GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

INTRODUCTION OF A CARSHARING PLATFORM CONNECTING RELEVANT SPANISH CITIES

Autor: Irene Naranjo Romero

Director: Ali Haghani

Madrid

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INTRODUCCIÓN DE UNA PLATAFORMA DE *CARSHARING* QUE CONECTE CIUDADES ESPAÑOLAS RELEVANTES

Autor: Naranjo Romero, Irene.
Director: Haghani. Ali.
Entidad Colaboradora: University of Maryland, ICAI – Universidad Pontificia de Comillas

RESUMEN DEL PROYECTO

En este proyecto, se ha desarrollado un modelo de localización de vehículos para una plataforma de *carsharing* a nivel nacional que permita cubrir largas distancias entre ciudades españolas.

Para el desarrollo del modelo se considerarán solamente 6 ciudades: Madrid, Barcelona, Valencia, Sevilla, Zaragoza y Málaga. Estas ciudades se han seleccionado por ser las más pobladas del territorio español.[1]

Palabras clave: *Carsharing*, modelo de localización de vehículos, escala nacional, vehículos compartidos.

1. Introducción

A lo largo de los últimos años, se ha podido comprobar el enorme potencial de las plataformas de vehículos compartidos, o de *carsharing* en numerosas grandes ciudades. Diferentes modelos de *carsharing* se encuentran presentes en la actualidad:

***Tipos de* carsharing**	***Definición***
Free-floating *carsharing*	Se utiliza a escala urbana, en el que existe la posibilidad de alquilar un vehículo y realizar un pago por minutos.
***Carsharing* estacionario**	Permite el alquiler de vehículos para realizar viajes de más larga distancia, pero que requieren la restitución de los vehículos en la misma localización en la que habían sido inicialmente alquilados.
Peer-to-peer *carsharing*	Permite utilizar vehículos privados a través de una app o plataforma. Los precios se acuerdan con anterioridad.
Plataformas tradicionales de alquiler de vehículos	Permiten a los usuarios alquilar durante un periodo de tiempo fijado con anterioridad un vehículo para su uso

Tabla 1: Tipos de carsharing existentes. Fuente:[2]

Sin embargo, se ha podido observar la inexistencia de una plataforma diferente, que permita cubrir grandes distancias y se adapte de una forma más acertada a las necesidades de los usuarios, en la que el tiempo de alquiler del vehículo sea flexible y se permita el pago solamente por el tiempo de utilización del servicio.

2. Definición del proyecto

A partir de las observaciones que se han realizado, se ha desarrollado una idea para este trabajo. En este proyecto, por lo tanto, se intenta ir un paso más allá, buscando la creación de una plataforma distinta, que permita realizar trayectos en vehículos compartidos dentro de todo el territorio español, y en la que sea posible realizar un pago en función del trayecto que se vaya a realizar.

El principal objetivo de la realización de este proyecto es la asignación óptima de un número indefinido de vehículos en las seis ciudades que se han comentado anteriormente. Para ello, se han tenido en cuenta diferentes parámetros, que se han estudiado y tratado de forma numérica con la finalidad de poder determinar cuáles son los parámetros más relevantes para la localización de los vehículos.

Los parámetros que se han elegido son:

- La distancia entre las ciudades seleccionadas.
- El número de vehículos existentes en cada una de las localizaciones.
- El número de vehículos con una antigüedad mayor a 10 años en cada ciudad.
- El acceso a medios de transporte alternativos al coche en cada ciudad.
- La renta per cápita en cada localidad.
- El número de vehículos de *carsharing* existentes en cada ciudad en la actualidad.
- El número de cargadores de vehículos eléctricos públicos (aunque no necesariamente gratuitos) existentes en cada localidad.
- El número de cargadores de vehículo eléctrico existente entre ciudades.
- El número de turistas que cada ciudad recibe anualmente.

En el proyecto se ha realizado un análisis detallado de cada uno de estos factores y del efecto que ellos tienen sobre las soluciones obtenidas para el problema. Adicionalmente, se ha analizado la viabilidad económica del proyecto.

3. Descripción del modelo/sistema/herramienta

Con la finalidad de realizar una evaluación objetiva del efecto que cada uno de los parámetros tiene sobre la solución al problema, se han planteado nueve problemas distintos, en los que se ha utilizado la misma formulación, pero se ha realizado una modificación en los datos introducidos (en función del parámetro considerado).

MATLAB ha sido la herramienta seleccionada para obtener una solución a cada uno de los problemas. Todas las soluciones obtenidas han servido para determinar los efectos de cada uno de los parámetros, permitiendo así realizar una selección de los parámetros que resulten más relevantes. Se ha realizado para ello una comparación con el llamado Problema Base, en el que únicamente se había considerado la población como dato relevante para la selección de la asignación óptima de los vehículos.

Una vez se ha realizado la selección de estos criterios, es posible obtener un modelo que pueda determinar las localizaciones óptimas de los vehículos. El proceso que se ha seguido para la ejecución de esta formulación es el siguiente:

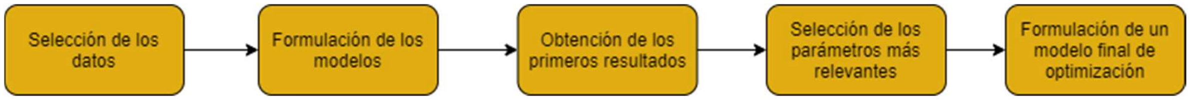

Ilustración 1. Fuente: elaboración propia.

El modelo final del problema que se ha planteado utiliza la misma formulación que los problemas más sencillos que han sido planteados, con la singularidad de que aúna, de forma ponderada todos los parámetros y factores que se habían considerado inicialmente para el problema.

La resolución de este problema final ha permitido obtener resultados concluyentes en cuanto a dónde deberían localizarse los vehículos.

4. Resultados

La ejecución del Problema Final que se ha ejecutado en MATLAB ha permitido determinar que la asignación óptima de vehículos sería:

Ciudad	***Número de vehículos***
Madrid	199
Barcelona	113
Valencia	60
Sevilla	49
Zaragoza	54
Málaga	34

Tabla 2: asignación óptima de vehículos para el Problema Final

A partir de esta tabla, se ha obtenido también el mapa que se muestra a continuación muestra cuál sería la localización óptima de vehículos de *carsharing* en función de los nueve parámetros que han sido considerados:

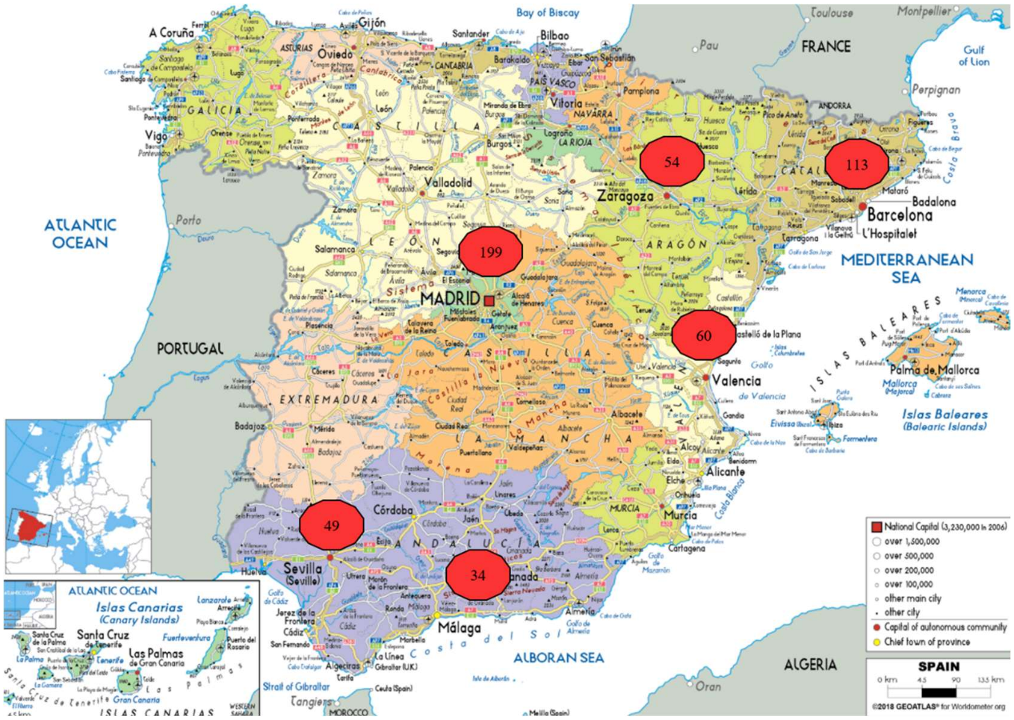

Ilustración 2. Mapa de la localización óptima de los vehículos de carsharing. *Fuente: elaboración propia.*

Como se puede observar, Madrid es la ciudad que tiene el número más alto de vehículos asignados, como cabría esperar debido a su población tan elevada.

Asimismo, Barcelona es la ciudad con el segundo puesto en cuanto al número de vehículos asignados, debido igualmente a su población tan elevada.

Valencia, que es la tercera ciudad por población, sigue a Barcelona en cuanto al número de vehículos.

Sin embargo, en las tres ciudades restantes, la asignación de vehículos no solamente ha tenido lugar teniendo en cuenta el número de habitantes: otros factores y parámetros que se han considerado a lo largo del trabajo han tenido un efecto mayor, provocando que en este caso ya no se siga el mismo orden que se había seguido en cuanto a tamaño de cada localidad.

5. Conclusiones

La primera conclusión que puede ser extraída de la realización de este proyecto es la importancia de la población a la hora de determinar cuál es la mejor localización para un vehículo: los parámetros que se han considerado no han hecho sino alterar los diferentes valores de la población que se han ido introduciendo en un mismo código en MATLAB, por lo que la única alteración que se ha realizado a lo largo de todo el problema y que ha resultado en soluciones tan diferentes ha sido la de la alteración del valor de la población.

Mediante la realización de este proyecto se ha podido observar asimismo como los parámetros que a priori parecían ser más relevantes para la optimización de las asignaciones de vehículos han sido, efectivamente los parámetros con un mayor efecto sobre el resultado. En particular, la distancia entre ciudades y la existencia de medios de transporte alternativos al coche en cada ciudad son los parámetros más relevantes.

Por otra parte, se ha podido observar también cómo algunos parámetros que podrían haberse considerado importantes hasta cierto punto, no resultan especialmente relevantes a la hora de decidir la localización óptima de los vehículos. Estos parámetros son la existencia de vehículos de *carsharing* en las ciudades que se han seleccionado, o el número de vehículos con más de 10 años en cada una de las localizaciones.

6. Referencias

[1] INE, "Cifras oficiales población resultantes de la revisión del Padrón Municipal a 1 de enero", Enero 2019 https://www.ine.es/jaxiT3/Datos.htm?t=2911#!tabs-tabla.

[2] Monitor Deloitte, "Carsharing in Europe: Business Models, National Variations and Upcoming Disruptions", Junio 2017

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Author: Naranjo Romero, Irene.
Supervisor: Haghani, Ali.
Collaborating Entity: University of Maryland, ICAI – Universidad Pontificia de Comillas

ABSTRACT

In this project, a model for the localization of vehicles in a national scale *carsharing* platform that allows to cover long distances between Spanish cities has been developed.

For the correct construction of this model, it is necessary to define a more broad scope, in which only 6 cities will be selected: Madrid, Barcelona, Valencia, Sevilla, Zaragoza and Málaga. These cities have been selected for being the most populated cities of the Spanish territory.

Keywords: *Carsharing*, Location optimization model, national scale, shared vehicles

1. Introduction

Throughout these past years, it has been possible to corroborate the enormous potential existing in *carsharing* platforms in big cities. Different models of *carsharing* are currently present.

***Types of* carsharing**	***Definition***
Free-floating *carsharing*	It is used in a urban scale, in which the possibility to rent a vehicle a perform a by-minute-payment exists.
Stationary *carsharing*	It allows the loan of vehicles to perform long-distance trips, but they require users to return the vehicles in the same place where they were originally rented.
Peer-to-peer *carsharing*	It allows to loan private vehicles throughout an app or a platform. Fares are agreed upon beforehand.
Traditional car renting platforms	They allow users to rent a vehicle for a previously set time.

Table 1: Types of carsharing *platforms. Source: [2]*

However, it has been noted the inexistence of a different platform, that can cover large distances, and is adapted in a more accurate way to users' needs. In this platform, renting time would be more flexible, and payments are only required for the time of use of this service.

2. Project definition

From the observations that have been made, an idea has been developed for this project. In this project, therefore, the aim is to go a step further, looking for the creation of a different platform, that allows users to travel longer distances in *carsharing* vehicles in the Spanish territory, and in which fares depend on the journey that is going to be performed.

The main goal of this project is the assignation of an indefinite value of vehicles in the six cities that have been previously mentioned. For this purpose, different parameters have been considered, which have been studied and treated numerically, with the aim to determine which are the most relevant parameters for the location of vehicles.

The parameters that have been selected are:

- The distance between existing cities.
- The number of existing vehicles at each location.
- The number of vehicles which are older than 10 years at each location.
- The access to alternative transportation means in each city.
- The yearly income at each city.
- The number of *carsharing* vehicles currently existing at each city.
- The number of public electric vehicle chargers (although not necessarily free), existing at each location.
- The number of EV chargers existing between cities.
- The number of tourists received every year at each location.

In the project, a detailed analysis of each of the factors has been performed, together with the effect of each of them on the obtained solutions for the problem.

Additionally, the economic viability of this project has been looked at.

3. Model/system/tool description

With the end to perform an accurate and objective evaluation of the effect that each of the parameters has on the solution to the problem, nine different problems have been formulated. in which the same formulation has been used, although different data has been used (depending on the considered parameters).

MATLAB has been the selected tool to obtain a solution for each of the problems. All obtained solutions have served to determine the effects of each of the parameters, allowing us to perform a selection of the most relevant ones. In order to do so, a comparison with the so called Base Problem has been made, in which only the population had been considered relevant data for the selection of the optimal assignment of the vehicles.

Once the selection of the criteria that will be used has been done, it is possible to obtain a model that will help determine the location of these vehicles. The process that has been followed for the execution of this formulation is as follows:

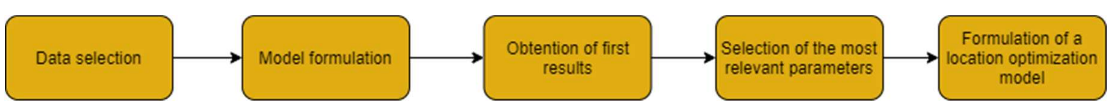

Figure 1: Steps used in the development of this problem. Source: elaborated by the author.

The final model that has been formulated for the problem also uses the same formulation than the easiest problems that had been formulated, with the singularity that it joins all the weighted parameters and factors that had initially been considered for the problem.

The final resolution of the problem, has allowed us to obtain conclusive results, that inform us on where the vehicles should be located.

4. Results

The execution of the MATLAB code has allowed us to obtain a solution, which is provided in the following table:

City	*Number of vehicles assigned*
Madrid	191
Barcelona	107
Valencia	62
Sevilla	47
Zaragoza	52
Málaga	37

Table 2: Final assignation of vehicles

From this table, a map has been obtained, in which the optimal location of the *carsharing* vehicles has been defined:

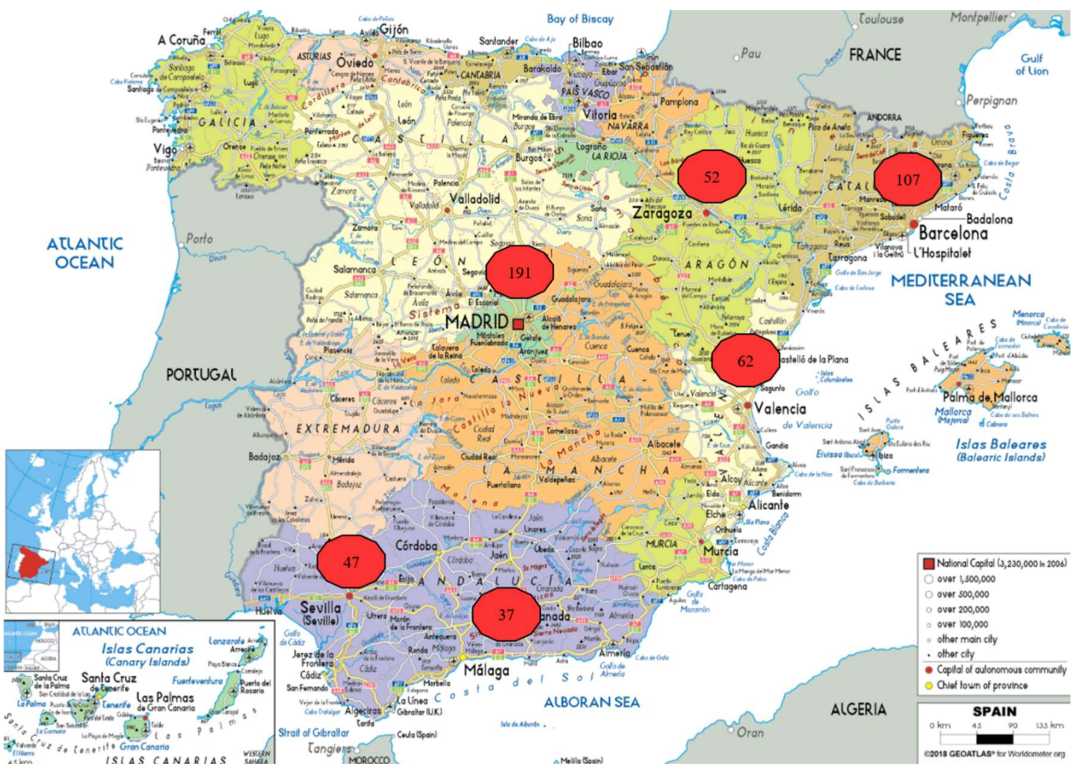

Figure 2: Map of the optimal location of the carsharing *vehicles. Source: elaborated by the author.*

As it can be observed, Madrid is the city with the greatest number of vehicles assigned, as it would be expected due to its high population.

In the same way, Barcelona is the city with the second greatest number of vehicles assigned, due to its high population as well.

Valencia, which is the third city in population, follows Barcelona in number of assigned vehicles.

In the other three cities however, the assignation of vehicles does not depend only in the number of inhabitants: the other factor and parameters that have been considered throughout the problem have had a greater effect, causing them not to follow the same ranking that was followed when ordering them based on their population.

5. Conclusions

The first conclusion that can be excerpted from the development of this project is the importance of population when it comes to determining what the best location for a vehicle is: the parameters that have been considered only altered the different values for the population that were introduced in a single MATLAB code. The only alteration that was made therefore was the changing of the population, which later resulted in different solutions.

Through the development of this project, it has been possible to note as well, how all the parameters that initially seemed more relevant for the optimization of the assignment of vehicles, were in fact the parameters with the greatest effect on the results. More particularly, the distance between cities, and the existence of alternative transportation means are the most relevant parameters.

On the other hand, it has also been observed how, some parameters that could have been considered relevant to a point, turned out to be not so relevant when deciding the optimal location of vehicles. Those parameters are the existence of *carsharing* vehicles in the selected cities, or the number of vehicles that are older than 10 years at each location.

6. References

[1] INE, "Cifras oficiales población resultantes de la revisión del Padrón Municipal a 1 de enero", January 2019 https://www.ine.es/jaxiT3/Datos.htm?t=2911#!tabs-tabla

[2] Monitor Deloitte, "Carsharing in Europe: Business Models, National Variations and Upcoming Disruptions", June 2017

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Autor: Irene Naranjo Romero

Director: Ali Haghani

Madrid

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1. INTRODUCTION

Nowadays, time has become one of the most valuable things people can have: jobs pay per hours of work, people pay per time in entertainment…

In spite of this, it is estimated that in big cities, such as Madrid, a person spends in average 42 hours every year fighting traffic jams (INRI19). 40% of this traffic has been shown to be due to the lack of parking spots. (BMW20)

Spanish cars spend an average of 97% of the time parked (this means between 22 and 23 hours per day parked) (SANZ14), and therefore, it is estimated that one single shared vehicle could substitute between 8 and 20 private automobiles (BMW20). Vehicles that are not in use take parking spots and this leads to the unavailability that later develops in a large waste of time looking for parking spots. Therefore, by reducing the number of vehicles in cities, it would be possible to also reduce traffic jams.

For this purpose, *carsharing* initiatives have appeared in most European cities. *Carsharing* platforms consist of shared vehicles, property of a company, who allows users to rent this vehicle for a very flexible time, which is usually not very long, and makes profit of it.

Some of these platforms, such as Car2Go, DriveNow or Enjoy, allow users to make use of their automobiles in many different cities throughout Europe; others, such as Zity in Madrid, Hiyacar in London or Free2Move in Washington D.C. are more particular to a single city.

Not only does this initiative contribute to traffic decongestion, but it also plays a part in improving the environmental status of the planet. About a fifth of a total car emission during its lifetime is released during its manufacturing process (SCHM18). By reducing the production of vehicles, it would be possible to reduce overall carbon emissions. Additionally, when eliminating private vehicles, they would be substituted by newer public vehicles, that would also reduce their emissions.

In addition to this, most *carsharing* platforms are made up by either electric cars (usually small, such as Smart Fortwo or Renault Zoé) or plug-in hybrid vehicles (such as Nissan Niro). The use of electric vehicles also helps reduce GHG release and encourages the development and implantation of electrical vehicles in our society.

Savings derived from the implementation of this initiative would not only be limited to time or pollution. Economical savings for the users are also involved in these kinds of initiatives. The purchase of a car involves many expenses for the owner, aside from the cost of the vehicle itself: insurances, maintenance, parking… Costs derived from the ownership of a vehicle sometimes may add to as much as the price of the automobile itself.

Additionally, it has been noticed that 25.7% of Spanish homes do not own a private vehicle, and 42.7% of Spanish homes (formed by at least two people) only have one private vehicle, which may not be enough sometimes (SANZ14). *Carsharing* platforms may be a helpful initiative for these homes.

1.1 STATE OF THE ART

When looking at the alternatives currently available in the market, several different options have been found to solve the issue of transportation. These initiatives aim to help users cover any distances without necessarily having to own a private vehicle:

- In the first place, carsharing platforms are available. These initiatives allow users to rent a vehicle for an indefinite period of time from an app on their cell phone. They only need to register the first time they use it and write down personal information, such as their address and drivers' license or bank information.

  Three different kinds of carsharing platforms could be considered: Free-floating carsharing, stationary carsharing and peer-to-peer (P2P) carsharing. (DELO17)

  - Free-floating carsharing is the kind we generally speak of. It is generally used in an urban scale.

    This renting method is very convenient in the extent that it is fast and easy to use. Customers pay only for the time in which they have made a use of the automobile. The platform allows customers to return the vehicle in any location of a designated area (generally within a distance of the center of the city, but sometimes may be a larger area, such as the region marked inside of a highway).

    However, most of those vehicles are electrical, so their mileage is quite limited. Often times, the region in which they can be driven is also restricted: companies usually don't allow the cars to run out of the designated parking region.

  - Stationary carsharing is very similar to the traditional renting service, which will be treated below. It has been available for a longer period of time, but it is not as known as the free-floating carsharing. Since customers usually travel longer distances using these vehicles, his type of carsharing allows users to choose between a wider range of cars, such as SUVs or 4x4s. However, customers must return the vehicle in the same place they picked it up from. Fares are based on the distance covered during the trip, instead of on the time of usage.

One example of this kind of carsharing would be the new Hyundai VIVe proposal. In this project, Hyundai wants to develop a carsharing platform in certain rural areas in Spain. For starters, it will be implemented as a pilot project in the village of Campisábalos, in the region of Guadalajara, where people will be able to rent Hyundai cars from their cell phones and drive to other regions within a distance of 250 km.

  - Peer-to-peer carsharing is a very recent movement. In this kind of carsharing, users rent private vehicles from their owners through an app or a platform. The automobile must be returned in the same place it was taken from, and fares are agreed between both users. (DELO17)

- On a more traditional way, rental opportunities are also available. Automobile rental leaves open the possibility of travelling longer distances for longer periods of time. This option, however, may not be as convenient or easy, since it requires customers to rent their vehicles for a definite time schedule, and a flat fee.

  In order to rent a vehicle, users usually need to previously make a reservation. Information has to be provided every time that the car is to be rented and the process is usually quite long and heavy. The process is sometimes not adapted to modern times.

In spite of their limitations, these two areas of work (*carsharing* and vehicle rental industris) have expanded throughout the last years. Both, *carsharing* and rental industries, have been shown to be growing: It is estimated that by the end of this year, a growth of *carsharing* platforms will have grown 32% (DELO17); Car rentals have also experienced a big increase in the last years: during year 2018 (most recent year from which data is available), the industry experienced a growth of 3.7% (ELEC19).

However, as it was previously said, there are some limitations in the currently available options. Users' needs are not always satisfied.

The platform Wible, in the city of Madrid, in Spain, would be closer to the idea that is going to be developed throughout this project. Despite being a carsharing initiative (usually operates in cities or more urban regions), this platform also allows users to rent a vehicle in the more traditional time, for a price per day, and a relatively flexible period of time. In additions, these vehicles are plug-in hybrids, which allows for a larger mileage and gives users the chance to travel farther distances. (WIBL18)

1.2 PROJECT OBJECTIVES

As it was previously mentioned, 25.7% of Spanish homes do not have a car. (SANZ14). Those homes will be concentrated in the cities in which this proposal will be implemented: Madrid, Barcelona, Valencia, Sevilla, Zaragoza and Málaga, the six largest cities in the country in terms of population (INE19).

Even though cars may not be needed daily in those locations, it is possible that people can eventually find themselves in the need of a vehicle to take a longer trip.

Therefore, the main objective of this project will be to create an alternative option to be able to travel longer distances. Creating a new accessible transportation mean implies the opening new opportunities: new business opportunities, greater cultural and educational chances, development of the travelling industry…

In addition to that, the initiative would also reduce and renew the current Spanish car fleet, contributing to environmental improvements. Substituting many older vehicles by a smaller number of newer vehicles would have a very positive impact on issues such as CO_2 emissions or global warming.

That, without taking into consideration that this new car fleet would be formed by electric vehicles, which would lead to an even greater reduction of GHG. The implementation of an electric car platform would also help to implement electric vehicles as part of our society's daily life.

Despite being more pollutant than trains or buses, cars are still a better option when it comes to atmospheric emissions than planes. In fact, the recently appointed Spanish government is working on laws that will make it even harder for travelers to take planes for short distance trips: additional fees will be set on plane tickets, which will eventually lead in a reduction of travelers and flight availability therefore. Thus, by reducing plane transportation between cities, CO_2 emissions would also be reduced.

The development of this project is aligned with the pursue of the Sustainable Development Goals (UN12). More particularly, the goals that are aligned the most are #9 (Industry, Innovation and Infrastructure), #11 (Sustainable Cities and Communities), #12 (Responsible Consumption and Production) and #13 (Climate Action). This section will be further developed in ANNEX I.

2. WORKING METHODOLOGY

In this section, the methodology that will be used to develop this project will be looked at thoroughly.

The whole project has been categorized into seven steps:

1. Definition of the problem.
2. Data gathering.
3. Initial problem formulations.
4. Initial resolution.
5. Final add-up.
6. Final resolution.
7. Economic evaluation.

All the steps followed are necessary so that a final conclusion can be successfully reached. In this conclusion, both the final resolution and the economic evaluation are put together. By doing so, it is possible to have a clear definition of how this *carsharing* platform is going to be built and implemented.

In each of these steps, different tasks are carried out. These tasks are listed in the form of questions in the figure that is provided in the following page:

Figure 3: Steps considered for the project. Source: elaborated by the author.

Figure 3 goes over the steps of the project, together with some of the questions that need to be solved at each of the steps considered. The following passages go over each of the steps that have been carried out in the development project.

2.1 DEFINITION OF THE PROBLEM

This project will focus on determining the minimum number of vehicles required to fulfill the needs at each city and locating them, so that they are placed in the most optimal location according to different criteria.

Additionally, a clear scope of the issues the project will focus on needs to be defined:

- The problem will not consider a fixed number of vehicles. It will aim to find out what is the minimum number of vehicles required to fulfill the demand, and where they should be located.
- The problem will look at populations at each location. Different populations will be assumed for cities depending on the criterion that is selected. The changing parameter throughout the project will be the population of each city.
- The designated locations will be considered as a single nucleus of population, where no additional locations can be defined. Therefore, locations inside of each of the cities will not be considered.
- Issues such as the mileage that vehicles allow, or places to recharge electric vehicles batteries will not be considered throughout the project. However, the project will take into consideration the existence of the charging points between locations and will locate more vehicles in cities where the number of chargers is greater.
- This project will not consider the required displacement between vehicles in order to reach the optimal number of vehicles in each situation. Some thoughts on strategies that can help the movement of vehicles take place will be added, but they will not be thoroughly developed.

2.1.1 Justification of the project

In the State Of The Art, the different options currently available for *carsharing* were defined, together with their characteristics.

However, after examining all available options, it is possible to reach the conclusion that the available services do not cover all current needs: the accessible services either allow for a very flexible time for rental, with a very limited mileage and a very restrictive region where cars are allowed to run; demand users to return the vehicle in the same place as it was picked up from; or require users to rent the vehicle for a fixed time and a flat fee.

The VIVe project or the Wible platform would be closer to the platform developed in this project, but still face several limitations with respect to the location where vehicles need to be returned.

For this purpose, a different model of carsharing will be developed throughout this project. The platform will allow users to travel much longer distances with a very flexible time of rental.

This initiative will combine the advantages of all currently existing options. Users will only pay for the time they actually use their rental vehicle. People travelling from any of the 6 biggest Spanish cities in population (over 500,000 people) will be able to freely park their vehicle in any of those cities. After the customer stops using the vehicle in this city, they will not need to keep paying, even if they still want to use it the following day. However, this surely does not guarantee that the vehicle will not be rented by another user during the time when the vehicle is unused.

This project will fulfill user's real needs, while creating a profitable business model.

2.2 DATA GATHERING

Data will need to be obtained regarding each of the cities that will be looked. The selected data will complete the formulations, so that each of the problems can be solved. Some of the information that will be used will be:

- Population at each of the locations that has been selected. In addition to the general population, it would be better to obtain the population within a driving age at each of the cities (ages 18 to 65 will be considered).
- Distances between each of the locations and the time to cover each of them with different transportation means. For instance, the considered means will be airplane, train, car and bus.
- Number of vehicles existing at each location. In addition to this, the number of vehicles older than 10 years will be looked at.
- Electric vehicle chargers. The number of electric vehicle chargers will be looked at, together with the number of chargers existing at each of the possible routes that are allowed in the project.
- Yearly income at each location. The income per person of each of the cities that have been selected will be considered for the formulation of the problem.
- Yearly tourists. The number of tourists that each location received in year 2019 will be considered in the formulations as well. Existing *carsharing* platforms. Although the existing *carsharing* platforms are different from the proposed model, the number of *carsharing* vehicles existing at each city will give an idea of the acceptance that cities have to these kinds of initiatives.

In order to obtain more detailed information, a survey was also carried out.

2.2.1 Conducted Survey

As it was previously mentioned, with the purpose to learn more information on the currently existing habits of the population related to transportation, a survey was conducted. The results that were obtained, together with a deep analysis of them has been developed in ANNEX II.

The intent of this section is to give a brief overview of what were the purposes and results of this questionnaire.

The survey consisted of 9 questions. Some of the questions wanted to ensure that recorded answers were from potential users, such as:

- Range of age.
- Whether users had a driver's license or not.

Other questions, aimed to learn about the transportation habits of users when travelling relatively long distances:

- Frequency of trips that are longer than 400 km.
- Preferred transportation means for trips of a length greater than 3 hours by car.
- Safety of Spanish roads and highways.
- Responders' preference for automobiles and the reasons why so.
- The maximum length for a trip that responders would be willing to drive by car.

The results that have been used throughout the project will be shown in the following section.

2.2.2 Recorded Responses

Some of the responses that were obtained from the survey were very necessary for the analysis of data that was later performed in the project. These responses are shown in this section.

2.2.2.1 Responder's profile

Initially, it was necessary to limit the number of responses that were recorded. For instance, 352 responses were recorded, but some of them belonged to population of ages below 18 or above 65, so cannot be considered for the problem.

Additionally, other users did not have a driver's license, so were not in a position to drive. Their responses were also discharged for this reason.

This left the survey with 285, which was still a significant sample of responses to consider for the evaluation of the data of the problem.

2.2.2.2 Transportation habits

The responses related to the transportation habits of responders are looked at in this section.

- For starters, the first question that was asked was related to the frequency of travelling. The question intended to separate responders into two categories: frequent travelers and non-frequent travelers. For this purpose, 4 responses were available: 'never', 'occasionally', 'often', and 'very often'.

  Responders who answered any of the two responses were considered non-frequent travelers, whereas population who replied 'often' or 'very often' was considered to be frequent travelers. Responses given by frequent travelers were weighted more than responses given by non-frequent travelers for the problems.

  The following graph shows how the surveyed population was distributed into the four categories.

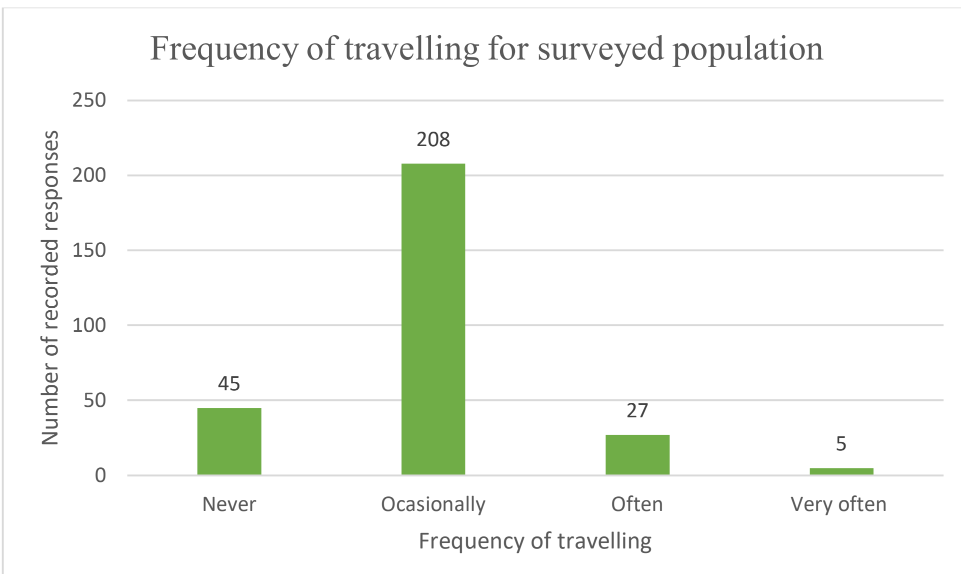

Figure 4: Surveyed population separated into four categories depending on the frequency of travelling. Source: elaborated by the author

  253 people were therefore considered as non-frequent travelers (88.77%), whereas 32 people were considered as frequent travelers (11.23%).

- Next, the question that was made was related to the preferred transportation means of responders. The aim was to find out how many responders would select 'car' as their preferred transportation mean in trips of over 3 hours by car.

As it was found out, AVE (High Speed Trains) are the preferred transportation mean for most people, followed by car, airplane and conventional train.

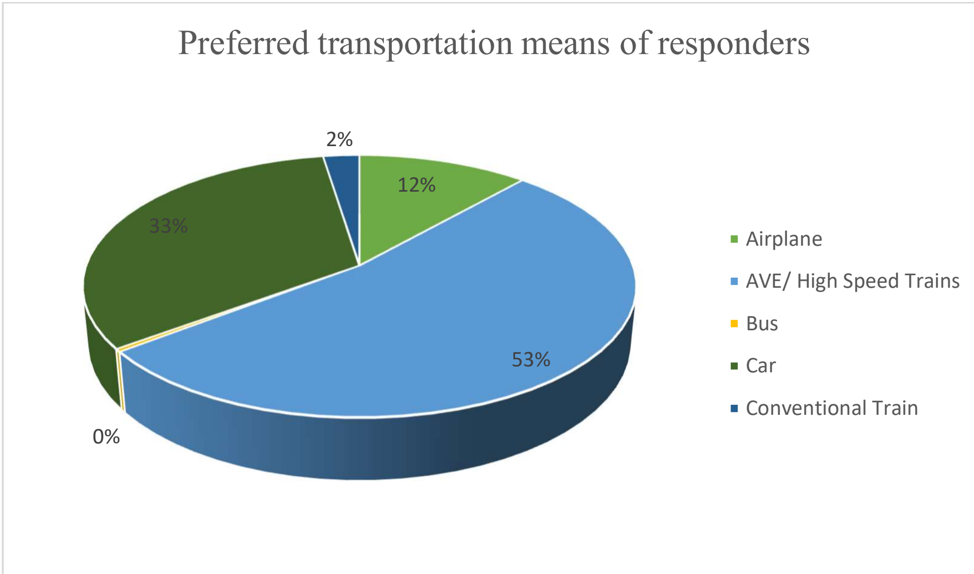

Figure 5: Preferred transportation mean by responders. Source: elaborated by the author.

33 % of the responders (94 people) responded that they would prefer to travel by car.

- The third question that was asked, related to the habits of the responders when travelling, was about the safety of the Spanish Highway System. One of the main considerations made to determine whether people would rent the vehicles or not is related to the safety on the roads. Users need to feel safe when making use of this *carsharing* platform that is aimed to be implemented.
  As it can be noted in the figure incorporated below, most responders felt that the Spanish Highway System was good enough when it comes to travelling long distances:

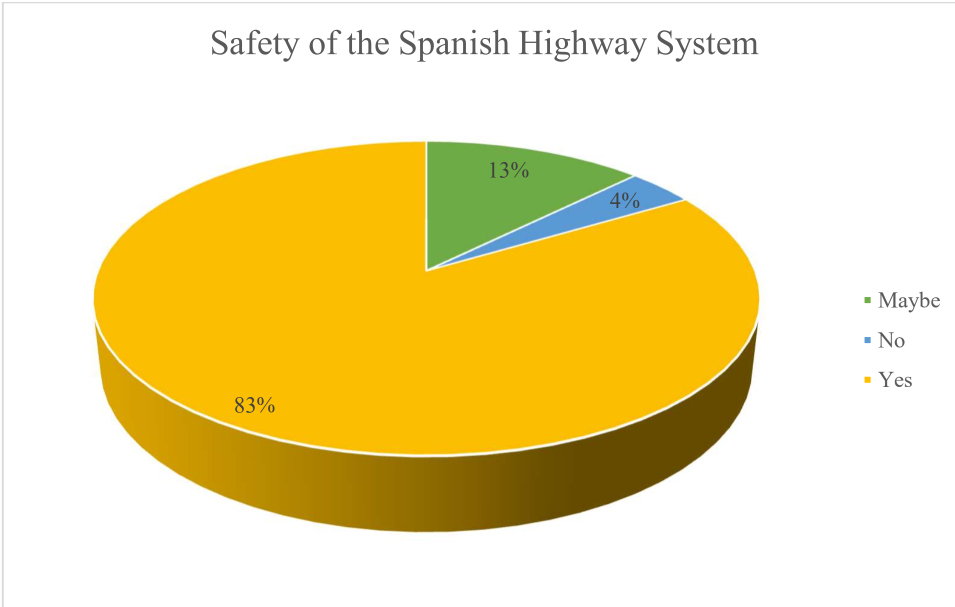

Figure 6: Responses recorded to the question on whether users felt that the Spanish Highway System was safe enough. Source: elaborated by the author.

- The next question formulated in the survey was related to responder's preferences for cars. This question wanted to know whether users would still choose car to travel to a destination, even if it was not their preferred transportation mean.

  The following graph shows the responses that were recorded for the problem:

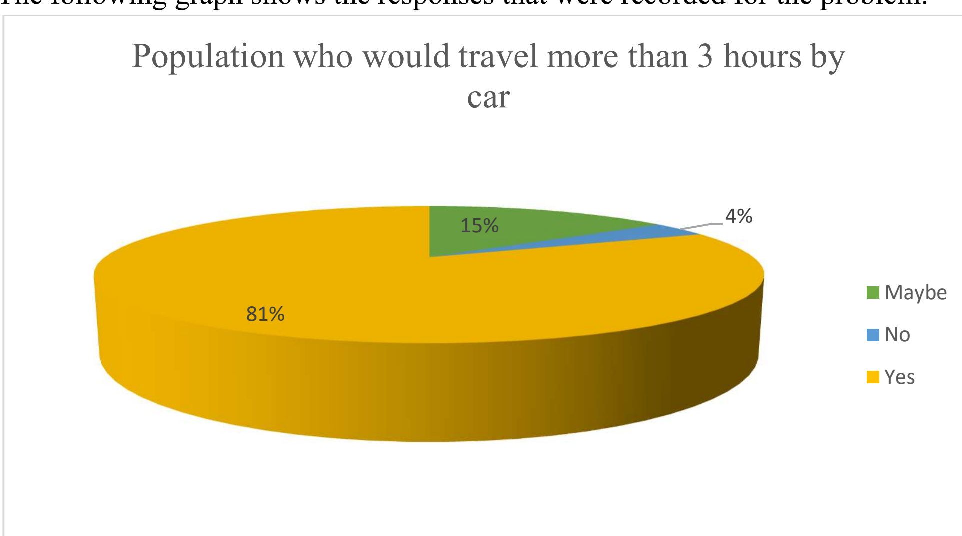

Figure 7: Population that would consider 'car' as their travelling transportation for trips longer than 3 hours. Source: elaborated by the author

As it can be seen in the graph, 81% of responders, (231 people) said that they would consider travelling by car for trips over 3 hours. This shows that the model that is going to be presented in this project could be used by up to 81% of the population.

- The final question was the most relevant for the development of the project. It asked the surveyed population what the maximum distance was they would be willing to travel by car.

The responses that were recorded and put together in the following table:

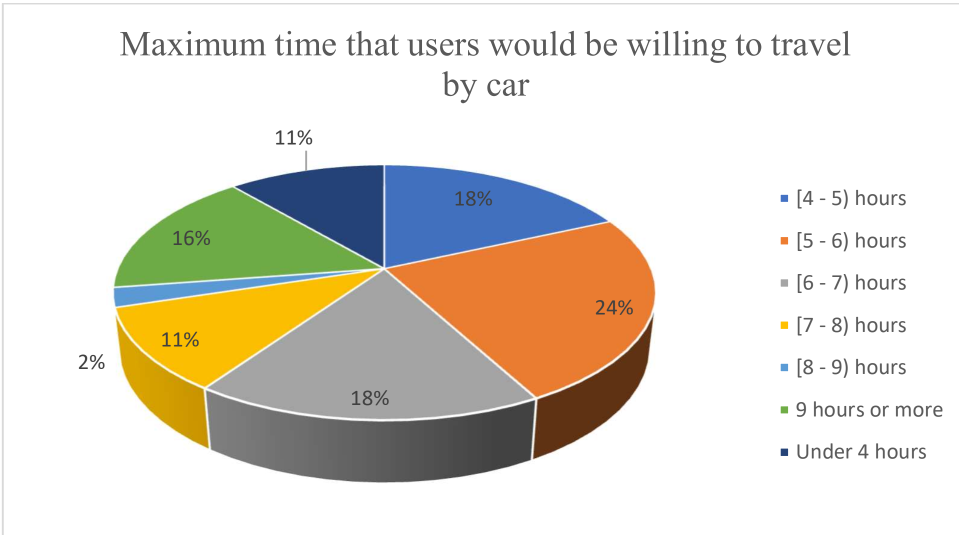

Figure 8: Maximum time that users would be willing to travel by car. Source: elaborated by the author.

As it can be seen in the graph, the responses for this question are very various. Most responders said they would travel up to between 5 and 6 hours, but there were a lot of different answers. For this question, the percentage of population that selected each possible option was separated in frequent travelers and non-frequent travelers and weighted together. The following graphs show the results obtained for frequent travelers and non-frequent travelers.

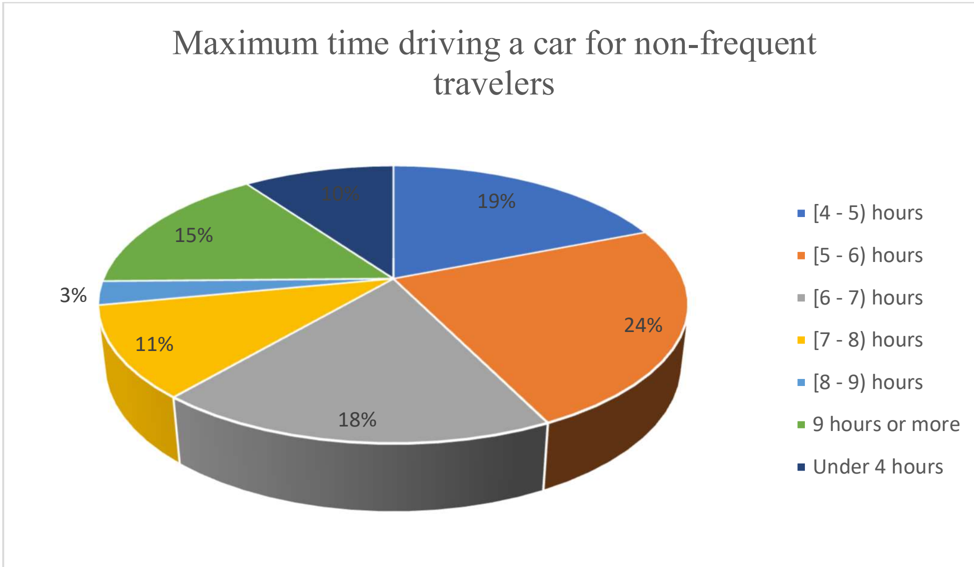

Figure 9: Maximum time non-frequent travelers would be willing to travel by car. Source: elaborated by the author.

As it can be seen in this graph, the obtained results are very similar to the results that had been obtained for the general graph.

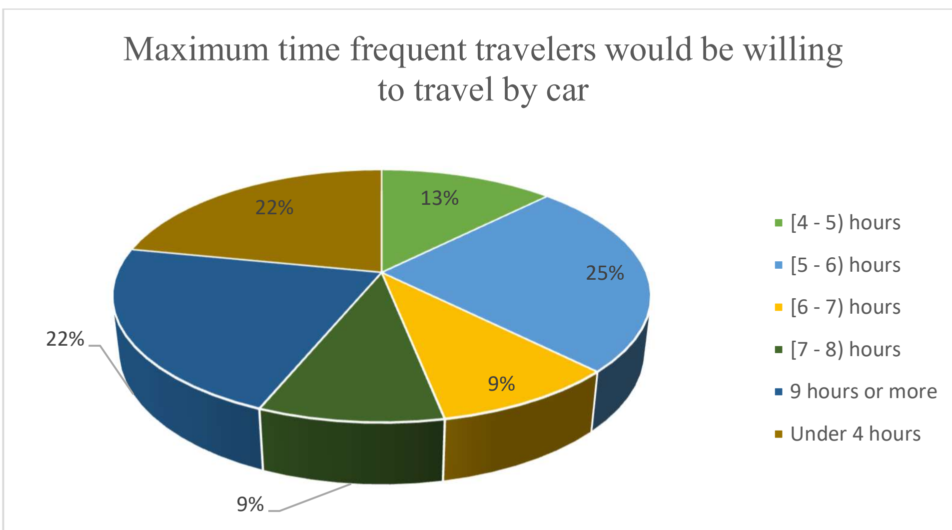

Figure 10: Maximum time frequent travelers would be willing to travel by car. Source: elaborated by the author.

In the graph for frequent travelers, though, the responses experience a greater change. As it can be seen, there is three big groups of responses that users responded: 9 hours or more; between 5 and 6 hours; and under 4 hours.

2.3 INITIAL PROBLEM FORMULATIONS

Because of the high volume of information obtained, not all the data can be used at once to solve the problem. A criterion for the relevance of each of the parameters introduced in the problem needs to be made up.

To determine the relevance that each of the different data areas has, several simple problems have been formulated. In those problems, individual parameters are considered to obtain specific results.

The intend of making these initial problem formulations is shown in Figure 11, provided next:

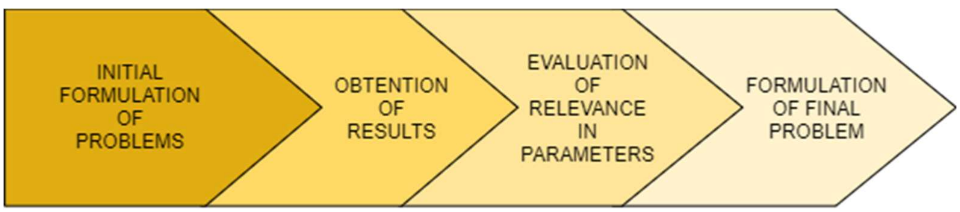

Figure 11: Goal of initial formulations

As it was previously mentioned, different problems will be established, in which different parameters will be considered to determine the relevance of each of them.

Problem number	***Parameters considered***
Base Problem	Population of ages 16 to 65
Problem 1	Distance between the locations
Problem 2	Number of vehicles at each location
Problem 3	Number of vehicles older than 10 years at each location
Problem 4	Access to other transportation means at each location
Problem 5	Yearly income at each location
Problem 6	Number of *carsharing* vehicles existing at each city
Problem 7	Number of EV chargers available in each city
Problem 8	Number of EV chargers available in each journey
Problem 9	Number of tourists received by each city

Table 3: Formulated problems in the project

Table 3 displays what each of the initial problem formulations will contain and aim to solve.

To obtain objective and accurate solutions, all problems were formulated using a homogeneous criterion, where a non-unitary factor related to the parameter that was considered was obtained, and later multiplied by the original population of each city. The result of this multiplication gave out a value that was later added to the original population of the cities. The value obtained for the population was later corrected, so that all problems would give out the same number of total vehicles, but distributed in a different way between the selected cities.

An array of six decision variables will be set for all the problems, together with a general objective function, and some constraints. However, each of the problems will change the population array that is introduced into the formulation in order to obtain different results.

2.4 INITIAL RESOLUTIONS

In this step, the results of each of the individual problems that were formulated has been looked at.

First, the solutions for each individual problem are shown. The number of required vehicles and their locations are shown in a table, accompanied by a map indicating where a number of vehicles would be placed.

In addition to this, each of the problem solutions that has been obtained is accompanied a table indicating the variation of the results obtained with respect to the Base Problem that was solved, where no parameters, aside from the population of each of the cities are considered.

To conclude this section, a final summary of all results has been included. In this final part, a table with all results obtained for all problems has been added, together with two graphs representing, one the individual results that were obtained for each of the cities and how they changed depending on the parameters that were taken into account; and the other, the spread and dispersion of the results that have been obtained.

In order to come up with a final formulation, it is especially useful to look at the overall change that each of the parameters produces in the problems with respect to the Base Problem.

2.5 *FINAL ADD-UP*

In this section, the final formulation of the problem has been obtained. By combining all the previously made formulations, it is possible to reach a final problem that will give out a solution for the project.

In order to do so, an order of relevance for each of the considered parameters was first needed. This ranking of importance was made by looking at the variation that each of the parameters produced on the results obtained for the problem in comparison to the Base Problem. The variation is given in a percentage, which makes it possible to objectively rank them from greater to smaller.

Because the objective function and the constraints that were set up for the initial problem formulations was said to be generic for all the initial problem formulations, they have also been maintained for the final problem formulation.

Since the only difference between all formulated problems is the population array that is introduced in the problem, the formulation for the final problem will focus on a variation of the population at each location. The new values were obtained by weighting each of the populations that were used for the individual problems, depending on the relevance that was noted for each of them.

2.6 FINAL RESOLUTION

In the Final Resolution section, the results for the final problem have been provided. A table with the solutions that were obtained has been added, together with a map indicating the optimal number of vehicles that should be located at each city.

However, not only have the results been provided, they have also been analyzed. A comparison with the base problem and with each of the individual problems has been made, in order to determine whether the obtained results make sense for the project.

The final resolution puts an end to this project.

3. DATA GATHERING

A lot of data has been considered for the development of this project. Although many parameters were looked at, and a lot of research was performed, after an evaluation of the importance of the information obtained, a conclusion has been reached that the information that will be needed and considered will be:

- Population at each location.
- Population between 18 and 65 years old at each location.
- Distance between locations, and percentage of population willing to travel that distance.
- Number of vehicles existing at each location.
- Number of vehicles older than 10 years at each location.
- Available alternatives at each location.
- Yearly income of population at each location.
- Existing *carsharing* platforms at each city.
- Number of tourists that each city receives yearly.
- Electric vehicle chargers at each location and in between locations.

Each of the needed information needed will be looked thoroughly in the following sections.

3.1 POPULATION AT EACH LOCATION

The population at each of the selected cities has been determined to be the most important parameter when determining the optimal number of vehicles at each location. The following table shows the values that have been considered:

Location	***Population***
Madrid	3,266,000
Barcelona	1,637,000
Valencia	794,000
Sevilla	688,000
Zaragoza	674,000
Málaga	574,000

Table 4: Population at each selected location. Source: INE19.

3.2 POPULATION BETWEEN 18 AND 65

Although the population at each city was known, the data that was actually required was the population between ages 18 and 65, which would be considered as the driving age in Spain.

However, no censuses were available of population between that range. Instead, data on population between 16 and 65, the working age in Spain, was available.

The following table provides data on the population in that age range at each city:

City	***Population***
Madrid	2,085,675
Barcelona	1,058,000
Valencia	521,816
Sevilla	457,455
Zaragoza	430,029
Málaga	383,350

Table 5: Population between ages 16 and 65 Source: INE16

Note that both, Spanish and non-Spanish inhabitants were considered at each city.

3.3 DISTANCE BETWEEN LOCATIONS

For this section, the first information needed was the distance between each of the cities. The distance was considered to be covered by car, and this was also the time taken into account.

From	*To*	*Distance in km*	*Distance in hours*
Madrid	Barcelona	625	6.3
Madrid	Valencia	355	3.6
Madrid	Sevilla	532	5.05
Madrid	Zaragoza	317	3.45
Madrid	Málaga	531	5.3
Barcelona	Valencia	352	3.75
Barcelona	Sevilla	997	9.93
Barcelona	Zaragoza	314	3.28
Barcelona	Málaga	998	9.88
Valencia	Sevilla	654	6.4
Valencia	Zaragoza	309	3.3
Valencia	Málaga	618	6.26
Sevilla	Zaragoza	845	7.96
Sevilla	Málaga	205	2.25
Zaragoza	Málaga	835	8.13

Table 6: distance between cities. Source: MAPS20.

For this project, the goal is that cities that are closer to other locations have preference when locating vehicles. For instance, Barcelona, is only relatively close to Barcelona and Valencia, but is very far from other locations, such as Málaga or Sevilla, so it should not have preference when locating vehicles here.

However, Zaragoza, for instance, is close to Barcelona, Valencia, and Madrid, and relatively close to Sevilla and Málaga. It should therefore have preference when locating vehicles.

3.4 AVAILABLE VEHICLES AT EACH LOCATION

For this section, the most interesting part is to look at the number of vehicles per inhabitant at each location. Since some of the cities have a much greater population than other cities, looking at an absolute number of vehicles does not give out enough information. Therefore, the relative number of vehicles will be calculated.

The following table displays the existing number of vehicles per person at each location.

City	*# of vehicles*	*Population*	*# of vehicles per person*
Madrid	1,484,015	2,085,675	0.71
Barcelona	565,130	1,058,000	0.53
Valencia	357,616	521,816	0.69
Sevilla	324,074	457,455	0.71
Zaragoza	262,109	430,029	0.61
Málaga	263,384	383,350	0.69

Table 7: Available vehicles at each city. Source: DGT17.

Table 7 only shows passenger cars: no vans or buses are shown anywhere in this project.

It can also be noted from the table that the cities with the greatest number of vehicles per person are both Madrid and Sevilla, with 0.71 automobiles per inhabitant. When looking at one more decimal point, it can be noted, though that Sevilla actually has 0.708 vehicles per inhabitant, whereas Madrid has 0.712. Madrid is therefore the location with the greatest number of vehicles per inhabitant. The city with the least number of cars per person is Barcelona, with only 0.53 cars per person. [1]

This will need to be considered in order to establish where should vehicles be located, since cities that do not have as much cars per person should have preference when it comes to locating the vehicles.

3.5 VEHICLES OLDER THAN 10 YEARS

The following table shows the number of vehicles existing in each city, and the number of vehicles that are older than 2010. The data was recorded in 2017, so it can be assumed that these vehicles would now be 10 years.

[1] Note that commercial vehicles have also been considered for this problem.

City	*Total number of cars in the city*	*Number of cars older than 2010*	*% of vehicles older than 2010*
Madrid	1,484,015	61,940	4.17%
Barcelona	565,130	21,355	3.78%
Valencia	357,616	13,819	3.86%
Sevilla	324,074	14,010	4.32%
Zaragoza	262,109	10,766	4.11%
Málaga	263,384	10,927	4.15%

Table 8: Number of vehicles older than 10 years at each location. Source: DGT17.

Table 11 displays both the absolute number of old vehicles existing at each city, together with the percentage. Since the existing number of vehicles in each city is different, in order to make a proper comparison it will be necessary to look at the percentages.

Looking at the data that was gathered, it is possible to determine that the city that has the oldest cars is Zaragoza, with a 2.22% of vehicles that are older than 10 years. However, it can also be noticed in the table above that the values are very similar between cities. Therefore, the only consideration that will be made is that Zaragoza is the city that has the greatest number of old cars, and Sevilla the one that has the least number of old cars.

3.6 AVAILABLE ALTERNATIVE TRANSPORTATIONS

In this section, alternative transportation means have been considered. As it was previously mentioned, the considered transportation means are car, bus, train and airplane.

The following table shows the time required to cover each of the distances by those alternative transportation means:

From	*To*	*Time required by car*	*Time required by plane*	*Time required by train*	*Time required by bus*
Madrid	Barcelona	6.3	1.25	2.75	7.85
Madrid	Valencia	3.6	1	1.88	4.25
Madrid	Sevilla	5.05	1.08	2.53	6.5
Madrid	Zaragoza	3.45	-	1.67	4.65
Madrid	Málaga	5.3	1.25	2.42	6
Barcelona	Valencia	3.75	1	2.67	5.83
Barcelona	Sevilla	9.93	1.58	5.50	14.75
Barcelona	Zaragoza	3.28	-	1.42	4.62
Barcelona	Málaga	9.88	1.58	5.93	14.75
Valencia	Sevilla	6.4	1.25	-	9.75
Valencia	Zaragoza	3.3	-	-	4.65
Valencia	Málaga	6.27	1.67	4.68	9.5
Sevilla	Zaragoza	7.97	-	-	-
Sevilla	Málaga	2.25	-	1.92	3.25
Zaragoza	Málaga	8.13	-	5.23	-

Table 9: Time required to cover the distances with each of the selected transportation means. Source: MAPS20

As the table shows, some of the distances between cities cannot be covered using some transportation means. The table then gives out a '-', indicating that this option is not available.

3.7 YEARLY INCOMES

Another parameter that needs to be considered is the economical aspect. Yearly incomes at each of the locations have also been looked at.

The gross income has been obtained for each of the locations that has been considered. This value takes into account the addition of all income that a person has, minus the costs that have been incurred to earn that income. This value does not take into consideration taxes. The average gross income in Spain is of 24,895 € per person. The following table shows the income that each persona has at the selected locations:

City	*Yearly income per person*
Madrid	38,224 €
Barcelona	37,124 €
Valencia	29,498 €
Sevilla	28,633 €
Zaragoza	27,968 €
Málaga	25,694 €

Table 10: Yearly gross income at each city. Source: DATO17.

As it can be seen in the table provided, as the population in the city decreases, the yearly income is also reduced. This can be presumably due to the fact that as the population decreases, the cost of living at that city is reduced too.

3.8 EXISTING CARSHARING VEHICLES

As a part of the data that has been gathered, it would also be useful to look at the existing *carsharing* companies at each city. Although the model that this project aims to create is different from already existing *carsharing* platforms, the current existence of them is an indicator of the population acceptance to new transportation alternatives. For instance, in the city of Madrid a lot of new platforms have appeared in the past years. This has two main causes: on the one hand, the practicality of these transportation alternatives, that have been greatly accepted, especially between the younger population; and on the other hand, the lack of private vehicles at homes.

The number of *carsharing* automobiles already existing at each city is shown in the following table. Because each of the numbers has been obtained from a different source, a column for the sources of information has been added as well:

City	*Number of vehicles*
Madrid	2,635
Barcelona	300
Valencia	100
Sevilla	0
Zaragoza	100
Málaga	10

Table 11: Number of carsharing *vehicles at each location. Sources: (RODR18), (MERI19), (BART19), (AMEN19), (NUEV19), (RUIZ15).*

It should be noted that Madrid is the only city were *carsharing* initiatives are completely established. The city of Barcelona, despite having such a big potential because of its large population, has imposed several legal limitations to these kinds of initiatives.

By considering the number of *carsharing* vehicles that there are at each location, the legal restrictions at each city are already taken into account.

3.9 ELECTRIC VEHICLE CHARGERS

Another important consideration that is made is the existence of electric vehicle chargers at each of the possible routes. Although this project does not focus on the selection of the vehicles (whether they should be combustion or electric), a good indicator of the kind of vehicle needed to be used would be the number of existing chargers between cities and within cities.

In the year 2019, it was estimated that there were 4,545 public charging points in the Spanish territory (BBVA2019). In this section, the focus will be on the number of electric vehicle chargers, both at each city and in the available connections between cities.

The chargers that were looked at were mainly fast chargers, where more than 50 kW per hour are allowed. Additionally, the type of connectors was also selected: Type 2, CHAdeMO, CCS2, Type 1 and Tesla Chargers were considered.

For starters, the number of electric chargers at each city will be obtained:

City	*Number of EV Chargers*
Madrid	54
Barcelona	32
Valencia	14
Sevilla	8
Zaragoza	5
Málaga	14

Table 12: Number of fast EV chargers at each city. Source: ELEC20.

Coincidentally, as it can be seen in the table provided above, the cities that have a great population and are located in the seaside are more prone to have a higher number of electric vehicle chargers. This may also be due to the tourism that these regions tend to experience, where millions of visitors go every year, resulting in a large increase of the population[2].

In addition to the number of EV chargers at each location, it is necessary to look at the number of EV chargers between locations. For the same filters, the following table shows the number of chargers between cities:

City of origin	*City of destination*	*Number of chargers between cities*
Madrid	Barcelona	25
Madrid	Valencia	20
Madrid	Sevilla	19
Madrid	Zaragoza	13
Madrid	Málaga	15
Barcelona	Valencia	28
Barcelona	Sevilla	51
Barcelona	Zaragoza	12
Barcelona	Málaga	44
Valencia	Sevilla	23
Valencia	Zaragoza	11
Valencia	Málaga	16
Sevilla	Zaragoza	32
Sevilla	Málaga	4
Zaragoza	Málaga	28

Table 13: Number of EV chargers in between cities. Source: ELEC20.

As it can be seen in the table provided, the number of chargers that are found does not depend on the distance travelled. For instance, the distance between Valencia and Zaragoza is similar to the distance between Barcelona and Zaragoza. However, there is more than twice as many chargers of difference between both journeys.

It is because of this that charges will be looked at in terms of charger/ kilometer of distance, as it will be seen in Problem 8.

[2] This number of tourists will also be considered as a parameter that will need to be looked at.

3.10 NUMBER OF ELECTRIC VEHICLES AT EACH CITY

Another important factor that needs to be looked at is the number of electric vehicles that are present at each city.

These values are provided in the table below:

City	*Number of EVs*
Madrid	3,282
Barcelona	758
Valencia	123
Sevilla	181
Zaragoza	98
Málaga	131

Table 14: Number of electric vehicles at each location. Source: DGT17.

It is important to point out that these numbers of vehicles represent only fully electric cars. Hybrid vehicles are not displayed in the table, nor are other vehicles, such as vans or buses.

3.11 NUMBER OF TOURISTS RECEIVED PER YEAR

The number of tourists received every year at every city is also an important indicator. Although the population of cities like Málaga is not very large, because of the number of visitors that are received every year, it increases by a very high number.

Although this number of visitors would not increase the population of the cities per se, it would also mean an increase in the number of potential customers.

The number of visitors at each location have been obtained for the year 2019 and are shown in the table below. The sources for these values have been included in an additional column:

City	*Number of tourists*
Madrid	10,400,000
Barcelona	11,977,300
Valencia	5,276,700
Sevilla	4,270,600
Zaragoza	1,180,700
Málaga	1,400,000

Table 15: Number of tourists received at each location. Sources: (MADR20), (MONT20), (EURO20), (20MI20), (EURO20), (MARI20).

4. INITIAL PROBLEM FORMULATIONS

As it was previously mentioned, in this section different formulations are proposed for the same problem. Although the formulations will consider different parameters and formulations, the main body of the problem will be the same for all the proposed criteria.

For starters, each of the possible locations will be assigned a variable number:

Number of the location (n)	***Location where each vehicle will be assigned***
1	Madrid
2	Barcelona
3	Valencia
4	Seville
5	Zaragoza
6	Malaga

Figure 12: Available locations

4.1 GENERAL FORMULATIONS

For the problem formulations, the number of vehicles are unknown, and need to be found out.

There are 6 decision variables (one for each possible location). The variables are integer and acquire the value of the number of automobiles that needs to be placed in the location.

In order to program all of the problems, a variable array has to be set up as it follows:

City 1	x_1
City 2	x_2
City 3	x_3
City 4	x_4
City 5	x_5
City 6	x_6

The goal of the linear program that has been set up is to minimize the number of vehicles at each city, while still being able to cover all the population.

$$minimize \sum_{n=1}^{6} x_n$$

Although it does not come up in the objective function, it should be remarked that all problems have been formulated around the population existing at each location.

The main assumption that has been made for the formulation of all problems is that each vehicle covers the demand of 10,000 people. This assumption has been made based on data from existing *carsharing* initiatives. It has been noted that, on average, each vehicle covers demand for 5,000 people (BERN18). Because of the uncertainty of the project that is being proposed, this number has been doubled.

In addition to the decision variables, a general parameter p_n has bene defined. This parameter is the array that defines the population at each given location. It has been individually included in data treatment section for each problem formulation that is provided below.

All problems consider the general objective function that was given, together with two constraints, applicable for all of them. The constraints that are applied are the following:

1. Every city should have at least 5 vehicles:

$$x_n \geq 5$$

2. Additionally, to ensure that all vehicles can cover as much as 10,000 people, it has been imposed that:

$$p_n \geq 10{,}000\, x_n \quad \forall\, n = 1 \ldots 6$$

This p_n has been modified for each problem formulation, depending on the data that needs to be

4.2 BASE PROBLEM

4.2.1 Definition

The base problem that has been formulated here serves as a comparison with each of the problems that has later been solved. For this problem, only the population between ages 16 and 65 has been be considered. This population adds up to 4,936,325 people, and has been used throughout the whole project.

4.2.2 Problem formulation

The array p_n is given by the population between 16 and 18 at each of the locations:

$$p_n = [2{,}085{,}668 \;\; 1{,}058{,}000 \;\; 521{,}816 \;\; 457{,}455 \;\; 430{,}029 \;\; 383{,}350]$$

4.3 PROBLEM 1

4.3.1 Definition

For this problem, distance between cities has been considered the single criteria (in particular, the time needed to cover them by car), together with the population of each of the locations. The population has been combined to the amount of time needed to cover each of the distances to obtain an array of population.

4.3.2 Data treatment

The data that was obtained on the distances needs to be combined with willingness of users to travel those distances by car. In order to do so, the data that had been collected from the survey was put to use.

To perform an accurate analysis of the amount of people covering these distances by car, the population who took the survey was separated into two different groups: frequent travelers, and non-frequent travelers.

As it is shown in the survey analysis performed in ANNEX II, frequent travelers have a greater impact in the estimated percentage of travelers than non-frequent travelers. There are 32 frequent travelers in the survey (11.23%), and 253 non-frequent travelers (88.77%). Therefore, a ponderation of 20% for frequent travelers, and 80% for non-frequent travelers will be considered.

¡Error! No se encuentra el origen de la referencia. shows the percentage of population willing to travel each time interval. This table also shows the cumulative percentage of people willing to do the journey, since the survey looked at the maximum distance users were willing to travel.

Time interval	*Percentage for non- frequent travelers*	*Percentage for frequent travelers*	*Weighted percentage for travelers*	*Cumulative weighted percentage for travelers*
Less than 4 hours	11%	22%	13.2%	92.80%
[4-5) hours	18%	13%	17%	79.60%
[5-6) hours	24%	25%	24.2%	62.60%
[6-7) hours	18%	9%	16.2%	38.40%
[7-8) hours	2%	9%	3.4%	22.20%
[8-9) hours	3%	0%	2.4%	18.80%
9 hours or more	15%	22%	16.4%	16.40%

Table 16: Weighted percentage for each interval.

As it can be seen, the total percentage does not add 100%. This is one expected result of using a weighted percentage.

This percentage will then need to be corrected, so that it does consider the total population at all locations.

Time interval	*Corrected cumulative weight*
Less than 4 hours	100%
[4-5) hours	85.5%
[5-6) hours	67.5%
[6-7) hours	41.4%
[7-8) hours	23.9%
[8-9) hours	20.3%
9 hours or more	17.7%

Table 17: Corrected weighted percentage for each interval.

Because it is necessary to consider the number of people willing to do each of the trips, a new table has been put together. Journeys will be classified into the intervals that had been previously established.

City of origin	*City of destination*	*Time interval*	*Percentage of population*	*Population*
Madrid	Barcelona	[6-7) hours	41.4%	863,469
Barcelona	Madrid	[6-7) hours	41.4%	438,012
Madrid	Valencia	Under 4 hours	100%	2,085,675
Valencia	Madrid	Under 4 hours	100%	521,816
Madrid	Sevilla	[5-6) hours	67.5%	1,407,831
Sevilla	Madrid	[5-6) hours	67.5%	308,782
Madrid	Zaragoza	Under 4 hours	100%	2,085,675
Zaragoza	Madrid	Under 4 hours	100%	430,029
Madrid	Málaga	[5-6) hours	67.5%	1,407,831
Málaga	Madrid	[5-6) hours	67.5%	258,761
Barcelona	Valencia	Under 4 hours	100%	1,058,000
Valencia	Barcelona	Under 4 hours	100%	521,816
Barcelona	Sevilla	9 hours or more	17.7%	187,266
Sevilla	Barcelona	9 hours or more	17.7%	80,970
Barcelona	Zaragoza	Under 4 hours	100%	1,058,000
Zaragoza	Barcelona	Under 4 hours	100%	430,029
Barcelona	Málaga	9 hours or more	17.7%	187,266
Málaga	Barcelona	9 hours or more	17.7%	67,853
Valencia	Sevilla	[6-7) hours	41.4%	216,032
Sevilla	Valencia	[6-7) hours	41.4%	189,386
Valencia	Zaragoza	Under 4 hours	100%	521,816
Zaragoza	Valencia	Under 4 hours	100%	430,029
Valencia	Málaga	[6-7) hours	41.4%	216,032

Málaga	Valencia	[6-7) hours	41.4%	158,707
Sevilla	Zaragoza	[7-8) hours	23.9%	109,332
Zaragoza	Sevilla	[7-8) hours	23.9%	102,777
Sevilla	Málaga	Under 4 hours	100%	457,455
Málaga	Sevilla	Under 4 hours	100%	383,350
Zaragoza	Málaga	[8-9) hours	20.3%	87,296
Málaga	Zaragoza	[8-9) hours	20.3%	77,820

Table 18: Population considered for each journey.

Data from Table 18 has been obtained by computing the percentage that had been previously calculated with the population of the city of origin of each of the journeys.

Using the population obtained from Table 18, has been obtained. This table displays the population willing to travel in each of the 6 cities that have been selected. In order to obtain each value, the values corresponding to the same cities of origin have been added. The reason to do so is that the car-sharing vehicles will be located at the city of origin.

Selected city	***Travelling population***
Madrid	7,850,481
Barcelona	2,928,544
Valencia	1,997,512
Sevilla	1,145,925
Zaragoza	2,457,961
Málaga	946,491

Table 19: Final population travelling from each city.

For example, Zaragoza, which is a city located very closely to many other cities (Barcelona, Madrid and Valencia) will experience a large increase in its population.

However, because the total population obtained by making use of this data is a lot greater than the original population that was chosen to be used for this problem, the array has to be corrected.

City	*Fictional population*	*Corrected population*
Madrid	7,850,481	2,236,551
Barcelona	2,928,544	834,323
Valencia	1,997,512	569,078
Sevilla	1,145,925	326,467
Zaragoza	2,457,961	700,257
Málaga	946,491	269,649

Table 20: Corrected population for each location.

This population agrees with the intend for the problem. The greatest populations considered for this part are Madrid, Barcelona, and Zaragoza, in that order.

A table has been built, which includes the variation in population that each city has experienced for the problem formulation:

City	*Corrected population for this problem*	*Real population for the base problem*	*Variation experienced in populations*
Madrid	2,236,551	2,085,675	7.23%
Barcelona	834,323	1,058,000	-21.14%
Valencia	569,078	521,816	9.06%
Sevilla	326,467	457,455	-28.63%
Zaragoza	700,257	430,029	62.84%
Málaga	269,649	383,350	-29.66%

Table 21: Variation experienced in the population with respect to the original population.

The average variation that each of the problems has experienced is 26.43%. This value has been obtained by obtaining the average of the absolute value of the percentages of variation.

As it can be seen, Madrid is the city with the greatest population considered because it is located close to other locations (as it can be seen in the map, it is placed in the middle of the Iberian Peninsula), but also has a very large population.

Barcelona, however, has experienced a very large loss in its population due to the fact that is located on the top corner of the Peninsula, resulting in needing a long time to travel to other cities by car.

Zaragoza, however, has a very small population (in fact, it was originally the fifth city in population, not the third). In spite of this, Zaragoza is located in a very strategic point. It is close to many cities by car, which makes it ideal to locate *carsharing* cars

Once the population has been given a value, the p_n array will be defined as shown below:

$$p_n = [2{,}236{,}551 \;\; 834{,}323 \;\; 569{,}078 \;\; 326{,}467 \;\; 700{,}257 \;\; 269{,}649]$$

4.4 PROBLEM 2

4.4.1 Definition

This problem has considered the number of vehicles at each of the cities. It makes use of a ratio of vehicles over population to make it as objective as possible.

4.4.2 Data treatment

Because there is now need to consider the number of vehicles per inhabitant existing at each city, a new parameter has been created. The following table shows the number of vehicles per person at each of the cities.

City	*Number of vehicles per person (#vpp)*
Madrid	0.71
Barcelona	0.53
Valencia	0.69
Sevilla	0.71
Zaragoza	0.61
Málaga	0.69

Table 22: Number of vehicles per inhabitant at each city.

With this number, it is possible to create the new parameter. This parameter has been obtained in the form of a factor, that was multiplied by the population considered for the problem and later corrected to add up for the total population that should be considered for this problem.

The factor that is going to be used will be the following:

$$f_n = \frac{\#vpp_2}{\#vpp_n}$$

In this way, it has bene ensured that the cities that have the greatest number of vehicles per person are be the ones with the smallest factor, whereas the cities that have the smallest number of vehicles per person have the biggest factor (the factor is not bigger than 1, since the biggest one is Barcelona's, which is going to be 1). This problem wants to give preference when assigning vehicles to the city of Barcelona, which is the city that has the least number of vehicles per inhabitant

City	***Number of vehicles per person (#vpp)***	***Obtained factor***
Madrid	0.71	0.75
Barcelona	0.53	1.00
Valencia	0.69	0.78
Sevilla	0.71	0.75
Zaragoza	0.61	0.88
Málaga	0.69	0.78

Table 23: Factor for each of the cities.

In order to include this part in the problem formulation, the factor will be included as a part of the p_n as it shown.

$$p_n^{extra\,2} = f_n p_n$$

$$p_n^2 = p_n^{extra\,2} + p_n$$

$$\forall\, n = 1 \ldots 6$$

By including this factor in the population, the objective function will increase the possibility of vehicles being placed in the places where the factor number is greater (those with less vehicles per citizen).

However, as it was previously stated, the total population obtained from the use of this factor will be smaller than the population that is needed to consider. This will be fixed by adding a corrected population column in the following table.

City	***Population to be added for the problem***	***Population for the problem***	***Corrected population for the problem***
Madrid	1,565,733	3,651,408	2,005,719
Barcelona	1,058,000	2,116,000	1,162,319
Valencia	406,706	928,522	510,037
Sevilla	344,918	802,373	440,743
Zaragoza	376,857	806,886	443,222
Málaga	298,033	681,383	374,284

Table 24: Final population for the Problem 2.

Only by looking at the population values that have been obtained, it is possible to ensure that this formulation for the problem makes sense.

The variation that the population at each location has experienced is shown in the following table:

City	***Corrected population for the problem***	***Original population for the base problem***	***Variation***
Madrid	2,005,719	2,085,675	-3.83%
Barcelona	1,162,319	1,058,000	9.86%
Valencia	510,037	521,816	-2.26%
Sevilla	440,743	457,455	-3.65%
Zaragoza	443,222	430,029	3.07%
Málaga	374,284	383,350	-2.37%

Table 25: Variation experienced in the population for Problem 2

It can be noted that Barcelona, which was the city with the smallest number of vehicles per person, is the one that has experienced the greatest growth. On the opposite , it can be seen that Sevilla, which is the city with the greatest number of vehicles per person is also the one that has experienced the greatest reduction of population.

It should be remarked that this reduction or growth does not mean that those cities are the ones with the ones with the largest or the smallest population: it means that they are the ones that experience the greatest percentual growth or decrease of population.

The array p_n that was used for this problem is given as it follows:

$$p_n = [2{,}005{,}719 \;\; 1{,}162{,}319 \;\; 510{,}037 \;\; 440{,}743 \;\; 443{,}222 \;\; 374{,}284]$$

4.5 PROBLEM 3

4.5.1 Definition

In this problem, not only the number of existing vehicles has been considered, but the age of the car fleet in each city has also been taken into account. For instance, cities with the greatest number of vehicles that are older than 10 years are considered to have an extra need for newer, more reliable vehicles.

4.5.2 Data treatment

From the data obtained for all cities, it has been possible to also come up with a parameter, in the shape of a factor, that is loaded into the p_n array information on which of the cities is the one with the highest percentage of old cars.

In order to compensate the existence of older vehicles, more *carsharing* vehicles should be placed in the locations where there are older cars.

Even though the principle to obtain the factor is the same to the factor obtained in the previous problem, the procedure to obtain it is opposite to the previous section: in this problem, the locations where more *carsharing* vehicles should be located are the ones with the greatest percentage of old vehicles, whereas in the previous problem, the cities where mode vehicles are desired are the ones with the smallest number of vehicles per person.

The formula used in order to obtain the new value will be as it follows:

$$w_n = \frac{Percentage\ \ of\ old\ vehicles\ for\ city\ n}{Percentage\ of\ old\ vehicles\ for\ Sevilla}$$

The obtained values for each of the cities are shown in the table provided below:

City	***Percentage of old vehicles***	***Obtained value for the factor***
Madrid	4.17%	1.10
Barcelona	3.78%	1.00
Valencia	3.86%	1.02
Sevilla	4.32%	1.14
Zaragoza	4.11%	1.09
Málaga	4.15%	1.10

Table 26: Obtained factor for Problem 3.

These values have been included into the objective function by computing them into the p_n as well. Therefore, the new equation to define it would be:

$$p_n^{extra\ 3} = w_n p_n$$

$$p_n^3 = p_n^{extra\ 3} + p_n$$

$$\forall n = 1 \dots 6$$

However, as it was done in the previous problem, it is also necessary to make a correction in the population considered for the array. This correction will also be shown in the third column of the table provided below:

City	***Population to be added for the problem***	***Population for the problem***	***Corrected population for the problem***
Madrid	2,303,713	4,389,388	2,115,278
Barcelona	1,058,000	2,116,000	1,019,716
Valencia	533,612	1,055,428	508,619
Sevilla	523,349	980,804	472,656
Zaragoza	467,433	897,462	432,493
Málaga	420,878	804,228	387,563

Table 27: Corrected population for Problem 3.

Once this population has been corrected, it can be noted that the total population that has been considered for this problem is of 4,936,325 people, which is the same population that was considered for the Base Problem and for all the problems that have been formulated after that.

The following table shows the variation that the population at each of the locations has experienced:

City	*Corrected population for the problem*	*Original population of the base problem*	*Variation of the population*
Madrid	2,115,278	2,085,675	1.42%
Barcelona	1,019,716	1,058,000	-3.62%
Valencia	508,619	521,816	-2.53%
Sevilla	472,656	457,455	3.32%
Zaragoza	432,493	430,029	0.57%
Málaga	387,563	383,350	1.10%

Table 28: Variation of the population for Problem 3.

Note that this formulation makes sense: Sevilla is the city with the greatest percentage of cars older than 10 years, so it is also the city that has experienced the greatest growth in its population (that does not mean that it is the largest population, of course). The opposite thing happens with Barcelona, which is the city with the smallest percentage of vehicles older than 10 years: it is the one that has experienced the greatest reduction of population.

Additionally, it should be remarked that the differences between the percentages of vehicles older than 10 years is very minimal between cities.

With this newly obtained population, the p_n array can be defined:

$$p_n = [2{,}115{,}278 \;\; 1{,}019{,}716 \;\; 508{,}619 \;\; 472{,}656 \;\; 432{,}493 \;\; 387{,}563]$$

4.6 PROBLEM 4

4.6.1 Definition

For this problem, other transportation means have been considered. Only time and price ranges have be considered in order to develop the formulation of the problem. The considered alternatives are airplane, train, or bus. They have been compared both in price, time and user preference.

4.6.2 Data treatment

For starters, it should be noted that although transportation by plane is usually the shortest trip, at least 2 hours of additional timing should be considered due to the special needs when travelling through airplane (security controls, baggage check-ins…). In addition, airports are usually located far from the cities, and extra time needs to be considered to cover that distance as well. The timings have been corrected, to ensure that this fact is taken into account in the following table:

City of origin	*City of destination*	*Time required by car*	*Time required by plane*	*Time required by train*	*Time required by bus*
Madrid	Barcelona	6.3	3.25	2.75	7.85
Madrid	Valencia	3.6	3	1.88	4.25
Madrid	Sevilla	5.05	3.08	2.53	6.5
Madrid	Zaragoza	3.45	-	1.67	4.65
Madrid	Málaga	5.3	3.25	2.42	6
Barcelona	Valencia	3.75	3	2.67	5.83
Barcelona	Sevilla	9.93	3.58	5.50	14.75
Barcelona	Zaragoza	3.28	-	1.42	4.62
Barcelona	Málaga	9.88	3.58	5.93	14.75
Valencia	Sevilla	6.4	3.25	-	9.75
Valencia	Zaragoza	3.3	-	-	4.65
Valencia	Málaga	6.27	3.67	4.68	9.5
Sevilla	Zaragoza	7.97	-	-	-
Sevilla	Málaga	2.25	-	1.92	3.25
Zaragoza	Málaga	8.13	-	5.23	-

Table 29: Corrected timings for each of the alternative transportation means.

In the definition of this problem, it was stated that the price itself would not be considered as a parameter of the problem. However, a range of prices has been defined for the transportation means as it is shown in the following table:

Position	*Transportation mean*
1	Train
2	Airplane
3	Car
4	Bus

Table 30: Transportation prices, going from most expensive to the cheapest.

As it was previously stated, this has been the only consideration made, pricewise.

However, more data can be extracted from the survey that was performed. For instance, the preferred transportation mean by users has been considered for the problem.

As it happened with Problem 1, an analysis has been made both for all travelers, and for frequent travelers. Therefore, values for non-frequent travelers needed to be pondered by 80% and values for frequent travelers will be pondered by 20%.

Transportation mean	***Percentage for non-frequent travelers***	***Percentage for frequent travelers***	***Weighted percentage***
Airplane	11%	19%	12.60%
Train	54%	47%	52.60%
Car	33%	31%	32.60%
Bus	0%	0%	0%

Table 31: Weighted percentages for each transportation mean.

However, Table 31 only shows the results of the survey from a generalized point of view. It does not depict the availability of these transportation means, nor their quality.

Because nobody chose bus as their preferred transportation mean, it has not been considered in the formulation of this problem.

As it happened in the previous problem, the total percentage that was added did not sum 100%. This is a result of computing the original percentages that were obtained in the survey that was carried out.

A new table, provided below, was made, considering this correction:

Transportation mean	***Corrected weighted percentage***
Airplane	12.88%
Train	53.78%
Car	33.33%

Table 32: Corrected weighted percentages for each transportation mean.

Once the bus has been eliminated from the table, and airplane has been corrected by adding more time to consider the additional timing required, the obtained table would be as it follows:

From	*To*	*Time required by car*	*Time required by plane*	*Time required by train*
Madrid	Barcelona	6.3	3.25	2.75
Madrid	Valencia	3.6	3	1.88
Madrid	Sevilla	5.05	3.08	2.53
Madrid	Zaragoza	3.45	-	1.67
Madrid	Málaga	5.3	3.25	2.42
Barcelona	Valencia	3.75	3	2.67
Barcelona	Sevilla	9.93	3.58	5.50
Barcelona	Zaragoza	3.28	-	1.42
Barcelona	Málaga	9.88	3.58	5.93
Valencia	Sevilla	6.4	3.25	-
Valencia	Zaragoza	3.3	-	-
Valencia	Málaga	6.27	3.67	4.68
Sevilla	Zaragoza	7.97	-	-
Sevilla	Málaga	2.25	-	1.92
Zaragoza	Málaga	8.13	-	5.23

Table 33: Corrected timings for all transportation means considered.

Because the timings cannot be directly used in this project, it would be convenient to treat them in order to obtain a value that can be introduced into the problems.

In order to express this, other criteria have been created:

- In those cases where one of the transportation means is not available, the percentage of people who chose to use it will be divided by the rest of the available transportation means (For example, since there is not an airport in Zaragoza, traveling by plane would not be an option in order to arrive to this city, and 12.6% of the population, which would be the weighted percentage of people who chose in the survey to travel by plane, would be proportionally split between the rest of transportation means).
- Additionally, for the transportation means that take longer or within a 0.75 hour range and are more expensive than car, their percentage will be divided by two and the other half will be given to the other transportation means (for example, the time required to go from Valencia to Málaga by train is longer than the time required to fly there. Therefore, the percentage of people selecting to travel by

train would be split in half, leaving only 26.3% of the population choosing to travel by train. The remaining half (the other 26.3%) would be split proportionally between the other transportation means).

- In addition, if the difference between train and plane is over one hour, the consideration to be made will be that only 25% of the population will still select to travel this distance using that transportation mean (for example, between Barcelona and Málaga, it takes 3.58 hours to travel by plane. However, traveling by train requires 5.93 hours and therefore only 25% of the original percentage of population who selected to travel by train would still make this trip by train).

In case the procedure used is not clear enough, ANNEX III explains in more detail the steps that have been taken in order to obtain the following percentages in each case

City of origin	***City of destination***	***Percentage for train***	***Percentage for plane***	***Percentage for car***
Madrid	Barcelona	52.6%	12.6%	32.6%
Madrid	Valencia	56.5%	6.3%	35.0%
Madrid	Sevilla	56.5%	6.3%	35.0%
Madrid	Zaragoza	60.4%	0.0%	37.4%
Madrid	Málaga	52.6%	12.6%	32.6%
Barcelona	Valencia	26.3%	19.9%	51.6%
Barcelona	Sevilla	13.2%	23.6%	61.1%
Barcelona	Zaragoza	60.4%	0.0%	37.4%
Barcelona	Málaga	13.2%	23.6%	61.1%
Valencia	Sevilla	0.0%	27.3%	70.5%
Valencia	Zaragoza	0.0%	0.0%	100.0%
Valencia	Málaga	13.2%	23.6%	61.1%
Sevilla	Zaragoza	0.0%	0.0%	100.0%
Sevilla	Málaga	30.2%	0.0%	60.7%
Zaragoza	Málaga	60.4%	0.0%	37.4%

Table 34: Percentages considered for the problem.

Once the percentages have been obtained in Table 34, they need to be applied to the original population for the problem.

The following table expresses the final population that has been considered for each journey

City of origin	***City of destination***	***Original population of the city of origin****¡Error! No se encuentra el origen de la referencia.*	***Percentage applied***	***Population obtained for Problem***
Madrid	Barcelona	2,085,675	32.60%	679,930
Barcelona	Madrid	1,058,000	32.60%	344,908
Madrid	Valencia	2,085,675	35.00%	729,986
Valencia	Madrid	521,816	35.00%	182,636
Madrid	Sevilla	2,085,675	35.00%	729,986
Sevilla	Madrid	457,455	35.00%	160,109
Madrid	Zaragoza	2,085,675	37.40%	780,042
Zaragoza	Madrid	430,029	37.40%	160,831
Madrid	Málaga	2,085,675	32.60%	679,930
Málaga	Madrid	383,350	32.60%	124,972
Barcelona	Valencia	1,058,000	51.60%	545,928
Valencia	Barcelona	521,816	51.60%	269,257
Barcelona	Sevilla	1,058,000	61.10%	646,438
Sevilla	Barcelona	457,455	61.10%	279,505
Barcelona	Zaragoza	1,058,000	37.40%	395,692
Zaragoza	Barcelona	430,029	37.40%	160,831
Barcelona	Málaga	1,058,000	61.10%	646,438
Málaga	Barcelona	383,350	61.10%	234,227
Valencia	Sevilla	521,816	70.50%	367,880
Sevilla	Valencia	457,455	70.50%	322,506
Valencia	Zaragoza	521,816	100.00%	521,816
Zaragoza	Valencia	430,029	100.00%	430,029
Valencia	Málaga	521,816	61.10%	318,830
Málaga	Valencia	383,350	61.10%	234,227

Sevilla	Zaragoza	457,455	100.00%	457,455
Zaragoza	Sevilla	430,029	100.00%	430,029
Sevilla	Málaga	457,455	60.70%	277,675
Málaga	Sevilla	383,350	60.70%	232,693
Zaragoza	Málaga	430,029	37.40%	160,831
Málaga	Zaragoza	383,350	37.40%	143,373

Table 35:Weighted population for each journey.

A table has been obtained, showing what would be the population who would be willing to rent a car at each location.

City	***Total population considered***
Madrid	3,599,875
Barcelona	2,579,404
Valencia	1,660,419
Sevilla	1,497,250
Zaragoza	1,342,551
Málaga	969,492

Table 36: Final population considered for Problem 4.

As it happened in previous problem formulations, the total population had to be corrected to match the overall population considered for the Base Problem. The following table provides the population and the corrected population:

City	***Population for the problem***	***Corrected population for the problem***
Madrid	3,599,875	1,525,467
Barcelona	2,579,404	1,093,037
Valencia	1,660,419	703,612
Sevilla	1,497,250	634,468
Zaragoza	1,342,551	568,913
Málaga	969,492	410,828

Table 37: Corrected population for Problem 4.

A table including a comparison between the original population that was taken into consideration and the population considered for this problem has also been performed for this problem:

City	*Corrected population for the problem*	*Original population for the base problem*	*Variation of the population*
Madrid	1,525,467	2,085,675	-26.86%
Barcelona	1,093,037	1,058,000	3.31%
Valencia	703,612	521,816	34.84%
Sevilla	634,468	457,455	38.70%
Zaragoza	568,913	430,029	32.30%
Málaga	410,828	383,350	7.17%

Table 38: Variation between populations for Problem 4.

As it can be seen in the data, the only city that has experienced a reduction in the total population considered is Madrid. Spain has a very centralized transportation system, where most means of transportation are accessible from Madrid to other locations, so this reduction matches the reality of the transportation system.

It can also be noted that cities, such as Zaragoza, that does not have an airport and has experienced a very large growth in the population.

The p_n array used for this problem is:

$$p_n = [1{,}525{,}467 \;\; 1{,}093{,}037 \;\; 703{,}612 \;\; 634{,}468 \;\; 568{,}913 \;\; 410{,}828]$$

4.7 PROBLEM 5

4.7.1 Definition

In this problem, the yearly income per inhabitant has been considered at each of the possible locations. The problem aims to locate the vehicles in locations with the greatest income.

4.7.2 Data treatment

Similarly to previous cases, a new parameter needed to be obtained for this situation. The parameter, given by a factor, was later multiplied by the original population considered..

The factor has been obtained by considering Málaga as the city with the lowest income per person. The rest of the incomes have been divided by the income of the city of Málaga as following:

$$a_n = \frac{Yearly\ income\ in\ city\ n}{Yearly\ income\ in\ Málaga}$$

The following table shows the values obtained for each of the factors:

City	***Factor a_n***
Madrid	1.49
Barcelona	1.44
Valencia	1.15
Sevilla	1.11
Zaragoza	1.09
Málaga	1.00

Table 39:Factor obtained for Problem 5.

Once these factors have been obtained, they will be multiplied by the actual population at each location, and then corrected, so that the sum of the population at all locations still adds up to 5,066,073 people.

$$p_n^{extra\ 5} = a_n p_n$$

$$p_n^5 = p_n^{extra\ 5} + p_n$$

The table provided below shows the population that would be obtained from this multiplication (second column), and the corrected population (in the third column).

City	***Population to be added for the problem***	***Population for the problem***	***Corrected population for the problem***
Madrid	3,102,780	5,188,455	2,221,703
Barcelona	1,528,652	2,586,652	1,107,608
Valencia	599,071	1,120,887	479,965
Sevilla	509,781	967,236	414,172
Zaragoza	468,088	898,117	384,575
Málaga	383,350	766,700	328,302

Table 40:Corrected population for Problem 5.

As previously, a table with the variation that these populations have experienced has been included:

City	*Corrected population for the problem*	*Original population for the base problem*	*Variation of population*
Madrid	2,221,703	2,085,675	6.52%
Barcelona	1,107,608	1,058,000	4.69%
Valencia	479,965	521,816	-8.02%
Sevilla	414,172	457,455	-9.46%
Zaragoza	384,575	430,029	-10.57%
Málaga	328,302	383,350	-14.36%

Table 41: Variation for the population in Problem 5.

The average yearly income between all cities is 31,190 €. As it can be seen in the table, the population in Madrid and in Barcelona are the ones that have greatly increased. Those are also the two locations with the greatest yearly income per person. More particularly, they are the only cities that have their yearly income above the average.

However, the other locations have significantly reduced their population. This is also due to the fact that the yearly income is below the average between all six cities.

The array p_n has been obtained as:

$$p_n = [2{,}221{,}703\ \ 1{,}107{,}608\ \ 479{,}965\ \ 414{,}172\ \ 384{,}575\ \ 328{,}302]$$

4.8 PROBLEM 6

4.8.1 Definition

In this problem, the existence of other carsharing initiatives has been looked at in every designated city. By introducing the acceptance of carsharing vehicles at each location, the aim was to determine what are the locations where this service will be most used.

4.8.2 Data treatment

The data that was obtained for this section is very limited. Due to the particular laws and regulations at each city, the information that could be gathered is not objective, nor representative of the situation.

Additionally, most of the *carsharing* platforms that were looked at, aside from Madrid, were pilot projects, where the initiatives were still getting tested and an evaluation process was still going on.

The city of Sevilla, for instance, lost its only *carsharing* platform, Cochele in the year 2018 (DIAR19).

Because of all of this, this information cannot really be treated objectively. However, with the available information, a conversion will be made, so that the population is increased in the city of Madrid.

Because the number of vehicles is so small, it is not really representative in comparison with the already existing vehicles. In order to make a justified conversion of the data, the carsharing vehicles will be first multiplied by 20 (as it was said in the INTRODUCTION section, every *carsharing* vehicle is estimated to substitute around 20 privately owned vehicles).

Once this has been done, the number of vehicles will be divided by the vehicles found per person at each location, resulting in a number of people that will be added to the Table 4: Population at each selected location. Source: INE19.

Population between 18 and 65.

The process is shown in the following table.

City	***Existing carsharing vehicles***	***Fictional carsharing vehicles***
Madrid	2635	52700
Barcelona	300	6000
Valencia	100	2000
Sevilla	0	0
Zaragoza	100	2000
Málaga	10	200

Table 42: Existing carsharing *vehicles at each location.*

With this information, it is possible to obtain a factor, similarly to how it was done in previous problems.

The factor that has been obtained for this problem divided the number of *carsharing* vehicles at each location by the number of vehicles. The following formulae show the procedure that was followed:

$$s_n = \frac{\text{carsharing } vehicles\ in\ city\ n}{vehicles\ in\ city\ n}$$

$$p_n^{extra\ 6} = s_n p_n$$

$$p_n^6 = p_n^{extra\ 6} + p_n$$

$$\forall\ n = 1..6$$

The factors s_n that were obtained are provided in the following table:

City	*Factor* s_n
Madrid	3.55E-02
Barcelona	1.06E-02
Valencia	5.59E-03
Sevilla	0
Zaragoza	7.63E-03
Málaga	7.59E-04

Table 43: Factor for problem 6.

Once this table has been filled out, the factors were multiplied by the original population at each location, and a population to be added has been obtained. From here, it was easy to obtain a final population. Because the desired population is of 4,936,325, the final population should be corrected in the problem.

City	***Population to be added for the problem***	***Population for the problem***	***Corrected population for the problem***
Madrid	74,066	2,159,741	2,120,314
Barcelona	11,233	1,069,233	1,049,714
Valencia	2,918	524,734	515,155
Sevilla	0	457,455	449,104
Zaragoza	3,281	433,310	425,400
Málaga	291	383,641	376,638

Table 44: Corrected population for Problem 6.

The following table indicates the variations that were experienced:

City	*Corrected population for the problem*	*Original population for the base problem*	*Variation of population*
Madrid	2,120,314	2,085,675	1.66%
Barcelona	1,049,714	1,058,000	-0.78%
Valencia	515,155	521,816	-1.28%
Sevilla	449,104	457,455	-1.83%
Zaragoza	425,400	430,029	-1.08%
Málaga	376,638	383,350	-1.75%

Table 45: Variation of the population in Problem 6.

As it can be seen, the alterations in the population in this section have not been very significant. This has resulted in a solution that is very similar to the solution obtained in the Base Problem.

The obtained p_n array is as it follows:

$$p_n = [2{,}120{,}314 \;\; 1{,}049{,}714 \;\; 515{,}155 \;\; 449{,}104 \;\; 425{,}400 \;\; 376{,}638]$$

4.9 PROBLEM 7

4.9.1 Definition

In this problem, the only data that was used is the number of electric vehicle chargers found at each possible location. In case of selecting electric vehicles as the desired transportation mean that will be used for this platform, it would be necessary to give priority to the locations that have a greater number of chargers.

4.9.2 Data Treatment

From Table 12, provided in the Electric Vehicle Chargers section, it is possible to see that Madrid is the city that has the greatest number of chargers. However, Madrid is also the city with the greatest number of electric vehicles, so it is clear that the number of chargers itself is not a very good indicator.

Therefore, the value that was used for the evaluation of this problem is given by the number of electric vehicles per charger at each location. This ratio has been calculated in the following table:

City	*Vehicles per charger*
Madrid	61
Barcelona	24
Valencia	9
Sevilla	23
Zaragoza	20
Málaga	9

Table 46: Vehicles per EV charger at each city.

As expected, the cities that have the greatest ratio of vehicles per charger are the ones that should have the least priority when it comes to assigning vehicles. For instance, Madrid is the city with the least priority. Cities with the smallest ratio are the ones that had the highest priority (Sevilla would be the one to prioritize in this situation).

Knowing this, it is possible to obtain a factor that has been later multiplied by the population and obtain the population that has been added, and later corrected. The following formulae show how the calculations will be performed:

$$q_n = \frac{vehicles\ per\ charger\ in\ Valencia}{vehicles\ per\ charger\ in\ city\ n}$$

The following table shows the values obtained by the factor q_n is given in the table provided below:

City	*Factor q_n*
Madrid	0.13
Barcelona	0.43
Valencia	0.61
Sevilla	1.00
Zaragoza	0.60
Málaga	0.56

Table 47: Factor for Problem 7.

Once the factor was obtained, it was multiplied by the original population of the problem, using the following formulae:

$$p_n^{extra\ 7} = q_n p_n$$

$$p_n^7 = p_n^{extra\ 7} + p_n$$

$$\forall\, n = 1..6$$

These calculations resulted in the following table:

City	*Additional population for the problem*	*Population for the problem*	*Corrected population for the problem*
Madrid	301,494	2,387,169	1,712,174
Barcelona	392,413	1,450,413	1,040,295
Valencia	521,816	1,043,632	748,535
Sevilla	177,638	635,093	455,515
Zaragoza	192,761	622,790	446,690
Málaga	359,939	743,289	533,117

Table 48: Corrected population for Problem 7.

The following table has been obtained to show the variations that the population has experienced in this problem with respect to the original data:

City	*Corrected population for the problem*	*Original population for the base problem*	*Variation of population*
Madrid	1,712,174	2,085,675	-17.91%
Barcelona	1,040,295	1,058,000	-1.67%
Valencia	748,535	521,816	43.45%
Sevilla	455,515	457,455	-0.42%
Zaragoza	446,690	430,029	3.87%
Málaga	533,117	383,350	39.07%

Table 49: Variation of population for Problem 7.

As it can be seen in this table, Valencia is the city that has experienced the greatest growth, closely followed by Málaga. Madrid, on the other hand, is the city that has experienced the greatest reduction of population.

However, the other three cities, Barcelona, Sevilla and Zaragoza, have barely experienced any variations. This is mainly due to the fact that the number of vehicles per charger in those cities is very close to the average of all the values, which is 24.

The array p_n has therefore already been defined:

$$p_n = [1{,}712{,}174 \;\; 1{,}040{,}295 \;\; 748{,}535 \;\; 455{,}515 \;\; 446{,}690 \;\; 533{,}117]$$

4.10 PROBLEM 8

4.10.1 Definition

In this problem, the main consideration that has been made is the number of chargers existing between cities.

4.10.2 Data Treatment

Because some of the routes that have been looked at are much longer than others, the important value to look at is the ratio of kilometers that each charger must cover between each city. The following table summarizes those numbers:

City of origin	City of destination	Number of chargers	Kilometers	Kilometers per charger
Madrid	Barcelona	25	621	28.84
Madrid	Valencia	20	359	17.95
Madrid	Sevilla	19	531	27.95
Madrid	Zaragoza	13	314	24.15
Madrid	Málaga	15	532	35.47
Barcelona	Valencia	28	352	12.57
Barcelona	Sevilla	51	997	19.55
Barcelona	Zaragoza	12	314	26.17
Barcelona	Málaga	44	979	22.25
Valencia	Sevilla	23	655	28.48
Valencia	Zaragoza	11	309	28.09
Valencia	Málaga	16	618	38.63
Sevilla	Zaragoza	32	845	26.41
Sevilla	Málaga	4	205	51.25
Zaragoza	Málaga	28	835	29.82

Table 50: Ratio of kilometers per charger.

As it can be seen in the table, the journey with the greatest number of chargers per kilometer (or least number of kilometers that each charger needs to cover) is from Barcelona to Valencia. More particularly, there is a charger every 12.57 kilometers.

However, the journey from Sevilla to Málaga, despite being the shortest one out of all the possibilities that have been provided is the one with the smallest number of chargers per kilometer. There is a charger every 51.25 kilometers.

Because of the nature of this problem, it is necessary to prioritize de routes that have the greatest number of chargers per kilometer. For instance, the route going from Barcelona to Valencia should be the one with the greatest priority, whereas the route going from Sevilla to Málaga the one with the least priority.

Same as in previous problems, a new way to evaluate this number of chargers needs to be formulated.

For starters, it will be necessary to take into account both ways of a single journey (i.e. in the journey from Madrid to Barcelona, the trip from Barcelona will also need to be taken into account). This will help come up with a final factitial population, similarly to how it was done in previous problems.

The selected treatment that the data will receive is that the population will be divided by the ratio that was obtained in the previous section. For instance, it will follow the following formula:

$$Population\ on\ one\ direction = \frac{Population\ at\ city\ of\ origin}{Obtained\ ratio}$$

It is important to point out that since the vehicles will be used from the departure point, the population considered on each journey will be the population of the city of origin.

The following table shows the population considered at each direction:

City of origin	*City of destination*	*Population of city of origin*	*Ratio*	*Population considered for city of origin*
Madrid	Barcelona	2,085,675	24.84	83,964
Barcelona	Madrid	1,058,000	24.84	42,593
Madrid	Valencia	2,085,675	17.95	116,194
Valencia	Madrid	521,816	17.95	29,071
Madrid	Sevilla	2,085,675	27.95	74,622
Sevilla	Madrid	457,455	27.95	16,367
Madrid	Zaragoza	2,085,675	24.15	86,363
Zaragoza	Madrid	430,029	24.15	17,807
Madrid	Málaga	2,085,675	35.47	58,801
Málaga	Madrid	383,350	35.47	10,808
Barcelona	Valencia	1,058,000	12.57	84,169
Valencia	Barcelona	521,816	12.57	41,513
Barcelona	Sevilla	1,058,000	19.55	54,118
Sevilla	Barcelona	457,455	19.55	23,399
Barcelona	Zaragoza	1,058,000	26.17	40,428
Zaragoza	Barcelona	430,029	26.17	16,432
Barcelona	Málaga	1,058,000	22.25	47,551
Málaga	Barcelona	383,350	22.25	17,229
Valencia	Sevilla	521,816	28.48	18,322
Sevilla	Valencia	457,455	28.48	16,062
Valencia	Zaragoza	521,816	28.09	18,577
Zaragoza	Valencia	430,029	28.09	15,309
Valencia	Málaga	521,816	38.63	13,508
Málaga	Valencia	383,350	38.63	9,924
Sevilla	Zaragoza	457,455	26.41	17,321
Zaragoza	Sevilla	430,029	26.41	16,283
Sevilla	Málaga	457,455	51.25	8,926

Málaga	Sevilla	383,350	51.25	7,480
Zaragoza	Málaga	430,029	29.82	14,421
Málaga	Zaragoza	383,350	29.82	12,855

Table 51: Computed population for the problem.

As it was done in previous problems, the populations of all cities of origin has been added to obtain a fictional population. The following table shows the addition of these values:

City	***Population to be added for the problem***
Madrid	419,944
Barcelona	268,857
Valencia	120,990
Sevilla	82,076
Zaragoza	80,251
Málaga	58,296

Table 52: Added population for each city.

As it happened in previous problems, the total population that was obtained for this problem was 1,030,415. However, because the population needs to match the population selected for the project, it needs to be corrected:

City	***Population for the problem***	***Corrected population for the problem***
Madrid	2,505,619	2,072,916
Barcelona	1,326,857	1,097,718
Valencia	642,806	531,798
Sevilla	539,531	446,357
Zaragoza	510,280	422,158
Málaga	441,646	365,377

Table 53: Corrected population for Problem 8.

A table displaying the variation of the population at each city has been obtained:

City	***Corrected population for the problem***	***Original population for the base problem***	***Variation of population***
Madrid	2,072,916	2,085,675	-0.61%
Barcelona	1,097,718	1,058,000	3.75%
Valencia	531,798	521,816	1.91%
Sevilla	446,357	457,455	-2.43%
Zaragoza	422,158	430,029	-1.83%
Málaga	365,377	383,350	-4.69%

Table 54: Variation for the population in Problem 8.

The variation of the population in all cities can be considered homogeneous. Although there are differences in that variation, all cities experience a large change in their population.

Especially remarkable is the change in the city of Málaga, that has reduced its population in almost s 30%. The city of Barcelona has the greatest growth of population, a 21.74%.

The p_n array is therefore:

$$p_n = [2{,}072{,}916 \;\; 1{,}097{,}718 \;\; 531{,}798 \;\; 446{,}357 \;\; 422{,}158 \;\; 365{,}377]$$

4.11 PROBLEM 9

4.11.1 Definition

In this problem, the number of tourists that each city received in the year 2019 was looked at.

4.11.2 Data Treatment

Because of the different size of all cities, it is not possible to evaluate the number of tourists received at each location per se. An indicator needed to be made up to decide which were the locations that were to be given preference. The indicator that was decided upon was the number of vehicles per tourist.

The first step that was therefore taken was obtaining this ratio, which is provided in the table below:

City	***Vehicles per tourist***
Madrid	0.14
Barcelona	0.05
Valencia	0.07
Sevilla	0.08
Zaragoza	0.22
Málaga	0.19

Table 55: Number of vehicles per tourists.

If the number of vehicles at each city per tourist is low, it could be considered as if there were not enough vehicles for such a large volume of people.

As it can be seen in the table, Barcelona is the city that has the smallest ratio, followed by Valencia. The city that has the highest ratio was Zaragoza, with 0.22 vehicles per tourist.

These values obtained for the number of vehicles per tourist, have been able to give an idea of how much should the population be increased.

The ratio in the city of Barcelona (which is the lowest), has been then divided by the ratio at each city to obtain a factor, as shown.

$$t_n = \frac{vehicles\ per\ tourist\ in\ Barcelona}{vehicles\ per\ tourist\ in\ city\ n}$$

The table provided below showed the factor obtained for each location:

City	***Factor***
Madrid	0.33
Barcelona	1.00
Valencia	0.70
Sevilla	0.62
Zaragoza	0.21
Málaga	0.25

Table 56: Obtained factor for each city.

This ratio will then be multiplied by the actual population at each location, to set a value for the population that will be added.

$$p_n^{extra\,11} = t_n p_n$$

$$p_n^{11} = p_n^{extra\ 11} + p_n$$

$$\forall\ n = 1..6$$

The following table will give out the numbers of how much will the population be increased at each city.

The final value for the population that has been obtained will then be corrected, so that the total population that is used in this problem is the same as it was used in previous problems, 5,066,073 people.

City	***Additional population for the problem***	***Final population for the problem***	***Corrected population for the problem***
Madrid	689,655	2,775,330	1,821,981
Barcelona	1,058,000	2,116,000	1,389,136
Valencia	363,290	885,106	581,065
Sevilla	284,435	741,890	487,045
Zaragoza	91,400	521,429	342,314
Málaga	96,144	479,494	314,784

Table 57: Corrected population for Problem 9.

A table including the variation that has been experienced between populations has also been included in this section:

City	***Corrected population for the problem***	***Original population for the base problem***	***Variation of population***
Madrid	1,821,981	2,085,675	-12.64%
Barcelona	1,389,136	1,058,000	31.30%
Valencia	581,065	521,816	11.35%
Sevilla	487,045	457,455	6.47%
Zaragoza	342,314	430,029	-20.40%
Málaga	314,784	383,350	-17.89%

Table 58: Variation of the population for Problem 9.

As it can be seen, the population of cities such as Barcelona has a great increase. Barcelona is currently the most visited city in Spain, and one of the most visited cities in the world, so it was expected that it would experience a great growth in the population.

The location that has experienced the greatest reduction of population is Zaragoza, the city with the smallest number of tourists, from all of the locations that were selected.

Other cities, such as Sevilla and Valencia also augmented their population, whereas Madrid and Málaga reduced them.

The obtained array p_n is:

$$p_n = [1{,}821{,}981 \;\; 1{,}389{,}136 \;\; 581{,}065 \;\; 487{,}045 \;\; 342{,}314 \;\; 314{,}784]$$

5 INITIAL RESOLUTIONS

Once all the problems were properly formulated, solutions needed to be obtained. The selected tool for the resolution of the problems was MATLAB[3].

The formulations that were obtained correspond to a MILP (Mixed Integer Linear Problem). All the codes that have been used for the resolution of the problem were very similar, with the single alteration of the p_n array.

5.1 BASE PROBLEM

As it was previously said, the formulation of this problem only involves the population between ages 16 and 65 at each location.

This problem was too simple to be considered as a part of the formulation for the final problem. However, it helped to gain understanding in the situations that are developing at each different problem formulation. It especially served as a reference to compare the results obtained to.

The following table shows the distribution of vehicles obtained as a result for the problem:

City	*Number of vehicles*
Madrid	209
Barcelona	106
Valencia	53
Sevilla	46
Zaragoza	44
Málaga	39

Table 59: Results for the Base Problem.

The following figure shows how would the vehicles be distributed in a map of Spain:

[33] The codes used are available in ANNEX IV

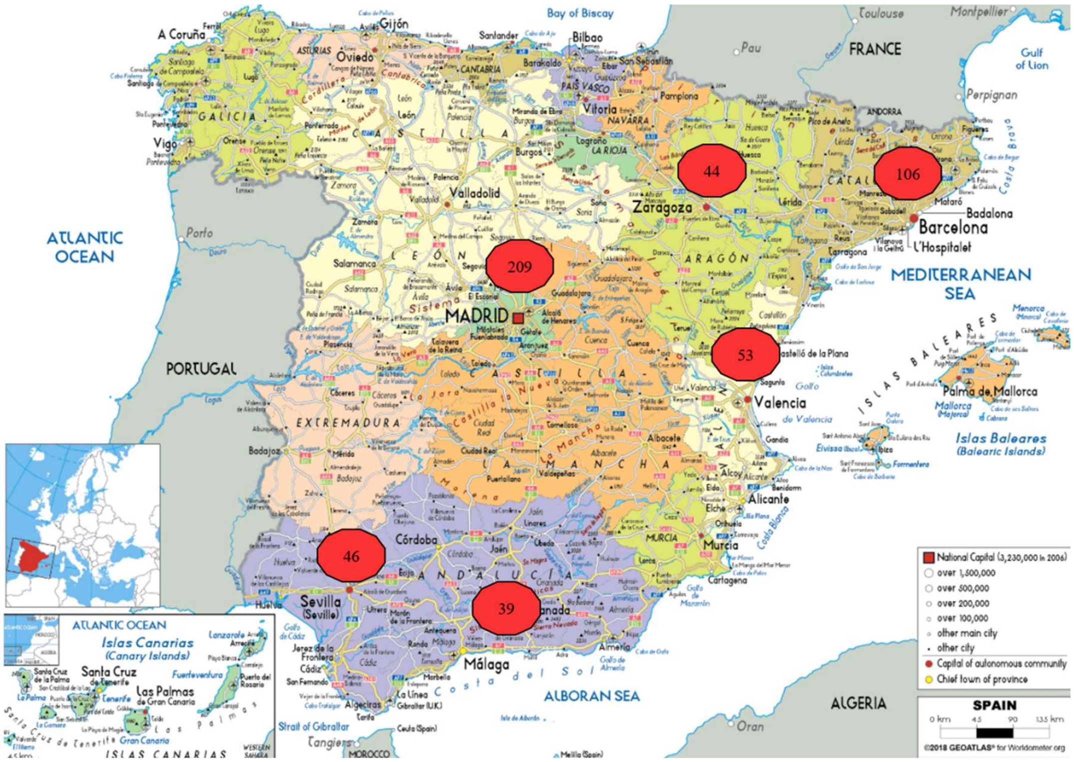

Figure 13: Solution obtained for the Base Problem.

As it can be seen, Madrid, which was the city with the greatest population is, in fact, the city with the greatest number of vehicles assigned, 209.

The total number of vehicles that have been considered for the problem were 497.[4]

The results that have been obtained for this problem served as a comparison for the other problems. The variation caused by each of the parameters was obtained in terms of these results.

5.2 PROBLEM 1

For this problem, the distance between cities was considered, in addition to the population of each of the cities.

Once this problem was executed on MATLAB, a value for the number of assigned vehicles at each location was set. These values are shown in the following table:

[4] Since the total population considered for all problems was the same, the total number of vehicles must be around 497 for all problems. Some variations may occur due to the differences in the distribution of the population.

The cars will be distributed as shown in the table provided below:

City	*Number of vehicles*
Madrid	224
Barcelona	84
Valencia	57
Sevilla	33
Zaragoza	71
Málaga	27

Table 60: Results obtained for Problem 1.

As it can be noted, the total number of vehicles obtained for this problem is 496 (almost the same as in the Base Problem, as it was expected).

The location of each of the vehicles is shown in the following map:

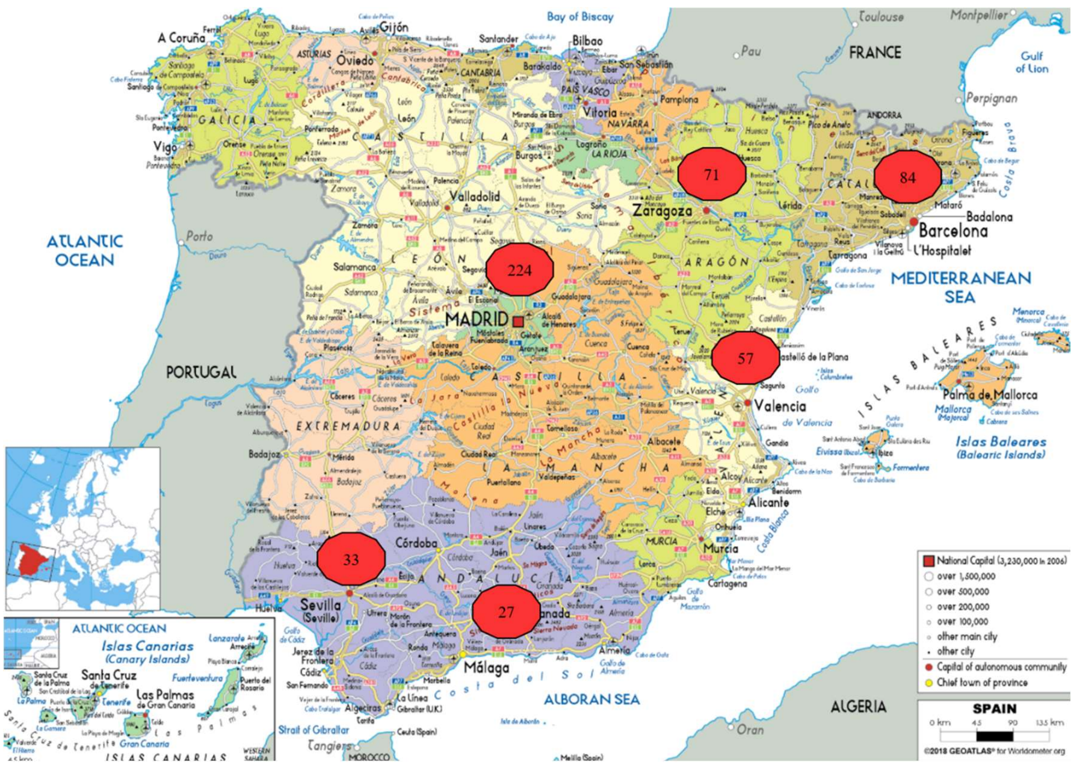

Figure 14: Solution for Problem 1.

The difference between the results obtained for the Base Problem, which serves as a reference, and the results obtained for this problem are shown in the table shown next:

City	*Results for Problem 1*	*Results for the Base Problem*	*Percentage of increase*
Madrid	224	209	7.18%
Barcelona	84	106	-20.75%
Valencia	57	53	7.55%
Sevilla	33	46	-28.26%
Zaragoza	71	44	61.36%
Málaga	27	39	-30.77%

Table 61: Variation of results for Problem 1.

It also should be noted that the total variation that was experienced was of 25.98%.

As it can be seen, when comparing the results obtained here with the results that were obtained for Problem Base Problem, it can be noted that the number of vehicles located in Madrid is greater (from 209 vehicles to 224). This growth in the location of vehicles is also experienced in other cities, such as Valencia (from 53 to 57 vehicles) and Zaragoza (went from 44 to 71 automobiles), that are located close to other cities.

Especially remarkable is the case of Zaragoza, that has increased the number of vehicles that should be located here by over one half.

5.3 PROBLEM 2

For this problem, the existing number of vehicles was considered, in addition to the population of each of the cities.

The obtained results of the optimization problem are shown in the following table:

City	*Number of vehicles*
Madrid	201
Barcelona	117
Valencia	52
Sevilla	45
Zaragoza	45
Málaga	38

Table 62: Results obtained for Problem 2.

By performing a simple addition, it is possible to note that 498 vehicles in total are needed to supply the demand of the population. This is, as it was expected, a similar number to the obtained for the Base Problem.

The following figure shows where the vehicles would be in a map:

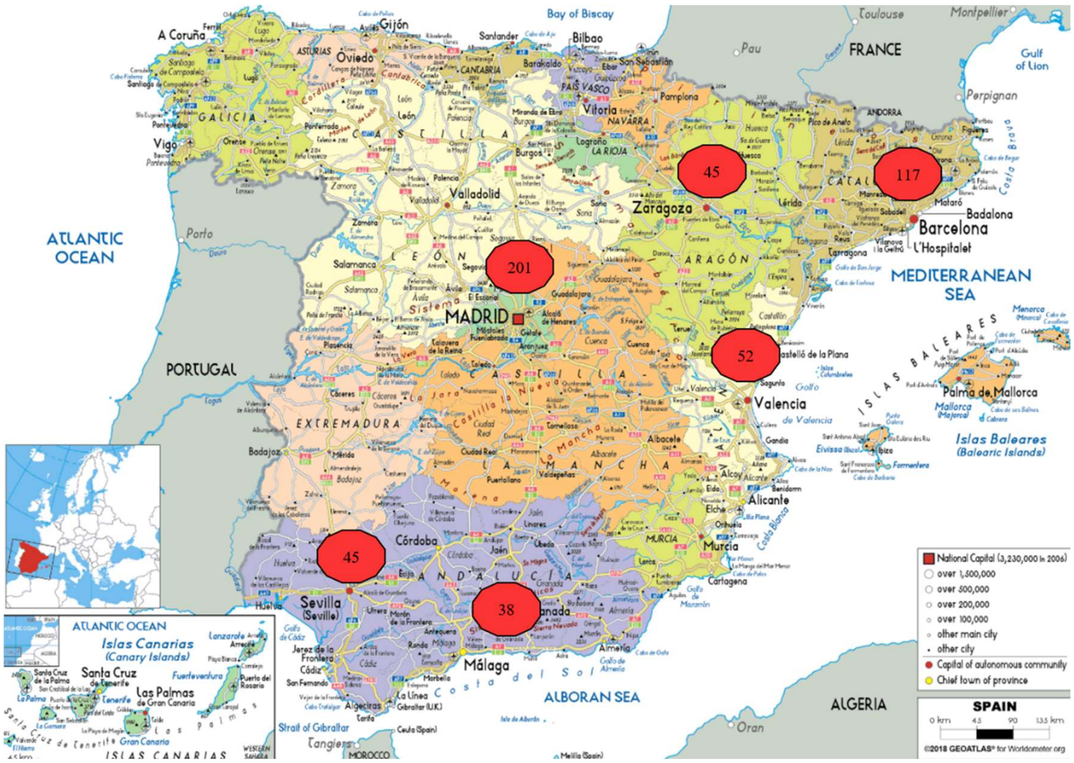

Figure 15: Solution obtained for Problem 2.

The difference between the results obtained for the Base Problem, which serves as a reference, and the results obtained for this problem are shown in the table shown next:

City	***Results for Problem 2***	***Results for the Base Problem***	***Percentage of increase***
Madrid	201	209	-3.83%
Barcelona	117	106	10.38%
Valencia	52	53	-1.89%
Sevilla	45	46	-2.17%
Zaragoza	45	44	2.27%
Málaga	38	39	-2.56%

Table 63: Variation for the results obtained in Problem 2.

The overall variation in the results with respect to the Base Problem was of 3.85%.

As it can be noted, the obtained results do make sense with respect to **¡Error! No se encuentra el origen de la referencia.** Base Problem. The population of cities such as Barcelona or Zaragoza has increased, resulting in an increase of the number of vehicles that are also located in them (from 106 to 117 in the case of Barcelona, and from 44 to 45 in the case of Zaragoza). However, the population of cities like Madrid has been reduced, which also results in a decrease of the number of vehicles located in that city (it went from 209 to 201 vehicles).

5.4 PROBLEM 3

For this problem, the number of vehicles of over 10 years at each city was considered, in addition to the population of each of the cities.

The resolution of this problem was performed in the same way as all previous problems. The total number of vehicles obtained also matches the vehicles that were obtained for the Base Problem.

The following table shows how the vehicles would be distributed:

City	*Number of vehicles*
Madrid	212
Barcelona	102
Valencia	51
Sevilla	48
Zaragoza	44
Málaga	39

Table 64: Results obtained for Problem 3.

The addition of all vehicles is 496 (as in the previous problems, like it was mentioned before).

The distribution of the automobiles is summarized in the map:

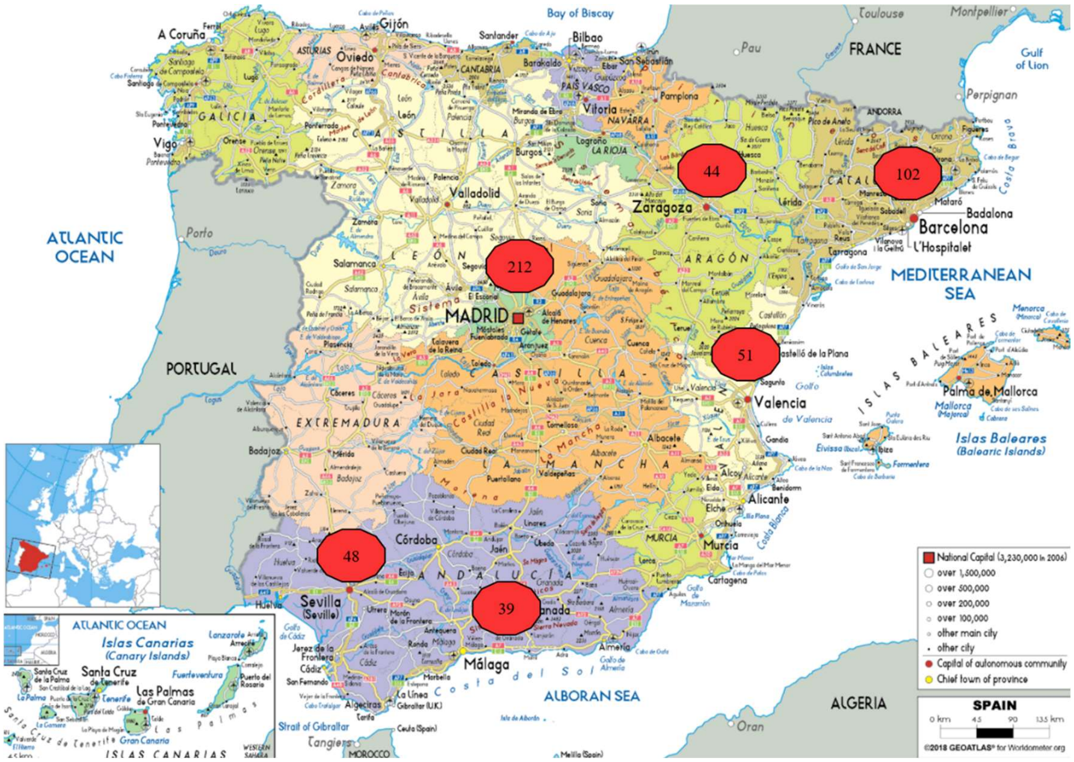

Figure 16: Solution obtained for Problem 3.

The difference between the results obtained for the Base Problem, which serves as a reference, and the results obtained for this problem are shown in the table shown next:

City	***Results for Problem 3***	***Results for the Base Problem***	***Percentage of increase***
Madrid	212	209	1.44%
Barcelona	102	106	-3.77%
Valencia	51	53	-3.77%
Sevilla	48	46	4.35%
Zaragoza	44	44	0.00%
Málaga	39	39	0.00%

Table 65: Variation for the solutions obtained for Problem 3.

The total variation that has been experienced in these solutions is of only 2.22%, accordingly to the small variation that each of the locations has experienced.

The obtained result makes sense as well. As it was mentioned in section, it could be noted that Sevilla was the city with the greatest percentage of vehicles older than 10 years. As a result, the number of vehicles assigned to this city is greater than the numbers that had been obtained for the Base Problem (the number of vehicles went from 46 to 48).

However, for Barcelona, which is the city with the smallest percentage of vehicles that are older than 10 years, this number has reduced, going from 106 to 102. However, as it was previously noted, since the difference between all percentages is not very large, the difference that the distribution of vehicles will experience is not very large either.

One of the main conclusions that can be obtained from the resolution of this problem is that this parameter (the percentage of vehicles that are older than 10 years at each location) does not have a very significant effect on the final solution of the problem.

5.5 PROBLEM 4

For this problem, existing alternative transportation means in each city were considered, in addition to the population of each of the cities.

Once the MATLAB code has been executed, it was possible to obtain the results given in the following table:

City	*Number of vehicles*
Madrid	153
Barcelona	110
Valencia	71
Sevilla	64
Zaragoza	57
Málaga	42

Table 66: Results obtained for Problem 4.

As before, since the total population of all cities is the same as for other problems, 4,936,325, the total number of vehicles that are considered for this problem is the same, 497

The following image shows how the vehicles would be located.

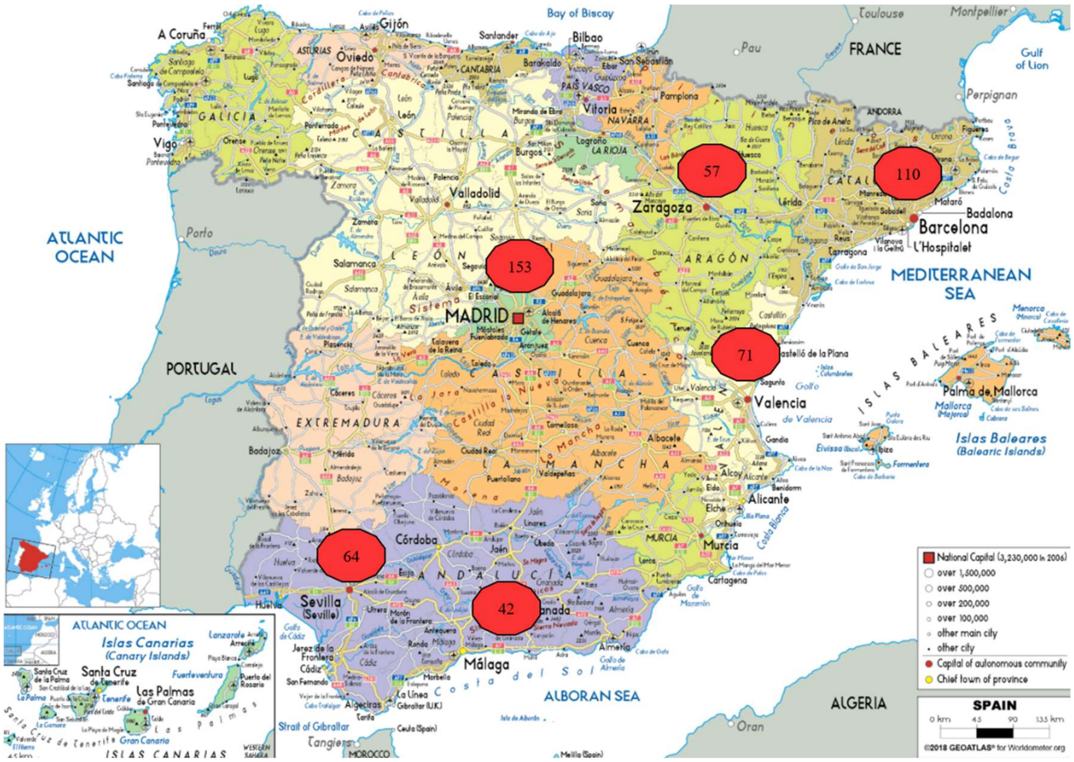

Figure 17: Solutions obtained for Problem 4.

The difference between the results obtained for the Base Problem, which serves as a reference, and the results obtained for this problem are shown in the table shown next:

City	*Results for Problem 4*	*Results for the Base Problem*	*Percentage of increase*
Madrid	153	209	-26.79%
Barcelona	110	106	3.77%
Valencia	71	53	33.96%
Sevilla	64	46	39.13%
Zaragoza	57	44	29.55%
Málaga	42	39	7.69%

Table 67: Variation for the results obtained for Problem 4.

The total variation that has been experienced in the results in comparison with the Base Problem is of 23.48%.

As it can be noted in the final results that have been obtained, the only location where the number of vehicles has been reduced is Madrid. This matches the fact that alternative means of transportation are very centralized in Spain, so they are very accessible from the capital, Madrid. It is because of this that the other cities have experienced an increase in the number of vehicles accordingly.

Cities like Barcelona, with actual large populations, also have a good access to alternative means of transportation (still not as good as Madrid, thought), so have not experienced an increase as large in the number of vehicles assigned.

Additionally, Zaragoza, a city that does not even have an airport, has experienced a large increase in the number of vehicles assigned, although not as large as other locations such as Valencia or Sevilla.

5.6 PROBLEM 5

For this problem, yearly income at each location was considered, in addition to the population of each of the cities.

Once the MATLAB code has been executed, the following results have been obtained:

City	*Number of vehicles*
Madrid	223
Barcelona	111
Valencia	48
Sevilla	42
Zaragoza	39
Málaga	33

Table 68: Results obtained for Problem 5.

A total of 496 vehicles were obtained as a solution for this problem.

To show the obtained results, a more visual display in the form of a map has been done:

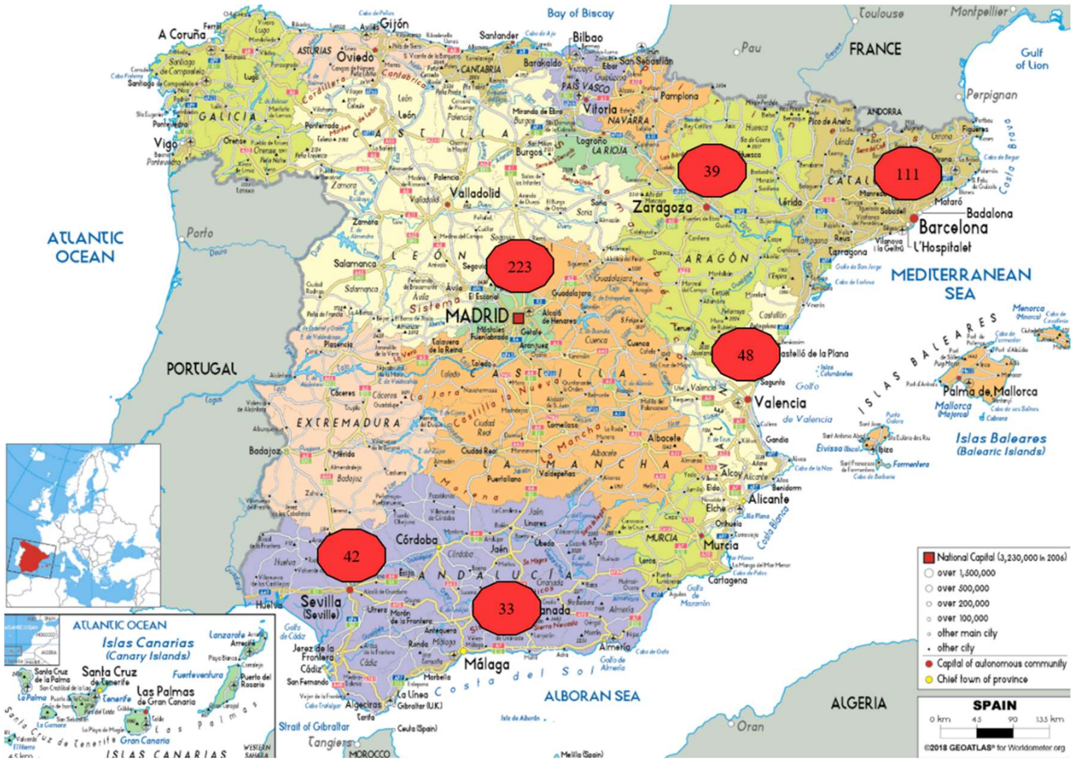

Figure 18: Solutions obtained for Problem 5.

The difference between the results obtained for the Base Problem, which serves as a reference, and the results obtained for this problem are shown in the table shown next:

City	***Results for Problem 5***	***Results for the Base Problem***	***Percentage of increase***
Madrid	223	209	6.70%
Barcelona	111	106	4.72%
Valencia	48	53	-9.43%
Sevilla	42	46	-8.70%
Zaragoza	39	44	-11.36%
Málaga	33	39	-15.38%

Table 69: Variation for the results obtained for Problem 5.

The total variation that has been experienced is of 9.38%.

As it can be noted in this map, the number of vehicles located in Madrid, the city with the greatest yearly income (over 20% higher than the average between the six locations), is significantly larger than the number of vehicles that were located in Madrid in the Base Problem.

However, other locations, such as Málaga, which has an income that is over 15% lower than the average has experienced a significant reduction in the number of vehicles that should be optimally located here.

5.7 PROBLEM 6

For this problem, the number of existing *carsharing* vehicles in each of the cities was considered, in addition to the population of each of the cities.

Once the data has been properly introduced in MATLAB, the obtained solution is the following:

City	***Number of vehicles***
Madrid	213
Barcelona	105
Valencia	52
Sevilla	45
Zaragoza	43
Málaga	38

Table 70: Resolution for Problem 6.

As it can be noted, in this situation, the obtained number of vehicles is 496.

The following map gives a clearer perspective of how the vehicles should be distributed:

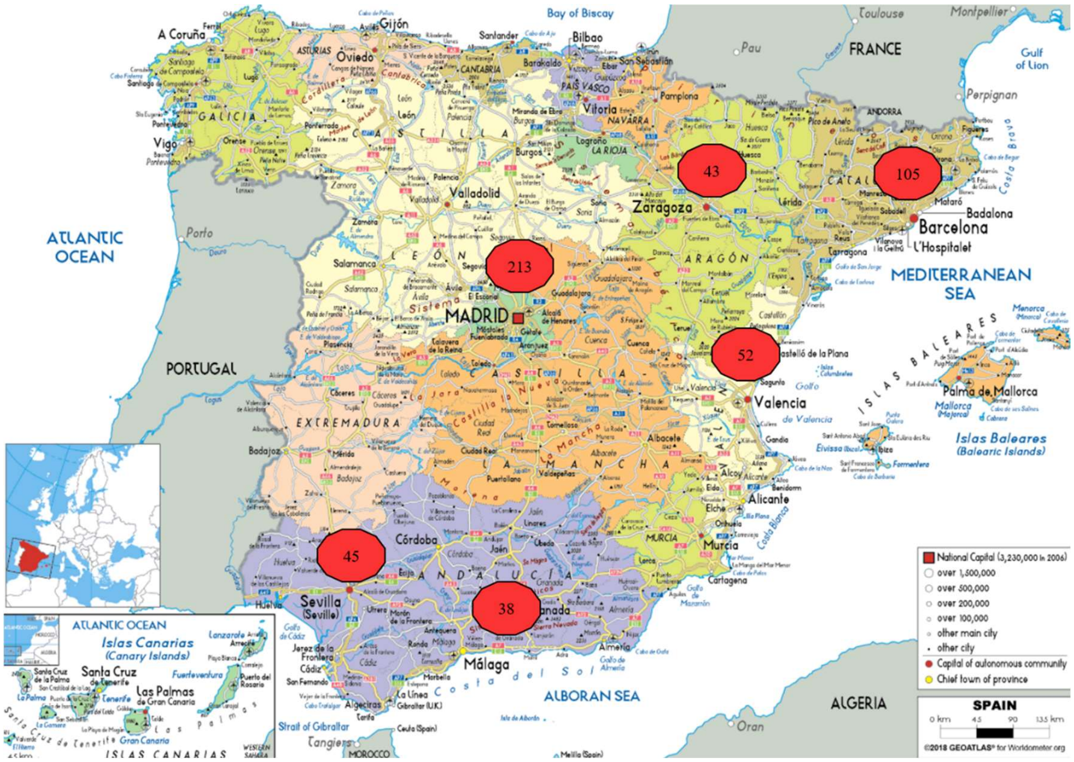

Figure 19: Solution obtained for Problem 6.

The difference between the results obtained for the Base Problem, which serves as a reference, and the results obtained for this problem are shown in the table shown next:

City	***Results for Problem 6***	***Results for the Base Problem***	***Percentage of increase***
Madrid	213	209	1.91%
Barcelona	105	106	-0.94%
Valencia	52	53	-1.89%
Sevilla	45	46	-2.17%
Zaragoza	43	44	-2.27%
Málaga	38	39	-2.56%

Table 71: Variation for the results obtained for Problem 6.

The total variation that has been experienced in the results obtained for the problem is of 1.96%. As it can be noted, the variation is barely noticeable.

However, a slight growth in the assignation of vehicles can be noticed in Madrid, whereas in all other cities, a reduction has taken place for the number of vehicles assigned. This matches the reality, since Madrid is the only city where *carsharing* initiatives have been fully established.

5.8 PROBLEM 7

For this problem, existing electric chargers in each city were considered, in addition to the population of each of the cities.

The MATLAB code has been executed and the following results have been obtained:

City	***Vehicles assigned***
Madrid	172
Barcelona	105
Valencia	52
Sevilla	45
Zaragoza	43
Málaga	38

Table 72: Results obtained for Problem 7.

The total number of vehicles that have been considered for this solution are 497 vehicles, that have been distributed between all the cities. The following map shows the results obtained put into a map:

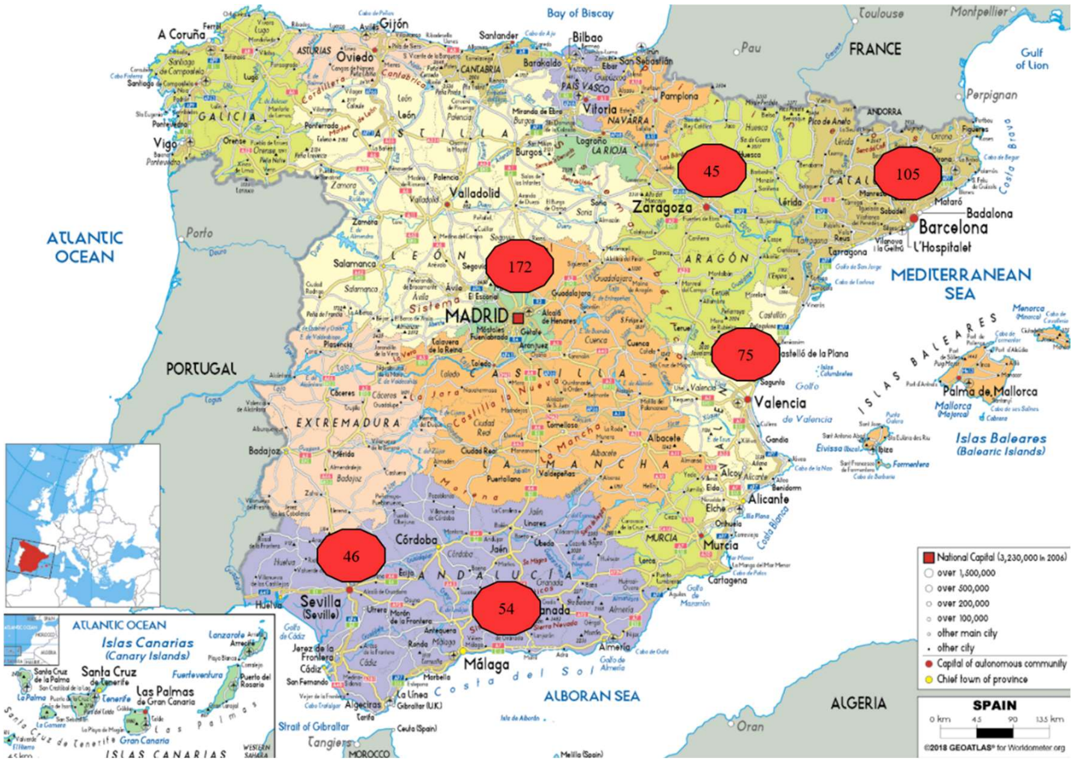

Figure 20: Solutions obtained for Problem 7.

The following table shows the difference between the results obtained for the Base Problem, which is treated as the reference, and this problem:

City	*Results for Problem 7*	*Results for the Base Problem*	*Percentage of increase*
Madrid	172	209	-17.70%
Barcelona	105	106	-0.94%
Valencia	75	53	41.51%
Sevilla	46	46	0.00%
Zaragoza	45	44	2.27%
Málaga	54	39	38.46%

Table 73: Variation for the solution obtained for Problem 7.

The overall variation that has been experienced in this problem is of 16.82% in comparison with the results for the Base Problem.

The city of Valencia, which is the one that has the least number of vehicles per charger, has experienced a large increase in the number of vehicles assigned to it (from 53 to 75).

Málaga has also experienced a great growth in the number of vehicles assigned, going from 39 to 54.

It should also be noted that the number of vehicles assigned in Sevilla has stayed the same.

5.9 PROBLEM 8

For this problem, existing electric chargers between city were considered, in addition to the population of each of the cities.

The results that have been obtained once MATLAB has been executed are the following

City	*Number of assigned vehicles*
Madrid	208
Barcelona	110
Valencia	54
Sevilla	45
Zaragoza	43
Málaga	37

Table 74: Results obtained for Problem 8.

497 vehicles are considered for this problem in total. The results are also shown in a map.

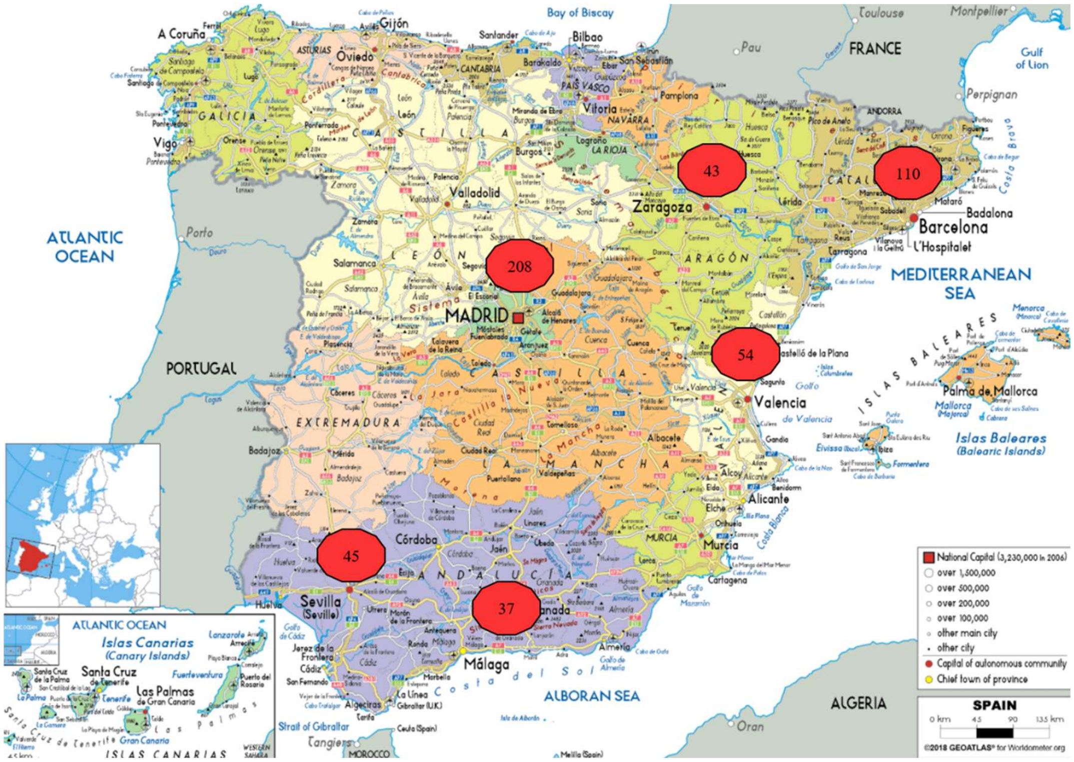

Figure 21: Solution obtained for Problem 8.

In order to be able to obtain a clear understanding of what has happened, at each city, the increase will be looked at in terms of percentages as shown in the table provided below:

City	***Results for Problem 8***	***Results for the Base Problem***	***Percentage of increase***
Madrid	208	209	-0.48%
Barcelona	110	106	3.77%
Valencia	54	53	1.89%
Sevilla	45	46	-2.17%
Zaragoza	43	44	-2.27%
Málaga	37	39	-5.13%

Table 75: Variation for the results obtained for Problem 8.

The total variation that the results of the problem have experienced is of 2.62%.

As it can be seen in the results obtained, Barcelona is the city that has experienced the greatest growth in the distribution of vehicles (going from 106 to 110 automobiles). Málaga is, however, the city with the greatest reduction of vehicles.

Although it was not possible to determine which were the cities that were going to experience a decrease on the number of vehicles assigned to them, it is easy to notice that the ratio of kilometers per charger was good in journeys such as Barcelona to Valencia, whereas it was very high on other trips, such as the trip from Sevilla to Málaga. Although these two ratios do not directly have an impact on the number of vehicles assigned, they are very representative of the final distribution. For instance, Barcelona and Valencia are the only cities that have experienced an increase in the number of vehicles assigned, whereas Sevilla and Málaga are the cities that have experienced the largest decrease.

5.10 PROBLEM 9

For this problem, the number of tourists received in each city in the year 2019 was considered, in addition to the population of each of the cities.

After introducing the population into de MATLAB code that had previously been formulated, the obtained results are:

City	*Number of assigned vehicles*
Madrid	183
Barcelona	139
Valencia	59
Sevilla	49
Zaragoza	35
Málaga	32

Table 76: Results obtained for Problem 9.

497 vehicles were considered for as the total number of vehicles for this problem. Similarly to previous problems, the results will be looked at in a map:

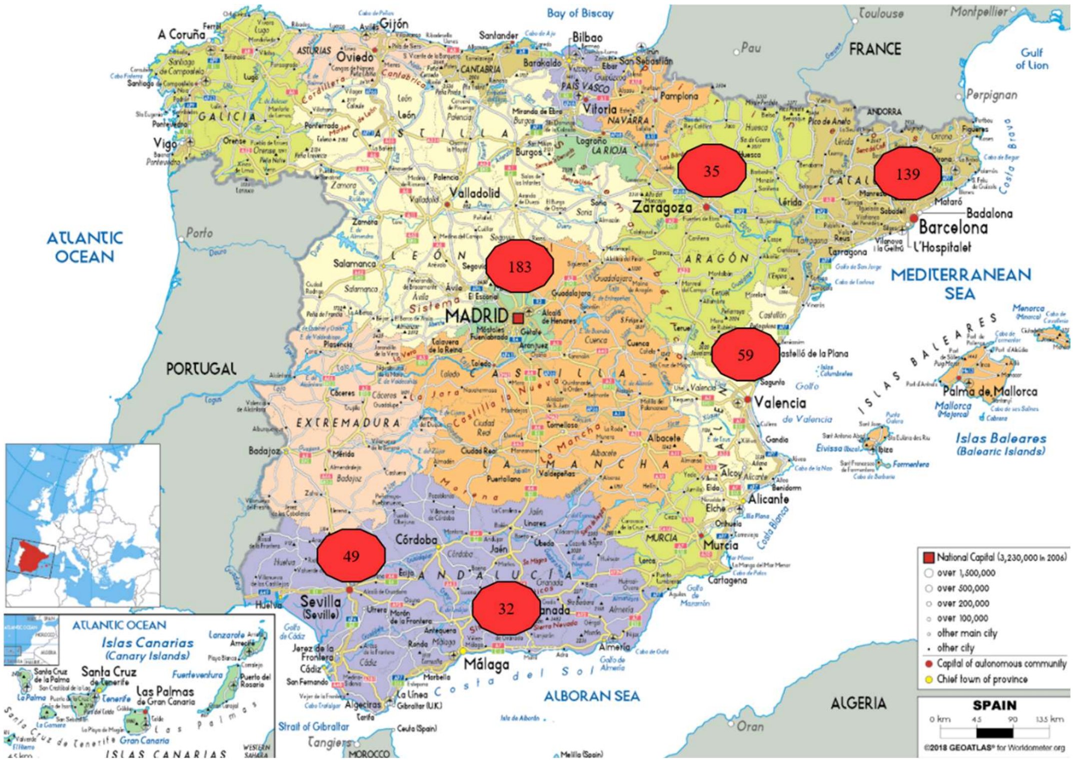

Figure 22: Solution obtained for Problem 9.

In order to be able to obtain a clear understanding of what has happened, at each city, the increase will be looked at in terms of percentages as shown in the table provided below:

City	*Results for Problem 9*	*Results for the Base Problem*	*Percentage of increase*
Madrid	183	209	-12.44%
Barcelona	139	106	31.13%
Valencia	59	53	11.32%
Sevilla	49	46	6.52%
Zaragoza	35	44	-20.45%
Málaga	32	39	-17.95%

Table 77: Variation for the results obtained for Problem 9.

The total variation that has been experienced in the solutions of this problem is of 16.64%.

As it can be seen, Barcelona is the city that has experienced the greatest growth of vehicles assigned (from 108 to 155). This matches the impressions obtained from the information that was obtained, where Barcelona was by far the city with the greatest population.

5.11 SUMMARY OF RESULTS

All the results that have been obtained are shown in the following table:

City	*Base*	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*P9*
Madrid	209	224	201	212	153	223	213	172	208	183
Barcelona	106	84	117	102	110	111	105	105	110	139
Valencia	53	57	52	51	71	48	52	75	54	59
Sevilla	46	33	45	48	64	42	45	46	45	49
Zaragoza	44	71	45	44	57	39	43	45	43	35
Málaga	39	27	38	39	42	33	38	54	37	32

Table 78: Summary of all results obtained for the Initial Problem Formulations.

Additionally, to obtain a clearer evaluation of the results at each of the cities, individual graphs of the results have been made:

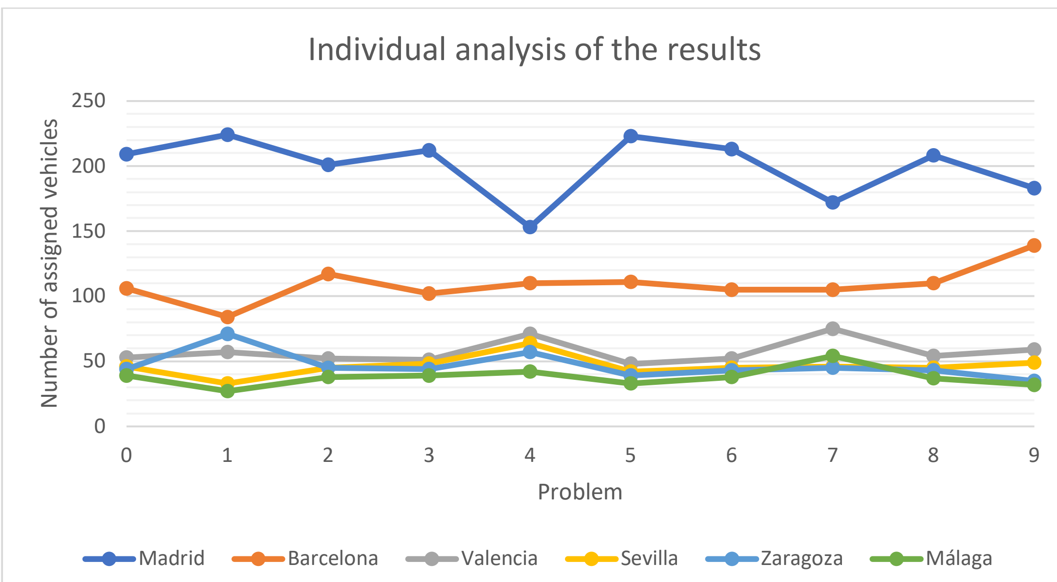

Figure 23: Graph displaying all results that were obtained for the problem formulations.

Problem 0, which is displayed in the graph, shows the result that was obtained for the Base Problem.

It can be pointed out that as expected, Madrid, which is shown in dark blue in the graph is always the city that has the greatest number of vehicles assigned. This was an expected result, due to the difference between populations that exists between Madrid, and all the other locations. Although Barcelona is also a city with a large population, it never reaches the population of Madrid.

However, as it can be seen, the obtained result is not consistent: the variation between results is very large. It can be concluded that the number of vehicles that are assigned to the city of Madrid are very dependent of the parameters that can be used to determine the distribution of vehicles. For instance, in Problem 1 the value that it acquires is 224, whereas in Problem 4 it only has the value of 153.

Barcelona can also be marked as one of the locations with the highest number of vehicles. The main difference that may be noted from the results obtained for Madrid, and obtained for Barcelona, aside from the values themselves, is that Barcelona stays much more consistent: the graph obtained is almost a straight line from Problem 2 to Problem 7, which means that the results obtained for each of the problems are very similar: the parameters that can be used do not have a great effect on the results obtained.

Aside from Madrid and Barcelona, not much difference can be noted from the solutions obtained in the other cities. All of them stay in a very similar range and do not experience great variations.

Additionally, to add even more statistical information to the problem, a whiskers plot has been obtained, which will show the dispersion and the range of the solutions that have been obtained for each city.

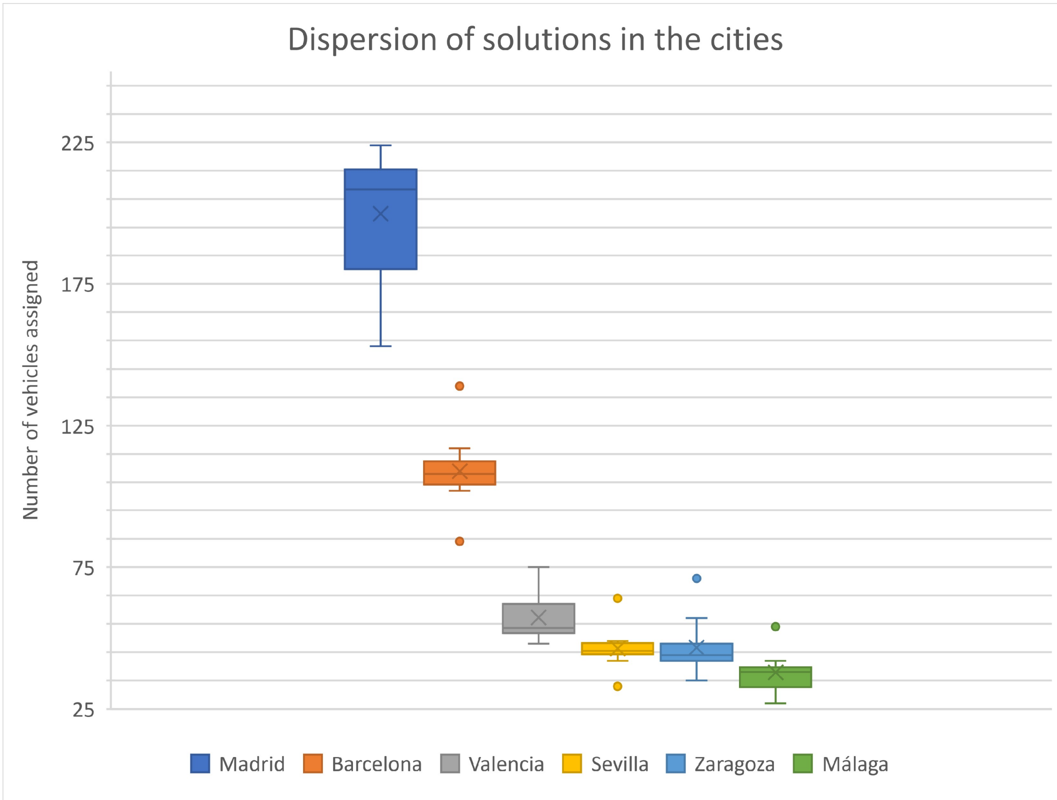

Figure 24: Whiskers plot for the solution obtained for all problems.

As it can be seen in the plot, Madrid and Barcelona are the cities that have the greatest spread in the results obtained. More particularly, Madrid is the one with the greatest dispersion in the number of vehicles assigned, which as it was previously stated, go from 153 to 224.

Additionally, a summary of statistical elements that can be pointed out from the whiskers plot has been made in the following table:

City	***Quartile 1***	***Median***	***Quartile 3***	***Interquartile range***	***Min***	***Max***	***Range***	***Average***
Madrid	187.50	208.5	212.75	25.25	153	224	71	199.8
Barcelona	105.00	108	110.75	5.75	84	139	55	108.9
Valencia	52.00	53.5	58.5	6.50	48	75	27	57.2
Sevilla	45.00	45.5	47.5	2.50	33	64	31	46.3
Zaragoza	43.00	44	45	2.00	35	71	36	46.6
Málaga	34.00	38	39	5.00	27	54	27	37.9

Table 79: Statistical data for the results of the problem.

From this whiskers plot, it is important to note the lack of spread in the results obtained for Valencia, Sevilla, Zaragoza and Málaga. Although they experienced some dispersion in the solution, in comparison to the dispersion experienced in other cities, such as Madrid, is minimal.

Additionally, Barcelona, Sevilla, Zaragoza, and Málaga had some abnormalities. For all of them, a value above the maximum spread considered was obtained: Barcelona had 139 vehicles assigned in Problem 9 and 84 vehicles assigned in Problem 1; 64 vehicles were assigned in Sevilla for Problem 4; 71 vehicles were assigned to Zaragoza in Problem 1; and 54 vehicles were assigned to Málaga in Problem 7.

Málaga was overall the city that had the least number of vehicles located.

6. FINAL ADD-UP

In this section, the final problem will be put together. The formulation of the problem will be put together, and the parameters that were looked at in previous sections will be ranked in order of relevance, to determine which are the factors that are more critical to the optimization problem.

All the parameters that have been used throughout the project were treated so that they generated different values for the population, which was corrected, so that it would add up to the total population considered in these 6 cities. Those values for the population will be introduced in the MATLAB code and generate a solution.

Ultimately, the final problem is going to have an equal formulation to all the previous problems, since it aims to solve the same problem. However, the issue comes when deciding what should be the values of population that are introduced into the MATLAB code.

The objective function for this problem, will also be given by:

$$minimize \sum_{n=1}^{6} x_n$$

The problem will also be subject to:

$$x_n \geq 5$$

and

$$p_n \geq 10{,}000\, x_n \quad \forall\, n = 1 \ldots 6$$

Therefore, the only change that this problem has experienced, compared to the other problems that were formulated and solved in previous sections, was be the population that was introduced into the problem.

For starters, to make up a new value for all the populations, a criterion needed to be made up so that the relevant parameters can be distinguished from those that are not relevant.

The main indicator of the change that the solution of the problem experiences was the percentage obtained to compare the obtained solution with the solution obtained for the Base Problem, as it was shown in the previous section for each of the problems. However, to decide whether the parameter has an effect that is important enough on the final problem or not, the average percentage of the variation at all cities will be calculated.

The following table shows the variations experienced at each of the problems:

Problem	*Variation*
Problem 1	25.98%
Problem 2	3.85%
Problem 3	2.22%
Problem 4	23.48%
Problem 5	9.38%
Problem 6	1.96%
Problem 7	16.82%
Problem 8	2.62%
Problem 9	16.64%

Table 80: Percentage of variation of the results obtained in each problem.

These percentages give enough information to understand how big is the effect of each parameter that was used. For instance, Problem 6 (in which the number of *carsharing* vehicles at each location is considered), is the one that causes the smallest variation, only a 1.96% of the initial values that were obtained. However, Problem 1 (in which the distances between cities are looked at), is the one that causes the greatest variation, a 25.98%.

The criterion that has been decided for this matter is a representation of this variation. Since the variation that each parameter caused on the formulation of the problem was obtained, it was chosen that this percentage would also be the ponderation that the population obtained for the problem would have.

This process is shown step by step in the following paragraphs.

For starters, the percentages needed to be corrected: the total percentage that was obtained by adding all of percentages was 102.95%. However, it needs to add 100%, so it will have to be corrected.

Problem	*Original percentage*	*Corrected percentage*
Problem 1	25.98%	25.24%
Problem 2	3.85%	3.74%
Problem 3	2.22%	2.16%
Problem 4	23.48%	22.81%
Problem 5	9.38%	9.11%

Problem 6	1.96%	1.90%
Problem 7	16.82%	16.34%
Problem 8	2.62%	2.54%
Problem 9	16.64%	16.16%

Table 81: Corrected percentage of variation for the results obtained for each problem.

As it can be seen, the obtained percentages now add up to 100%, as it is required for the final problem.

A table summarizing all the populations that were obtained for all problems will now be provided.

Problem	***Madrid***	***Barcelona***	***Valencia***	***Sevilla***	***Zaragoza***	***Málaga***
P1	2,236,551	834,323	569,078	326,467	700,257	269,649
P2	2,005,719	1,162,319	510,037	440,743	443,222	374,284
P3	2,115,278	1,019,716	508,619	472,656	432,493	387,563
P4	1,525,467	1,093,037	703,612	634,468	568,913	410,828
P5	2,221,703	1,107,608	479,965	414,172	384,575	328,302
P6	2,120,314	1,049,714	515,155	449,104	425,400	376,638
P7	1,712,174	1,040,295	748,535	455,515	446,690	533,117
P8	2,072,916	1,097,718	531,798	446,357	422,158	365,377
P9	1,821,981	1,389,136	581,065	487,045	342,314	314,784

Table 82: Corrected population that was used for each problem.

Now the population of each city in every problem will be multiplied by the percentage that was obtained in the previous table, as shown in the following formula:

$$p_n^{final} = \sum_{i=3}^{11} W_i p_n^i$$

Where W_i is the percentage that will be applied to the population of Problem i, and p_n^i the population of city n in Problem i.

By applying this formula, it is possible to obtain the following population.

City	***Population***
Madrid	1,902,714

Barcelona	1,068,623
Valencia	617,412
Sevilla	464,555
Zaragoza	514,559
Málaga	368,462

Table 83: Weighted population for the final problem.

This gave out the array:

$$p_n = [1{,}902{,}714\ \ 1{,}068{,}623\ \ 617{,}412\ \ 464{,}555\ \ 514{,}559\ \ 368{,}462]$$

To observe the difference between the population that was obtained and the original population at each city, a table of comparison has also been made up, which includes the percentage of difference between both populations:

City	***Population for the problem***	***Original population***	***Variation***
Madrid	1,902,714	2,085,675	-8.77%
Barcelona	1,068,623	1,058,000	1.00%
Valencia	617,412	521,816	18.32%
Sevilla	464,555	457,455	1.55%
Zaragoza	514,559	430,029	19.66%
Málaga	368,462	383,350	-3.88%

Table 84: Variation of the population for each city.

The average of the absolute value of the variations has been obtained, which gives out 8.42%

As it can be seen, only the populations of Madrid and Málaga have been reduced. Zaragoza, on the other hand, is the city that has experienced the greatest growth of population (19.66%). All other locations have also experienced growths, although not as great.

7. FINAL RESOLUTION OF THE PROBLEM

The p_n array was introduced in the MATLAB code and executed. The following results were obtained:

City	***Final solution***
Madrid	191
Barcelona	107
Valencia	62
Sevilla	47
Zaragoza	52
Málaga	37

Table 85: Result obtained for the final problem.

The distribution of vehicles has been put into a map to ensure a clearer understanding:

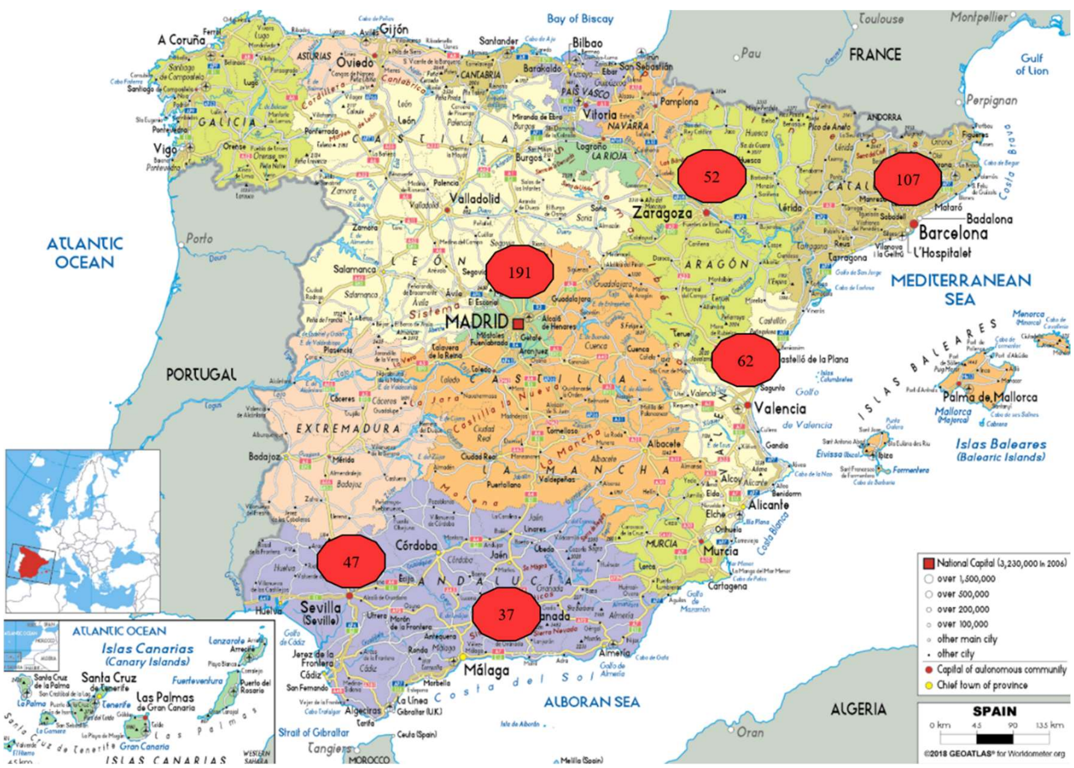

Figure 25: Solution obtained for the final problem.

The variation that has been experienced from the results obtained for the Base Problem to these results is also shown in the following table:

City	*Results for Final Problem*	*Results for the Base Problem*	*Percentage of increase*
Madrid	191	209	-8.61%
Barcelona	107	106	0.94%
Valencia	62	53	16.98%
Sevilla	47	46	2.17%
Zaragoza	52	44	18.18%
Málaga	37	39	-5.13%

Table 86: Variation for the results obtained for the final problem.

The average of variation that has been obtained is 8.67%. As it can be seen, Madrid and Málaga, that were the only locations where the population had decreased, are the only cities where the number of vehicles assigned has also been reduced.

Additionally, Zaragoza, which was the city where the population had increased the most, is also the city where the number of vehicles assigned has increased the most.

In the final problem that has been formulated, the population that has been obtained is originated, in order of priority from: the distance between locations, the alternative transportation means at each city, the number of EV chargers existing at each location, the number of tourists visiting each year, the yearly income per person at each location, the number of existing vehicles at each location, the number of EV chargers existing between cities, the number of vehicles older than 10 years at each city, and finally, the number of existing *carsharing* vehicles at each location.

8. ECONOMIC ANALYSIS

In this section of the project, an economic analysis of the development of the initiative has been included. A study of the viability of the problem has been performed to determine what the incurred costs of the implementation of the platform would be.

The section is divided into different subsections, where each of the topic that need to be considered for a correct evaluation of the problem are treated. It is important to remark, however, that all evaluations that have been performed in this section are hypothetical, and based on other experiences.

The platform will be working 365 days a year, 24 hours a day, so there will be an absolute availability of the vehicles at any time.

8.1 VEHICLES AND INITIAL EXPENSES

The selected vehicles for the implementation of this platform will be preferable electric. This initiative aims to contribute to the development of a more sustainable environment, so it would be ideal that these kinds of vehicles were the selected ones to be implemented in the initiative.

However, electric vehicles present a huge inconvenient when travelling long distances: the mileage. Although the field of batteries is in continuous improvement, there is still a long way to go until mileages are similar to combustion automobiles.

One of the big inconveniences would therefore be the need of users to recharge their batteries at least once in all trips.

A SWOT analysis has been presented, to cover all positive and negative aspects of the selection of electric vehicles:

Figure 26: SWOT analysis of the implementation of electric vehicles. Source: elaborated by the author.

Additionally, one of the strengths when selecting any of the three fist scenarios would be the availability of exclusive Tesla chargers, and especially the Tesla Superchargers. Tesla superchargers allow EV vehicles to charge to up to 250 kWh (TESL20). This service has a price of 0.29 €/kWh in Spain (for instance, the Tesla Model 3 SR Plus has 75 kWh of battery) (TESL20).

In this section, a particular vehicle is not selected. However, a list of the electric vehicles with the highest mileage is provided below, together with their market price. This list will include vehicles from highest mileage to smallest:

Vehicle	*Mileage*	*Market price*
Tesla Model S	539 km	80,180 €
Tesla Model X	474 km	85,980 €
Hyundai Kona	415 km	40,000 €
Tesla Model 3 SR Plus	409 km	48,200 €

Table 87: Four electric vehicles with the greatest mileage. Source: GORZ19.

The vehicles that have been listed are all high-end vehicles. They need to be big enough that travelling on them is comfortable and safe enough while ensuring a good mileage.

As it can be noted, the Tesla Model S is the vehicle with the largest mileage right now. However, it is also the second most expensive vehicle. However, in all cases, mileage would not be enough to cover trips such as Madrid to Barcelona, with over 600 km of distance. Users would then need to charge their vehicles halfway into the trip.

Additionally, it should be noted that in most *carsharing* platforms, automakers also contribute to their implementation, generally by lowering the price of vehicles to make them more accessible. The market price that has been listed is therefore higher than the actual price that vehicles would have. Especially when considering that 497 vehicles would be needed to cover the demand that has been established.

In the existing vehicles, it has been seen that by receiving help from carmakers, prices for vehicles have gone from 24,000 € to 15,000 €. This would be a 37.5% of discount when it came to the purchase of vehicles (BERN18).

In this project, the same reduction of price has been considered. A table has been included, containing the calculated price for each vehicle:

Vehicle	***Mileage***	***Reduced price***
Tesla Model S	539 km	50,513.40 €
Tesla Model X	474 km	54,167.40 €
Hyundai Kona	415 km	25,200.00 €
Tesla Model 3 SR Plus	409 km	30,366.00 €

Table 88: Reduced price for the four vehicles with the greatest mileage.

The cost of these vehicles would be considered as part of the initial investment that is performed in every project.

Four different scenarios have been considered, in which the initial investment of the project changes because of the change in the selected vehicle.

Scenario	***Vehicle used***	***Initial Investment in vehicles***
1	Tesla Model S	25,105,159.80 €
2	Tesla Model X	26,921,197.80 €
3	Hyundai Kona	12,524,400.00 €
4	Tesla Model 3 SR Plus	15,091,902.00 €

Table 89: Initial investment for the scenarios that have been suggested.

As it can be seen, the lowest initial investment would be given by the 4th scenario, where the Hyundai Kona is selected as the best vehicle, whereas the most expensive one would be given by the 3rd scenario, where the Tesla Model X would be selected.

Although the greatest part of initial expenses is accounted in the purchase of the vehicles, it should also be noted that the purchase of licenses and permissions would also require an investment, together with the development and launch of the app or platform that would allow customers to make use of the service.

These costs, however, are not considered, in this project, due on the one hand to the lack of data, but mainly because these costs could be considered negligible in comparison with the cost of the vehicles.

8.2 FARES

The price of the service would be automatically calculated when the user ends the trip.

For starters, once the customer starts the service, he would have to select a destination for the trip. Depending on that destination, a different fare would be applied. The app would locate all existing vehicles and compare their distribution to how the optimal distribution should be.

Based on the differences, it would be determined where each vehicle would optimally go, so that the optimal number of vehicles is reached. This assignation of vehicles will always be pursued.

This method is similar to what some bike rental platforms do. For instance, to avoid having to move all bikes from a part of the city to another part, users are rewarded if they take the bikes from a station with over 70% of occupancy and leave it in one with less than 30% of occupancy. This way, the direction of the displacement is encouraged, and the desired location of the vehicles can be reached (PICA14).

8.3 PERSONNEL AND YEARLY EXPENSES

To follow legal regulations, and to ensure the safety of customers, all vehicles need to have an insurance that covers them.

For instance, free floating *carsharing* vehicles currently include an all coverage insurance with a deductible of 500 € (BERN18).

The insurance included in these vehicles would be similar. However, the cost of this service for high range vehicles would be greater than the cost that these companies incur.

Some companies, such as Wible, directly add the cost of the insurance to the price of their service. For instance, when the receives the bill, there is a section covering the insurance (WIBL18).

From what has been noted, these kinds of insurances would cost about 600 € per year and per vehicle (RAST20). It is not possible to determine whether this would be the real cost incurred, since other characteristics would have to be considered, such as the fact that these vehicles would not always have the same driver, that their conduction would not be very uniform, or that the service would be purchased for a large volume of vehicles.

Additionally, costs related to personnel, although not being the main cost incurred, would take for a big part of the yearly expenses.

People need to work in the company to ensure everything happens as it would be expected: the vehicles are in good conditions, the technological part of the initiative works accurately and is in constant development, users always have assistance when needed…

The fact that the vehicles are spread throughout the whole country means that employees should also be spread around the six cities that have been selected.

In other free-floating *carsharing* initiatives, it has been recorded that there are 150 employees, that receive a payment of 30,000 € every year. Since the floats of vehicles are very similar (of around 500 vehicles), the same costs would be considered for this initiative (BERN18).

Additionally, these workers need to spend 200 € on each vehicle per month on maintenance (mainly on the cleaning of the vehicle) (BERN18).

Origin of the cost	***Cost incurred***
Insurance	3,578,400 €/ year
Personnel	4,500,000 €/year
Maintenance	1,192,800 €/year

Figure 27: Yearly expenses of the initiative. Source: BERN18.

Costs derived from the recharge of the vehicles are not considered in this section. They have been counted as part of the cost that the user will have to cover.

8.4 LOSS OF VALUE OF THE ASSETS

To avoid a very critical lost of value in the assets of the company, vehicles need to be sold as fast as possible. For every year that vehicles are still circulating, they lose value.

Additionally, because of the use that these vehicles would receive, with various drivers and long trips, the condition at which they would be sold would be worse than that of a regularly used vehicle.

Free-floating *carsharing* vehicles are usually sold after only 5 years of use. Additionally, it has been known, that it is reasonable to consider that if the market price of these vehicles is of around 24,000 €, they are sold for about 10,000 € (BERN18). This would mean that the vehicles are sold for 41.6% of their original market price.

The same criterion has also been applied for the electric vehicles that have been selected for this initiative. The results for each of the vehicles are shown in the following table, together with the total amount that would be recovered (for the 497 vehicles):

Vehicle	*Price of sale*	*Total recovery*
Tesla Model S	21,047.25 €	10,460,483.08 €
Tesla Model X	22,569.75 €	11,217,165.57 €
Hyundai Kona	10,500.00 €	5,218,499.92 €
Tesla Model 3 SR Plus	12,652.50 €	6,288,292.40 €

Table 90: Amount recovered from the sale of the assets.

As it can be seen in the table, the loss of value that the vehicles would experience after only five years would not be very severe. This is the reason why this would be the selected period of time to perform the sale.

8.5 EXPECTED INCOME

In this section, the cashflow that is expected each year has been calculated. Because after only 5 years all assets would be sold, the calculations have only been made for a 5-year period.

Because of the novelty of this initiative, it would not be expected that the year the service is launched the income is the same as in the final year considered. Additionally, to gain spread between the public, it would be necessary to launch promos and discounts during the first year. For instance, companies such as Zity or Wible allowed their users to register for free during a short period of time when they were first launched.

Since free-floating *carsharing* was first launched in the world. the number of users has made nothing but grow. The following graph shows the millions of users of *carsharing* platforms all over the world.

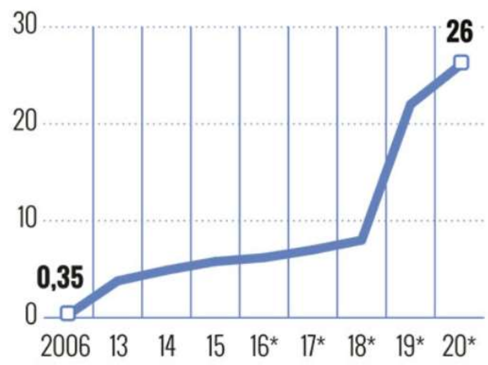

Figure 28. Millions of carsharing *users in the world. Source: FOMB18.*

Note that in the graph that has been provided, data from the years that are accompanied of an asterisk has been estimated.

However, a very large growth can be noted since its origins. Since free-floating *carsharing* initiatives are already very well established in some regions, it could be expected that this initiative would not require such a long time to generate profits.

An estimation needs to be made to determine what the growth of the initiative will be each year. For the provided graph, it can be seen that in the year 2013, there were approximately 3 million users. However, in year 2015, that number had grown to be 5.5 million approximately. This means that a 83% growth was experienced in two years, while the product was still being started (41.5% every year).

From this point, the line gets a smaller slope, going from 5.5 to 7.5 approximately from 2015 to 2018. This growth represents a 36.36% for the 3-year period (12.12%).

The same growth has been considered for this project: the first two years, a growth of 41.5% will be experienced every year, whereas the last three years, a growth of only 12.12% will take place.

Once this estimation has been made, the next thing that has been done is to calculate the inflation that would take place during the next 5 years. In order to do so, it will be necessary to look at values from previous years.

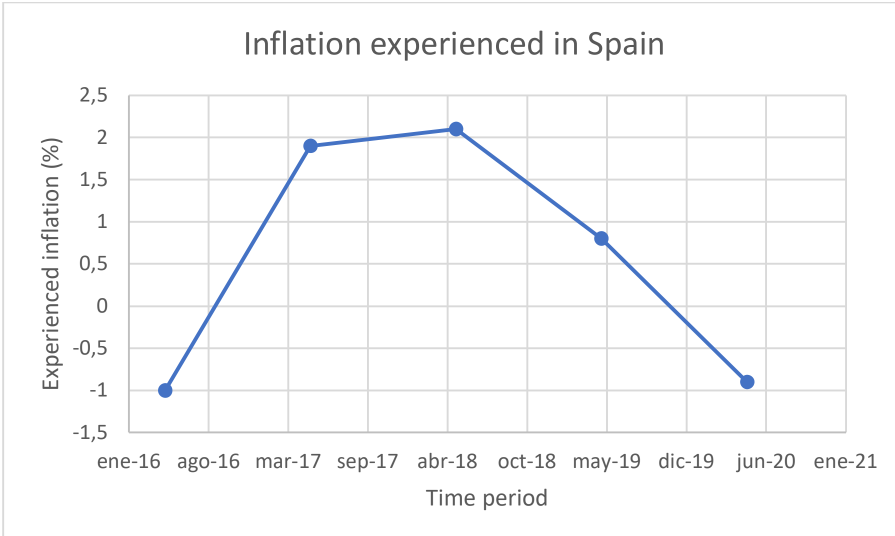

Figure 29: Inflation experienced in Spain in the last 5 years. Source: INE20.

The data has also been obtained in form of a table. the numerical values, although not as visual, will help to calculate the estimated inflation that will be experienced in the upcoming years:

Time period	05.15-05.16	05.16-05.17	05.17-05.18	05.18-05.19	05.19-05.20
Variation experienced	-1.0%	1.9%	2.1%	0.8%	-0.9%

Table 91: Inflation experienced in Spain in the last 5 years. Source: INE20.

As it could be seen, the data that has been looked at is from the previous 5 years.

Because no information is available whatsoever on what will be the changes taking place in the CPI (Consumer Price Index), the average of these past 5 years has been calculated and assumed to be the variation that will be experienced every upcoming year.

It should be noted that due to the COVID-19 crisis, it is predicted that a large variation will be experienced. Due to a lack of existing historic data, it is not possible to know what the real effects will be, so they will not be considered.

Additionally, this makes sense because of the tendency of these past years. Because of the currently existing EU policies, the euro has experienced minimal changes in its value in the past years.

Overall, the inflation that has been considered will be 0.58% yearly.

This inflation has been applied on the yearly costs (vehicle insurances, wages, and maintenance of the vehicles), but also on the yearly income that the company receives.

The cashflow for each year is going to be calculated for each of the scenarios that has been set.

Because the income that this service is not yet known, it all the calculated values are negative. The necessary income for each of the scenarios has been calculated in the following section, in order to determine whether the project is viable or not.

Note that the purpose of developing this yearly cashflow is to find out what should be the yearly income that the company receives to recover the initial investment.

In order to find out this value, the Net Present Value has been equaled to zero:

$$NPV = -I_0 + \frac{F_1}{(1+i)} + \frac{F_2}{(1+i)^2} + \frac{F_3}{(1+i)^3} + \frac{F_4}{(1+i)^4} + \frac{F_5}{(1+i)^5} = 0$$

The initial investment for this project has already been calculated: The cost of purchasing the vehicles. However, both the discount rate (i) and the yearly cashflow (F_n) are unknown and need to be calculated.

The calculation of the discount rate has been performed first. The calculation of this rate is not certain, This follows the following equation:

$$WACC = RFR + k_e$$

Where each of the terms means the following thing:

- RFR: Risk Free Rate. This number represents the minimal rentability that is expected of the project to recover the costs. To simplify the calculations, it is going to be assumed that the full initial investment is loaned, with an interest that matches the Euribor plus an additional 1%. This would represent today a 0.88% of interest in the project. Therefore,
  $$RFR = 0.88\%$$
  The reasoning behind this number is based on the current value of treasure bills, which have traditionally been considered as risk free rates. However, due monetary measures that have been taken by central banks, it has been found that these rates are now in negative values, which does not adjust to the reality of this project.
  Therefore, a positive value, which can be considered reasonable has been adopted.
- k_e: Cost of capital. This additional percentage needs to be added to cover for the incertitude generated by the project. Because this project is a new initiative, and because previous similar projects have been proven to not be very successful, investors expect to receive a high remuneration of the invested capital. The formula that has been applied to obtain this value is the following.
  $$k_e = BI\ (R_m - R_f)$$

In this formula, the BI represents the return of the market, and (R_m-R_f) the Market Premium.

The BI has been considered to have a value of about 10%, which is approximately the return required for very leveraged projects, such as financial services, or this one.

The value that has been selected for the (R_m-R_f) is 1.8%, which means that BI will be incremented on an 80%. As it was previously said, this matches the nature of this project, where a lot of uncertainty is accounted for.

$$WACC = 0.88\% + 10\% \cdot 1.8\% = 18.88\%$$

This rate of discount is, however, not yet adapted to the inflation. It has been modified to take it into consideration by using the following formula:

$$i = WACC + g + WACC \cdot g = 18.88\% + 0.58\% + 18.88\% \cdot 0.58\% = 30.41\%$$

As it was previously mentioned, the inflation that has been considered for the upcoming five years is of 0.58%

Finally, the rate of discount that has been considered for all problems is therefore 30.41%.

However, the cashflows are discounted semester-wise to reduce the error accounted for. Because of this, the rate of discount that was obtained, which was a yearly rate of discount, had to be converted into a half-yearly rate of discount. The following formula has been used:

$$(i + 1)^2 = (1 + 30.41\%)$$

$$i = 14.20\%$$

The next step in order to calculate the income needed in each scenario, was to calculate the yearly cashflows for each project.

The tables provided below show the calculation of each of these cases. The formulae for the calculation of the income have also been added. However, the values obtained are shown in the next section, in order to be able to show a good comparison between all results obtained.

	Year 0	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Purchase of vehicles	-25,105,159.80 €					
Insurance		-3,599,154.72 €	-3,620,029.82 €	-3,641,025.99 €	-3,662,143.94 €	-3,683,384.38 €
Wages		-4,526,100.00 €	-4,552,351.38 €	-4,578,755.02 €	-4,605,311.80 €	-4,632,022.61 €
Maintenance		-1,199,718.24 €	-1,206,676.61 €	-1,213,675.33 €	-1,220,714.65 €	-1,227,794.79 €
Income						
Sale of vehicles						10,460,483.08 €
Cashflow	-25,105,159.80 €	-9,324,972.96 €	-9,379,057.80 €	-9,433,456.34 €	-9,488,170.39 €	917,281.31 €

Table 92: Yearly cashflow for Scenario 1: Tesla Model S

The cashflows have been applied to the NPV formula, taking into consideration the expected growth of the income. In this formula I represents the yearly income of the company, and I/2 the income of the company during a semester. The use of the formula, has allowed to obtain a value for the expected income:

$$0 = -25{,}105{,}159.80 + \frac{-9{,}324{,}972.96 + I \cdot (1+0.0058)}{(1+0.142)} + \frac{-9{,}379{,}057.80 + (1+0.415) \cdot (1+0.0058)^2 \cdot I}{(1+0.142)^3}$$
$$+ \frac{-9{,}433{,}456.34 + (1+0.415)^2 \cdot (1+0.0058)^3 \cdot I}{(1+0.142)^5} + \frac{-9{,}488{,}170.39 + (1+0.415)^2 \cdot (1+0.1212) \cdot (1+0.0058)^4 \cdot I}{(1+0.142)^7}$$
$$+ \frac{-917{,}281.31 + (1+0.1212)^2 \cdot (1+0.0058)^5 \cdot I}{(1+0.142)^9}$$

	Year 0	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Purchase of vehicles	-26,921,197.80 €					
Insurance		-3,599,154.72 €	-3,620,029.82 €	-3,641,025.99 €	-3,662,143.94 €	-3,683,384.38 €
Wages		-4,526,100.00 €	-4,552,351.38 €	-4,578,755.02 €	-4,605,311.80 €	-4,632,022.61 €
Maintenance		-1,199,718.24 €	-1,206,676.61 €	-1,213,675.33 €	-1,220,714.65 €	-1,227,794.79 €
Income						
Sale of vehicles						11,217,165.57 €
Total	-26,921,197.80 €	-9,324,972.96 €	-9,379,057.80 €	-9,433,456.34 €	-9,488,170.39 €	1,673,963.80 €

Table 933: Yearly cashflows for Scenario 2: Tesla Model X

The cashflows have been applied to the NPV formula, taking into consideration the expected growth of the income. In this formula I represents the yearly income of the company, and I/2 the income of the company during a semester. The use of the formula, has allowed to obtain a value for the expected income:

$$0 = -26{,}921{,}197.80 + \frac{-9{,}324{,}972.96 + I \cdot (1+0.0058)}{(1+0.142)} + \frac{-9{,}379{,}057.80 + (1+0.415) \cdot (1+0.0058)^2 \cdot I}{(1+0.142)^3}$$
$$+ \frac{-9{,}433{,}456.34 + (1+0.415)^2 \cdot (1+0.0058)^3 \cdot I}{(1+0.142)^5} + \frac{-9{,}488{,}170.39 + (1+0.415)^2 \cdot (1+0.1212) \cdot (1+0.0058)^4 \cdot I}{(1+0.142)^7}$$
$$+ \frac{1{,}673{,}963.80 + (1+0.1212)^2 \cdot (1+0.0058)^5 \cdot I}{(1+0.142)^9}$$

	Year 0	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Purchase of vehicles	-12,524,400.00 €					
Insurance		-3,599,154.72 €	-3,620,029.82 €	-3,641,025.99 €	-3,662,143.94 €	-3,683,384.38 €
Wages		-4,526,100.00 €	-4,552,351.38 €	-4,578,755.02 €	-4,605,311.80 €	-4,632,022.61 €
Maintenance		-1,199,718.24 €	-1,206,676.61 €	-1,213,675.33 €	-1,220,714.65 €	-1,227,794.79 €
Income						
Sale of vehicles						5,218,499.92 €
Total	-12,524,400.00 €	-9,324,972.96 €	-9,379,057.80 €	-9,433,456.34 €	-9,488,170.39 €	-4,324,701.85 €

Table 944: Yearly cashflows for Scenario 3: Hyundai Kona

The cashflows have been applied to the NPV formula, taking into consideration the expected growth of the income. In this formula I represents the yearly income of the company, and I/2 the income of the company during a semester. The use of the formula, has allowed to obtain a value for the expected income:

$$0 = -12{,}524{,}400 + \frac{-9{,}324{,}972.96 + I \cdot (1+0.0058)}{(1+0.142)} + \frac{-9{,}379{,}057.80 + (1+0.415) \cdot (1+0.0058)^2 \cdot I}{(1+0.142)^3} + \frac{-9{,}433{,}456.34 + (1+0.415)^2 \cdot (1+0.0058)^3 \cdot I}{(1+0.142)^5} + \frac{-9{,}488{,}170.39 + (1+0.415)^2 \cdot (1+0.1212) \cdot (1+0.0058)^4 \cdot I}{(1+0.142)^7} + \frac{-4{,}324{,}701.85 + (1+0.1212)^2 \cdot (1+0.0058)^5 \cdot I}{(1+0.142)^9}$$

	Year 0	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Purchase of vehicles	-15,091,902.00 €	-15,091,902.00 €				
Insurance			-3,599,154.72 €	-3,620,029.82 €	-3,641,025.99 €	-3,662,143.94 €
Wages			-4,526,100.00 €	-4,552,351.38 €	-4,578,755.02 €	-4,605,311.80 €
Maintenance			-599,859.12 €	-603,338.30 €	-606,837.67 €	-610,357.32 €
Income						
Sale of vehicles						
Total	-15,091,902.00 €	-15,091,902.00 €	-8,725,113.84 €	-8,775,719.50 €	-8,826,618.67 €	-8,877,813.06 €

Table 955: Yearly cashflow for Scenario 4: Tesla Model 3 SR Plus

The cashflows have been applied to the NPV formula, taking into consideration the expected growth of the income. I represents the yearly income of the company, and I/2 the income of the company during a semester. The use of the formula, has allowed to obtain a value for the expected income:

$$0 = -15{,}091{,}902 + \frac{-9{,}324{,}972.96 + I \cdot (1+0.0058)}{(1+0.142)} + \frac{-9{,}379{,}057.80 + (1+0.415)\cdot(1+0.0058)^2 \cdot I}{(1+0.142)^3} + \frac{-9{,}433{,}456.34 + (1+0.415)^2 \cdot (1+0.0058)^3 \cdot I}{(1+0.142)^5} + \frac{-9{,}488{,}170.39 + (1+0.415)^2 \cdot (1+0.1212) \cdot (1+0.0058)^4 \cdot I}{(1+0.142)^7} + \frac{-2{,}641{,}011.98 + (1+0.1212)^2 \cdot (1+0.0058)^5 \cdot I}{(1+0.142)^9}$$

The following table shows the results that were obtained as a solution for the necessary income in each of the project scenarios:

Scenario	***Vehicle considered***	***Result obtained***
1	Tesla Model S	10,452,588.38 €
2	Tesla Model X	10,798,950.54 €
3	Hyundai Kona	8,053,135.49 €
4	Tesla Model 3 SR Plus	8,178,436.84 €

Table 96: Necessary income to cover the expenses in all scenarios

The results that have been obtained, show what would the income have to be during the first year of activity.

As it was expected, the 3rd scenario, where the Hyundai Kona is selected as the desired vehicle, is the investment that requires the least income to recover it. The Tesla Model X, however, is the scenario that would require the greatest investment, and the greatest income, therefore.

Each of these amounts have been divided, in order to find out how much should be earned every month in the following table. Additionally, a column has been included, in which it is shown how much should be made out of each vehicle

Vehicle considered	***Result obtained***	***Monthly income required***	***Monthly income per vehicle***
Tesla Model S	10,452,588.38 €	871,049.03 €	1,752.61 €
Tesla Model X	10,798,950.54 €	899,912.55 €	1,810.69 €
Hyundai Kona	8,053,135.49 €	671,094.62 €	1,350.29 €
Tesla Model 3 SR Plus	8,178,436.84 €	681,536.40 €	1,371.30 €

Table 97: Monthly income required to cover for investment.

When looking at what each vehicle needs to make, the results do not seem so large. However, to gain a better understanding of the situation, the obtained results have been broken apart even more. Two different cases have been set:

- First, it has been assumed that vehicles could be running for about 8 hours every day. This would be assuming that each vehicle makes around 2 trips every day. An average of 30 days has been set for every month, which leads to 240 hours of use every month. This has made it possible to obtain a fare per minute for each of the scenarios.

- Additionally, the price per kilometer has also been calculated. In order to do so, it has been assumed that every hour 100 km are covered on average.

The obtained prices for both cases have been calculated in each scenario:

Vehicle considered	*Needed monthly income*	*Price per minute*	*Price per kilometer*
Tesla Model S	871,049.03 €	0.122 €	0.073 €
Tesla Model X	899,912.55 €	0.126 €	0.075 €
Hyundai Kona	671,094.62 €	0.094 €	0.056 €
Tesla Model 3 SR Plus	681,536.40 €	0.095 €	0.057 €

Table 98: Required fare to cover for initial investment.

It should be noted that this is the minimum price that should be established, so that all expenses are covered. In order to be able to obtain profits, the price should be higher than what has been stated in the previous table.

In spite of this, the numbers that have been obtained seem to be very reasonable. For instance, the price for a trip from Madrid to Barcelona, of 621 km and 6.3 hours is calculated in the following table for each of the scenarios:

Vehicle considered	*Cost per minute*	*Cost per kilometer*
Tesla Model S	46.01 €	45.35 €
Tesla Model X	47.53 €	46.85 €
Hyundai Kona	35.45 €	34.94 €
Tesla Model 3 SR Plus	36.00 €	35.48 €

Table 99: Cost of a trip from Madrid to Barcelona for each of the possible scenarios

As it can be seen, although the numbers seemed very large in the beginning, once they have been broken through, a reasonable price has been reached for the service. Although, as it was previously mentioned the fares should not be constant but depend on the momentaneous distribution of vehicles around the six cities, this would give an idea of how much would a trip cost.

In all cases, the price of this trip would be cheaper than a train. Additionally, considering gas prices at the moment (1.033 €/liter on average)[5], and an average consumption of 6.5 liters/ 100km, the price of travelling this distance would be 41.70 €, which would still be more expensive than some of the scenarios that have been proposed. By making use of this initiative, it would be possible to not only contribute to a more sustainable transportation, and to development of electric vehicles, but it would also have a lower cost than alternative transportation means.

[5] It should be noted that gas prices are currently low due to the COVID-19 crisis, so prices would generally be higher, than now.

FINAL CONCLUSIONS

The purpose of this project was to come up with an initiative that would allow users to travel between cities at a reasonable price, and with the level of comfortability that is given by private cars.

The idea was to develop a *carsharing* initiative, where the ideal location for vehicles would be determined based on different parameters.

This task was successfully carried out, and it was possible to discover that the three most relevant criteria when determining where to locate the vehicles are, in order of relevance the distance between locations, the existing alternative transportation means at each city, and the number of electric vehicle chargers at each location.

These parameters would in fact be intuitively selected as the most important factors for the location of vehicles, so it can be excerpted that the results that have been obtained, make sense.

Although these parameters have altered the results that were obtained, the results are still based on the population of each city, which is also reasonable. Although the distribution of vehicles changed by adding the parameters, Madrid is still the city with the greatest number of vehicles assigned, followed by Barcelona and Valencia. Sevilla and Zaragoza have a very similar population, so in this case, the parameters have altered the order in the number of vehicles assigned. Although Sevilla has a greater population, it received less vehicles than Zaragoza, which is located very closely to many other cities, and does not have many alternative transportations means. Málaga, with the smallest population, was the location with the smallest number of vehicles assigned.

Once this evaluation was performed, an economic analysis of the project was also carried out. In this analysis, it was determined that this initiative would be in fact, possible to sustain. Although the initial investment would be large (at least of 12.5 million euros), it would be possible to recover it within five years. To do so, the fares required would be reasonable: cheaper than other transportation means, such as train or plane, and even cheaper than private vehicles in some cases.

By making use of this transportation mean, users would therefore save money, while still contribute to the fight against climate change and to the development of electric vehicle

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ANNEX I: ALIGNMENT WITH SDG

This project has been developed throughout the whole semester in alignment with the SDGs (Sustainable Development Goals). In this section, the relationship between those goals and the particular goals of the project has been looked at.

Three main categories of SDGs that are covered by this project can be differentiated: economic, social and environmental goals. More particularly, these categories are sustained by goals #9, related to industry, innovation, and infrastructure; goal #11 concerned with sustainable cities and communities; goal #12, which coordinates responsible consumption and production; and #13, related to climate action.

The main purpose that can be perceived in this research though, would be Goal #9. The project refers particularly to the infrastructure section of this goal. This would therefore be the primary goal fulfilled by the pursuit of this project.

Section 9.1 of this goal states that one of the targets is to *'Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all'* (UN15).

This project creates a new type of transportation network throughout the entire country. The network relies on previously existing infrastructure, such as roads or parking lots, but also constitutes itself a new kind of transportation infrastructure, available for all inhabitants of the 6 selected cities, or eventually even other cities from the Iberian Peninsula.

As it was previously stated, 25.7% of Spanish homes don't own a private vehicle, and in addition to this, 42.7% of Spanish families only have a single automobile, which sometimes may not be enough for all family members (SANZ14). This kind of service would open a new opportunity for this population, creating an alternative to the already existing infrastructure (trains, airplanes, etc.). Additionally, as it has been shown in the economic analysis carried out, the infrastructure, would be sustainable, since it is based on electric vehicles; and affordable, since it can cost even less than performing trips by a privately owned vehicle.

One way in which the success of the project to fulfill the goal could be measured would be by finding out how many people, out of the initiative's users, previously had issues when it came to travelling between any two selected cities (could be because of lack of a vehicle, because the vehicle was not in condition to cover long distances…). This number could be found by carrying out a survey or by analyzing the customer travelling habits and their changes once the initiative was to be implemented.

Goal #9 has been chosen as the primary goal that this project aims to fulfill. This is because this goal is in reality the purpose of the development of this project: the creation of a sustainable vehicle network that connects cities and allows users to make use of affordable and comfortable vehicles.

The scope of this project also covers goal #11, related to sustainable cities and communities. In this project, the main focus within this goal is the environmental impact.

60% of the world's population lives in cities. Cities occupy only 3% of the planet's surface. However, they contribute to up to 80% of the world's energy consumption (UN15). By reducing energy consumption and carbon emissions in cities, a lot could be achieved.

Target 11.6 in this goal summarizes very well the part covered by this project: *'By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management'* (UN15).

In particular, it is estimated that around 40% of the traffic in cities such as Madrid is due to the search of parking spots. By reducing the number of private vehicles (which would be one of the main long term effects of this new initiative), the time required to find a parking spot would be smaller than now. This would lead to a 40% reduction of emissions in Madrid.

One of the ways in which the consecution of this could be measures, would be the variations in the pollution of air in cities. Implementing this could contribute to a reduction of pollutants in the air.

Despite the desperate need to fulfill this goal, it will only be considered to be a secondary goal for this research. This is because the achievement of goal #11 would be one of the consequences of the achievement of goal #9 too. The project is not focused on the consecution of this though.

Goal #12 has also been selected as one of the goals aimed to be covered by this project, related to a responsible consumption and production.

For starters, this project aims to reduce the existing car fleet. As it was previously said, Spanish vehicles spend about 97% of the time parked (SANZ14). This number gives information of how too many vehicles are purchased and produced, but not needed. By implementing this initiative, it would be possible to also reduce the number of vehicles in the road.

Some of the targets that have been noted to be fulfilled by this project are:

- Target 12.2, which states: *'By 2030, achieve the sustainable management and efficient use of natural resources'* (UN15). The implementation of electric vehicles especially contributes to the completion of this target.

- Target 12.5, which stated: '*By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse'* (UN15). The reduction of use of vehicles, and their sale after five years, in order to be used by a third party are part of the "3Rs rule: reduce, recycle"*, reuse* initiative.

The way in which the achievement of this goal could be measured would be by looking at the number of new vehicles that are produced every year. An increase in the use of shared vehicles should result on a decrease in the number of vehicles that are purchased and produced every year.

Finally, the third goal to be covered is #13, related to climate action. This would be perhaps the most evident goal. The implementation of electric vehicles, and the reduction of combustion vehicles would directly contribute to the reduction of CO_2 emissions and the development of electric vehicle.

Target 13.3 of this goal, '*Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning'* would be covered by the initiative. One of the contributions of the implementation of this platform would be the settlement of electric vehicles in our society. This, however, is a long-term goal.

The SDGs that can be achieved throughout this project can be summarized in the following table:

SDG dimension	***SDG identified***	***Role***	***Goal***
Economy	SDG9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.	Primary	Create a sustainable and affordable platform that connects different point of Spain
Society	SDG11: Make cities inclusive, safe, resilient and sustainable.	Secondary	Reduce the existing number of vehicles in cities.
Society	SDG12: Ensure sustainable consumption and production patterns	Secondary	Reduce private vehicle purchases and ensure the "3Rs" rule is followed
Biosphere	SDG13: Take urgent action to combat climate change and its impacts	Secondary	Reduce CO_2 emissions and contribute to the development of electric vehicles.

Table 100: Categorized SDGs applicable to this project. Source: UN15

ANNEX II: CONDUCTED SURVEY

In order to add up to the data found online, a poll was conducted through Google Forms. This poll consisted of 9 different questions and was carried out in 300 Spanish people. Following up, each of the individual questions will be examined, together with the response gathered.

A total of 352 people were surveyed. The questions that were asked to them are shown below, together with the obtained results, which are also analyzed.

Question 1: Age range of the surveyed person

Only data from users ranged between age 18 and 65 will be used, since that is the group of potential users: only people above 18 have legal ability to drive; on the other hand, people of age over 65 may not have ideal driving conditions, though being legally allowed to drive.

Population were also ranged in this interval: from 18 to 26 years old, drivers are still considered new drivers by insurance companies; despite being potential users, this age interval will not be our target age. People aging between 27 and 40 will be our target population: in this age interval, users are considered to be mature and experienced enough to drive; in addition to this, they will still be young enough to have good reflexes and fast reactions. After age 40, physical degradation starts to occur: drivers start to lose their reflexes and reactions start to slow down. Therefore, despite being potential customers as well, drivers between ages 40 and 65 will not be our targeted age group either.

¡Error! No se encuentra el origen de la referencia. displays the age distribution of surveyed population:

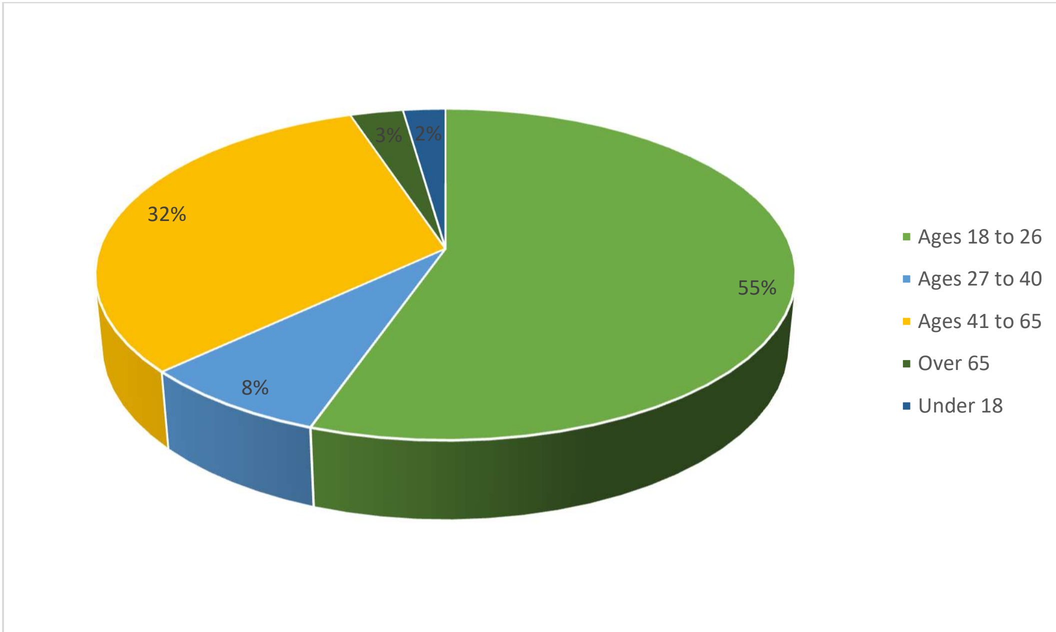

Figure 30: Age distribution of the poll

As it can be extracted from the previous data chart, most of the users that carried out the survey were between the ages of 18 and 26. ‘Ages 41 to 65’ were also a big group of the examined population.

Although users from ages 27 to 40 are the target population of this initiative, ‘Ages 18 to 26’ and ‘Ages 41 to 65’ will also be taken into account for the sake of data accuracy. However, people under 18 or over 65 will not be considered.

After removing the data that did not meet the requirement that had been established, Figure 31 was obtained. This graph shows the age division in the selected age groups.

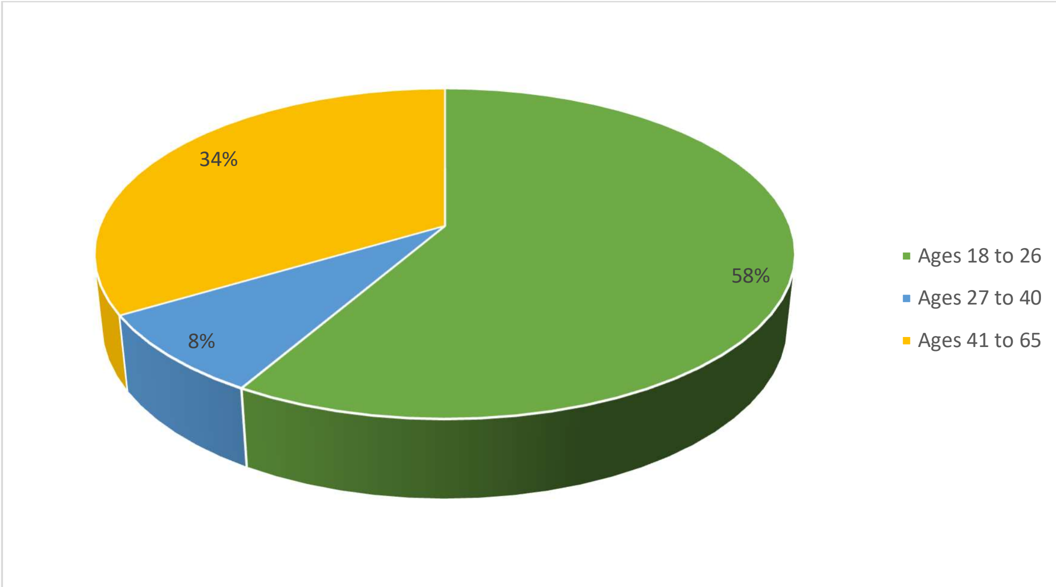

Figure 31: Depurated age ranges of the survey

After depurating the data, 334 responses were left for this project.

Question 2: Do you have a driver's license?

This question was set up in order to ensure that the obtained data would be realistically applied into the problem. Only users with legal capability to drive would be potential customers, although users who do not drive could also be considered at certain times: for example, if a group of people wants to cover a distance, despite not being able to rent the vehicle themselves, people who do not have a driver's license's preferences also have an impact on the preferred transportation mean.

Figure 32, shown below, illustrates the percentage of surveyed people who have legal authorization to drive[6].

[6] Note that this percentage is referred to the previous changes made, where only population of ages 18 to 65 will be considered for this project.

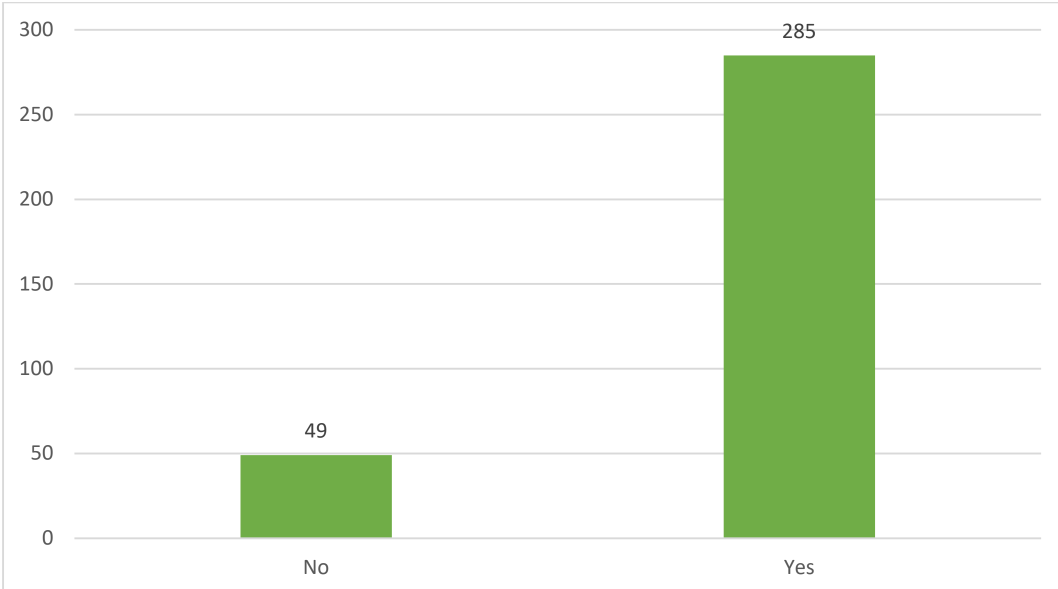

Figure 32: Surveyed population who has a driver's license[6]

Despite having an effect of the choice of a vehicle when it comes to covering big distances, this project is going to consider that these kinds of users will be negligible. Therefore, this data will not be considered either.

After taking this into consideration, 285 responses are considered valid answers. Those are the only data that will be considered from this point.

Figure 33 depicts the age ranges of population who have a driver's license[6].

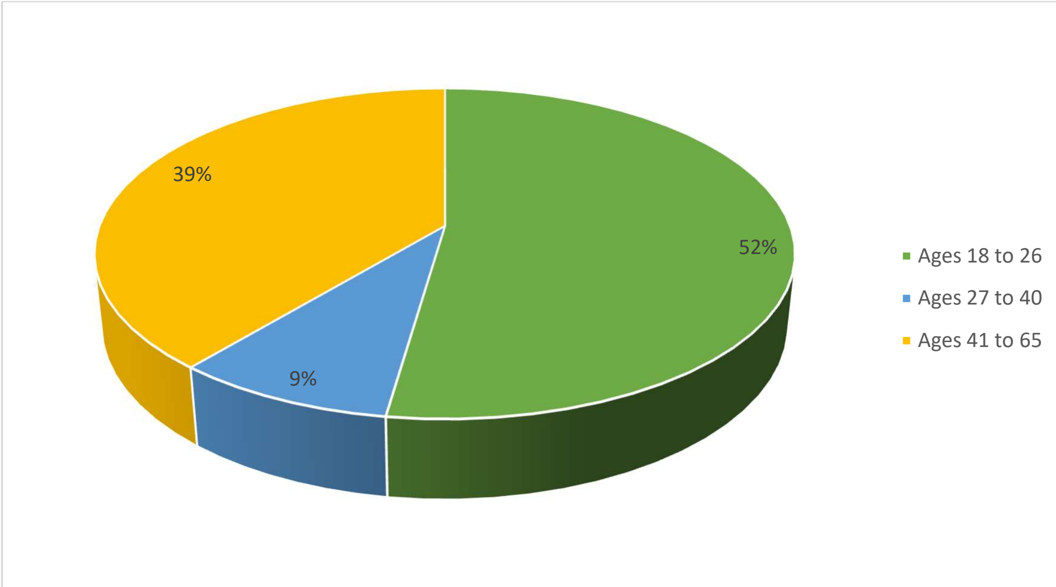

Figure 33: Age ranges of population betwen 18 and 65 who have a driver's license

As it can be extracted from the previous graph, most users who do not have a driver's license range ages 18 to 26. However, very little population between 27 and 65 years old does not have a driver's license. By setting a requirement that customers need to have legal ability to drive, the impact of 'Ages 18 to 26' has reduced, but 'Ages 27 to 40' and 'Ages 41 to 65' have increased.

Question 3: How often do you travel distances of over 400km (around 4 hours by car)?

This question focused on the frequency at which users would make a use of this service. In addition to this, people travelling longer distances more often may have a more reduced budget when it comes to a single trip. However, users who very rarely travel long distances may be willing to occasionally spend more money on a more comfortable transportation.

The more often users travel long distances the greater their impact will have in the percentage of population covering long distances.

Figure 34 represents how much people selected each frequency as their most representative frequency for travelling long trips.

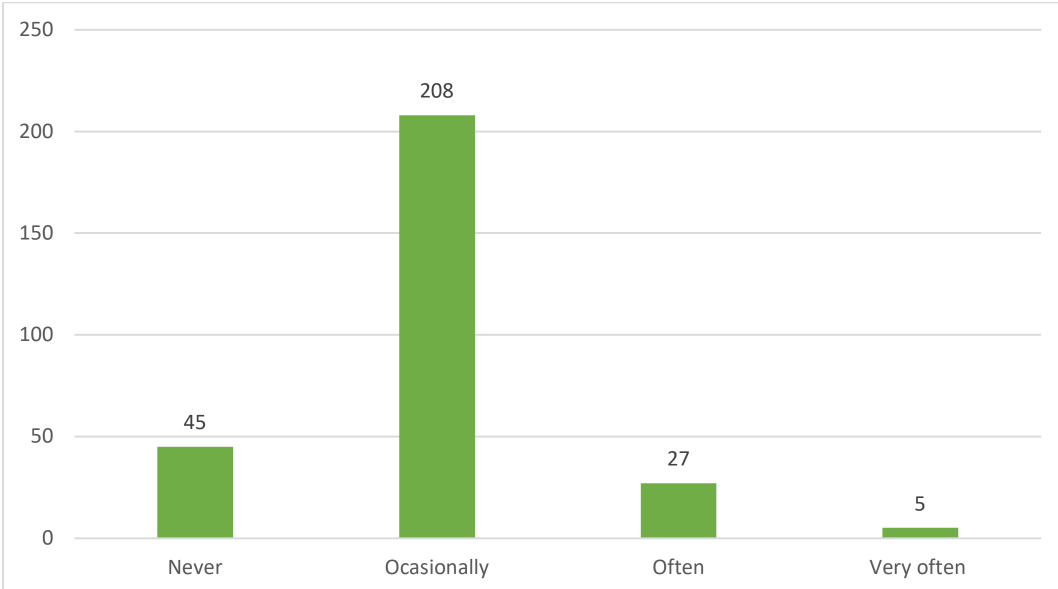

Figure 34: Frequency at which population travels long distances

Question 4: When it comes to travelling long distances (over 3 hours driving), what would be your preferred transportation mean?

Several options were given as possible responses for this question:

AVE/ High Speed Trains
Conventional Trains
Airplane
Car
Bus

This question wanted to focus on which are the most popular travelling alternatives when it comes to covering long distances.

Figure 35 is a sector graph that displays the preferred transportation means of the surveyed population[7].

[7] As it was previously mentioned, the utilized data has only considered people who are between ages of 18 and 65 and have a driver's license.

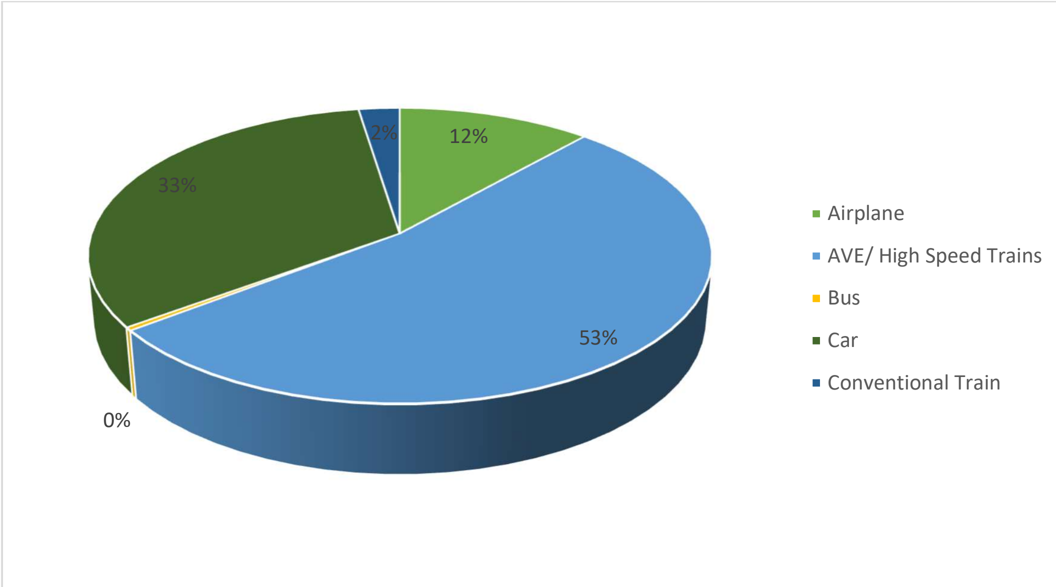

Figure 35: Preferred transportation mean[7]

As it can be excerpted from the data obtained, the greatest part of the surveyed population prefers to either travel by AVE (High Speed Trains) or Airplane.

This question will allow to weigh the importance of available transportation means in each of the permitted locations. It will be helpful for a lot of the criteria we have selected. For instance, after examining the results, bus results may not need to be considered.

However, it can also be deducted that other transports, such as AVE will need to have an additional impact on this research.

Question 5: Looking at the transportation mean that you selected in the previous question, and based on its speed, comfortability, pricing, etc. would you be willing to make use of it?

This question was linked to question 2, which focused on how often users cover these long distances and how often would they be willing to use it.

For example, AVE, which was selected on Question 4 as the most popular transportation mean, is not always economically accessible for all population. It may be someone's preferred choice; however, this person may not be willing to spend a big budget on it.

Both, question 2 and question 5 have been put together in order to find out the preferred transportation means of frequent travelers in Figure 36[7].

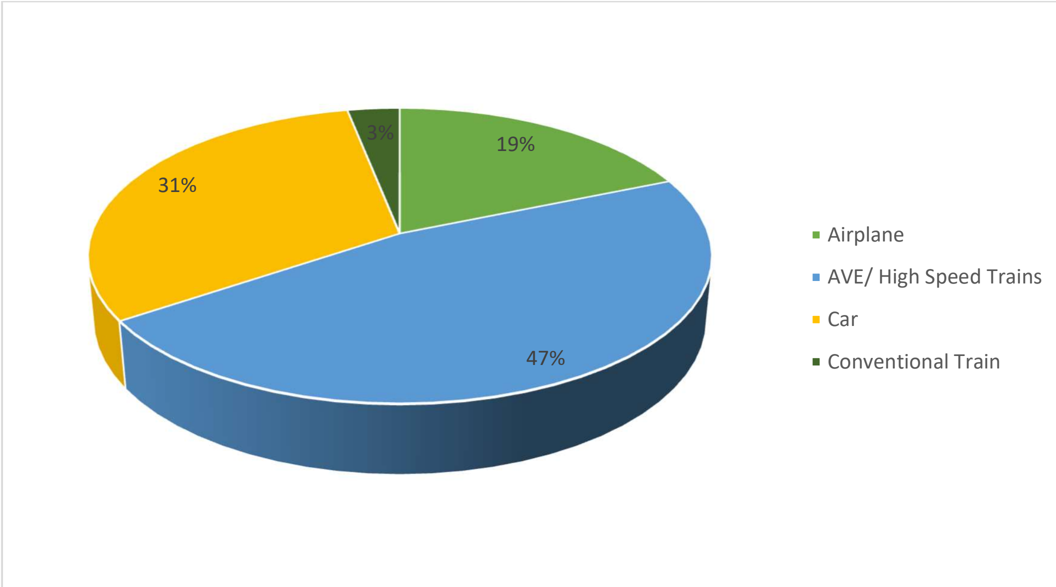

Figure 36: Preferred transportation mean for frequent travelers[7]

Examination of the graph allows to deduct that people who travel frequently prefer to travel more in Airplane and car than people who do not travel as frequently.

This may be due to the pricing of the selected transportation means. Population travelling more often have a tighter budget when it comes to selecting a transportation mean.

By obtaining two graph that combine this question with the frequency one, it is possible to make a comparison between the satisfaction of the population's selected transportation mean and the frequency at which they travel.

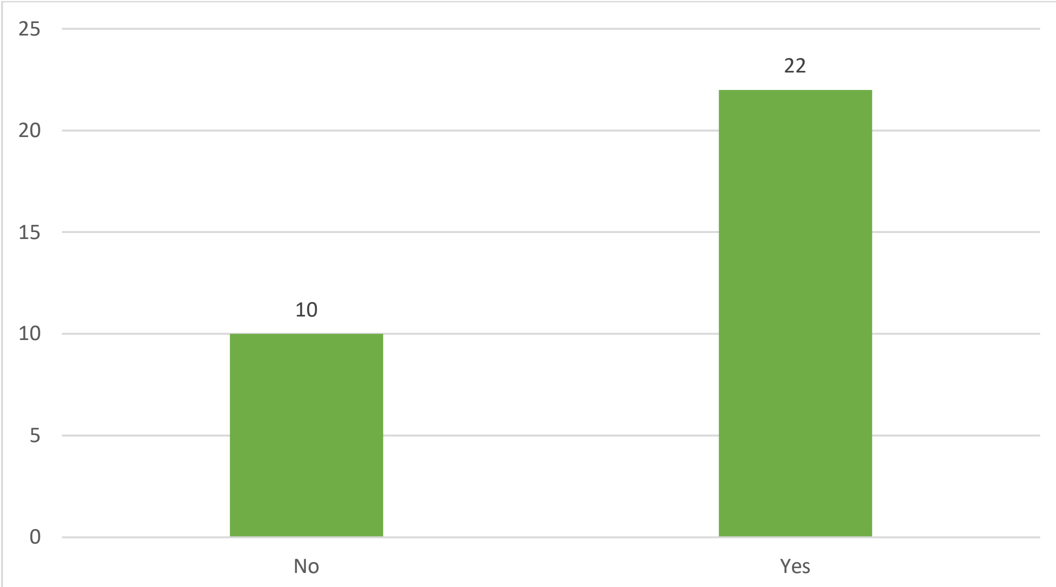

Figure 37: Frequent travelers' possibility of actually selecting their chosen transportation mean[8]

For non-frequent travelers, the selected transportation mean is the following:

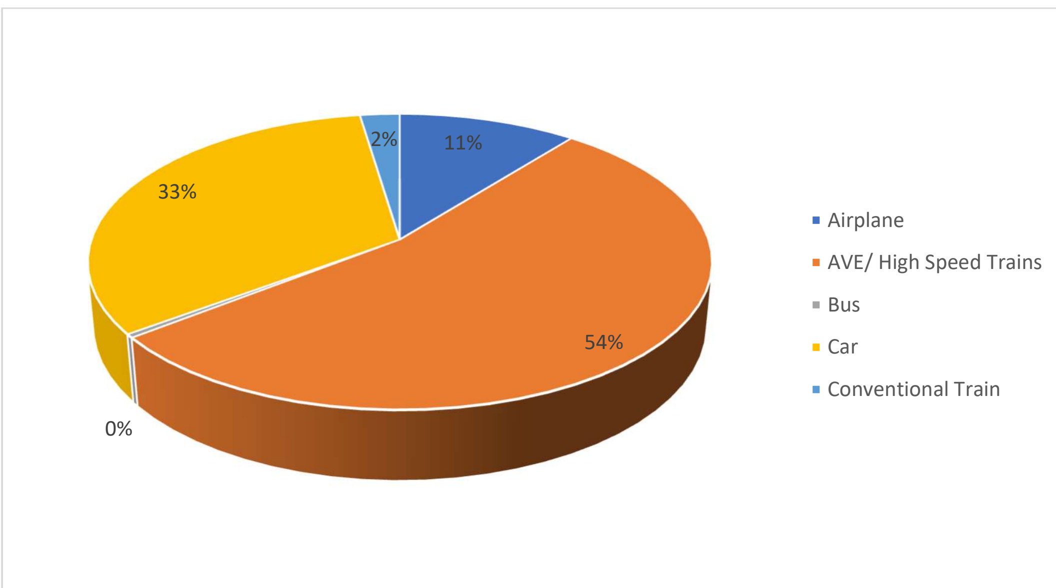

Figure 38: Preferred transportation mean for non-frequent travelers

[8] Consider only frequent travelers (population who said travelled either often or very often) who are between the ages of 18 and 65 and have a driver's license. Only 32 people are considered in this category.

As it can be seen, most non-frequent travelers prefer High Speed Train as their transportation mean. For these kind of population, price is not as much of an issue, since the considered trips are occasional and non-frequent.

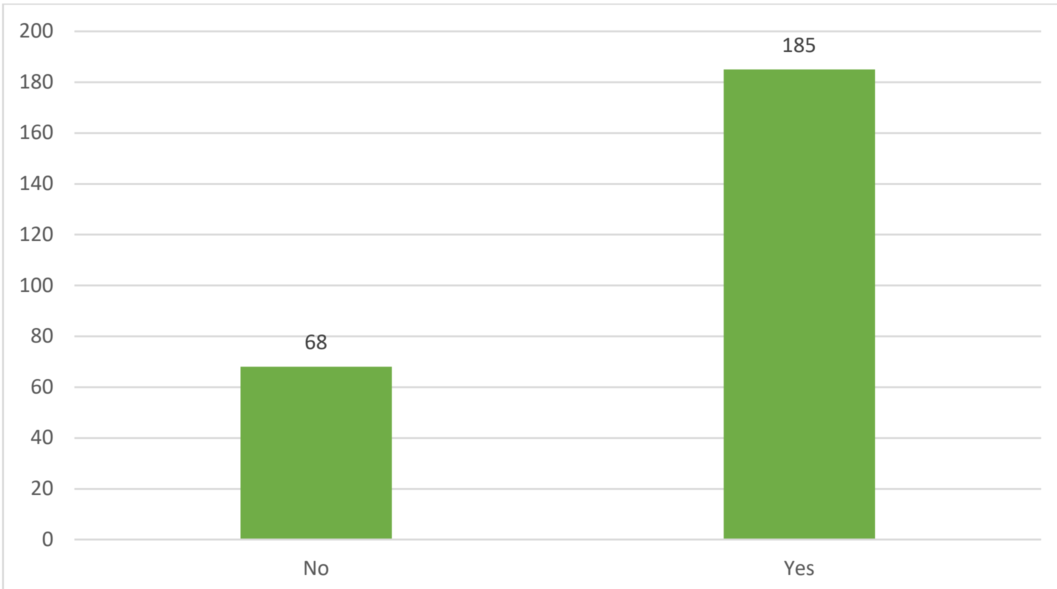

Figure 39: Non- frequent travelers' possibility of actually selecting their chosen transportation mean[9]

On a deeper analysis of these two graphs, it can be noted that the amount of available data for both examinations may not be comparable.

However, for demonstrational purposes, calculations will be made with the obtained data:

As it can be noted from Figure 37, out of the 32 people who travel often[8], 10 people responded that they would not actually pick their selected transportation mean to travel distances greater than 300km (reasons are not stated); this adds up to a 36% of the population.

As it can be seen in Figure 39, out of the 253 people who do not frequently travel[9], 68 responded that they would not actually use their selected transportation mean. This adds up to 27% of the population.

It can be noted that the percentage of population who would be willing to actually spend money on their selected transportation mean is 9% higher for non- frequent travelers than in frequent travelers.

[9] A total of 253 people between ages 18 and 65 and in possession of a driver's license were considered for this graph. Population in this category selected 'Never' or 'Occasionally' as the frequency at which they cover distances greater than 300km.

Question 6: Do you consider that the Red de Carreteras del Estado (Spanish Highway Network) allows the population to comfortably drive?

The purpose of this question, once again was to ensure that potential customers consider driving to their destination instead of making a use of alternative transportations a good option too.

The overall responses of this question are displayed in Figure 40[7]. As it can be seen, most surveyed population agreed that the Red de Carreteras del Estado (Spanish Highway Network) is allows to travel by car very comfortably.

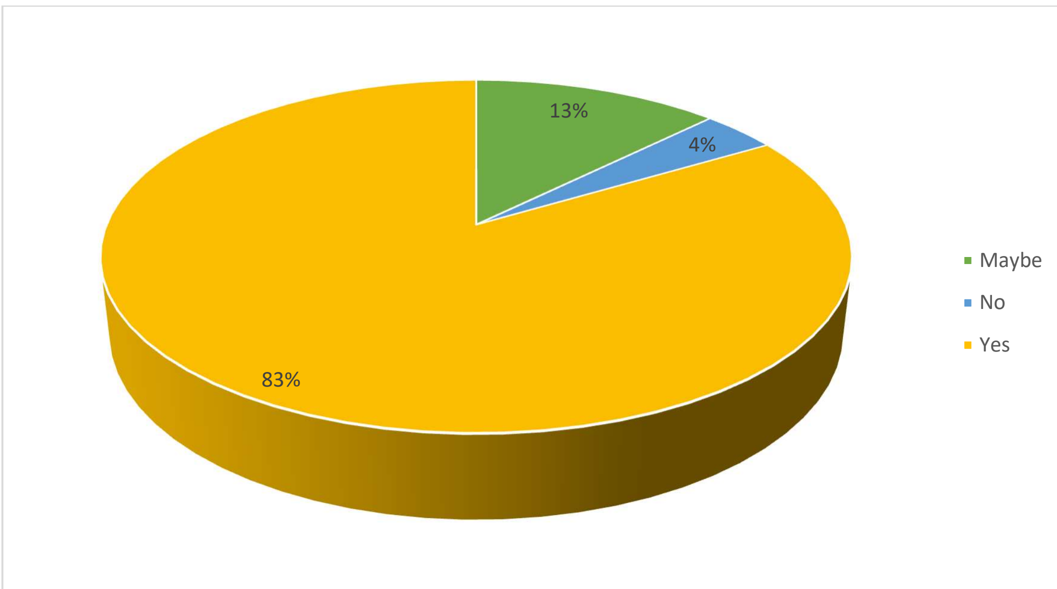

Figure 40: Responses of all examined population to Question 6[7]

This question will be examined more particularly: for example, only population who selected car as their preferred transportation mean will be assessed, together with the population who frequently travel too.

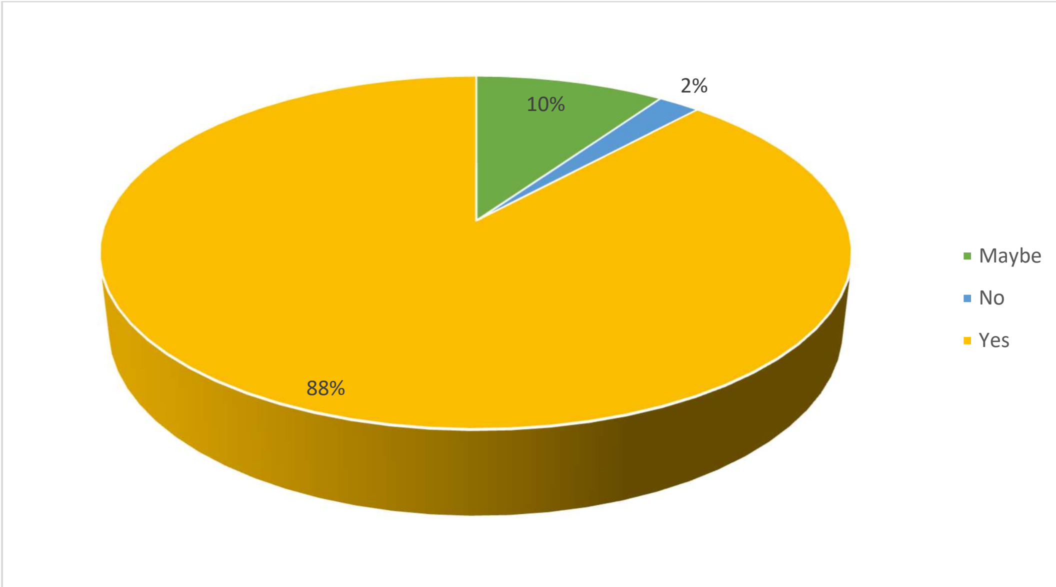

Figure 41: Responses of population who responded 'Car' to Question 4

As was expected, in Figure 41 it can be seen that a greater portion of the population who selected car as their preferred transportation mean responded ‘Yes’ to this question.

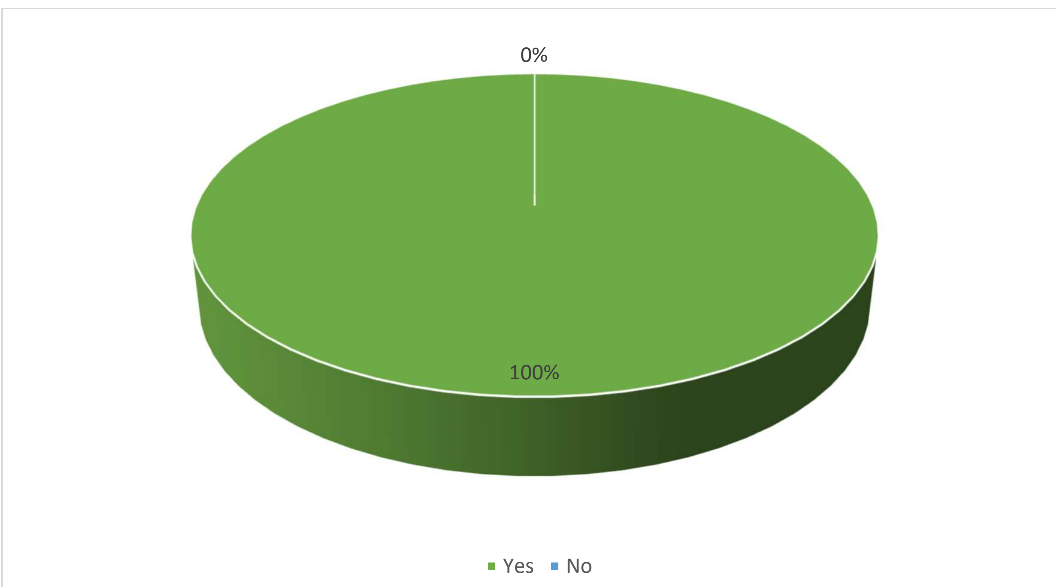

Figure 42: Responses of frequent travelers who responded 'car' for Question 4

As it can be seen in Figure 42, users who frequently travel and selected ‘car’ as their preferred transportation mean all agreed that the Red de Carreteras del Estado (Spanish Highway Network) allows to travel comfortably. For obvious purposes, these responses will have a greater impact on the problem considerations than the responses of non-frequent travelers who do not consider cars as their preferred vehicles.

Question 7: When covering distances greater than 300km (around 3 hours driving), do you think about travelling by car?

Same as the previous questions, this question wants to learn about user's transportation means habits. The main purpose of the question is to find out whether it would be possible to make a change of those habits and get customers to transition from other alternatives, such as airplanes or AVE into automobiles.

Figure 43 shows the percentage of the analyzed population[7] who would consider car as their transportation man when covering distances over 300km.

As it can be extracted from this graph, 81% of the people would mark 'Yes' as their response. However, as it was previously mentioned, only 33% of the population responded 'Car' in Question 4 (When it comes to travelling long distances (over 3 hours driving), what would be your preferred transportation mean?).

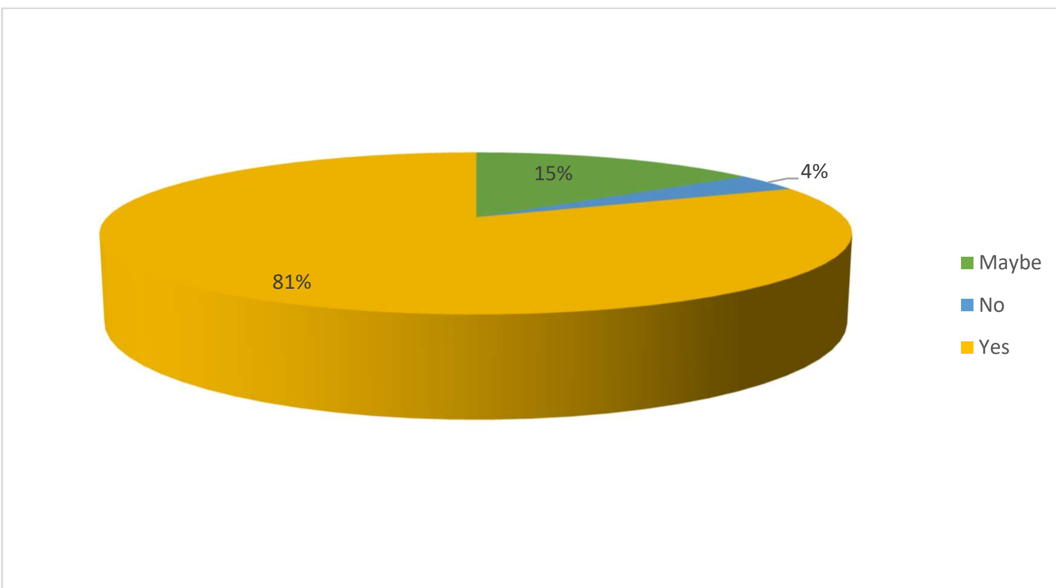

Figure 43: Responses to Question 7[7]

The graph is a good indicator that despite not being the first choice, most users would be willing to change their travelling habits and cover long distances by car.

After analyzing the overall responses, Figure 44 gives a better perspective of how much user's choice could swift.

This figure illustrates the percentage of users that, despite not choosing 'Car' as their preferred transportation mean, said they would consider automobiles when covering distances greater than 300km.

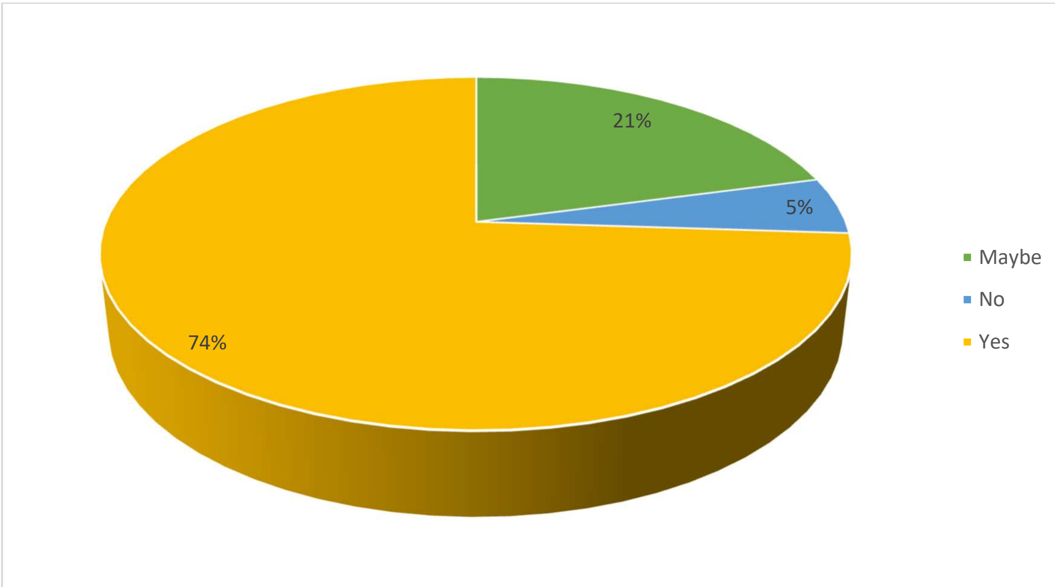

Figure 44: Response given by users who did not select 'Car' as their preferred transportation mean

As it can be seen in the graph, the percentage of population who selected 'Yes' has reduced from 81% to 74%. However, the 'Maybe' responses have raised a lot.

Question 8: If your answer to the previous question was 'Yes', what are your reasons?

Several options were given for this option, such as economical reasons, comfortability, independence and more flexibility, allows for a greater load or more freedom in the final destination.

Because of the great variety of answers that was reported, the obtained results are shown in the following table. It should be noted that more than one response could be responded by each person being surveyed:

Response	*Number of recorded responses*
No response	30
Comfortability	115
Independence and flexibility	167
Greater storage for carrying things	86

Economic reasons	103
More freedom in final destination	113
Fears and phobias to other transportation means	6
Transportation of medical equipment	1
More fun	2

Table 101: Responses recorded for Question 8

As it can be seen, there are various reasons why cars are selected as the preferred transportation mean, being 'Independence and Flexibility' and 'More freedom in final destination' the most selected options, and followed by 'Economic reasons'.

As it can be seen, in spite of the apparition of new transportation options, private automobiles are still a very popular option when it comes to travelling.

Question 9: Considering only gas prices (do not consider other expenses, such as mechanical expenses, tire degradation, etc.), what is the maximum time you would be willing to travel by car?

Time intervals were given as possible answers for this question. The given ranges of time were as it follows:

Under 4 hours
Between 4 and 5 hours (the last one not being included)
Between 5 and 6 hours (the last one not being included)
Between 6 and 7 hours (the last one not being included)
Between 7 and 8 hours (the last one not being included)
Between 8 and 9 hours (the last one not being included)
9 hours or more

The goal of this question was to determine the maximum time a person would be willing to travel by car. This question helps realize which are the displacements that could be happening. Based on it, the percentage of people travelling time intervals will be determined.

Figure 45 shows the percentage of the population who selected each time interval. This helps to get a better understanding of how many hours would users be willing to travel.

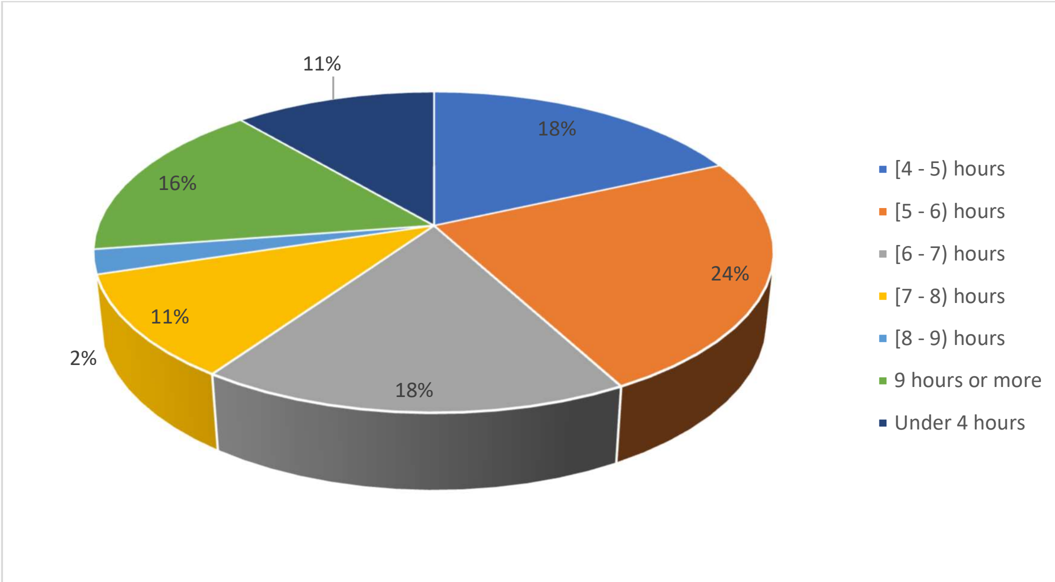

Figure 45: Users willing to travel a certain amount of hours[7]

As it can be seen in the graph, most general users[7] would be eager to travel distances longer than 6 hours by car.

A further examination will also be done with frequent travelers in Figure 46. These travelers will have a greater impact on the final decision of which percentage of population would travel each distance.

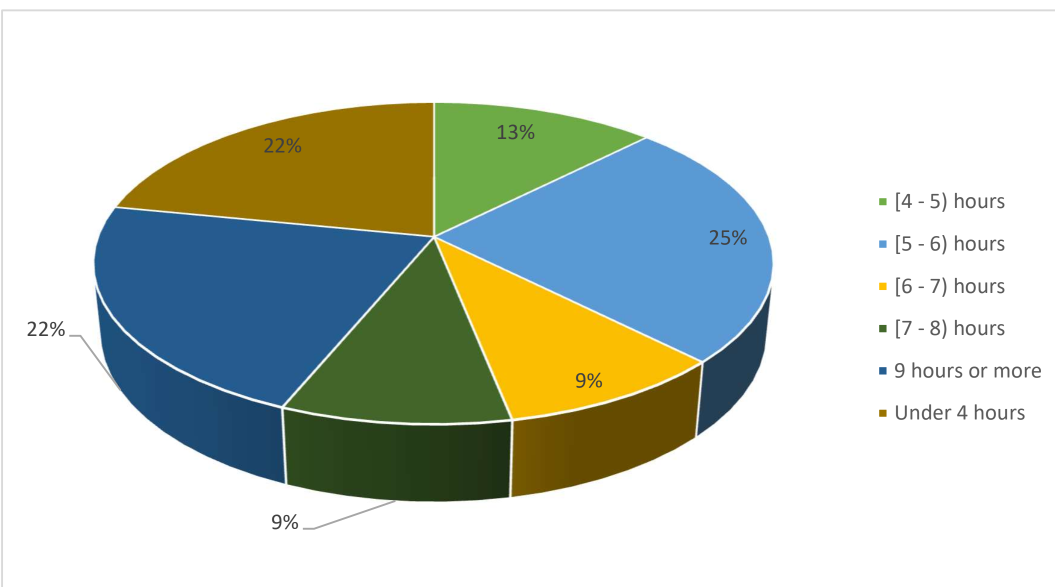

Figure 46:Frequent travelers willing to travel a certain amount of hours

As it can be seen, the results are similar to the previous figure, in that the most popular time interval is between 5 and 6 hours.

However, one great difference between both extracted data is the second maximum amount of time that users would be willing to travel: 18% of general users would travel between 4 and 5 hours, or between 6 and 7 hours; However, users who travel frequently would be more eager to travel that much time by car. The second position for the frequent traveler's data is tied between 'Under 4 hours' and 'Between 4 and 5 hours'.

Figure 47 shows the same data provided in Figure 46, but for a group of people who are non- frequent travelers.

Despite being more significant, the percentages for the frequent travelers are measured on a

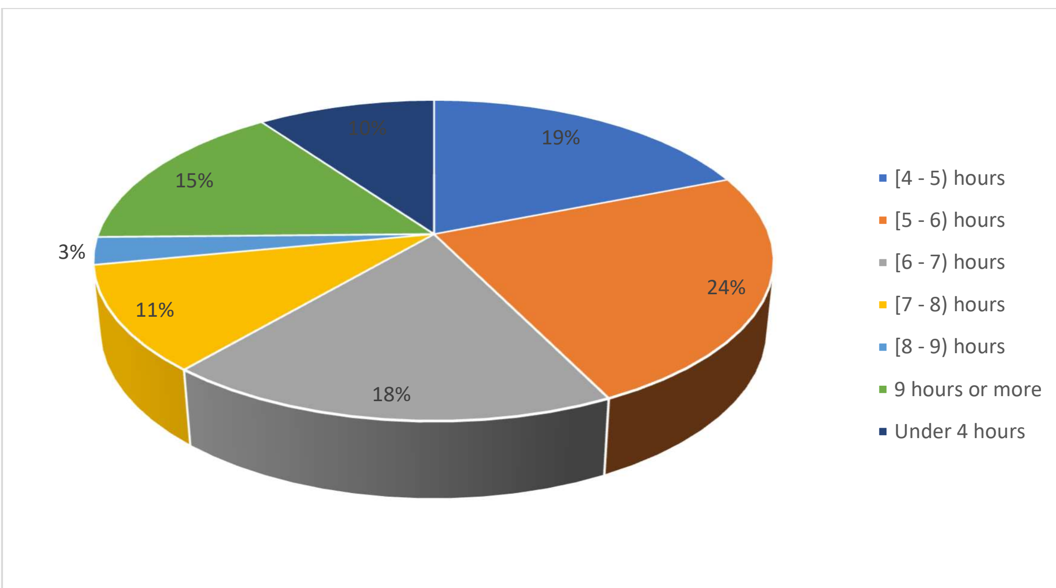

Figure 47: Non- frequent travelers willing to travel a certain amount of hours

It can be extracted as a main conclusion, that users who travel more often do not cover such long distances by car.

ANNEX III: CLARIFICATION FOR OBTAINED DATA.

Problem 4

The main part of this problem that requires a special clarification would be the percentages obtained for each distance covered.

For this problem, as it was stated three different criteria have been used:

1. Whenever one transportation mean is not available, the percentage of people traveling by it will be zero. Since these population will still need to travel, but using other mean of transportation, the percentage that has been removed will be split between the two remaining transportations. However, in order to make this division as fair as possible, it will not be equally split, but based on the percentage of population that had chosen each mean in the survey.
2. If the time variation between two transportation means is between zero a 0.75h, the most expensive one will not be considered a desired transportation mean. This will result on the percentage of the most expensive one being split equally in 2. One of the parts will stay in this transportation mean, whereas the other half of the percentage will be proportionately split between the remaining transportation means.
3. Finally, if a more expensive transportation mean requires more time than a cheaper one, the expensive one will only be left with 25% of its original percentage. The remaining 75% will be proportionately split between the other two transportation means.

In this section the calculations for each individual situation will be performed, showing the method that has been followed at each part.

- Madrid-Valencia:

Time requirements:

Car	*3.6 h*
Plane	3 h
Train	1.8 h

Figure 48

It can be observed in the previous table, that the time difference between car and plane is only 0.6 h, which is under 0.75 h.

In this case, the second criteria would therefore be applied.

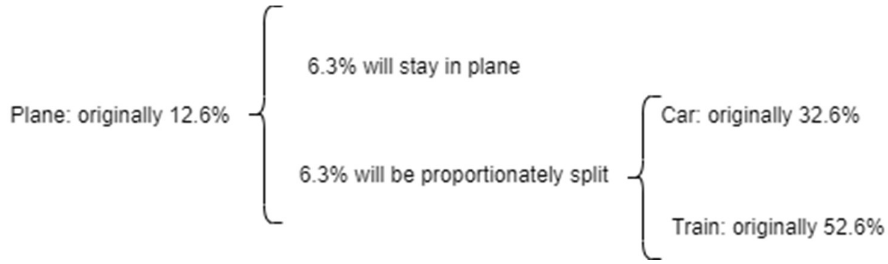

Figure 49

However, as it can be seen, the percentage that chose to travel by train and the percentage that chose to travel by car do not add up to 100%. Therefore, they will need to be normalized. This means that each of the percentages will be converted into an 'over 100%' percentage. In order to do so the following formula will be applied:

$$\%_{normalized} = \frac{100 \cdot \%_{non-normalize}}{\%_{total}}$$

In this case, the obtained normalized percentages would be as it follows:

$$\%\ by\ car_{normalized} = \frac{100 \cdot 32.6\%}{32.6\% + 52.6\%} = 38.26\%$$

$$\%\ by\ train_{normalized} = \frac{100 \cdot 52.6\%}{32.6\% + 52.6\%} = 61.74\%$$

Once the percentages have been obtained, they will be applied on the 6.3% that was removed from the total percentage of people travelling by plane.

$$\%_{car} = 0.3826 \cdot 6.3\% = 2.41\%$$

$$\%_{train} = 0.6174 \cdot 6.3\% = 3.89\%$$

Now, this obtained percentage will be added to the initial one:

Transportation mean	***Percentage of people using this transportation mean***
Car	35.01%
Plane	6.30%
Train	56.49%

Figure 50: Percentage obtained for trip Madrid-Valencia

These will be the percentages that are shown the Data Treatment for Problem 4

ANNEX IV: MATLAB CODES

Base Problem:

```
%introduce the data
p=[2085675 1058000 521816 457455 430029 383350];
%define the problem:
Prob=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob.Constraints.con_1=x>=5*ones(6,1);
prob.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob);
```

Problem 1:

```
%introduce the data
p=[2236551 834323 569078 326467 700257 269649 ];
%define the problem:
prob_1=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_1.Constraints.con_1=x>=5*ones(6,1);
prob_1.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_1.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_1);
```

Problem 2

```
%introduce the data
p=[2005719 1162319 510037 440743 443222 374284];
%define the problem:
prob_2=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_2.Constraints.con_1=x>=5*ones(6,1);
prob_2.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_2.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_2);
```

Problem 3

```
%introduce the data
p=[2115278 1019716 508619 472656 432493 387563];
%define the problem:
prob_3=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_3.Constraints.con_1=x>=5*ones(6,1);
prob_3.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_3.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_3);
```

Problem 4

```
%introduce the data
p=[1525467 1093037 703612 634468 568913 410828];
%define the problem:
prob_4=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_4.Constraints.con_1=x>=5*ones(6,1);
prob_4.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_4.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_4);
```

Problem 5

```
%introduce the data
p=[2221703 1107608 479965 414172 384575 328302];
%define the problem:
prob_5=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_5.Constraints.con_1=x>=5*ones(6,1);
prob_5.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_5.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_5);
```

Problem 6

```
%introduce the data
p=[2120314 1049714 515155 449104 425400 376638];
%define the problem:
```

```
prob_6=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_6.Constraints.con_1=x>=5*ones(6,1);
prob_6.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_6.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_6);
```

Problem 7

```
%introduce the data
p=[1712174 1040295 748535 455515 446690 533117];
%define the problem:
prob_7=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_7.Constraints.con_1=x>=5*ones(6,1);
prob_7.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_7.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_7);
```

Problem 8

```
%introduce the data
p=[2072916 1097718 531798 446357 422158 365377];
%define the problem:
prob_8=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_8.Constraints.con_1=x>=5*ones(6,1);
prob_8.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_8.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_8);
```

Problem 9

```
%introduce the data
p=[1821981 1389136 581065 487045 342314 314784];
%define the problem:
prob_9=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_9.Constraints.con_1=x>=5*ones(6,1);
```

```
prob_9.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_9.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_9);
```

Final Problem

```
%introduce the data
p=[1902714 1068623 617412 464555 514559 368462];
%define the problem:
prob_f=optimproblem('ObjectiveSense','min');
%define the decision variables:
x=optimvar('x',6,1,'Type','integer','LowerBound',0);
%define the constraints
prob_f.Constraints.con_1=x>=5*ones(6,1);
prob_f.Constraints.con_2=transpose(p)<=10000*x;
%define the objective function:
prob_f.Objective=sum(x);
%solve the problem:
[x,fval,exitFlag,output]=solve(prob_f);
```