona will change the concession of Bicing to Cespa (that will be in charge for the next 10 years), that will start implementing some improvements for Bicing. Among them, there will be a unification in price between mechanical and electrical Bicing (€ 50 annually instead of the € 61.16 of electrical and the € 47.40 for mechanical bicycles). This will probably increase the number of people that use the electrical service, since it will not have one of the drawbacks it currently has: the extra price needed to pay just to become a user of the service.

In addition, the price charged for every half an hour will be reduced to 35 cents (reduction of 10 cents). However, the additional halves of hour up to two hours will be charged with a higher price, 90 cents each (10 cents more expensive), and users that use the service for more than two hours will have to pay € 5 (this remains unchanged).

So, we can conclude that the goal of these changes is to increase the users of electrical Bicing, but in short journeys.

In order to see if this is efficient, it would be useful to compute the annual price of the service after applying these changes, and under the same conditions as before: assuming an average usage of half an hour journey per day, so as to compare the two results.

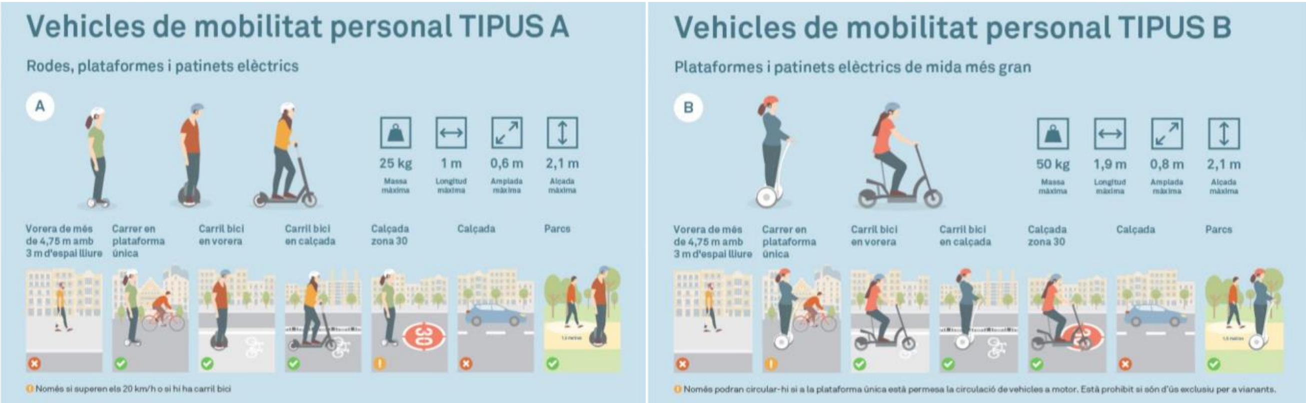
The fixed costs are composed of the mechanical and the electrical Bicing fees, now amounting to € 50 yearly. Regarding the variable costs, they would amount to € 127.75 (€ 0.35 per journey * 365 journeys). Thus, the total annual cost of using electrical Bicing for the assumed usage rate would sum € 177.75. So, the same person, using electrical Bicing one time per day during up to half an hour would save € 47.65.

However, this does not solve the whole problem, so having improved the issue with the price, the proposal we make is based on the quantity and distribution of electrical bikes. Even if it is true that Cespa will increase the number of electrical bikes to 1,000 (700 more than now), they should start the path towards a substitution of mechanical Bicing by electrical Bicing. And not only by substituting all the bicycles by electrical ones, but by achieving to design stations that are accessible and able to charge the vehicles at the same time.

3.3. Electric scooters

Another aspect to be taken into account is the fact that in the recent years, there has been an increasing trend for electrical scooters: more and more people are buying and using them. So, another possibility to solve the presented problem would be substituting the bikes for scooters, since they are cheaper to buy, maintain and repair. In addition, they are smaller, so there could be more spots per station.

Barcelona City Council does not have a registry for electric scooters, since it in not considered a vehicle itself. Thus, it is difficult to estimate the current quantity of these circulating in the city. There are around 1,000 of them approximately. It is important to notice that some of these electric scooters can reach a higher speed compared to bikes or mopeds. Therefore, since July 2017, personal mobility vehicles (PMV) and cycles with more than two wheels have had their own regulations, which establish the maximum speed electric scooters can reach, as well as the areas in which they can move around.



Figures 4 & 5. Regulations for personal mobility vehicles.
Source: Barcelona Town Council

There are different ways to implement electric scooters in Barcelona. On the one hand, the City Council could make a massive investment by creating a network of electric scooters which would be managed by the Administration. However, its financing would be quite costly making it difficult to include it in the yearly budget. Another option is signing a partnership with a company so that the management, implementation and investment costs would be shared. There are some American startups like Lime, that have already been established in many European cities with the objective of introducing this new way of transportation outside the US.

Nonetheless, establishing new partnerships with rental electric scooters companies is not what the council has showed interest in recently, as the new mobility regulations state that rental scooters can only be used with a guide who represents the group, meaning that they can only be used for touristic purposes, apart from private usage. Companies like Wind already tried to implement this trendy transport in Barcelona, but it failed, since the police withdraw all Wind’s scooters scattered around the city.

Therefore, under the current situation, the City Council should change again the mobility regulation so that it allowed electric scooters’ rental companies to operate in Barcelona. However, since it is unlikely to happen, another alternative should be considered. Thus, fostering the use of the private use of electric scooters through subsidies, discounts and improved facilities can be a better choice so that Bicing is less collapsed.

3.4. Logistical solution

We have based our proposal on the requirements that Bicing gave on their public tender back in 2017. This public tender was won by Cespa, a subsidiary of *Ferroviaria*, which proposed the solution that had more points based on the City Council criteria. Although this new solution is not available to the public, the minimum requirements for Bicing 2.0 are:

- Creation of three zones with different reposition logistics and different levels of service. Creation of clusters and sub-clusters by the aggrupation of stations with the same usage trends. Scheduling of the operation based on a stable demand guideline.
- 6000 mechanic bikes and 1000 electrical bikes in an initial phase. The transition towards 100% electric bikes is heartily encouraged.
- A minimum of: 26 logistic vehicles at service for the day shift on business days; 12 logistics vehicles at service for the night shift, weekends and holidays; 16 logistic vehicles at service for the day and evening shift on weekends and holidays.
- At least 50% of those vehicles must be either electric or hybrid.
- A minimum service quality ratio based on data that Bicing would provide to contractors.
- A minimum of 2 logistics centers in Barcelona for the realization of maintenance and warehousing. As a complement, there is the possibility of having more logistics centers with the aim to improve the redistribution of bikes.

Our analysis will just focus on providing partial solutions to these constraints, given the unavailability of data we encountered. Had we had the data, a more specific and practical analysis could have been done.

<u>Demand forecasting of Bicing users and their distribution across Barcelona</u>

The target for Bicing users is people from 16 to 50 years old on average. In 2017, according to the Barcelona's census 760,321 citizens fit that target. The ratio of the potential target with respect the total population in Barcelona in 2017 is 0.4691. Currently Bicing has 105,545 active users. The ratio of actual active users with respect to the total target is 0.1388.

If we compute:

$$\left(\# \; of \; citizens \; per \; neighborhood * \frac{total \; target \; bicing}{total \; citizens \; in \; BCN}\right) * \frac{actual \; users}{total \; target} = potential \; demand \; per \; neighborhoo$$

Neighborhood	Estimation of users
Ciutat Vella	6,601
Eixample	17,347
Sants - Montjuïc	11,844
Les Corts	5,341
Sarrià - Sant Gervasi	9,720
Gràcia	7,901
Horta - Guinardó	10,988
Nou Barris	10,846
Sant Andreu	9,610
Sant Martí	15,335

Table 1. Estimation of Bicing users per neighborhood. Source: own calculations.

The total sum of potential users is **105,533.** Not far from the actual number of 105,545 users. In the following map we can see the distribution of the estimated demand across all neighborhoods.

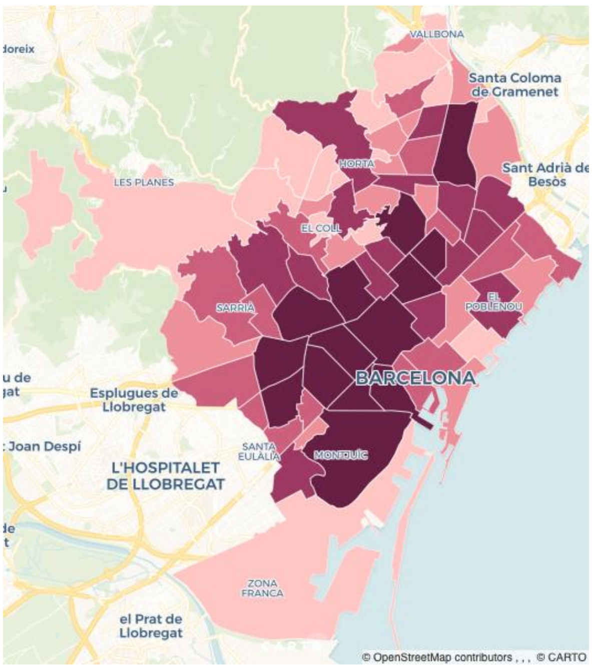


Figure 6. Map of estimated Bicing user's density. Source: own source.

How to distribute the number of stations per neighborhood

$$\#\ of\ stations\ per\ neighborhood = \alpha + \beta * \widehat{Demand} + \gamma * \widehat{Height}$$

Where α is the minimum number of stations per neighborhood, β is how a change in demand affects the # of stations and γ is how a change in height affects the # of stations.

The demand can be found in *Table 1*. As for the height, we have approximated the average height of each neighborhood by doing the mean between the highest and the lowest point in each neighborhood.

Neighborhood	Average height above sea level (meters)
Ciutat Vella	9
Eixample	32
Sants - Montjuïc	28.5
Les Corts	90.5
Sarrià - Sant Gervasi	95.5
Gràcia	73.5
Horta - Guinardó	83
Nou Barris	82.5
Sant Andreu	33
Sant Martí	11

Table 2. Estimation of the average height above the sea level of each neighborhood.
Source: own calculations.

First, we must decide the value of α. Currently there are 428 stations across Barcelona. We will assume that 40% of it represents the minimum service level Bicing has, and the remaining 60% are the stations placed based on the specifications of each neighborhood. Therefore 171 stations would be evenly placed across all 10 neighborhoods, meaning that each neighborhood requires a minimum of 17 stations.

Since we do not have accurate data on the demand trends in each Bicing station, β will have to be approximated. Had we had this information we would have run a multiple regression in STATA to find the exact effect of demand on the distribution of Bicing stations per neighborhood.

If demand refers to the usage of the station per day, β is equal to the effect in # of stations of increasing one more usage per day. Thus, a good value for β would be 0.02. Meaning that, for an increase in usage of a hundred more users per day, 2 more stations would need to be added.

In the other regressor, Height, γ has to be negative because more height means that less people use the stations since users only do a trip when it is downward sloping not upwards. However, γ has to affect less to the number of stations than, demand is a far more important regressor than height in this regression. γ should then be of 0.01. Meaning that, for every 100 meters of increase in height there is 1 more station added.

Notice that this regression, due to lack of data, it's biased and that the regressors are imperfectly multicollinear since height also affects demand. However, this regression fits us to illustrate a way to compute the distribution of stations and which are its drivers.

So, in conclusion, the final equation for the # of stations per neighborhood would be the following:

$$\#\ of\ stations\ per\ neighborhood = 17 + 0.03 * \widehat{Demand} + 0.01 * \widehat{Height}$$

<u>Creation of 3 zones</u>

The division of Barcelona in 3 zones each with different logistics strategies facilitates the efficiency and quickness of the reposition and movement of bikes. The criteria used for the selection of these three zones has been based on the proximity of the neighborhood and same trends in terms of demand (*a grosso modo* since we do not have the data). Height has not been taken into considerations since it is already inside the proximity criteria.

Zone 1: Sarrià-Sant gervasi, Les Corts and Sants Montjuïc

These three neighborhoods have low demand and neutral demand of spots.

Zone 2: Eixample, Ciutat Vella and Sant Martí

High demand in terms of users and spots.

Zone 3: Gracia, Horta-Guinardó, Nou Barris and Sant Andreu

Lowest demand of spots but high number of users.

Zone	# of users	# of stations	# of spots
1	26905	∑ # of stations in z1	# stations * k
2	39283	∑ # of stations in z2	# stations * k
3	39345	∑ # of stations in z3	# stations * k

Table 3. Results of the division of users by zones.
Source: own calculations.

(k needs to be defined as a constant that represents the average spots depending on the demand of spots in each zone)

<u>Location of the 2 warehouses</u>

The location of each of the two warehouses has to serve as a strategic hub for the reposition and movement of bikes. Therefore, the synergies between the three zones will take place in these two locations.

One warehouse has to be located at the border between zone 1 and 2. The other one at the border of zone 2 and 3. This way, when zone 2 is crowded with bikes at night because of the user trends, these bikes can be carried to either Warehouse 1 or Warehouse 2 to redistribute them to the empty spots on higher neighborhoods in zone 1 and 3.

A practical example of the different routes using *Clarke & Wright* to optimize the routing:

Let's set a warehouse in *Plaça Espanya*, in border from zone 1 and zone 2, *Sants-Montjuïc* and *l'Eixample*. In reality a warehouse could not be placed in *Plaça Espanya*, however near *Poble Sec* or *Montjuïc* is feasible to place the warehouse.

Let’s take into consideration the *La Maternitat i Sant Ramón* neighbourhood, which is situated in *Les Corts* and only has 7 stations.

Using the software, we geolocate the 7 stations and set the demand of each one as the number of spots the station has. The demand for the warehouse would be 215, the aggregate demand of the 7 stations.

We use only one truck to do all the routing, since in reality only one truck would be available for an specific neighborhood.

The results are the following:

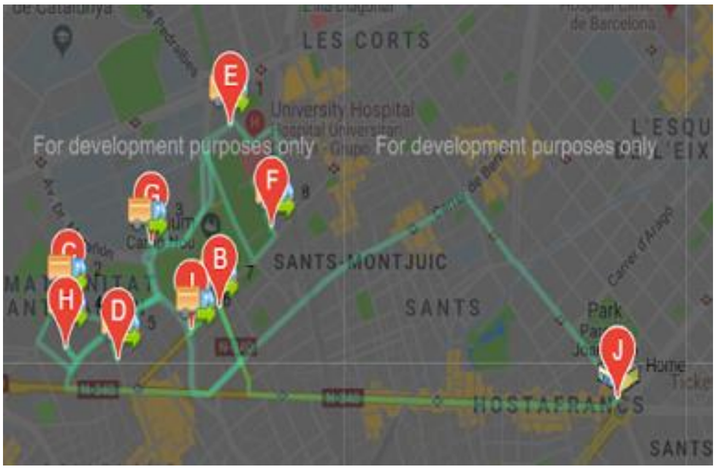


Figure 7. Map of the routing proposal.
Source: own source.

The initial and final point would be the warehouse in Plaça Espanya. This would be the optimal routing option for the La Maternitat i Sant Ramón Bicing stations if the warehouse was at the border of zone 1 and zone 2.

Customer	1	2	3	4	5	6	7	8
Demand (U)	28	31	25	25	25	23	33	25
Depot (0)	4	3	5	3	3	2	2	5
1	0	2	1	2	1	1	1	0
2		0	1	2	0	2	1	3
3			0	0	0	1	1	1
4				0	0	1	1	2
5					0	1	1	2
6						0	0	2
7							0	2
8								0

Figure 8. Matrix of transportation data.
Source: own source.

In the first matrix we can find the distances from the different stations to the warehouse and also the distance within stations.

So, in conclusion, with the demand forecasting, the approximation of number of stations and the different transportation routes for the reposition of bikes a proper model to a new logistics approach on Bicing could be done.

Unluckily, we have found impossible to obtain this data, so we have only proposed the theoretical basis without the exact calculations of the model.

Had we had the demand, an accurate demand forecasting could have been done in the sense of distribution of demand across Barcelona. That would have given us an accurate picture of the system and indicators as were to increase or decrease the amount of stations.

Also, with the demand information, an accurate and unbiased regression could have been made to recalculate the distribution of stations using constraints as the correlation between demand and number of spots and the correlation between demand and height.

As for the routes, a more powerful software would have been needed to calculate the routes between the two warehouses and the 428 stations. Although the routes could be computed focusing at one zone at a time, the matrix would be still too large to compute it with http://vrp.upf.edu/

4. CONCLUSION

Probably by this time next year, the new company managing the service will have already solved many of the issues we mentioned by adding more electrical bikes. Still, the problem with the redistribution of the mechanical ones will remain, and even the redistribution of the electrical ones won't be perfect either, for instance, for rainy days as mentioned above. So many of the strategies we proposed could be interesting for a better redistribution for the new company.

The best idea would be to implement a combination of the strategies analyzed. One of the proposals, the one of the electrical bikes, is already being implemented and this will solve a part of the problem, but the best idea would be to think about a complete substitution of the mechanical bikes by the electrical ones in the medium run. Still, redistribution would be necessary, and the other strategies could help making it more efficient. The use of economic incentives seems a good idea to foster the automatic redistribution, especially since it is really simple and cheap to implement.

The proposal of changing the logistics behind the redistribution, even if it can be costlier to implement at the beginning, in the medium/long run the savings can easily compensate this, since the service is to be provided in the city indefinitely. Also since the implementation of the other proposals will theoretically reduce the number of bikes that need to be reallocated, it seems interesting to make the logistics as efficient as possible to save money, which could even be used to offer even higher economic incentives for the redistribution of bikes, or reduce the annual tariff, which would probably help attract even more users to the service, which would turn Barcelona into a more smart, progressist, efficient and environmentally-friendly city.

About the proposal of the scooters, it seems the most difficult and expensive one to implement, even though it could result to be much better than the bikes, due to its lower price and reduced size. The main problem would be that the investment made by the Administration in Bicing, could hardly be reused, and would imply a lot of money lost and more money to be invested in the scooters. Still, many cities such as Madrid and Paris already use scooters and seem to work well enough, so it would be really interesting to take advantage of the experience of these other cities. And if the system is to work better than Bicing, the city should consider the investment in Bicing a sunk cost, forget about it and implement the most efficient system. Especially since the service can be assumed to endure for many decades, the savings of a more efficient system would pay-off in the end. Also, a slow and progressive implementation could be considered, just the way they are introducing the electrical bikes, to make a softer transition and avoid the impact of a huge investment.

5. ANNEXES

We created a dynamic online map with the data we gathered by hand by using the CARTO maps logistic tool.

https://daemon124.carto.com/builder/b9bee7c8-c6b6-4e55-a5a2-54f7a8a58e1c

We also tried to create a Python program to use the heuristic method to create a route between all the Bicing stations. The problem is that we only had the geographical coordinates of the stations, so we had to use the Haversine formula to approximate the distance between them, which resulted inaccurate, so the program created a strange route.

```
from math import sqrt,sin,cos,pi,asin

file = open('coords.txt', 'r')

x_coord = []
y_coord = []

for line in file:
    l = line.split(',')
    x_coord.append(l[0].strip())
    y_coord.append(l[1].strip())

def dist(stat1, stat2):
# HAVERSINE FORMULA

    r = 6371000 #Earth radius in meters

    c = pi/180 #Constant to turn degrees to radiants

    long1 = float(x_coord[stat1])
    lat1 = float(y_coord[stat1])

    long2 = float(x_coord[stat2])
    lat2 = float(y_coord[stat2])

    d = 2*r*asin(sqrt(sin(c*(lat2-lat1)/2)**2 + cos(c*lat1)*cos(c*lat2)*sin(c*(long2-long1)/2)**2))

    return d

def heuristic():

    mindist = 99999999999999
    mindistid = 0
    route = [1]

    while (len(route) != len(x_coord)-1):
        mindist = 999999999

        for i in range(2,len(x_coord)):
            d = dist(route[-1], i)

            if (d < mindist and not(i in route)):
                mindist = d
                mindistid = i

        route.append(mindistid)

    route.append(1)

    print route

heuristic()
```

```
[1, 116, 416, 368, 29, 367, 215, 25, 118, 117, 17, 366, 18, 27, 273, 274, 20, 19, 161, 276, 275, 277, 238, 236,
237, 244, 285, 235, 124, 101, 100, 129, 130, 138, 132, 131, 142, 147, 378, 151, 150, 388, 148, 149, 418, 158, 14
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288, 291, 295, 286, 290, 297, 293, 252, 259, 256, 253, 241, 239, 287, 240, 278, 289, 279, 219, 220, 66, 71, 74,
85, 363, 193, 300, 331, 332, 334, 333, 330, 328, 326, 325, 327, 329, 299, 298, 1]
```

If we consult the route by looking at the map at the Bicing webpage, we see that the route is incorrect. Had we had the accurate data of the distances between stations, the program would probably work.

The program uses the following file:

```
/station/long/X,/station/lat/Y
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2.17706,41.39553
2.181299,41.394055
2.181555,41.39348
2.180223,41.391075
2.18061,41.391349
2.183251,41.388856
2.183568,41.389088
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2.195761,41.386861
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2.186711,41.398237
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2.170726,41.403282
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2.17568,41.401684
2.171812,41.392526
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2.164373,41.396897
2.17064,41.405422
2.170028,41.401132
2.182286,41.402046
2.18895,41.37481
2.188927,41.373698
2.190773,41.376862
2.175247,41.387074
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2.181888,41.381226
2.186397,41.381129
2.186576,41.381046
2.187093,41.382335
2.189906,41.379326
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2.187111,41.402285
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2.142868,41.385081
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2.147734,41.376428
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2.197936,41.411908
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2.20077,41.3942
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2.196261,41.398389
```

Districte	Barri	Població (2017)	Percentatge (%)	Bicing mecànic (espais per bicis)	Bicing mecànic (estacions)	Bicing elèctric (bicicletes)	Bicing elèctric (estacions)	nºusuaris aprox per barri	Cota altímetrica mitjana (m)
	El Raval	47.608	2,94	355	15	22	2	3100	9
	Barri Gòtic	16.062	0,99	309	13	34	2	1046	9
	La Barceloneta	14.996	0,93	394	17	36	3	976	9
Ciutat Vella	Sant Pere, Santa Caterina i la Ribera	22.721	1,40	384	14	12	1	1479	9
	El Fort Pienc	32.016	1,98	320	12	10	1	2085	32
	La Sagrada Família	51.539	3,18	287	12	24	1	3356	32
	La Dreta de l'Eixample	44.052	2,72	858	33	72	4	2868	32
	L'Antiga Esquerra de l'Eixample	42.284	2,61	276	12	12	1	2753	32
	La Nova Esquerra de l'Eixample	58.180	3,59	407	16	34	3	3788	32
Eixample	Sant Antoni	38.345	2,37	449	18	0	0	2497	32
	El Poble Sec - El Parc de Montjuïc	40.228	2,48	147	6	12	1	2619	28,5
	La Marina del Prat Vermell - AEI Zona Franca	1.149	0,07	0	0	0	0	75	28,5
	La Marina del Port	30.584	1,89	236	8	0	0	1991	28,5
	La Font de la Guatlla	10.401	0,64	0	0	0	0	677	28,5
	Hostafrancs	15.904	0,98	138	6	12	1	1036	28,5
	La Bordeta	18.530	1,14	151	6	0	0	1207	28,5
	Sants - Badal	23.987	1,48	103	4	12	1	1562	28,5
Sants - Montjuïc	Sants	41.127	2,54	173	7	0	0	2678	28,5
	Les Corts	46.009	2,84	432	16	22	2	2996	90,5
	La Maternitat i Sant Ramon	23.948	1,48	228	8	12	1	1559	90,5
Les Corts	Pedralbes	12.076	0,75	109	4	12	1	786	90,5
	Vallvidrera, el Tibidabo i les Planes	4.670	0,29	0	0	0	0	304	95,5
	Sarrià	25.032	1,54	168	6	12	1	1630	95,5
	Les Tres Torres	16.667	1,03	218	8	0	0	1085	95,5
	Sant Gervasi - La Bonanova	25.774	1,59	81	3	12	1	1678	95,5
	Sant Gervasi - Galvany	47.666	2,94	395	15	10	1	3104	95,5
Sarrià - Sant Gervasi	el Putxet i el Farró	29.470	1,82	27	1	12	1	1919	95,5
	Vallcarca i els Penitents	15.759	0,97	0	0	0	0	1026	73,5
	el Coll	7.412	0,46	0	0	0	0	483	73,5
	la Salut	13.185	0,81	0	0	0	0	858	73,5
	la Vila de Gràcia	50.662	3,13	209	8	0	0	3299	73,5
Gràcia	el Camp d'en Grassot i Gràcia Nova	34.329	2,12	64	3	0	0	2235	73,5
	Horta	26.715	1,65	45	2	0	0	1739	83
	el Baix Guinardó	25.672	1,58	117	5	12	1	1672	83
	Can Baró	8.994	0,55	0	0	0	0	586	83
	el Guinardó	36.467	2,25	104	4	12	1	2374	83
	la Font d'en Fargues	9.383	0,58	27	1	0	0	611	83
	el Carmel	31.551	1,95	0	0	0	0	2054	83
	la Teixonera	11.619	0,72	0	0	0	0	757	83
	Sant Genís dels Agudells	6.854	0,42	0	0	0	0	446	83
	Montbau	5.102	0,31	0	0	0	0	332	83
	la Vall d'Hebron	5.784	0,36	0	0	0	0	377	83
Horta - Guinardó	la Clota	610	0,04	0	0	0	0	40	83
	Torre Baró	2.856	0,18	0	0	0	0	186	82,5
	Vilapicina i la Torre Llobeta	25.591	1,58	81	3	12	1	1666	82,5
	Porta	25.000	1,54	140	6	0	0	1628	82,5
	el Turó de la Peira	15.467	0,95	27	1	0	0	1007	82,5
	Can Peguera	2.271	0,14	0	0	0	0	148	82,5
	la Guineueta	15.231	0,94	53	2	0	0	992	82,5
	Canyelles	6.856	0,42	0	0	0	0	446	82,5
	les Roquetes	15.590	0,96	0	0	0	0	1015	82,5
	Verdun	12.353	0,76	0	0	0	0	804	82,5
	la Prosperitat	26.389	1,63	24	1	0	0	1718	82,5
	la Trinitat Nova	7.261	0,45	0	0	0	0	473	82,5
	Ciutat Meridiana	10.342	0,64	0	0	0	0	673	82,5
Nou Barris	Vallbona	1.372	0,08	0	0	0	0	89	82,5
	la Trinitat Vella	9.983	0,62	73	3	0	0	650	33
	Baró de Viver	2.539	0,16	27	1	0	0	165	33
	el Bon Pastor	12.560	0,77	79	4	0	0	818	33
	Sant Andreu	57.183	3,53	401	16	12	1	3723	33
	la Sagrera	29.084	1,79	198	9	12	1	1894	33
	el Congrés i els Indians	14.116	0,87	80	3	0	0	919	33
Sant Andreu	Navas	22.129	1,37	108	4	0	0	1441	33
	el Camp de l'Arpa del Clot	38.168	2,35	81	3	0	0	2485	11
	el Clot	27.039	1,67	127	5	0	0	1761	11
	el Parc i la Llacuna de Poblenou	15.134	0,93	245	10	12	1	985	11
	la Vila Olímpica del Poblenou	9.367	0,58	413	17	0	0	610	11
	el Poblenou	33.843	2,09	399	15	24	2	2204	11
	Diagonal Mar i el Front Marítim del Poblenou	13.629	0,84	209	8	12	1	887	11
	el Besòs i el Maresme	23.009	1,42	170	6	12	1	1498	11
	Provençals del Poblenou	20.487	1,26	159	7	0	0	1334	11
	Sant Martí de Provençals	26.146	1,61	75	3	0	0	1702	11
Sant Martí	la Verneda i la Pau	28.691	1,77	131	5	0	0	1868	11
		1.620.809	**100,00**	**10511**	**415**	**504**	**39**	**105533**	

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