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A METHODOLOGICAL APPROACH TO SUPPORT CAR SHARING PLANNING

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Abstract

Over recent years, different innovative transport solutions are emerging with the potential for mitigating the primacy of private car. Car sharing is one of them, although it presents some critical aspects which can lead to the failure of the service if neglected. The mutual influence between demand and supply, environmental impacts, relationship with public transport, operator's economic issue, as well as the "novelty" for citizens are some of the main factors which characterise this new mobility service and influence its success.

An intensive literature analysis reveals that a precise planning phase, able to consider all the critical aspects of the system, is lacking. This research work aims to develop a global and structured methodological approach, capable of supporting the designer in a new car sharing service planning, handling all the key aspects and their relationships.

The developed methodology is "multi-step", i.e. there are several phases, based on different theories and tools such as stated preference survey, discrete choice model, optimisation process, which are related to each other since the outputs of a step are the inputs of the following one. Furthermore, an algorithm, developed for dimensioning the supply's elements, is integrated into a phase of the suggested methodology.

The methodological approach is tested, applying it to the planning of a car sharing service dedicated to the University of Trieste students' night trips. Several design options are tested until defining the supply elements of the one which best balance the different objectives. It transpires that the proposed procedure can be a reliable support for the planning process management, allowing the designer to consider all the aspects for the new service success, attesting to be a simple, flexible and accurate instrument.

This research provides evidence that car sharing planning is a complex process and defines a methodology which is expected to contribute to the definition of successful services. It also highlights how the different planning aspects are related and the importance of considering all of them jointly.

Sommario

Negli ultimi anni stanno emergendo diverse soluzioni innovative di trasporto, potenzialmente atte a limitare il primato dell'auto privata; il car sharing è una di queste, sebbene presenti alcuni aspetti critici che, se trascurati, possono portare al fallimento del servizio. Tra i principali fattori che caratterizzano questo nuovo tipo di servizio di mobilità e ne influenzano il successo emergono, per citarne alcuni, la stretta relazione tra domanda e offerta, gli effetti sull'ambiente, la relazione con il trasporto pubblico, il tema economico per l'operatore e, non da ultimo, il fattore "novità" per i cittadini.

Riscontrata dalla letteratura la mancanza di una precisa fase progettuale, capace di tenere in considerazione tutti gli elementi cardine del sistema, il presente lavoro di ricerca si pone l'obiettivo di sviluppare un approccio metodologico globale e strutturato, in grado di supportare il progettista nella pianificazione di un nuovo servizio di car sharing, tenendo conto degli aspetti critici e delle loro mutue relazioni.

La metodologia sviluppata è di tipo "multi-step", ovvero sono presenti diverse fasi che si basano ciascuna su diverse teorie e strumenti, quali, sondaggi alle preferenze dichiarate, modelli alle scelte discrete, processi di ottimizzazione, relazionati ed integrati tra loro poiché gli output di una fase sono gli input di quella successiva. Inoltre, un algoritmo, sviluppato per il dimensionamento degli elementi dell'offerta, è stato integrato in una delle fasi della procedura.

Al fine di avallarne le sue potenzialità, la metodologia è stata testata, contestualizzandola ad un caso di studio, mirato alla progettazione di un servizio serale di car sharing destinato agli studenti dell'Università degli Studi di Trieste. Diverse soluzioni progettuali sono state testate, consentendo di individuare e dimensionare la soluzione che meglio bilancia gli obiettivi del progetto. Da ciò si evince che la metodologia possa offrire un utile supporto al progettista, consentendogli di gestire il processo di pianificazione senza tralasciare aspetti importanti per il futuro successo del servizio, offrendo uno strumento semplice, flessibile ma allo stesso tempo accurato.

La ricerca mette in luce la complessità della pianificazione di un servizio di auto condivise e valuta gli strumenti necessari per migliorarla, evidenziando come i diversi aspetti della progettazione vadano considerati in un'ottica integrata.

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1 Introduction

The transport sector plays a crucial role, since the growing request for connecting people, services and goods. It is pivotal both at the national level, to foster the countries development and economy, and at an individual level to facilitate people daily activities and increase the socialisation and employment opportunities [1].

Nowadays, the transport system has required to be efficient and effective, capable of responding to all the citizens mobility needs, and, at the same time, it is wanted to be sustainable, accessible, safe, seamless, integrated among other modalities, able to boost the social equity, the quality of life and health, also enhancing the attractiveness of the urban environment [2]. With the adjective sustainable it is intended to be able to satisfy the needs of the present generation as well as of the future one considering all the dimensions, i.e. from an economic, social and environmental point of view [3].

At an international level, these challenges are including in the vision of COP 21 Paris Agreement, establish as priorities by the Horizon 2020 Transport Work Programme [4] and identified as crucial in the 2030 Agenda for Sustainable Development [5].

In this framework, even if the private car is still a largely preferred transport mode, also its downsides are emerging. These are principally related to traffic (high congestions levels, especially in urban areas), health (stress, disease due to pollutants emissions), impossibility of accessing certain zones (pedestrian areas and limited traffic zones), parking (lots are limited and expensive, especially in urban areas), expenditures (owning a car is very costly), loss of time (people are even more inclined to be transported instead of drive), environment (emissions of air pollutants, GHG effect, impact on the landscape) [1].

Consequently, new and old forms of mobility are evolving [6], to boost people toward new transport mode, diverse from the private vehicle, in particular, enhancing the concept of multi-modality and inter-modality. The presence of a wide range of different means of transport allows the user to choose, time to time, the service most suitable for him and for his needs: this is called multi-modality, i.e. the possibility of choosing the most convenient mobility solutions instead of the only usage of

the private car. If the number of available alternatives is large, more probability will have the user to find out proper mobility solutions. Inter-modality, instead, appears when the user changes the means of transport in order to reach his final destination, i.e. different transport services are used in sequence, and each of them is complementary to the other. An efficient inter-modality allows users to percept the service competitive with the door-to-door solution provided by the private vehicle. It emerges that only if all the services are efficient, then the whole solution can be competitive with private car [7].

Moreover, the increased attention towards the environmental issue, the climate changes and the widespread concept of "usage over ownership", are encouraging people to evaluate the chance to shift from the private vehicle to a more sustainable alternative according to their personal, endogenous, motivation [8].

All these factors are boosting people towards the adoption of different means of transport, and car sharing can be a satisfactory alternative [9]. In a nutshell, car sharing is a flexible service which provides access to a vehicle, without the burden of ownership.

In the last years, it is becoming even more popular, considering that in Italy in 2018, the car sharing users were more than 1,8 million with a constant positive growth rate [6].

Nevertheless, there are some concerns related to this service, which affect its success. When planning a new car sharing service, the complexities which arise are numerous. The studies conducted during this doctorate period, bring out which are the elements, that seems to most influence the success of a car sharing service, both from the demand and the supply side. Transport demand stands for transport needs, and it is expressed as the number of people per unit of time and space. Transport supply is the capacity of the infrastructures and services, and it is assessed in different ways, like services' frequency, network coverage, infrastructure capacity and surface, per a certain period of time and space [1].

1.1 Research Objective

From the literature analysis emerges that, when planning a new car sharing service, very few studies approach the issue exhaustively, taking into account critical elements such as the interaction between demand and supply [8], the financial aspects and the interplay of car sharing with public transport services, during the planning phase. Moreover, often, new services are implemented on-field [10] without a proper planning phase.

From the analysis of the state of art, it seems to be pivotal to develop a structured and holistic planning methodology which aims to support the designer in the definition of a new car sharing service. When planning a new service, the key questions are: "Will the new car sharing be attractive?

Which are the elements which bring the service to be appealing? Will the service be profitable for the operator? Will it produce positive impacts on the environment/other public transport modes/modal shift?". Providing the designer with a tool which makes him capable of answering to these questions is the key objective of this research work which presents a new methodological approach useful to plan a car sharing service, in particular, station-based. In order to fulfil this objective, the conducted researches can be principally split into two categories: from one side the main techniques, relevant to plan the service, have been deepened. Stated preference surveys, discrete choice models, optimisation approaches have been investigated from a theoretical and also applicative perspective, supported by the implementation of several tests and basic case studies in order to prove their goodness. In addition, specific software, essential for the application of the aforementioned techniques, has been approached. On the other side, car sharing has been analysed, focusing on its key feature and planning procedure, mainly examining the literature on the issues and exploring real cases. The researches have primarily been carried out with the purpose of brings to light the relationship among the different techniques and design elements. A systemic approach has been adopted to investigates the problem from several different perspectives: not only the technical one, but also taking into account the other available public transport services, the environmental issue and the global sustainable mobility policies.

On the basis of those analyses, a methodological proposal is made with the purpose of providing support to the designer in the pre-implementation phases of a new car sharing service. The suggested approach is aimed to be a valuable tool to ease the design process until defining the elements which characterise the solution which better balance the different objectives. Furthermore, the method allows the designer to take into consideration all the different elements involved in the process, highlighting the crucial connections which exist among all the different steps of the planning procedure and the mutual influence of some design choices. The case study, reported in the present dissertation, is used to endorse the developed methodology.

1.2 Thesis Structure

The thesis is structured in order to conduct the reader to a deeper comprehension of the research work, starting from the context, from which the work evolves, to the presentation of the developed planning methodology and its application to a case study, used as a test.

Chapter 2 reports the literature analysis, split into three sections; the first one (*2.1*) introduces the sharing economy and the sharing mobility, which constitutes the background for the understanding of the thesis specific focus, i.e. car sharing. Furthermore, a special focus is dedicated to students in relation to the sharing mobility, since they are also potentially attractive targets for car sharing. This

latter is explored focusing on several aspects: its functioning, the service typologies, the impacts on the environment, society, economy and on the whole transport system; the most recurring characteristics of shared vehicles users are inspected, together with the potential of adopting electric cars in the fleet. Particular attention is dedicated to the pivotal relationship between car sharing and public transport. The state of art on car sharing modelling is reported in the second section (*2.2*), considering data collection and data analysis, which are crucial issues for purchasing the thesis' objective. The last section of the literature analysis chapter (2.3) describes two methods stated preference surveys and discrete choice models, which are included in the suggested planning methodology. So, from a sequential point of view, they should be reported in Chapter 4 which presents the methodology, but, since they are important, quite complex and worthy of a particular focus, they are described in this separate section. Another reason to dedicate them a separate section is that, differently from the methodology, which has been developed during the doctorate period, the two methods are explored from a literature point of view, i.e. reporting the research works of other authors.

Chapter 3 highlights the problems encountered analysing the state of art on the topic; the consciousness of these issues constitutes the basis for the development of the car sharing planning methodology, presented in the *fourth chapter*. The methodology aims to provide a practical tool for the planning of a new car sharing service and, since it is a "multi-step" procedure, the chapter is divided into separate sections, one for every step of the methodology. The steps are deeply related to each other, and so, the leading relations among them are explicitly reported.

The methodology is composed of different methods and tools, someone already explored in the literature (discrete choice model, stated preference survey, optimisation approach) and others developed explicitly for the purpose. The structured relationship of all these elements is the milestone of this work.

With the aim of testing the potentials of the developed planning methodology, *Chapter 5* reports a case study. It aims to implement a car sharing service for university students and has been tested at the beginning of 2019 at the University of Trieste. *Chapter 6* is dedicated to the discussion on the case report results and on the elements which, from the methodology application, emerge as pivotal for the success of the car sharing planning process. Finally, conclusions and future research are presented in the last *chapter*, number *7*.

2 Literature Review

Short Summary

The literature review includes the current knowledge on the topic and it is pivotal to delimitate the research problem, seeking support for the suggested methodology, identify the research gaps and better understand approaches and methods [11].
The chapter is split into three main parts: the first one (2.1) states the framework of the research work reported in this thesis, the second one (2.2) presents literature on car sharing service modelling, considering data collection and data analysis, which are pivotal issues for pursuing the thesis objective, i.e. defining a planning methodology. Finally, the third part (2.3) describes two methods, namely, stated preference survey and discrete choice model, which are embedded in the suggested methodology.

2.1 Car Sharing Framework

Short Summary

Car sharing evolves from a broader vision of the economy and mobility. Sharing economy is a new economic system, which is based on the concept of "access over ownership" and the sharing mobility is driven by the same principle. Car sharing is an emerging service, which keeps changing and adapting to different needs and situations, leading to experiment drivers and benefits, but also, barriers and adverse effects. The planning process and the implementation of this kind of new, sustainable services are affected by several issues and stakeholders.
Before introducing the key aspects of the conducted research work (2.1.3), it is useful to frame the issue drawing up the principal elements of the sharing economy (2.1.1) and the sharing mobility (2.1.2). Finally, considering the key role of the issue on the case study elaborated during the doctorate period and reported in the present dissertation, a paragraph (2.1.4) is dedicated to a peculiar target category, namely young people and, particularly, university students and their attitude towards sharing mobility.

2.1.1 Sharing Economy

"Airbnb", "BlaBlacar", "Cooking blogs", "Coworking", "Crowdfunding", "Cohousing" and "Orti Urbani", all of them are based on the sharing of resources: from houses to vehicles, from culinary skills to money or public lands, but they all refer to the same concept: people use and experience a benefit from the value created by the sharing of something and not by the owning of something. It is not a novelty since the long-established experience of the urban library or taxi services, but nowadays, this phenomenon is amplified and supported by digital technologies, which simplify the meeting of demand and supply.
Sharing economy is a new economic system, which is based on the concept of "access over ownership" [12], i.e. people have the chance to utilise something without owning it. In the sharing economy, the value of a product is created by the network of people who share their properties (goods, service, knowledge), differently from the classical economic theory in which the value of a product is an intrinsic property [12].
The concept lacks a single definition, and Schor J. concluded the following "Coming up with a solid definition of the Sharing Economy that reflects common usage is nearly impossible. There is great diversity among activities as well as boundaries drawn by participants" [13]. According to the

Osservatorio Nazionale Sharing Mobility [14], it can be defined as "a series of activities and models (consumption, production, learning models, etc.) which use digital technologies to simplify the resources sharing and maximise the usage benefits concerning the individual usage".

Sharing Economy involves different actors (individuals, non-profit and for-profit companies, public entities) and is based on the exchange of a wide range of tangible and intangible assets (good, services, capital, time) and promotes access to assets instead of ownership [15]. Its main features are [16]:

- resources optimization through the goods reutilisation instead of purchasing and access over ownership. This aspect leads to lower costs and the possibility of creating an income;
- digital technologies and web platform which facilitate the connection between people and assets. In particular, millennials are very enticed by social networking as an element of tendency lifestyle;
- sharing, relationship and trust [12]: these elements are essential to share goods with other community members who are strangers: these elements are made stronger by social networking and are encouraged when supported by altruistic and sustainability mindsets.

In Italy, the first sharing economy experiments were done in the 2000s but did not boom until 2011 [16]. In 2009 Airbnb offered two bedrooms, in 2015 the offered housings were two million: in only six years, the service provided more bedrooms than each of the three biggest hotel chains in the world [12]. The main sectors are the crowdfunding and the services dedicated to the consumer goods exchange, followed by the transport sector. The most crucial aspect is the reaching of the significant number of users so that to move up the chain: indeed, the sharing services yield the best results and can satisfy the demand with a high number of users.

Reaching the necessary number of users to bring about a virtuous circle is not effortless due to many factors, such as [16]:

- the novelty: people do not know the service, its functioning or its advantages and operators experience some difficulties in ensuring that people understand it;
- internet familiarity: several people, especially in Italy, are not familiar with the internet, neither with online payment;
- lack of experience: often the operators do not have a consolidate and successful example to which they can refer to, and so they experience difficulties in finding a strategy to launch the new service;
- lack of financial support in the launch phase;
- lack of partnership with public administration or large companies.

2.1.2 Sharing Mobility

Under the term "sharing mobility" can be set all the transport systems in which the user has to share the trip with other passengers, i.e. it involves all the mobility forms which do not require a personal vehicle [6]. Belong to this category both already well-known services such as bus, metro, train, taxi, and newer ones like car sharing, carpooling, bike sharing. Furthermore, these services can be split into those which can be used simultaneously (train, metro, bus) and those which are used in sequence (e.g. taxi, car sharing). The sharing mobility interventions are managed by an organisation, which provide the service and a plurality of persons who adopt it, sharing trips or vehicles. They can be supplied in a predefined itinerary with specific timetables (e.g. bus, tram, train) or can be "on-demand", i.e. provided upon request (e.g. taxi, Ncc, car sharing).

According to the "Osservatorio Nazionale Sharing Mobility" [14], the new sharing mobility is a socio-economic issue, which involves demand (i) and supply (ii) of the mobility services. Sharing mobility involves demand (i) because it produces a shift of the individuals' behaviour, towards sustainable measures which assure the temporary access to the mobility services only when they need, instead of the usage of the own vehicle. Also, it involves supply (ii) since it introduces new mobility services, which are based on several new elements, typical of sharing economy:

- digital platform: the virtual environment where demand and supply come together;
- community: the social network is a crucial element in boosting these mobility services;
- flexibility: the suggested solutions allow people to change their transport modality according to their convenience;
- peer cooperation: who offers the service, can be a citizen equal to users.

There are two main streams of the new sharing mobility evolutions [17]:

- services side;
- intermodal journey planner.

The first ones include new typologies of transport service and can be, in turn, split into vehicle sharing (where users share the means of transport, like car sharing, bike sharing, van sharing) or ride-sharing services (such as carpooling, ride-hailing, where the user benefits from a transport service). Through a platform or App, the intermodal journey planner provides real-time information to users and allows them to plan the trip combining intermodal solutions in order to define the best journey, in terms of time and cost-saving as well as travel experience. The journey planner provides a series of different trips with different modalities, and only one tool offers all the information (costs, tickets, time schedules, feedbacks collection). Some platforms, such as Whim in Helsinki or London, also allow users to buy a single ticket to benefit from several travel modes, like bus, metro, taxi, car sharing. These services are also known as MaaS, mobility as a service, indeed, the travellers can plan their journey in the best way possible since the platforms shall also provide real-time traffic info,

alert for accidents and for congestions caused in front of schools in the rush-hour when all students finish their lessons. The main goal of these services is to be competitive with the door-to-door solution, which can be offered by a private car [17].

While car sharing will be better explored in the following section, here a brief introduction on the principal different sharing mobility services is reported [15]:

- carpooling: people travel together in privately owned vehicles with a common destination, typically for commuting. In Italy, the most known carpooling service is "Blablacar", an interurban service, which allows people to get in touch through a platform, share the journey and then provide real-time feedback on the drivers and the users. In this way, vehicle occupancy is optimised, and the travel costs can be shared among travellers.
- bike sharing: travellers can pick up a bicycle, cycling until their destination and leave the mean and, in the end, they pay the service via internet payment or in cash. The service is very supporting for the first/last mile problem, and it is very successful in cities where there are efficient bicycle facilities.
- scooter sharing: it is very similar to the bike sharing service, but the fleet consists of scooters. It Italy, precisely in Milan, Rome and Turin, the scooter sharing companies provide the service with electrical vehicles (90% electric vehicles in 2018 [6]).
- vanpooling: is the sharing of a van by commuters travelling to and from the same place.

The proliferation of shared mobility options is related to several society trends [15], to name but a few:

- attention towards economic convenience;
- higher interest in promoting more active transport modes;
- increase of the mentality "work anywhere, anytime", teleworking thanks to internet access;
- the proliferation of digital sharing economy services which has permitted access to goods through information technologies;
- car ownership rate is declining among younger people [18];
- private cars are losing their appeal due to the high traffic congestion [19] and parking difficulties.

The sharing mobility effects depend on the type of service, and, most of the time, the different services are not rival but complementary, also with public transport, and only planning them jointly it is possible to achieve sustainable benefits [15]. The impacts of car sharing will be better explored in the following section, but, in general, the main implications of the sharing mobility services are related to the better exploitation of the available resources compared to their usage at an individual level, and can be summarised in [14]:

- reduction of the number of vehicles per household which brings to a reduction of the parking request;

- increase the vehicle occupancy level which leads to a decrease in the quota of cars on the road;
- usage of non-motorized modes;
- usage of vehicles based on more environmentally friendly technologies, such as electric vehicles;
- raise awareness towards the travel impacts which brings the traveller to evaluate the necessity of travelling and the travel modality continually. People are more inclined to assess, before every trip, on which is the better transport mode, allowing to evaluate all the transport mode and achieving a rational usage of the cars (against the common ground "I own a car, and I use it always").

It is not possible to state a general conclusion on the sharing mobility impacts since these services are numerous, operated in various ways and different from each other. Some studies affirm that the reduction of congestion, pollutant and acoustic emissions and fewer vehicle accidents are indirect effects of the implementation of these services [20], [21], [22], while others state that the congestion increases with their implementation [23].

2.1.3 Car Sharing

Short Summary

This section introduces the principles which underlie car sharing, reporting several issues which describe the study subject, delimit the research boundaries, identify the best practice and the elements which provide support to the planning methodology suggested in this dissertation. After a short introduction and the explanation of the operation of the service, are presented the car sharing impacts, focalizing on the relationship with the already existent services of public transport, the principal characteristics of the users, the introduction of electric vehicles in the fleet and the financial issues from the operator point of view. All these aspects provide a solid framework for the defined planning methodology. Finally, the car sharing situation in Italy is also briefly reported.

Car sharing is a service that provides members with access over a fleet of vehicles [24] by paying an annual quota, as well as a fee for the effective use of the cars. The service can be advantageous for the user (no need to own a car, more flexible than public transport, etc.), the non-users (less congestion, more parking lots available, etc.) and the environment [25]. Furthermore, it also reduces the request for parking spaces (private vehicles are parked for 95% of the time in their life) [26]. Car sharing initially developed in Switzerland (1948), and then in Germany, Austria and Netherland and,

in its current forms, car sharing started in Switzerland (Mobility Switzerland) and Germany (StattAuto Berlin) in the 1980s, with consolidation in 1990s [27]. Several authors analyse car sharing from a historical outlook [28], or with a geographical perspective from the American market [29] to the Asian market (Japan and Singapore [30], China [31], Australia, Malaysia, Indonesia and Thailand [32]) which today has many potentials as it is the largest car sharing area by number of members [33]. Also the worldwide perspective [34] and future trends [28] have been delineated.

There is not only one car sharing definition: according to the results of the Momo European project [35] "Car-sharing is a form of transport by which several persons, in turn, make use of one or more collective cars". Other authors provide different definitions: "Car Sharing is a service that provides members with access to a fleet of vehicles on an hourly basis" [24]. "Car Sharing consists of the usage of the same vehicle at different times by different users. Each user can drive the car the time he needed to satisfy his mobility needs. The users pay a quota for the effective usage of the vehicle" [36]. "Car sharing can be defined as a group of people sharing a fleet of cars by paying an annual fee, as well as paying for each kilometre travelled and the time per use" [37].

The key actors of car sharing are:

- operators, who [36]:
  - define the new services main features;
  - manage the fleet: the vehicle purchasing/leasing, maintenance (ordinary and extraordinary) and cleaning;
  - allow people to associate to the services;
  - control the car reservation process;
  - define the usage modality;
  - invoice the car usage;
  - promote the service;
- users: people who use the service once they have associated with the service and paid a fee.

There are different car sharing typologies, better explained in the next section, but it is possible to assess some common features, (some of them are, also, critical attributes of the sharing mobility), shared among all the different typologies [24]:

- presence of an organised group of participants;
- availability of a joint fleet: one or more vehicles to be shared;
- presence of a network of parking lots: in the station-based car sharing the cars must be left in specific parking lots, while it is not necessary for the free-floating car sharing (these concepts are better explored in 2.1.3.2);
- the chance (and sometimes the duty) to book in advance (except for free-floating car sharing);
- short time periods for car usage;

- self-accessing vehicles.

In the United Kingdom the term "car sharing" is referred to the service known as carpooling while they denote "car sharing" with the name "car club".

2.1.3.1 How Does It Work?

Figure 1: How Does It Work?

There are different kinds of car sharing, but they share some typical features: the new users have to register, to subscribe an agreement and, usually, pay a fee, sometimes together with an insurance and then they can book a vehicle typically calling a call-centre or through a web platform/App. According to the car sharing typology, cars can be parked in specific parking areas (station-based) or can be everywhere inside a defined perimeter (free-floating); in this latter eventuality, the vehicles can be detected through a smartphone App which receives the cars localisation from the GPS. The cars can be unlocked through the membership smartcard (RFID) or a QR code or a PIN (at the beginning of car sharing the operators used physical "locked box" for access). All the travel costs are covered by the fee and by the payment for the real vehicle usage (km and hours) which are recorded automatically by the technological device which is installed on board of the vehicle, allowing the car sharing operator to invoice users for car usage, at the end of the month (or term) - cf. Figure 1.
Vehicles are equipped with an ICT device which records the hours and km travelled and a technological system which allows access to the car (QR code, password, PIN, smartcard) [24]. These systems are one of the main success factors of the service since the manual system had several disadvantages [28] such as theft, vandalism, lack of accuracy in the bill estimation and high staff needed. Nowadays, even more, cars are equipped with Global Positioning System (GPS) which allows the operators to know the position of the vehicle in every situation. Usually, also the reservation system is automatized, allowing vehicle reservation (modification and cancellation) based on the real available cars.

2.1.3.2 Classification

There can be different classifications of car sharing; Table 1 reports the principal ones:

Table 1: Car Sharing Classification

Organisational Forms		
Source	**Type**	**Description**
[35]	Car Sharing by providers	The vehicles are made available by an external organisation (commercial firms, subsidiaries of car manufacturers, public transport firms, etc.). The cost depends mainly on the use, and the users are not responsible for the maintenance of the cars. Companies from various sectors are operating car sharing services, e.g., car rental companies (Avis with Zipcar), energy companies (Eni with Enjoy), automotive vehicle manufactures (Daimler with Car2go), startups, insurance companies, train service providers. The world's largest free-floating carsharing provider in terms of fleet size is Car2go.
[35]	Car Sharing via private car sharing groups	A group of people own the shared vehicles, and they mutually conclude a contract allowing them to use the joint fleet systematically. They self-manage cars and their usage.
[35]	Peer-to-peer car sharing	The vehicles are owned by citizens who allow others to use them at a previously agreed cost price. An organisation acts as an intermediary between car owners and users and provides compensation to the car owner for his car usage. The vehicles are supplied with a software, installed into the cars, and through which users' identification and billing are done.
[35]	Sharing municipal fleet with residents	Usually, the municipality's vehicles are used for a few hours a day and not during the weekends, so it can be convenient to share their cars with residents or municipal employees outside office hours.
[24]	Corporate car sharing or fleet sharing or business car sharing	The company (like private company, hotels, university campus) allows its employees to use the company fleet. In this way the company optimises the vehicles' management, reduces the vehicles costs, and, at the same time, its employees can have access to vehicle both in the off-work time (paying for the service) or during the working time for business trips. The service can be seen as a company benefit. Furthermore, vehicles can also be shared with users who are not company employees.
Depot Location and Trip Configuration		
Source	**Type**	**Description**
	Station-based	These systems provide dedicated stations where to park the vehicles: station-based car sharing can be further split into *one-way* and *round-trip* car sharing. The first one allows the users to take the car from one station and to give it back to any other one, giving more freedom to

		users, even if it may cause vehicle stock imbalance within the network, while in the latter configuration users have to return the vehicle to the same station where they picked it up. The relocation problem for one-way car sharing has been studied deeply, as it will be better exposed in the next chapters (2.2.2.2 and Step 11).
[38]	Free Floating	The absence of dedicated stations characterises free-floating car sharing: users can pick-up and drop-off the vehicles freely within a defined urban perimeter. Its first implementation was in Ulm, Germany, 2009, with the system "Car2go", launched by the car manufacturer Daimler. This system is very flexible and very suitable for the problem of the "last mile" of multi-modal trips [19].
Source of Capital		
Source	**Type**	**Description**
[24]	For-profit	Access to corporation capital or private funding.
	No-profit	Tap into government funding, and they are tax exempted.
	Cooperatives	Members provide capital, and the operators are cooperative members.
Customer group		
Source	**Type**	**Description**
[24]	Personal users	Individual or households joint the service and use the vehicles similarly to privately owned cars.
	Business users	The service is available for the company's employees; in this way, the company can replace its fleet (or part of the fleet)/ the car rental/ the reimbursement for employees using their car for business trips. This service can be an incentive for employees not to drive from home to work but assuring them the availability of a car during working time. Usually, during the evening and weekends, the vehicles are available as a standard car sharing service.
Service Area		
	Type	**Description**
	Urban	Urban car sharing is the most popular form of service. People can use the vehicles all around the city (or a portion of town).
	Regional	It is a more recent form of car sharing where people can take a car and leave it in another city. It is also a powerful means in boosting multi-modality, since, if the stations are located strategically, it can be used to reach the airports/railway stations.
	National	Probably there is only one national service, is Mobility car sharing in Switzerland [8].

2.1.3.3 Impacts

Several studies investigate the service impacts, which can be split into three areas [15]:

- impacts on the environment and community: fewer emissions, congestion, urban better design, more parking spaces, etc.;
- impacts on transport system: lower parking demand, more fuel-efficient vehicles (electric), fewer cars travel, reduction of accidents, etc.;
- impacts on individuals/business: cost savings, convenience, etc.

These last topics are primarily assessed by Burlando et al. [39] and by Bommarito [40], whose studies are available in the "Iniziativa Car Sharing" online repository. They compare the private car usage to the car sharing adoption and results that car sharing is convenient when the users dive less than 5.000 km/year (10.000 km/year if the vehicle is used, exclusively, for long trips).

The most significant efforts focus on these sectors:

- reduction in parking demand and fewer cars parked on the public street or car parks for extended periods [41], [42];
- reduction of vehicle ownership and increase of members' propensity in selling or suppressing the purchase of a personal vehicle [24], resulting potentially money-saving both for private citizens and companies [42], [43];
- boosting accessibility to vehicles to all citizens [44];
- reduction of the kilometres travelled caused by the absence of the personal vehicle which is always available when and where it is necessary [43] and consequent congestion reduction in urban areas [15];
- reduction of pollutant and greenhouse gasses emissions, since car sharing users drive fewer kilometres and, usually, car sharing fleets consist of new and eco-friendly vehicles [15]; Martin and Shaheen, (2011) [45] state that car sharing decreased emissions, on balance, but this result is not generalizable among all members; indeed, most of the members increase their annual emissions (especially the members who belonged to the careless household category), but those increases are individually small, while, on the other hand, who reduce their emissions are a minority but the volume of diminished emissions are higher and this compensates the increases of the majority;
- boosting of electric vehicles adoption [19], [46];
- changing in the modal split, increasing of "soft" modalities such as walking, bicycling [47];
- public transport is a very controversial aspect: form one side, car sharing reduces the usage of public transport, especially in the case of users who do not own a private vehicle [47]; but, on the other side, increase the public transport users since it facilitates inter and multi-

modalities and force its members to pay more attention when planning a trip [15]. Due to the complexity of this aspect, it is discussed, separately, in 2.1.3.4.

Most of these effects are deeply describe in Millard-Ball et al. (2005) work [24].

The impacts are linked to each other, e.g. the reduction of car ownership leads to lower transportation costs for households, a boost of public transport or different eco-friendly transport modes, as well as, lower parking demand and fewer kilometres travelled which is, in turn, related to less congestion, better mobility and fewer pollutant emissions.

"Osservatorio Nazionale Sharing Mobility" was launched in 2005 promoted by the "Ministero dell'Ambiente e della Tutela del Territorio e del Mare", by the "Ministero delle Infrastrutture e dei Trasporti" and by the "Fondazione per lo Sviluppo Sostenibile". It aims to provide a cooperation platform among researchers, public transport providers, public and private institutions, and to analyse, sustain and promote sharing mobility in Italy. In Italy, it is an authoritative source of data and their executive summary 2016 "La Sharing Mobility in Italia: numeri, fatti e potenzialità" [14] reports an assessment of the car sharing impacts: it was carried out comparing different sources and validating data with literature analysis. Investigations have analysed the transport behaviour of a unique sample before and after their car sharing adoption and also two separate samples: people who adopted the innovative service and people who did not change their transport modalities considering the same time and the same conditions (e.g. living in the same city, comparable age). A common way to collect data on transport behaviour is "travel diary", in which travellers report all their previous week/day trips. It provides exhaustive information but not always accurate since the high burden requested to answers. Nowadays, smartphone-based GPS-tracking data are very reliable and precise, but they are not always available to the researcher. Furthermore, some traffic models have been used to support the surveys' investigations.

The investigations agree that car sharing leads to a reduction of kilometres travelled and a modal shift, especially when the subject of the inquiry is the station-based car sharing, while for free-floating car sharing the decline of the travelled kilometres is lower.

For further details, the interested reader is redirected to the Osservatorio Nazionale Sharing Mobility report [14], however, in summary, they have analysed more than twenty authors who studied the car sharing impacts, all around the world between 2001-2015. The examined effects are related to:

- reduction of the kilometres travelled: the values for station-based car sharing ranges between 2-45% and for free-floating between 6-16%;
- modal shift: which is a very controversial issue since, some interventions experience a decrease in the public transport, while others report a related increase of the public transport (in Italy, +19% for new subscribers and +40% in total); all the studies show a boost of the walking mode;
- reduction in emissions and consumption.

- reduction of the owned vehicle: this impact has to be split according to different situations:
    - selling of the owned vehicle: ranges between 2-40%;
    - the scrapping of fleet vehicles: ranges between 7-21%
    - renouncement of purchasing of a new car for the household:14-67%;

2.1.3.4 Car Sharing and Public Transport

To reduce negative externalities, for many years, local governments enhance the use of public transport (PT) supporting this by providing appropriate infrastructure, particularly in urban contexts [48]. Public transport has many success factors from a social, environmental and economic point of view, and it is possible to define it as a sustainable transport system. Public transport is accessible to everyone (young, older people, people without a driving license, people with disabilities), upon payment of a fee which is usually very contained and can serve more users contemporarily. It helps to mitigate the negative impacts on the environment since a PT vehicle emits less pollutant per person that a private vehicle, alleviates the parking problems and helps to reduce congestions since, usually, the same number of people brought in a public means of transport, would need much more private vehicles. On the other hand, the service has some negative aspects for its users: PT does not offer enough flexibility for all purposes as private vehicles can do: the service has fixed trips and timetables, and the same route by car would take less time, due to the several stops that the PT vehicles are forced to do. Moreover, the service is fewer comfortable, especially when people travelling with luggage, and cannot be considered as a door-to-door service since sometimes users have to reach the stations/their destination running a long distance on foot or with another means of transport [49]. PT can serve long distances in extra-urban contexts (e.g. train) or short distances (bus, tram) or limited distances due to cost (taxi) [50].

As already affirmed, the effects of the introduction of a new car sharing service in relation to the already existent public transport services are very controversial. The research conducted by Martin and Shaheen (2011) [47] highlights this issue; they analyse 6281 surveys completed by American car sharing members (provided by 11 different companies) investigating on their behaviour before-and-after joining the car sharing, in particular on the relationship between this new modality and public transport. The results are very contrasting, since data are not uniform among all the car sharing associations and across the entire sample the impacts seem to be both positive and negative considering that 589 car sharing members reduce the rail usage, 828 reduce the bus usage, while 494 increase the bus usage and 732 increase the rail usage.

Both the services have the potentiality of reducing the negative effects of the private car usage, but if the implementation of the car sharing reduces the number of users of other public transport services, then these will earn lesser revenues from passenger fares, and this can trigger a vicious

cycle of reduction in frequencies, resulting in less efficient services [51]. The major benefits can be achieved if the synergies of the two services are strength towards the common objective of substituting private car. To reach this goal the two services must be services complementary [52]; car sharing can complement public transport aiming at reaching the door-to-door solutions desired by passengers. It is often referred to car sharing as the "missing link" among the several alternatives to private car [24].

Careful planning is crucial to achieving the most benefits from both the services, boosting inter-modality and multi-modality [52]. Car sharing should be implemented for the situation where PT is not very suitable, for example, for journeys with particular purposes, such as visiting places or transporting something, as well as travelling during the night-time, or when waiting for the service contributes to an increasing sense of unsafety [50]. Furthermore, for the long distance's trips, car sharing can complement train in the first-last mile problem [48]. Of course, their joint usage will be attractive, only if both services are efficient and there is a proper infrastructure supporting public transit and the other innovative modes (pedestrian and bicycle infrastructure) [47]: it is the first precondition for the setting of a win-win strategy [50].

The following studies present interesting strategies to make the services complementary; in the methodology suggested in this dissertation, all these considerations are taken into account.

Huwer (2004) [50] presents the results of a research project conducted in Germany to define the driver-factors for the integration of PT and car sharing and determining the effects of this relationship. Furthermore, car sharing helps people to think, before every trip, on which is the better transport mode, allowing to evaluate also the opportunity provided by the PT and achieving a rational usage of the cars (against the common ground "I own a car, and I use it always"). Car sharing can be a solution for pushing people away from cars instead of using "penalty" strategies against car users (e.g. car restrictions in the city centre, high parking fee). To design a combined service the essential element is the cooperation between PT and car sharing companies, sometimes the public transport company itself provide the car sharing service (e.g. in Italy the main partner of E-vai car sharing is Trenitalia the leading train company); the two company should plan together the following elements:

- providing discounts and promotion for the users of both services;
- offering the possibility of testing the new service to the PT users;
- creating spatial linkage, i.e. providing car sharing stations close to the PT stops;
- allowing universal access for both services (the same subscription/ an integrated ticket);
- assuring an adequate level of information /real-time information through shared platforms/call centre number;
- organising round tables with citizens;
- advertising campaign with a common slogan.

In the Huwer's research project some people have the chance to test the combined service: the 75% of whom who accepted to do the test will recommend the service to others, and a very high ratio is satisfied by the combined service. In particular, they appreciated the speed, cost-performance ratio and the interchange chances of public transport and, on the car sharing, they enjoy the accessibility, the booking phase, together with the vehicles itself in terms of availability, variety and conditions: the two services can be, not only, complementary but also very attractive.

In the case study of Istanbul, Canitez and Deveci (2017) [53] apply a model framework to provide better integration between car sharing and public transport, since they consider this lack one of the elements which brought to the failure of the previous car sharing experiment in the city. They state that the joint success of both services can be achieved only through a multi-stakeholder approach and identify the following elements as crucial for the success mentioned above:

- parking integration: it is necessary to have dedicated parking areas with parking lots dedicated to car sharing and, also, making deals with parking managers can be a successful element towards the reaching of the objective;
- physical location integration: to increase a positive integration with the public transport, it is essential to provide dedicated parking lots for the car sharing vehicles in walking distance from airports, metro, rail, ferry stations and public transport stops. Park and Ride facilities can be used as a parking area for the car sharing; furthermore, if available in the city, also bike sharing integration has to be evaluated;
- ticketing and fare integration: allowing PT users to benefit from car sharing with a discounted price and vice versa together with a unique payment method can be a driver for the combined usage of the two services; expressly, for electric cars should be provided free or reduced fees for parking lots with charging stations.
- information and data integration: providing APPs with real-time information on car sharing (stations location, fares and vehicle availability) jointly to information of the PT stop location or estimated arrival time at the nearest stop can help the boost of the two services.

According to the research, the most significant benefits of the integrated services are:

- rising of the accessibility to public transport thanks to the fact that car sharing compensates the missing connections helping to achieve solutions even more close to the door-to-door ones;
- reduction of the private vehicle necessity;
- increasing the request for demand responsive transit service (DRT);
- increasing the comfort level and, consequently, of the users' satisfaction.

In addition to these benefits there are the ones typical of car sharing: decreasing cost respect to the private car ownership, reduction of the harmful pollutant emissions, increasing of awareness on the

personal mobility behaviour and being more attracted by transport modes diverse from the private car.

The focus of the research conducted by Kumar and Bierlaire (2012) [54] is the optimisation of the car sharing stations location, but they also analyse the accessibility of the public transport in the car sharing stations: the physical proximity of the stations/stops improves the positive relationship between them. The tendency to use public transport is a driver in accepting other share modes of transport. In their study, they relate the public transport and car sharing usage data for each station, declaring that the correlation between the two of them is strong.

A different situation is examined by Tyndal (2019) [55], who exploits a transit rail service disruption in Vancouver, Canada, to investigate the utilisation of car sharing as a public transit substitute. He observes a sharp increase of the car sharing adoption during the transit outage, especially in proximity of the affected transit stations. He concludes that it is evident that travellers substitute between the two services and that PT and (free-floating) car sharing may be synergic, pushing the designers to locate car sharing stations near the transit stations.

From these papers, it emerges that, to achieve satisfying environmental results, car sharing must be planned with the aim of reducing the private cars use, without also reducing the users of the public transport: this can be reached only through integrated planning of the two systems. There is not only one transport mode, which can substitute private car, but each mode (walking, cycling, train, carpooling, car sharing, bike sharing) can be in the position of replacing the private vehicle for specific purposes. Therefore, all the alternatives should be made more efficient and planned jointly.

In the following section are reported some real-cases where the two services are integrated: "E-Vai" in Italy, "Cité Lib by Ha:Mo" in France and "Car sharing Alto Adige" in Italy as well.

Best-Practices

E-vai

E-vai, group FNM, was launched in August 2016 in cooperation with Enel, Regione Lombardia, Ferrovienord and Trenitalia and it is an extra-urban, station-based, car sharing. It is the first Italian regional car sharing (Lombaria), the first Italian service integrated with the train service as well as the first Italian service available in the airports. Its fleet is composed by more the 100 of cars, licensed to carry 4 or 5 passengers, all the vehicles have a low environmental impact (Fiat Panda, Punto, Panda TwinAir, Citroen C3) and more than 2/3 of the fleet is composed by electric vehicles (Renault Zoe, Peugeot iOn, Mitsubishi iMiev, Fiat Panda and Citroen CZero). The car can be picked up in a station and taken off in a different station of the same city without additional costs and all-around Lombardia paying a 10 € fee.

The service is very user-friendly: people have to register, book a vehicle on the website or at the E-vai points unlock the car with a code sent by SMS, unplug and reach their destination where they have to connect the cable to the recharging post socket to recharge the car and, finally lock it.
The tariff scheme is straightforward, and the annual subscription is free, so the users pay only for the active use. There are different tariffs for electric vehicles and internal combustion engine ones and also for hourly or daily use of cars. Besides, E-Vai offers select subscriptions for companies, hotels allowing access to one or more vehicles near the corporate headquarters/hotel.
Particular attention has to be paid to the effort of this company to the integration with other transport modes: there are special connection between the major cities and the airport and furthermore, is available a service called "Il Treno a Casa Tua – A Train at your Front Door" which try to cope with the first/last mile problem. This service is addressed to commuters, train users as well as companies which operate close to the railway stations. The suggested solution is that the commuters can use an electric car to drive the distance from home to the railway station in the morning and vice versa in the evening; they can use the car all year-round, on holidays, and weekend also, every day at exclusion of the time interval between 8 a.m. to 6 p.m. In fact, during this time the vehicle can be used by a company which work near the railway stations for its working trips, with the requirement for parking the car, before 6 p.m. in the same dedicated parking lots from which it was pick up. The commuter can pay an annual fee - 3.360 € (2019) - or a monthly fee -280 € (2019) -. A recharging station is installed near the member's home, and during the weekend and the holidays, the user can take advantages by the car 24 hours per day. What is more, the users are also allowed to share the trip with other commuters: this carpooling form has the advantages of reducing the number of driven cars, emitted pollution and to reduce the service costs. For the companies which can use the car from 8 a.m. to 6 p.m., there are three different tariff schemes: morning, afternoon or daily and the payment can be done on an annual base or monthly.

Cité Lib by Ha:Mo

Cité Lib by Ha:Mo, an acronym for "harmonious mobility", is a research project conducted by Toyota in the city of Grenoble, France: it is very innovative, offering ultra-compact electric vehicles to complement the existing public transport network, offering the ideal solution for short trips. The research project was launched on October 1st, 2014 and finished on November 30th, 2017 and its main partners were the City of Grenoble, Energy Company EDF, affiliate Sodetrel, Cité Lib and Toyota Motor Corporation. The service was station-based, one-way and, in the beginning, it offered 70 electric vehicles: 35 Toyota i-Road and 35 ultracompact COMS, distributed among 27 stations all around the city and its hinterland and 120 electric recharging stations and 41 plug-in stations were added in the city. The tariff scheme was very easy, known as "3,2,1 euro", indeed the first 15 utilisation minutes cost 3 €, the second and the third respectively, 2 and 1 € and for all who subscribed

an annual fee the tariff scheme was "2+1". One thousand five hundred subscribers utilized the service for their systematic trips (work/home commuting, accompany or pick up someone, visiting friends or family, leisure, sport) especially in the urban area, running on average 5 km in 45 minutes and 92% of them was delighted of the service [56]. The project confirms the complementarity of the service with other transport modes, in particular with public transport. Car sharing IT system was connected to Mètromobilitè, the multimodal IT system of the Grenoble metropolitan area and several service stations coincide with the main public transport stops/stations. 43% of the car sharing users have a public transport season ticket, 54% of them use the bicycle more than 2 or 3 times a week and, furthermore, the service can replace cars' usage since 74% of the users own a car.

Car sharing Alto Adige

Car Sharing Alto Adige started in May 2013 as a consortium. The first stations were in Malles, Merano and Bolzano thanks to the commitment of the Malles Municipality which was taking part in an EU project to starting up car sharing. The goal of the service is to enhance sustainable mobility in South Tyrol and boost inter-modality. Today, the fleet has also electric cars, and the stations are located all around the main Municipalities of South Tyrol. The key partners of the service are DB, the German Railway company, which manage the biggest car sharing network in Germany through DB Rent, Car Sharing Trentino and the Volkswagen Italia group. The service is planned in relationship with public transport, since, if the car sharing member also owns an "Alto Adige Pass" (a ticket for the utilisation of all the public transport modes in South Tyrol) he can use the same pass for the car sharing service and the subscription has a reduced price.

2.1.3.5 Users Behaviour

Several studies investigate the feature of the typical user and the shared characteristics among people who adopt car sharing: usually, they are between 35-45 (in Italy 30-39 [6]), highly educated, male, on an average income, users of public transport, living in medium to high-density areas, environmentally aware [57]. A study [58] highlights that the interest towards car sharing increase for people who already use means of transport different from the private vehicle and shows that bus users are more attracted from car sharing, the opposite of people who travel for many kilometres with high frequency (more than 10.000 km/year). To adopt a new service and change the users' transport behaviour, awareness and knowledge of car sharing are essential. Transport behaviour generally does not change suddenly, but people shift to car sharing more frequently when they are experiencing changes and have to organise their lifestyle differently, e.g. change/loss of the job, move to another city, having a baby, children leave home [50]. Car sharing can also be very attractive for those who only sometimes need a second (or third) vehicle but cannot afford to buy one. Car sharing can be a

solution even for who owns a car but, occasionally need a different type of vehicle for particular purposes (i.e. a minivan form moving, a more comfortable car for long trips, a luxury car for a special night) [43].
In Friuli-Venezia Giulia region, Italy, a telephone survey was conducted in 2014, and 1276 people were interviewed to assess the socio-economic factors which influence the adoption in car sharing [59]. It emerges that people who live in small to medium-size town are less interested in car sharing and also the advancing age and, in particular, the retiree status, have negative impacts on the service attractiveness. On the other side, car sharing seems to be very appealing for unemployed and for those who are aware of the environmental issue. Rotaris et al. (2019) [60] present a detailed table on the literature review around the socio-economic characteristics of the car sharing users.

2.1.3.6 Electric Car Sharing

Even if the majority (96% in 2019) of vehicles in the world are internal combustion engine powered by gasoline or diesel, there is a significative proportion of alternative fuel vehicles, especially hybrid, and, for a small percentage also electric batteries and hydrogen fuel cells [19]. Even if the electric battery technology is not a novelty its spread is now increasing due to several factors such as technological advances, political policies and subsidies (in particular after the signing of the Kyoto Protocol in 2002), investments in development and research (especially in the battery sector), in the electric car manufacturing industry and in the charging infrastructure.
According to Mounce and Nelson (2019) [19], electric vehicles (EVs) and car sharing are a crucial combo to achieve benefits from both the innovations, especially for the in loco pollutant and acoustic emissions reduction and for the increasing of the sensitisation and awareness towards the usage of an electric vehicle. The main obstacles are the purchasing price of EV, higher than internal combustion engine vehicles (ICEVs), and the requirement of charging infrastructures, the limitation on the running kilometres and the charging time. Always according to the two researchers, it is important that the charging points are installed in every station to assure users with the chance of recharge their vehicle, but it can also be inefficient since when no cars are parked, the charging stations are not utilized.
Early experiments of introducing electric vehicles in the car sharing fleet were carried out in San Francisco Area, in November 1995, with the introduction of 40 EVs in the Bay Area Rapid Transit station car demonstration program and in France, Paris, in October 1997, thanks to the "Praxitele" program which adopted 50 Renault EVs [61]. Today EVs are part of the car sharing fleet almost all over the world.
In Italy, for example, "Share'N go" offers an electric car sharing service in Milano, Firenze, Roma and Modena (2018) with little electric cars (two seats) produced by Xindayang (Geely Motor) with

an autonomy of 100 km. It is interesting to notice that the users of the electric car sharing, in Italy, on average, are younger than the users of the ICEV car sharing: indeed two out of three electric car sharing members are between 18-29 [6].

2.1.3.7 Financial Issue

In the methodology, suggested in this thesis, the service configurations are assessed also from a financial point of view, considering costs and revenues from the operator point of view. It is relevant to analyse and consider all the cost and revenue components, before the service implementation, although the profit of such a challenging service is also influenced by external factors which are not always under the designer's control, such as the involvement of citizens, public funds, Municipality policies. Expenditures and revenues for the service operators are strictly related to the car sharing form, e.g. peer-to-peer, private, by providers, cooperatives car sharing, on which depend the method of financing, the main costs and the available tariff schemes. Useful documents to better explore the costs and revenues elements are those provided within the European project Momo "more options for energy-efficient mobility through Car-Sharing" [62], [63]. Furthermore, information for the Italian market can be achieved by the documents drawn up by the ICS (Iniziativa Car Sharing), a national circuit of car sharing [64] and from several monitoring documents. Instead, academic literature does not very frequently discuss business and economical car sharing related issues.
All the reported documents and studies provide a solid background for the car sharing planning methodology, suggested in the present dissertation, especially in term of costs items individuation.
Brook (2004) [65] investigates these critical topics, focusing on the launching of a new car sharing service, providing a spreadsheet model to examine and compare different scenarios and to calculate when the breakeven will be reached. Cost and revenues are all expressed as a fixed value per time, and several assumptions have been made on the demand growth. He analyses the source of funding, pricing, insurance as well as marketing issue providing useful tips for who wants to start a similar service. He also studies the ordinary operation of the service, analysing the main elements which characterise car sharing: vehicles, parking, reservation systems, electronic and onboard computers and employees. Scott et al. (1997) [66] produce a business plan study of the car sharing in Portland. They develop a four-years cash flow assuming the membership level growing from 150 to 600 members and the fleet size is computed considering a ratio "members to vehicles" starting from 7,5:1, in the beginning, to 12,5:1. Their work is exhaustive, and all the items are specified and expressly reported. They state that the service can provide profit to its owners and stakeholders if managed appropriately, even if the profit margin is small, but it requires time to grow. Indeed, the pilot project is not expected to be profitable, since the launching phase is costly and the operative scale, both in terms of time and area (and consequently of members), is exiguous.

Perboli et al. (2018) [67] compare, in a standard and reproducible way, the business models of several Italian car sharing companies, stating that the crucial element is the delineation of customised tariff plans. Car sharing companies have to face high fixed (initial) costs, for example for the vehicle purchasing, for the development of the needed technology instruments, for the partnership with the parking managers (public or private). Moreover, they also have to cope with operating costs, including refuelling, cleaning, maintenance, relocations, together with taxes, agreement for the service authorisation and, naturally, employees' costs. All these high costs are barriers to car sharing penetration in the market.

The last two studies reported concern electric fleet: Galatoulas et al. (2018) [68] provide a cost analysis from the operator's point of view of a new one-way electric car sharing, considering the costs related to the design and construction of the charging station, the solar PV panels, LCD screens, the parking lots, permission, together with the costs of vehicles' purchasing and maintenance. Yoon et al. (2019) [61] analyse the car sharing system in China, assessing different aspects related to the service planning, i.e. demand, model estimation, fleet size an also exploring the economic issue. Electric vehicles require higher investment costs, also for the recharging infrastructure and the higher market cars cost. The research determinates the fleet type according to the payback period for the investment costs, defining the annual economic performance based on revenues and costs (infrastructure, vehicle depreciation, maintenance and fuel).

2.1.3.8 Car Sharing in Italy

In 1999/2000 started the "Car Sharing Program" from the will of the Italian Ministry of Environmental, according to the "Programma Stralcio di Tutela Ambientale". In order to assure homogeneity among the car sharing services in Italy, to boost this form of mobility, which was unknown in Italy, the Ministry assign the specific funding to the cities which presented projects on car sharing (Milano, Roma, Bologna) and started a coordination activity. In 2000 a memorandum of understanding was signed among the Ministry and several Italian cities with the aim of establishing a national system of car sharing and coordinate the project involving several local entities. In the same time, a technical office started to work in order to be able to support, from a technical point of view, local entities or Municipalities. "Iniziativa Car Sharing" (ICS), the umbrella organisation of the Italian car sharing network, was established in 2000.

In Italy in 2018, car sharing members were 1 million and 860 thousand and 90% of which are free-floating members. But, also, station-based car sharing is growing (+37% in the last year, about 110.000). Milan is the Italian city which is leading the car sharing sector with more than 3 thousand of vehicles, 24% of the fleet is composed by electric cars, and five different service operators are located on the territory (Car2go, Drivenow, Enjoy, Share'ngo, Ubeeqo) [6].

During this doctorate period, the services provided by the leading Italian operators have been analysed, classified according to the car sharing typology (free-floating vs station-based) and the eventual presence of electric vehicles [6] in the fleet. From the analysis emerges that in the metropolitan area, free-floating car sharing is very attractive and successful and at the same time complementary to the station-based. In Italy, in 2018, free-floating services were available only in Milan, Rome, Turin, Florence and Bologna, operated by Enjoy, Car2go, Drivenow, Adduma Car, Corrente and Share'ngo. Among the Italian service operators, there are services managed by start-up (PlayCar - Cagliari), by cooperative (Carsharing Trentino – Trento), by the main car sharing company in the world (Car2Go – Milan, Rome, Turin, Florence), by car manufacturer (Yuko with Toyota – Venice, Forlì), by big firm with important Italian companies (Enjoy in partnership with Trenitalia -FrecciaRossa, Eni, Fiat, Chicco, RDS, etc. – Milan, Rome, Turin, Florence, Catania, Bologna), etc.; most of the Italian car sharing companies are equipped with electric vehicles in their fleet, the electric cars are the 27% of the total fleet.

Recently several extra-urban services are arising (Table 2): car sharing can be a useful means of transport for the first last mile or for particular trips such as to/from the airport o occasional trips from one Municipality to another one.

Table 2: Car Sharing Operators in Italy (2019)

Extra-Urban Car Sharing Italy*			
		N° tot vehicle (31/12/2018)	***Electric vehicles***
Lombardia: Milano, Bergamo, Brescia, Como, Cremona, Lodi, Lecco, Mantova, Monza, Pavia, Sondrio, Varese, Abbiategrasso, Boscone, Cuggiono, Magenta, Rho, Casorezzo, Novate Milanese, Vimercate, Oro al Serio, Cesano Maderno, Desio, Busto Arsizio, Saronno, Legnano, Gallarate, Cairate, Tradate, Biandronno, Ternate, Travedona Monate, Maccagno, Laveno, Morbegno, Alzate Brianza, Erba, Mariano Comense, Tirano	E-vai	104	92
Sassari, Alghero, Olbia	Move Ecocarsharing	10	0
Brindisi, Lecce, Otranto, Gallipoli, Galatina, Maglie, Nardò, Tricase, Santa Maria di Leuca	4UsMobile - ICS	13	13
Trentino: Bolzano, Silandro, Lana, Chiusa, Merano, Dobbiaco, Brunico, Mules, Campo Tures	Carsharing Sudtirol	38	2

* Data from www.icscarsharing.it

2.1.4 Students: Sharing Mobility and Car Sharing

Since the case study, reported in this dissertation, is targeted to students it seems important to detail the sharing mobility and car sharing issues focusing on this peculiar category. There are several studies which focus on college students since it has been stated that they are more inclined to use transport modes which are different from the private car than other segments of the population [69]. Recently is emerging that in some countries, a proportion of young people do not see private car ownership as a status symbol anymore [70], [71]: in England the rate of people between 17 to 19 who have the driving licence dropped from 41% in 2000 to 35% in 2010 and for people between 21 to 29 dropped from 75% to 63% in the same years [72]. Furthermore, young students do not have the driving license or, after 18 (in Italy), often, they do not own a car and these aspects, together with young people natural inclination to try innovative experiences and absence of deep-rooted habits, make them very incline to share mobility. Car sharing can find fertile ground among university students since several studies show that the "typical car sharing user" shares the socio-economic characteristics with the majority of the university students. Namely, they are young, well educated [73], generally they do not own a private car, hold a positive attitude towards innovation, experimentation and shared transport modes and, furthermore, they are very technology/smartphone oriented [60]. Besides, university campuses deserve particular attention since they are critical trip-generation nodes.

In Italy, the "Decreto Ronchi", (decreto del Ministero dell'Ambiente 27/1998), introduced the company mobility manager: he/she plays an important role, planning the employees' travel to and from the workplace, optimising the company mobility's costs and promoting sustainable mobility. Recently an investigation on the sharing mobility among university students has been conducted in Italy [74] from which emerged that the most used mode to reach the university is public transport, followed by private car and walking, while little-used is made of the sharing modes (cf. Figure 2).

However, the modal split change among North, Centre or South of Italy: while in the north the slow mobility (walking and biking) is preferred to private vehicles (cars and moto/scooters), the opposite emerges in the Centre and South of Italy. 77,2% of the students know about sharing mobility with differences among North, Centre or South of Italy and among the university size (the rate is higher for university with more than 40.000 students). As shown in Figure 3, the most used sharing mobility service is the car sharing free-floating, followed by carpooling.

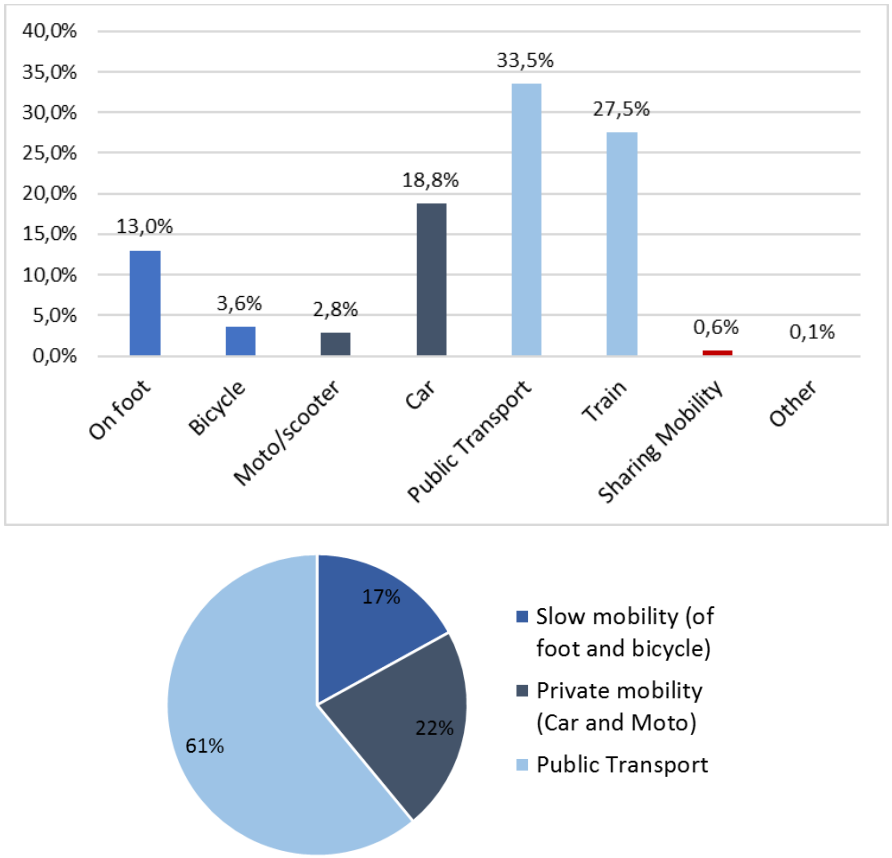


Figure 2: University Modal Split (2016) - Italy [74]

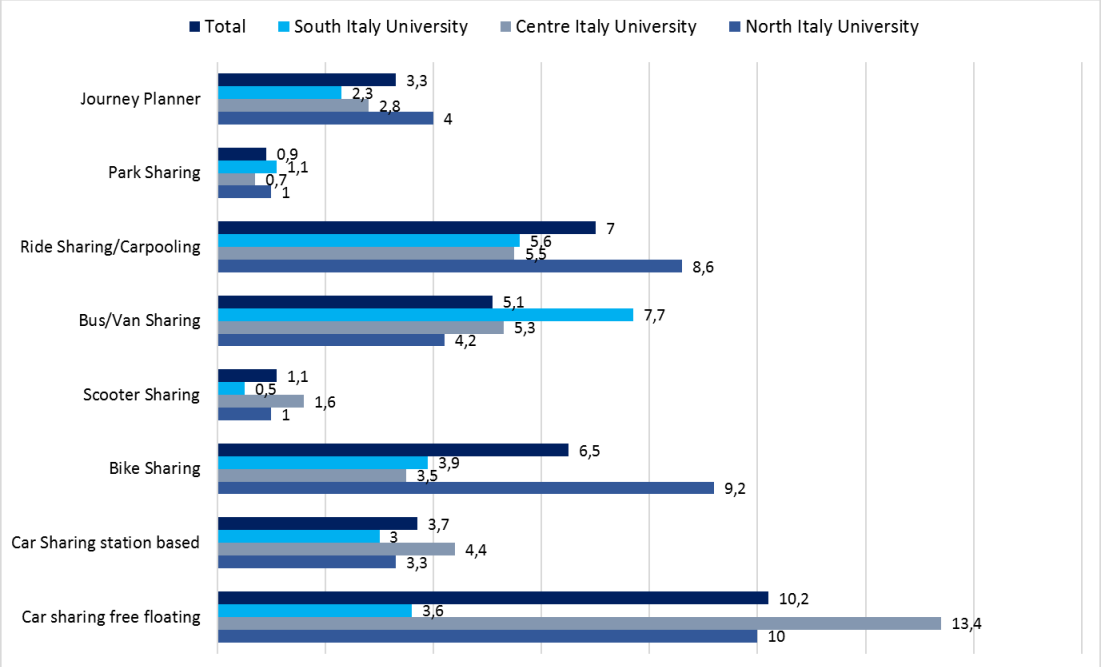


Figure 3: Used Sharing Mobility Services (2016) – Italy [74]

The sharing mobility is chosen primarily for its economic convenience together with the environmental awareness and to avoid the parking problem, while it is seen as non-convenient because of its inadequacy towards the personal needs, the high costs and the lack of available vehicles.

Several studies investigate the level of acceptance and the factors which boost the decision of shifting towards more sustainable transport mode among the students. Politis et al. (2012) [75] investigate the level of acceptance of the sustainable mobility initiatives among the university students of the Aristotle University of Thessaloniki, Greece. After a "free-car day" and the contemporary implementation of efficient public transport service, a questionnaire is administered among students to investigate their level of acceptance of the initiative. The authors affirm that the most significant factor which influences the level of acceptance of sustainable mobility activities is the travel behaviour, in particular, the mode choice and the daily car trip rate: frequent private car utilisation decreases the acceptance of sustainable mobility measures. Specifically, on car sharing, Zheng et al. (2009) [76] collect data from an stated preference survey (also embedded in the planning methodology suggested in this dissertation - cf. 2.3.1) submitted to the students of the University of the Wisconsin-Madison, USA, and then analyse the results through a logistic regression model. With this method, they can conclude that the acceptance of car sharing is strongly related to the status of people at the university (students, international students, staff) and their consciousness towards environmental and economic issues related to car ownership. Like Politis et al. (2012) [75], they conclude that the transport choices are influenced mainly by the previous transport behaviour, more than the sociodemographic variables.

Miralles-Guasch and Domene (2010) [77] define the main strategies to achieve a successful sustainable transport, such as a strong relationship between transport and land-use, governmental support (founding, agreements, laws and regulations), information and communication as well as a high involvement of all the implicated actors. The travel behaviour is a consequence of many factors (e.g. age, income, lifestyle as well as, distance, time, cost, road characteristics, public transport characteristics) and Miralles-Guasch and Domene aim to in-depth understand the factors which influence the change of travel mode from private vehicles to soft mobility or public transport. Through a survey administration among the students of the Autonomous University of Barcelona, Spain, they find that the main limitations for this transport mode shift are the lack of adequate infrastructure, the longer time spent using public transport and the absence of the bicycle culture. While a good communication strategy, together with a clear explanation of the environmental and social benefits of a more sustainable transport behaviour, will be very supportive for the adoption of more sustainable transport attitude. Furthermore, they highlight the importance of taking into account, not only environmental aspects, when planning sustainable mobility measures, but also issues related to equity, accessibility and social inclusion.

A stated preference survey was designed by Dell'Olio et al. (2014) [78] in order to assess whether the respondents would change their mobility behaviour, in favour of more sustainable means of transport. In particular, they investigate the relationship between the change in the transport mode and the introduction of different parking policies at the campus of Cantabria University, Spain. They state that the introduction of some penalties for the private car use and parking, together with the enhancement of bus and bike modes, will boost the change of the mobility patterns. Their work has been useful as groundwork to draw up the methodological guide for Mobility Plans for University Campuses. More recently dell'Olio et al. (2018) [79] through a SP – RP (pivoting design, cf. 2.3.1) survey, carried out among the students of the Cantabria University, collect all the data necessary to estimate a Mixed Logit model, which is then used to achieve the optimal scenario for parking fares by means of an optimization model. The introduction of fare for parking on campus results to be an incentive towards more sustainable transport mode against the private vehicle's usage: the same result is also obtained by Danaf et al. (2014) [80].

In recent times, some studies have been conducted on electric vehicles car sharing in the campuses: Galatoulas et al. (2018) [68] investigate a one-way electric car sharing service with the charging station, located at the university campus of Deusto, Spain. The study finds out that a high number of people are likely to rent an electric vehicle. They analyse the potential demand and costs for the implementation of an electric vehicle service with e-cars, e-scooters/e-motorcycle and e-bikes. They examine the potential users and their characteristics through a stated preference survey and also study the best cars typology and stations locations, mainly according to the highest potential users' concentration.

Recently, Rotaris et al. (2019) [60] assess the potential of car sharing among the university students of Rome and Milan, Italy. They conduct a stated preference survey with six hypothetical scenarios (both station-based and free-floating car sharing), in order to investigate the demand for car sharing when the supply elements change, and then develop a mixed logit model to estimate the interest towards this transport mode and simulate different scenarios. They conclude that car sharing is a good substitute of the private car, but it also substitutes public transport; students are attracted by the free-floating service (Rome and Milan are metropolises), electric vehicle and, of course, by low fare.

Finally, Danielis et al. (2015) [81] estimate potential demand for car sharing, analysing the case study of the University of Trieste, the same study area considered in this thesis work. They investigate on the potential car sharing demand among students applying a Monte Carlo simulation procedure, based on the hypothesis that the car sharing adoption probability is related to the general cost of car sharing compared to the other modes of transport. They simulate different scenarios and determinate that the potential service demand would be of 6400 students and this would vary by 2 to 6% when changes occur in the car sharing cost, time to access to a car or in the private parking availability.

2.2 Car Sharing Modelling

Short Summary

Planning a car sharing service is a very challenging issue due to the high number of elements involved. This review aims to explore the existent literature on the question. Car sharing modelling is detailed following the same logical order that should be followed when approaching the subject for the first time, considering two main aspects:

- *data collection: stated preferences, revealed preferences, geospatial big-data, questionnaire on the already available services;*
- *data analysis: logit model and linear regression, simulation, optimisation (also addressed to some specific technical aspects of the service);*

Of course, some studies could be clustered in both these categories. It should be noticed that the literature review conducted in this thesis is extensive but not exhaustive. It serves as a comprehensive base to introduce the starting point of the thesis work.
The interested reader is also redirected to the literature review carried out by Jorge and Correia (2013) [10], *Ferrero et al. (2018)* [82], *Cepolina et al. (2014)* [83], *Illgen, and Höck (2019)* [84].

Demand plays a crucial role in the analysis and modelling of transport systems in general and of car sharing services in particular. That is because the main goals of these services' implementation are the satisfaction of the transport demand and the improvement of the attractiveness of the services to address the demand towards more sustainable transport modes, considering that the performances of the supply significantly affect the service demand itself [85].
Only recently modelling studies are focusing on the free-floating car sharing (the car sharing typology without stations [86], which allows greater flexibility than the station based typology) since it is a relatively new market segment within car sharing. Becker et al. (2017) [87] investigate the drivers of free-floating car sharing and, (2018) [88], on the impacts on user travel behaviour; Ciari et al. (2014) [38] apply an improved station-based car sharing model to model free-floating car sharing and Cocca et al. (2019) [89] address the issue considering electric vehicles fleet: all of them explores state of the art on free-floating car sharing.
Two steps are fundamental in the modelling process: data collection (2.2.1) and data analysis (2.2.2).

2.2.1 Data Collection

It is fundamental to make the distinction between data collected to investigate the possible new service and data collected on the already existent service. Stated preference (SP) surveys (cf. 2.3.1) belongs to the first category and examine the potential users interested in initiatives which have not been implemented yet [90], while questionnaire addressed to the customers who already use the service, along with time series, belong to the latter category. Furthermore, the analysis of geospatial big data, collected through GPS or tracking devices, belongs to the second category of collecting data methods which analyse the existing traffic and current people mobility behaviour [91]. Questionnaires targeted to the already-users and time series analysis are usually applied to improve an available service (i) or for the investigation on the existing services in order to identify the best practice, and their principal elements, which could be exported to other situations (ii).
Goal (i) is pursued, for example, by Kumar and Bierlaire (2012) [54]: they estimate the key drivers of demand, starting with collecting data from the already-existent electric car sharing service in the city of Nice. From this starting point, they develop a model to identify the location of future stations for the service expansion, due to its initial success.
Aim (ii) is pursued by Morency et al. (2011) [92] who analyse, applying the data mining technique, a transaction dataset of a car sharing operating company in Montreal. The study aims to identify the main characteristics of users and group them into typology based on two indicators: the number of transaction and distance travelled. On the same dataset, Morency et al. (2012) [93] estimate a model to understand better the behaviour and the characteristics of users which mainly influence their decisions.
In the methodology presented in this thesis, stated preference surveys are applied to assess people's travel behaviour in a hypothetical scenario and investigate the potential car sharing demand when the service under investigation is not an already available alternative for citizens. Stated preference is a survey technique which can be very powerful since the research elements are under the designer's control, but at the same time they are based on real responses of the people who are interviewed. Furthermore, this technique is consistent with the random utility theory, which underlies the discrete choice models (cf. 2.3.2).

2.2.2 Data Analysis

Data analysis can be performed through several methods, those more often applied are logit models (cf. 2.3.2) and linear regressions [82], analysed below (cf. 2.2.2.3). Also, simulation (cf. 2.2.2.1) and optimisation (cf. 2.2.2.2) are applied to estimate demand, to define the service characteristics (e.g. fleet size, depot location) and the operational strategies (e.g. relocation strategy) to perform the

service in the best way possible, in particular, they are often used in studies related to one-way car sharing [82].

2.2.2.1 Simulation

Simulation enables experimentation in a safe environment, and even more frequently, it allows a digital representation of the model. Nowadays, simulation seems to be a useful tool for car sharing planning because of the growing complexity of these kinds of systems. The complexity is mainly related to the high number of actors involved – both public and private –, the market competition, the need for real-time planning strategies such as relocation problems.
Simulation models give the chance to collect performance data, and they can be implemented to compare different solutions. Furthermore, running simulation is also useful to consider the business model and the impact of different tariff schemes on the usage of the service [67].
Several simulation techniques, such as agent-based [38], discrete event [94], combined systems such as technology roadmap and system dynamics [95], have been tested in the car sharing sector. In particular, authors applied these techniques to estimate the potential service demand, the system's long-term evaluation or, even, to evaluate the growth of an already existent service. Differently, the methodology suggested in the present thesis simulates the effects of the main design choices through a spreadsheet which is employed before the optimization in order to define the inputs ranges and after the optimization to compare different efficient solutions. Indeed, the simulation does not provide optimal or near-optimal solutions, but the outputs of different scenarios' simulations can be compared, taking into account that the simulation strongly depends by the utilised framework and made assumptions [84].

2.2.2.2 Optimisation

In the vast majority of cases the designer who is planning a new car sharing service has to face multi-objective problems, i.e. he has to consider, at the same time, contrasting objectives, such as the maximization of the operator's profit, the performing of the best service for users and the maximization of the environment benefits. These objectives are contrasting, since the users are attracted by a valuable service (i.e. sufficient cars available, no long distances among the stations) which implies an increase of the costs for the operators, but at the same time a higher number of service's users means higher revenues and can lead to lower private cars ownership. Several authors applied different methods for the optimisation which can be classified according to three taxonomies: (i) the applied techniques, (ii) the aim of the process and (iii) the way in which demand is considered.

The principal applied techniques (i) are Genetic Algorithms (GA) [96], Mixed Integer Program (MIP) models [97], Decision Support System (DDS) [98], simulated annealing [99], linear regression [54] and the utilisation of multiple method in combination [100], [101].

As supported by the present study, an efficient optimisation process seems to be the application of the Design of Experiment -DoE- methodology, together with the Genetic Algorithms and the exploration of the Pareto solutions (cf. Step 19). Design of Experiment is a methodology able to create the population for the following application of the optimisation algorithm [102]. It maximises the knowledge gained from experimental data with the elimination of the redundant results in the interest of reducing the time of the experiment. The DoE main goal is the definition of how the output depends on one or more input variables so that the future output values can be predicted from the previous. GAs belong to the broader class of Evolutionary Algorithms and they are iterative and stochastic optimisers that apply processes very similar to the biochemistry ones: individuals' generation, reproduction, cross-over, mutation and selection, starting from the first solution through a process of recombination and introduction of new elements [103]. The algorithm defines new final solutions until it reaches the optimum one. Each solution stands for a possible combination of parameters to optimise [104], where the inputs are making varying within imposed rages. The Pareto solutions are those which cannot be improved in one dimension without being worsened in another [105]. The set of all the Pareto solutions, known as the Pareto front, is the representation of the problem trade-off and the final solution will be chosen from this front [106].

Sobol is a DoE methodology, applied in the case study, which is a deterministic algorithm which aims to obtain a uniform sampling of the design space, and it is appropriate when the number of input variables is lower than ten. In the case study, M.O.G.A. II (Multi-Objective Genetic Algorithm II) is the applied genetic optimisation algorithm which is based on the concept of natural selection: the best individuals have higher survival chances. With individual is intended a design solution.

By simplifying, it computes the following steps [102]:

- starting from an initial population, created by the DoE, the algorithm originates the next-generation through one process among the selection, classical cross-over, directional cross-over, mutation;
- the ability of an individual to meet the optimisation objectives is computed;
- all the Pareto solutions are copied and stored in an "elite set"
- the next generation is computed applying the algorithm again, in virtue of the parent generation and the elite set.
- the last three steps are iterated, until the maximum number of generations.

Genetic algorithms are also applied by Nakayama et al. (2002) [96] to identify the optimal solutions for a set of parameters (number of vehicles, number of members, etc.) related to the management of the electric vehicle sharing system in Kyoto. Also Xu et al. (2007) [107] use genetic algorithms; they

tune and optimise an evolutionary neural network model, with the final aim of forecasting the net flow, meant as the difference between demand and supply, of a car sharing system. They applied their model in the city of Singapore to provide the best service to the users and optimise the relocation issue.

The aim of the optimization (ii) is also a criterion for classifying the studies: the approach is implemented to define the optimal car sharing service solution in terms of station location [108], one-way relocation strategies [109], specific technical aspects of the service [110] and to define the optimal set of supply parameters (number of vehicles, parking lots, members, etc) [111], [101], which is also the aim of the optimisation procedure applied in the suggested methodology. In addition, some authors include in the optimization process also aspects which are related to the operative phase of the service: Kek et al. (2009) [112] present a tool capable of supporting the car sharing operators to define a set of near-optimal human resources and relocation parameter for the relocation system which is applied to a Singapore case study.

The individuation of the car sharing station locations is a crucial issue, primarily because stations too close to each other result in a waste of money for a non-utilized service, while a considerable gap between stations leads to a decreasing number of users, as they have to walk too many kilometres to reach the nearest station [54]. Kumar and Bierlaire (2012) [54] analyse the performance of the Nice (Switzerland) electric car sharing service to estimate the fundamental demand drivers and critical factors to define the attractiveness of a locality in which to set a car sharing station. Besides, they built an optimisation model based on linear regression with station performance as the dependent variable in order to determinate the potential attractiveness of different localities to identify optimal locations for new stations. De Almeida Correia and Antunes (2012) [97] suggest an optimisation approach to define the depot location in the one-way car sharing system through Mixed Integer Program (MIP) models whose objective is the maximisation of the operator profits, assuming a fixed and deterministic demand. In addition to the station location problem, Jorge et al. (2012) [109] develop an agent-based simulation model able to consider the relocation operations and the demand variability as well. These two studies are tested in the municipality of Lisbon.

Some authors adopt optimization process pursuing more than one goal at the same time: Cepolina and Farina (2012) [111] elaborate a methodology for the optimisation of the number of vehicles in the fleet and their distribution among stations. They suggested minimising the cost function which takes into consideration the transport system costs (cost of vehicles, management costs, etc.) and the users' costs, computed in terms of waiting time through a micro-simulation model. The stochastic method used for the optimisation is the Simulated Annealing scheme and was tested in Genova. They also chose Simulated Annealing to solve the optimisation problem which arises in the planning of a new urban car sharing system with fully automated personal vehicles [99].

Finally, service demand (iii) is usually considered as fixed and deterministic (census data) [97], sometimes it is considered in stochastic terms [108], but in the optimization problem rarely the mutual influence of supply and demand is taken into consideration [8]. Molnar and de Almeida Correia (2018) [100] assume demand as a constant input, taken from a fixed database. They aim to minimize the distance between the user and the available vehicle, maximize the operator profit, the reservation time, and the satisfaction of the demand. Differently, the methodology suggested in this dissertation considers demand as a function of the supply elements.

2.2.2.3 Stated Preference and Random Utility Model

Many studies estimate potential demand through stated preference (data collection – cf. 2.3.1) -SP- experiments and random utility models (data analysis – cf. 2.3.2). Also, the car sharing planning methodology suggested in this thesis indicates this technique to estimate the potential demand for the new service. These studies have, mainly, three primary objectives related to the demand estimation:

- to investigate the potential users' characteristics;
- to investigate the alternative selection among different options;
- to investigate the service characteristics (better explore in Step 11).

Most of the studies pursue more than one of these objectives simultaneously, such as in the project implemented by Yang et al. (2009) [113] who investigate different features of the introduction of new transport mode or new combination of existing modes (such as one-way car rental, minibus, carpooling, bus and heavy mode, park and ride services) in Lisbon. They aim at assessing the acceptability of these new services, evaluating the sensitivity to the variation of the characteristics of the services (cost, waiting time, etc.), measuring the willingness-to-pay and identifying the potential users' characteristics (age, employment status, household income, etc.) and their attitudes towards new transport modes. With the pilot study, they teste the SP survey structure and the accuracy of the experimental design and they find some attributes not to be so relevant as expected (e.g. waiting time). A correlated study, based on the same research project, is carried out by Choudhury et al. (2017), [114] who investigate the acceptability of three new smart alternatives (shared taxi, one-way car rental and a combination of park-and-ride service and school bus facilities) and variants of the existing options. They develop a multi-dimensional mixed logit model based on the data obtained from a complex survey with many alternatives and large choice set. The main finding is the diversification of the transport mode inclination: non-commuters prefer one-way car rental and shared-taxi, while commuters tend to prefer the improved version of traditional public transport modes.

Stated preference and discrete choice model techniques allow assessing the alternative selection among different options: Catalano et al. (2008) [115] build a model for the investigation on the modal split and the attractiveness of new transport mode under different scenarios in Palermo. They create an SP survey, answered by 500 respondents, with four alternatives (private car, car sharing, carpooling and public transport) and seven attributes. The calibrated model for the demand estimation is Multinomial Logit, even though also a nested structure is tested. They assert that the car sharing market could increase up to 10% in a future context characterised by policies directed to limit the private car use.

The users' socio-economic characteristics are explored in several studies and many authors agree in stating the importance of these features. Abraham J.E. (1999) [116] implements an SP survey to define what kind of car sharing organisation is the most desirable and which are the main socio-economic users' characteristics which influence their service adoption. The choices data are analysed through logit models in the interests of forecasting the ranking choices, comparing hypothetical scenarios characterised by different car sharing service's attributes (walking distance, reservation system, costs) and predicting the joint choices. Finally, he underlines that people and their characteristics are more important than the elements of the car sharing organisations themselves and so he states that it is crucial to focus on reaching the right market. Also, De Luca and Di Pace (2015) [52] conclude, in accordance with Abraham (1999) [116], that the propensity towards a car sharing system does not depend only on the level of service of the transport modes, but also on the potential users' socio-economic characteristics.

The study of Efthymiou and Antoniou (2016) [73] presents several aspects which have been encountered also in the present work case study (cf. Chapter 5): they targeted the research to young people, used mixed data collected through both paper and internet surveys and state that when people are highly satisfied with their current transport mode, it is scarcely probable that they will change toward new car sharing services, which brings the present work to concentrate on the mobility situation which is defined as problematic and unsatisfactory by the target. The Efthymiou and Antoniou's study was carried on among young Greek, with the purpose of assessing the characteristics of the potential car sharing users and modelling their propensity to join a car sharing service. They also demonstrate that people more likely to join a car sharing service are those who use the taxi for social activities, those with medium to low income and those with a high environmental consciousness. Similarly, De Luca and Di Pace (2014) [58] state that the non-satisfaction towards the existing systems increase the attractiveness of the car sharing service. They develop a nested logit model with 15 parameters based on the SP data collected from the 200 answers to the questionnaires carried out in Salerno; the questionnaire investigates the respondents' choices among four possible alternatives (bus, car as a driver, car as a passenger, carpooling). Moreover, they elaborate a model (comparing binomial logit model and mixed binary logit model) to analyse the

user's inclination to adhere to a car sharing service with two alternatives (interest, non-interest) and six parameters. In a subsequent and more recent paper (2015) [52], De Luca and Di Pace explore and compare different approaches and utility models, calibrated on the data of 500 respondents to the SP study carried out in Salerno with different modelling solutions (homoscedastic and heteroscedastic) in order to deal with different target groups (e.g. car users, bus users).

Other papers analyse the features which influence the car sharing adoption, declined in more specific characteristics such as the users' vehicle ownership, their values and lifestyle, the context or some service characteristics which are not very often taken into consideration. Dissanayake and Morikawa (2010) [117] investigate the household travel behaviour taking into account, in particular, the decisions on vehicle ownership. They explore the issue related to the mode choice and the shifting towards new transport mode (included car sharing), but they start their research by analysing the preference towards car ownership, motorcycle ownership and no-car ownership since they state that it is a crucial element in the travel decision process in Asia. They affirm that the key drivers which lead the decision on vehicle ownership, mode choice and trip sharing are household income, job status, age, presence of school children, long-distance travel and travel in the central business district. The context, together with the socio-economic users' characteristics, influences the choice of the transport mode: Molin and Timmermans (2010) [118] enquire into the influence of the context on the egress mode choice after the train trip towards the final destination. Seven egress modes are presented to the 996 respondents together with the context variable (luggage, weather, time of the day) in an SP survey, and the data are modelled through a Multinomial Logit model. The final result shows that the influence of the context varies according to some socio-demographic variables. Furthermore, Kim et al. (2017) [119] explore some car sharing characteristics which are often ignored but, nonetheless, crucial in the estimation of the potential service demand. They test the influence of some distinctive car sharing features such as the advance car reservation, travel time uncertainty, pay time-based costs and delay in departure time. Furthermore, they investigate the users' latent attributes which reflect values and lifestyles which influence people's attitude towards comfort, flexibility, convenience. They develop a hybrid choice model incorporating latent variables. The study reveals that people are negatively affected by time constraints, travel time variability and by the need of organising before leaving. Moreover, Kim et al. affirm that people tend to assess car sharing as more environmentally friendly than private car but less than public transport. They suggest that electric car sharing can help to boost this kind of sharing mobility. Electric vehicles are the subject of the investigation of several other papers on car sharing: Zoepf and Keith (2016) [120] do not examine potential-users, but already-users of the service to understand how important are the car sharing attributes for the customers, to evaluate their interest towards the alternative fuel vehicles and quantify the value of price, distance, schedule and vehicle type from their point of view. The data, collected through an SP survey, are modelled through both Multinomial and Mixed Logit

models. The research demonstrates that users prefer hybrid vehicles to electric vehicles, that there is a complementary relationship between car sharing and public transport and, obviously, that the highest utility derives from the vehicles' availability in the desired time and location.
Furthermore, an interesting study [121] carried out in China examined the factors which influence car sharing system as well as the potential of an electric fleet introduction in the system; they received an important non-result, electric vehicles by themselves are not more (or less) attractive then internal combustion engine ones. This conclusion is also be proved through the case study implemented during the doctorate period (cf. Chapter 5).
The last-mentioned research is the one developed by Kouwenhoven et al. (2011) [122]: they implement a methodology to predict the potential market share which shares some common feature with the one suggested in the present thesis. They evaluate the propensity to join a car sharing service in Paris, for estimating the potential demand and revenues for the service's operators and for defining the best possible service and the financial conditions. Furthermore, they develop a forecasting tool based on the sample enumeration procedure (cf. 2.3.2.3).

2.2.3 Car Sharing Modelling Summary

From this overview of the literature on car sharing, emerges that most of the studies focus on:

- demand analysis, without taking into account the dimensioning of the supply's elements;
- service optimisation without considering the influence of the supply changing on demand: demand is usually considered as static;
- analysis of the potential users' characteristics;
- optimisation of specific technical aspects of the service (e.g. relocation strategy);
- financial issue without taking into account the demand.

The lack of a structured carsharing planning procedure emerges, as expressed by Celsor and Millard-Ball (2007) [123]: "carsharing planning has often taken place through trial and error" and by Kumar and Bierlaire (2012) [54] "the selection of [station] locations so far has not followed any scientific approach, but relied on the gut-feel of the decision-maker".

2.3 Stated Preference Survey and Discrete Choice Model

Short Summary

Both stated preference surveys and discrete choice models are techniques incorporated in the developed car sharing planning methodology (respectively Step 13 and Step 14), presented in Chapter 4. So, from a logical point of view, it would be better to examine them in the chapter dedicated to the suggested methodology description. However, it has been decided to illustrate them here, for two main reasons: firstly, because they are part of the developed methodology, but they are already extensively discussed in the literature; and secondly, because they are quite complicated steps which deserve a particular focus.
The techniques have been investigated, studying, particularly the theory, from the books written by the sector's reference authors, and through an in-depth literature analysis also for better understand the potentiality of the methods as well as their possible applications and development concerning the new research on them.

2.3.1 Stated Preference Survey

Various techniques were developed to understand the behavioural response of individuals making their choices and, in the transport field, one of the most applied technique is stated preference survey. Differently from revealed preference (RP) technique which uses information from markets and investigate the actual situation, stated preference (SP) technique refers to survey which seeks to understand individuals' preference with direct or indirect questions in which the respondents must express their preferences out of a set of alternatives [124], [125]. Differently from RP, in the SP survey, the designer can control the experiment (alternative, attributes, their combination) and not only recording data [85].
The first pieces of work related to SP techniques were linked to experimental economics: according to Kagel and Roth (1995) [126], the first application of SP techniques was the study by Thurstone (1931) [127] who based his work on psychological theories on individual choices. In 1964 Luce and Tukey [128] introduced the concept of "Conjoint Measurement", asserting that the alternatives could be considered as a combination of different aspects, known as attributes. Later the SP technique was used to forecast individuals' choices for marketing purpose (Green and Rao 1971) [129]. In transport economics, the early application of the SP technique was made by Davidsone (1973) [130] to forecast the demand of new air service and by Louviere (1973) [131] and Johnson (1974) [132]. There are several ways of structuring the survey questions which influence the analysis of the collected data;

at the beginning, the respondents were asked to rank or rate their preferred alternatives and only in 1983 Louviere and Hensher [133] described a stated choice experiment in which the respondents have to choose the most preferred. Louviere and Street [134] stated that the best approach to SP, in terms of empirical success, is the application of the stated choice experiments which are consistent with random utility theory. This technique allows the researchers to identify the main elements which influence, both positively and negatively, the respondents' choices or behaviours and to develop statistical models, valuable also to forecast users' behaviours.

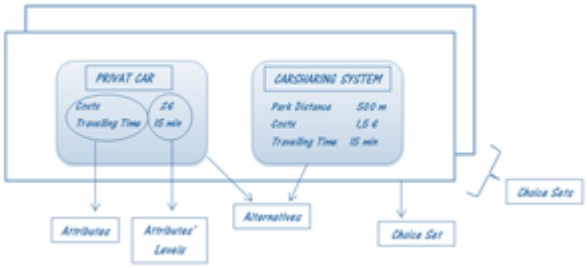


Figure 4: Stated Preference Scheme

The topic will be better explored, but, Figure 4 introduces some vocabulary adopted in the following sections: SP alternatives are presented to respondents, described by a list of attributes expressed according to different levels. More alternatives realise a choice set.
Before conducting an SP survey, several phases have to be designed: (I) preparatory stage, (II) development of the SP survey stage and (III) pilot and final survey administration: all of them can be further split into several sub-stages.

2.3.1.1 Preparatory Phase

This phase can be split into the following steps:

- objective declaration;
- choosing of the survey mode and the response form;
- definition of the target population;
- definition of the sample and choosing of the sample size.

Objective Declaration

Declaring the objective of the survey campaign is an essential starting point which influences all the next phases of the procedure. The survey's objectives must be in line with the project objective (cf. Chapter 4). In particular, the objectives impact on the target individuation and on the definition of the alternatives, attributes and levels, as will be better detailed in 4.1.

Choosing of the Survey Mode and the Response Form

The survey can be supported and administered in several ways, and this distinction classifies them into mail survey, web survey, telephone survey, face-to-face survey (in-home/intercept), computer assisted-survey and mixed-mode [124]. Mail surveys are relatively inexpensive and can be completed at the respondent's own place without the intermediation of the interviewer. However, they present several disadvantages: the response rate is low (25-50%), the sample is, of course, constitute only by people with an e-mail address (and moreover the interviewer must know their addresses), there is not the chance to better explain questions and it is not possible to adapt the questionnaire to the previous respondent's answer. Telephone interviews are cheaper than face-to-face interviews but more expensive than mail ones, they are relatively quick to administer, and the response rate is higher than mail (60-70%), but it is not possible to be supported by visual aids, and it is not possible to include in the sample people who do not have a telephone number. Personal interviews have a high response rate (more than 70%), are very flexible, permits clarification and adaptation to the respondents together with the use of visual aids; on the other hand, they are expensive both in terms of time and money and, especially for the intercept surveys, they must be short. Nowadays, web surveys are very used: they are substantially cost-saving, eliminating the issue of printing or emailing the questionnaires, and time-saving since data are already collected in an electronic format. Often, they are used in combo with mail survey: the web survey link is sent by mail to a selected number of respondents. In the computer-assisted survey, the interviewer records responses directly on the computer and/or respondent may respond to questions on a computer screen, speeding up analysis and permitting questionnaires more complex, providing high-quality data collection. A frequently used method is the computer-assisted personal interviews (CAPI) which is the technologic development of the personal face-to-face survey. The presence of the interviewer can be beneficial for the respondent. CAPI allows conducting "pivoting studies" through adaptive CAPI programs which are very powerful but, at the same time, very expensive and require internet access. This kind of survey allows to obtain both RP and SP data: the combination of RP and SP data is suggested by many authors [90], and hybrid SP and RP methods have been developed to increase efficiency. A method, known as RPSP pivoting combine both RP and SP choice in the same survey to improve response quality: first the data on actual choice is collected, and then the SP section is realised with attribute levels pivoted on levels reported in the first section (RP). Pivoting increase realism: it creates a reference point by which respondents can evaluate alternatives. RPSP pivoting method capture the "inertia effect" by including real choice variable: inertia is when the previous choice influences the next one, describing the influence of real travel respondent's behaviour. Traditional pivoting methods usually require the CAPI program to generate real-time attributes or two-parts paper-and-pen interviews (PAPI) survey, rising the researchers' burden. The SP pivoting approach, suggested by

Campbell et al. (2014) [135], allows to avoid the two-part PAPI survey and ensures a rapid data collection, also capturing the RPSP benefits: improving realism and capturing inertia effects. In the SP pivoting study, the responsibility for pivoting belongs to the respondent who estimates the attribute levels for the SP alternatives according to what he stated in the RP phase, i.e., according to his real experience and perception.

The response form is strictly related to the choice modelling data: the most used is the choice experiment where respondents choose one option among the suggested alternatives. After collected, this kind of data is consistent for the development of the discrete choice model, derived from the random utility theory, which reproduces users' choice behaviour [134], it is straightforward, and respondents provide an answer not subjected to ambiguous interpretations [85]. Other response forms are ranking, where respondents have to rank all the alternatives, rating where respondents have to rate all the alternative on some form of a scale (usually the rating scale is from 1 to 10 or 1 to 100 with the higher values representative of higher levels of preference. Another response mechanism is the so-called "best-worst" in which respondents must express what they consider the best and the worst option among all the suggested. It is similar to ranking, but this approach reduces the burden to respondents (especially when the number of presented alternatives is high) since they only have to distinguish between the more and least preferred options. The "best-worst scaling" is a form in which the respondents must not choose among the alternatives, but they are asked to assess only one alternative and select the best, and worst attribute for the presented alternative according to the attributes' levels shown to them [136].

Definition of the Target Population

The target population consists of those who are involved in the effects of the investigated system and includes both potential users and non-users of the system. The survey target population correspond to the target population, whom the project is addressed to, and it is detailed in Step 6.

Definition of the Sample and Choosing the Sample Size

The sample is a subset of the target population to whom the survey will be administrated, and its definition is essential in order to save time and cost that would be, otherwise, required to survey the entire population.

The main sample techniques can be split into [124]: (i) non-probabilistic design, (ii) probabilistic design. The first (i) technique is less expensive but does not allow the application of statistic theory and the control over the selection process is minimal: in this category can be included: convenience sample, judgment sample, and quota sample techniques. The letter (ii) techniques permit the use of statistic theory to derive the properties of the sampler estimators. Every element of the targeted

population has the non-zero probability of being chosen. Several techniques belong to this category, such as systematic sampling, cluster sampling, simple random sampling in which every element of the targeted population is given an equal chance to be selected and stratified sampling. This letter divides the sample frame into strata, and a sample is selected within each stratum using random sampling, with either the same sampling fraction for each stratum or different sampling fraction and, finally, the different strata are combined (this method is useful if there are different groups of interest).

Choosing the sample size is a balance between costs versus precision. One way of reducing sampling error and the variability is to increase sample size; of course, the bigger is the sample, the better is the accuracy of the collected information, but higher are the costs. There is not a unique general way to choose the number of the sample, there is not a rule for sampling size definition for use in all circumstance, but there is only suggested methodology.

The determination of the sample size depends on three principal factors [137]:

- the variability, over the target, in the parameters to be gauged;
- the required precision for each of the parameter valuation;
- the size of the population.

It is not intuitive, but the most important are the first and the second. The sample size is little affected by the size of the population. In the common practice the following formula is used:

$$(1) \quad n = \frac{(z(\alpha))^2 pq}{\delta^2}$$

Where n is the minimum sample size, δ the maximum error acceptable, p and q are the proportion of the population that do (p) and do not (q) have the characteristic of interest and z(α) is the normal distribution value: e.g. per 95 % confidence interval z(α)= 1,96 (from the table of unit normal distribution values); 90% confidence interval z(α)= 1,65.

The requirement of value "p" (q=1-p) is quite strange because it is precisely the goal of the research. However, it is requested to be estimated before surveying in order to calculate the sample size. Usually, it can be defined through previous studies, conducting a pilot survey, or it can be assumed p=q=0,5 which represents the maximum degree of variation within the population.

However, it is essential to compare the resulting population size with the cost affordable: if the final cost is not cost-effective, the researcher has to redefine the variability and the degree of precision desired. Sometimes there is a fixed budget for the survey administration, and this implies that the number of interviews is a priori restricted. In this case, it is essential to accept that, with a fixed confidence interval, there will be a defined error which will be higher with the decreasing of the number of the interview:

$$(2) \quad \delta = \sqrt{\frac{(z(\alpha))^2 pq}{n}}$$

Bliemer and Rose (2005, 2009) [138] and [139] demonstrated how to calculate a theoretical minimum sample size for any stated choice experiment. They demonstrate that it exists a correspondence between the expected standard errors and the sample size, using the expected asymptotic variance and covariance matrix. Furthermore, they also declare (2013) [140] that it is not possible to define a precise number for the minimum sample size. In fact, the sample size depends on several factors which are often a priori unknown, such as the model type, the design of experiment, the number of alternatives, attributes, levels and the likely parameter estimates.

A rule of thumb to estimate the minimum sample size (n) has been proposed by Johnson and Orme [141]. They suggest that the sample size is affected by the number of choice tasks (t), the number of alternatives (a) and by the largest number of levels for any of the attribute (c); if the experiment also involves the estimation of two-way interaction effects then c is equal to the largest product of levels of any two attributes:

$$(3) \quad n > \frac{500\ c}{t\ a}$$

2.3.1.2 Development of the Stated Preference Survey: Alternatives, Attributes, and Levels

In the stated preference survey, respondents are asked to express their choice among different alternatives, and the researcher must present them to the respondent. A discrete choice experiment (DCE) is composed of several choice sets, each containing two or more options (called alternatives). Respondents evaluate one choice set at a time and express their preference choosing among the alternatives. Each alternative is delineated by a set of attributes, and each attribute can assume different levels [142].

First of all, to develop a stated preference survey, it is necessary to make decisions on the number and values of alternatives, attributes, and levels.

- *Alternatives* have to reflect the service (or services) under investigation; the set of suggested alternatives has to reflect the reality and has to be feasible from a legal, environmental and economic point of view. The alternative can be "in-product," i.e. the respondent has to assess only one service/product according to its different characteristics, or "between-product", where the respondent has to express his opinion among different kind of alternatives (e.g. bus, car, and taxi). The design with the "none" alternative has been recommended [143], [124] in order to increase the experiment realism and improve the statistical efficiency of the parameters estimated from the discrete choice model. Nevertheless, the inclusion of the no-choice alternative can produce potential bias: respondents can select this alternative if they feel that the choice task is cognitively demanding, to limit their burden and expedite the questionnaire completion. Some mixed approaches can be used, for example, asking

respondents to select among all the alternatives, excluded "none" or the "status quo" and then make another choice also considering the "none" answer (non-forced choice) [144].

- A*ttributes* are the main characteristic of the alternatives and are elements which can change, or better, can have different levels. They can be service attributes (e.g. travelling time, costs, frequency, level of service) or socio-economic attributes (e.g. sex, age, occupation, household composition, level income). According to acknowledged authors [136] a limited number of attributes is positive because the respondents' burden is minimal, but, at the same time, it is detrimental since it makes the scenario too simplistic and without a proper realism, while adding more attributes can increase the realism of the scenario and this can improve the response quality. Furthermore, a higher number of attributes can hide the study purpose, avoiding "political vote" and provide the opportunity of having more details and the chance of investigating more service's aspects.
- Attribute *levels* are the values allocated to the attributes for each alternative. As for the attributes, they should be realistic, related to the respondent's experience and cover a sufficient range. Levels can be an absolute value (e.g. 5€) or, in order to be easier to understand, define as variations: as absolute changes (e.g. ±0,5 €) or proportional changes (e.g. ±30%). Each attribute can have a different number of levels. The number of levels are an intensely debated issue: a higher number of levels increase the number of possible combinations, improve realism and increase the richness of data, but, at the same time, more levels are used, the less efficient the design will be, creating much more choice sets, sometimes difficult to manage [136].

When answering people always confront the suggested option with their reference option (e.g. their current trip) and this is reflected in all their answers. For this reason, the experiments have to be designed accurately, trying to assess which is the individual reference (pivoting).

Discrete Choice Experiment Design

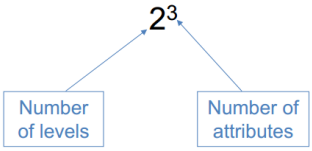
A choice experiment consists of a number of choice-sets each containing several alternatives; each alternative is described by a set of attributes with a certain number of levels. The design concerns how to combine attributes and attributes' levels in order to create the alternatives, and the choice sets to present to the respondents (sometimes these phases can be achieved together), with the aim of draw conclusions about people behaviour on the study issue from the results of the experiments. It is called "experimental" because some aspects of the choice set composition are under the control of the researcher.

There are different design strategies for the Choice Experiment Design [145]; the most applied in the field of transport are:

1. orthogonal design;

2. optimal orthogonal design;
3. efficient design;
4. adaptive design;

1. Orthogonal experiments are the ones in which all the data combinations are equally represented, and there are no missing values [146]. It ensures that the attributes presented to the respondents are uncorrelated, which means that each attribute is independent of the others. The design can be full factorial (with the description of all the possible alternatives) or fractional factorial (where only the main effects are orthogonal) [147]. The number of possible combination of attributes and levels can be very high: it is L^M, with M number of attributes and L number of levels. If the number of levels is different among the attributes, the values are multiplied together. (E.g. a design with two three-level attributes ad two two-level attributes would have $3^2*2^2=36$ scenarios or options).



The most common fractional factorial design is main effects plan (e.g. using a design catalogue).

Originally, the orthogonal design was the most applied strategy within the literature in this field, but currently, the orthogonality of the design seems not to be an essential property. Indeed, the orthogonal design is available only for a relatively small number of problems: it cannot be available when some combinations of attribute levels are unfeasible, or a nonstandard number of choice sets is desired or when a nonstandard model is used (i.e. a model with polynomial effects). Moreover, it requires a significant number of choice sets and therefore, a bigger effort by the respondents [148] [136].

2. Optimal orthogonal design (OOD) preserves the orthogonality within the alternatives, but it is obtained by maximising attribute level differences [149], [142]: common attributes among alternatives should never take the same level. In this way, it is possible to reduce the choice sets. The main disadvantages of this method are that sometimes, the realism of the alternatives can be lost and that it can generate designs only for generic attributes across alternatives [150]. However, Tang et al. (2014) [150] suggested a method to extend the OOD to alternative-specific attributes.
3. D-efficient design is typically a non-orthogonal design, but it is efficient because it minimises the variance and covariance of estimated regression coefficients of the model parameters (cf. 4.2.1.). It is always model-dependent, and the process tries to minimise the standard error of the parameters which are supposed to be known. In literature there are

several methods to evaluate the design efficiency, all related to the asymptotic variance-covariance (AVC), matrix of the estimated parameter: D-efficient design minimizes D-error [151] [152], which is a statistic that takes the determinant of the AVC matrix of the model parameters to get the smallest asymptotic standard error [153]. Similarly, the A-error is the (scaled) trace of the AVC matrix, which is simply the sum of the diagonal elements representing (the squares of) the standard errors.

(4) $D - error = (\det \Omega_N)^{1/k}$

(5) $A - error = \frac{(tr(\Omega_N))}{K}$

With Ω_N the AVC matrix for N respondents and K number of parameters.

This procedure allows the researcher to reduce the survey sample [154], to produce very reliable study results [150] and enables the presence of attributes with a mixed number of levels. Currently, state-of-art application on experiment design is opting for efficient designs [155].

4. The adaptive design allows to create the choice set on the earlier answer of the respondents and on its characteristics: this kind of design can be realised only through a computer software [148]. In this way, the survey gains reliability and reduces the respondents' burden [156].

Each kind of design can be performed through several methods: manual, computer-optimised, or computer randomise, and each approach can capture different effects and specific situation (e.g. interaction, alternative specific effects, cross-effects).

Bliemer and Rose (2011) [157] present the outcomes of different choice experiment design approaches, comparing the results: they compare orthogonal design and efficient design and confirm that the D-efficient design lowers standard errors in estimated model parameters and requires a smaller sample size. Furthermore, they feature a very useful state-of-art classifying paper according to the DCE design applied and its characteristics (e.g. the number of choice tasks, design size, type of model used for the parameters' estimation).

Several designs of the experiment also create the choice sets, but sometimes it is a procedure to conclude in a second moment: once the experimental design has been chosen, it is essential to "package" the alternatives in order to present them to the respondent, especially for "in-product" alternatives. To define the choice sets there are several strategies such as presenting all the alternatives identified in the experimental design and ask to choose among them, or rank or rate (known as "simultaneous choice sets creation"). In this case, each choice set contains N alternatives and M attributes of L levels, method L^{MN} (e.g. N=2 alternatives, M=3 attributes, L=3 levels, using full factorial design, this produces 3^{3*2}= 729 choice sets). Another strategy is the sequential choice sets creation, for binary "in-product" choice set or the randomise choice sets creation which can be

applied for both "in/between product" or the so-called "minimum overlap" since between every attribute of the alternatives the differences in the level's values are maximised.
If the choice sets are too numerous, it is possible to create some sub-sets, blocks, retaining the full experimental design but divided the tasks over a number of respondents: this procedure is called blocking and split the design into smaller designs. Attribute levels' balance has to be maintained within each block, such that respondents do not just face only low or high attribute levels for a specific attribute [158].
Furthermore, to reduce the number of choice sets and be more realistic, the researcher can [159]: remove the dominant scenarios, which results unrealistic or remove the scenarios which are technically impossible or unreasonable or, even, it is possible to keep some attributes in common among alternatives. All these strategies lead to a reduction of orthogonality but can achieve realism and simplicity.

2.3.1.3 Survey Structure and Survey Administration

The questionnaire is often split into several sections: besides the one that asks respondents to choose among the alternatives, there is another including socio-economic and demographic questions on the characteristic of the respondents, such as age, gender, job, income, household structure, number of cars, owning of the driving license. These questions are used to test the representativeness of the survey sample and study how the answers vary according to different respondents' characteristics.
The survey's structure has to be well planned, the problem under investigation has to be presented clearly, and the order of the questions is a fundamental importance problem the questions asked first can affect the next ones and can encourage/be a deterrent for continuing the survey. Sometimes, at the end of the questionnaire, some "no brainer" choices are included in order to evaluate the consistency of the answers: for example, a dominated choice can be added, and respondents who failed the test should be eliminated [136].
Pre-testing meaning to test out the survey on a small group of respondents in order to identify the potential problems and correct them before administering the survey [124]. The main phases of pre-testing are (i) focus group, (ii) interviews one-to-one, (iii) pilot survey.
A focus group (i) is a small group of people brought together, by a moderator, to focus on an issue in order to achieve deep insight into it. When well-executed, a focus group creates an accepting environment and participants can express their opinions openly. They can be instrumental in designing the questionnaires properly and achieving a broader problem's vision. The one-to-one interviews (ii) are done to single respondents after they have completed the questionnaire: they are asked to express their opinion on the survey structure, on the wording or the survey's comprehensibility: it provides beneficial feedback on the survey. Finally, the pilot survey (iii)

consists in administrating the survey to a small number of respondents, in order to extract information both on the survey structure as well as on the suitability of the requested data for the following data analysis/model implementation. For example, after the assessment of the answers to the pilot questionnaire can emerge that an alternative is unnecessary or that the difference among levels is almost imperceptible or that a fundamental question needed for the model development is missing. Of course, the sample of the pilot survey has to be similar to the one that will be used for the final survey and respects the same conditions and after the respondents finish to complete the pilot survey is useful to ask them if they encountered some difficulties during the compilation.

The quality of data is crucial for developing mathematical models, and there is a trade-off between data quality and sophistication of the modelling process. The three primary sources of systematic error (bias) are:

- non-response: an individual does not respond at all;
- non-reporting: an individual does not respond to certain questions;
- inaccurate reporting: some responses are objectively incorrect, incomplete or inaccurate.

To overcome and compensate these errors, Richardson et al. (1995) suggest several strategies [137]:

- editing: eliminating errors and omissions or correct them with objective judgments;
- coding: eliminating errors and identify inconsistencies among answers;
- weighting factors: the socio-economic information and the statistical adjustment are used in order to take account of the non-observed information.

2.3.2 Discrete Choice Model

To plan a new transport service, once the data has been collected, it is crucial to develop models which allow the researchers to do experiments and taste different solutions in a fictive environment. Massive innovation in the transport models was the development of disaggregate models based on individual choice analysis [160]. The psychologists (Thurston 1927) were the first who tried to define the individual's behaviour through the development of the random utility (RU) models, a subset of the class of probabilistic models [161]. The random utility models are behavioural models based on the hypothesis that users are rational decision-makers, i.e. they attempt to maximise the random utility through their choices: they select the alternative with the highest utility among those available [85]. Later, the economist Marschak (1960), adopted these models for the representation of the individuals' discrete choice applied to the theory of random utility maximisation [162]. McFadden (1968) applied the probabilistic choice models to the definition of stochastic utility starting from deterministic rules: utilities are treated as random variables to reflect the lack of information regarding the characteristics of alternatives and/or decision-makers. In 1973, Ben-Akiva [163]

published his PhD dissertation on the topic. The leading texts on the field are written by Train (1986) [164] and Ben-Akiva and Lerman (1985) [160].

The random utility theory is based on the following assumptions [85]:

- when the decision-maker "i" has to choose, he takes into consideration all the alternatives which are included in his choice set "I". The choice set can be different for each user;
- the decision-maker "i" associates each alternative "j", included in his choice set "I", to a perceived utility "U_{ij}" and he will select the alternative with the highest utility;
- the utility associated to each alternative depends on the attributes, i.e. measurable characteristics or intrinsic properties of the alternatives and depends on the specific decision-makers: $U_{ij} = U_i(X_{ij})$, with X_{ij}= vector of the characteristics of the alternative "j" and the decision-maker "i";
- the utility associated by the decision maker "i", to the alternative "j", is not known by the analyst, so it is a random variable.

The utility function is divided into two parts:

$$(6)\ U_{ij} = V_{ij} + \varepsilon_{ij}$$

$$(7)\ V_j(X_j) = \sum_k \beta_k X_{k,j}$$

The utility U_{ij} can be expressed as the sum of the systematic utility V_{ij} which represents the mean of the utilities perceived by the decision-makers and depends linearly on the (j) alternatives' attributes X_{ij}, and ε_{ij}, the disturbance, or random component, which captures the impact of all the unobserved factors that affect the individual's choices [165]. β are the parameters of the alternatives' attributes "k".

$$(8)\ \mathrm{Pr_i(j)} = \mathrm{Pr_i}(U_j > U_h) = \mathrm{Pr_i}(V_j + \varepsilon_j > V_h + \varepsilon_h) = \mathrm{Pr_i}(V_j - V_h > \varepsilon_h - \varepsilon_j)$$

$$\forall\, h \neq j \in j, h \in I^i$$

$\mathrm{Pr_i(j)}$ is the probability that the decision-maker (i) will choose the (j) alternative; I^i is the decision-maker (i) choice set. From equation (8) it is possible to notice that if the disturbance distribution is known, it is possible to achieve the distribution of the differences between the stochastic utilities and consequently the choice probability.

Varying the assumption of the functional form of the disturbance ε_{ij} leads to different choice models: the most widespread models applied are [85]: Multinomial Logit (MNL), Nested Logit [166] and their refinements, such as Generalized Extreme Value (GEV) (which is a generalization of the previous models), Probit Model, Mixed Logit Model [167], [168], [169] and their enhancement [170], [171], [172]. Nowadays, in order to capture even more complicated problems, latent class choice models are widely used. [173], [174].

Multinomial Logit is probably the most simple and applied model formulation; it is based on the hypothesis that (i) the disturbances (or random components) are extreme-value (or Gumbel) distributed and they are (ii) identically and independent distributed (IID) across alternatives and (iii)

across individuals (observations). The assumption of disturbance independence implies that the unobserved utility of an alternative is not correlated to the unobserved utility of a different alternative. Gumbel has the following cumulative distribution:

$$(9)\quad F_{\varepsilon} = e^{[-e^{-\alpha(\varepsilon-\eta)}]}$$

The probability density function:

$$(10)\quad f_{\epsilon} = \alpha e^{[-\alpha(\varepsilon-\eta)]} e^{[-e^{-\alpha(\varepsilon-\eta)}]}$$

Where α is the scale parameter which determines the variance of the distribution and η is the location parameter.

The mean and the variance of the distribution are:

$$(11)\quad mean = \eta + \frac{0{,}577}{\alpha}$$

$$(12)\quad variance = \frac{\pi^2}{6\alpha^2}$$

All the three hypotheses lead to a mathematical structure known as Multinomial Logit Model (MNL), which express the probability of an individual to choose each alternative as a function of a systematic portion of the utility of all the alternatives:

$$(13)\quad p(j) = \frac{e^{V_j}}{\sum_{h=1}^{m} e^{V_h}}$$

With *p(j)* the probability of the individual of choosing the (*j*) alternative, V_j the systematic component of the utility of alternative *j* and *h* the generical alternative. The MNL is S-shape (see Figure 5), the alternative's choice probabilities depend on the differences of the systematic utility, and the ratio of the choice probability of any pair of alternatives is independent of the attributes and availability of other alternatives [166].

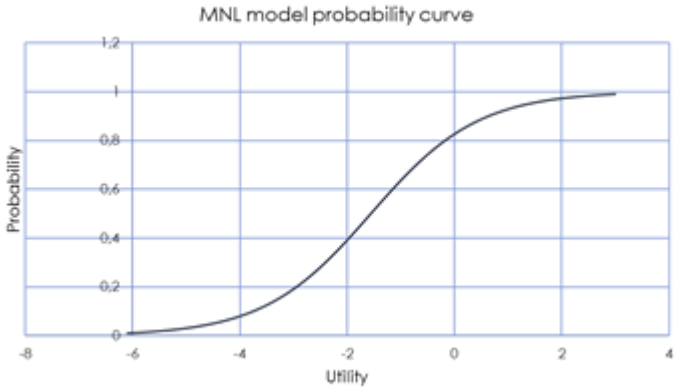


Figure 5: MNL S-Shape

It is called binary logit when the alternatives are only two. The Nested Logit Model (NL) (McFadden, 1978) [175] allows overcoming the assumption of independent random residuals of MNL. In the NL all the alternatives can be split in subsets or "nests", according to some similarities, shared by the alternatives but not included in the utility function. The random term of the nested alternatives can

be divided into a portion associated with each alternative and a portion associated with the nest of alternatives [166].

Before introducing the parameter model estimations and the tests used in the model development process, it is essential to realise that this process is not an "algorithmic process with clear-cut rules", but modelling also depends on the subjective judgements of the designer, on several assumptions and on formal and informal statistical methods. Moreover, it is important to underline that (i) a model which fit well the data not necessarily is the adequate model, that (ii) often more than one specification fit equally well the data and that sometimes a correct model specification would be practically infeasible.

2.3.2.1 Parameter Model Estimation

The problem of inferring the parameters β from a sample of observations is essential to obtain the model which best fits the data. The maximum likelihood [85] is the method most frequently used for the parameters' definition. Through this method, the researcher can estimate the unknown model parameters (β) maximising the probability of observing the choices made by the observed sample [85]. The likelihood of the sample is the probability of observing the choices, and it is related to the sampling strategy adopted as well as the choice mode adopted. The procedure consists of (i) developing a joint probability density function of the sample, i.e. the likelihood function, and (ii) estimating the values of the parameters which maximise the likelihood function [166].

2.3.2.2 Statistic Tests

There are several statistic tests to make inferences about the parameters; in this section, only the most relevant for the thesis purpose are reported. To evaluate the model structure, the most frequently applied tests on individual parameters are the informal test of the signs, the evaluation of the standard errors, the t-test. There are also other statistical tests to assess the goodness of fit of the entire model, such as the likelihood ratio test, the ρ^2 test, the Akaike information criterion (AIC) and the Bayesian information criterion (BIC), as well as the cross-validation [160], [176].

- Informal test – Sign test: it consists of a first comparison of the obtained sign of the parameters according to the priory expected. For example, travel cost is expected to have a negative coefficient, since higher is the cost and lower is the attractiveness of that alternative.
- The ratio between time and cost coefficients (β) is the VOT (value of time) and can be compared with other calibrations and can be assessed comparing it to literature values. For example, the value suggested by de Jong et al. (2014) [177] are:

Table 3: VOT (prices 2015)

	Type of traveller	€/hour
Passenger transport (€/hour/passenger)	Business	47,56
	Commuting	10,13
	Other	8,96
	All motives	13,55
Freight transport (€/hour/vehicle)	Truck	41,04
	Rail	1188,03
	Inland waterways	75,00 (waiting for quay) 324,00 (waiting for lock/bridge)

- Standard error defines how much the function reproduce the observed values: $st.error = \sqrt{var}$
- The t-test is used to test if a specific parameter in the model differs from some known constant (usually zero). The critical value for the t-test are percentiles of a standardised normal distribution (which is 1,96 for an interval of confidence of 97,5%). The null hypothesis is that the parameter is equal to zero (or a given value) at a certain level of confidence. The null hypothesis is rejected if |t|>1,96 (or a different value related to the interval of confidence).

(14) $$t = \frac{\beta_k}{Var(\beta_k)^{1/2}} = \frac{\beta_k}{st.error(\beta_k)}$$

The t-test can also be applied to test if two different coefficients are equal (null hypothesis)

(15) $$t = \frac{\beta_k - \beta_l}{[Var(\beta_k) + Var(\beta_l) - 2cov(\beta_k \beta_l)]^{1/2}}$$

It is noteworthy to underline that a low t-statistic does not necessarily mean that the corresponding variable has to be eliminated from the model. If there are strong reasons to believe that the variable is significant and the sign test is correct, it is reasonable to keep it in the model. Also, the low t-test for the alternative specific constants is not a good excuse for eliminating them from the model, since they represent the average effect of all the variables not included in the model [166].

- ρ^2 test or McFadden test: is similar to the R^2 test in regression analysis. It is used to test how the model replicates observed outcomes. The ρ^2 value is based on the relationship among the loglikelihood:

(16) $$\rho^2 = 1 - \frac{\mathcal{L}(\theta^*)}{\mathcal{L}(0)}$$

With $\mathcal{L}(\theta^*)$ is the loglikelihood of the estimated model, and $\mathcal{L}(0)$ is the null loglikelihood (zero coefficients).

$\bar{\rho}^2$ value is

(17) $\bar{\rho}^2 = 1 - \frac{\mathcal{L}(\theta^*) - K}{\mathcal{L}(0)}$

With K the number of parameters.

It varies between 0 and 1, where 1 stands for a perfect fit.

- Likelihood Ratio Test: is applied for the comparison between the goodness fit of two models, one of which (the null model with all the coefficient being zero) is a particular case, or the restricted model, of the other: restriction can be obtained, for example, by imposing some parameters equal to zero. The test is based on the likelihood ratio. The test statistic is: $-2\ [\mathcal{L}_R - \mathcal{L}_U]$ which is chi-squared distributed, with $\mathcal{L}_R$ the loglikelihood of the restricted model and the $\mathcal{L}_U$ those of the unrestricted model. The null hypothesis is that the restricted model is better than the unrestricted: this thesis is rejected if the test statistic is sufficiently large: sufficiently is specified on the base of the number of restrictions and interval of confidence desired:
  $-2\ [\mathcal{L}_R - \mathcal{L}_U] \geq \chi^2$, with χ^2 the critical chi-squared values (determinate thanks to table-value)

The model-building process is an iterative one, i.e. the designer set a first specification of the model, making some a priori assumptions and subsequently revised them on the basis of the tests and of the model prediction ability.

2.3.2.3 Aggregation

Through the stated preference techniques, the model is specified according to the investigation on individual behaviour, i.e. the probabilities with which any particular individual will take his transport choice are estimated, but, usually, the researcher is interested in the aggregate-demand, i.e. in the whole population behaviours [160].

Aggregation process, or population expansion, is not always easy because it is influenced by several factors [124], primarily related to the target population and to the chosen sample, which must be randomly selected and representative of the population. If the sample is selected according to the simple random sampling method, theoretically, the results of the questionnaire can be expanded to the whole population. Intuitively it is possible to say that the value for the population is the value of the sample multiply the ration between the population size and the sample size, but the process isn't so easy due to several factors [137], [124]:

- even with a simple random sample, there is no guarantee that the sample is truly representative of the population; some group of the population can be over-represented and others under-represented;
- if another sampling procedure has been used, it is possible that the chosen sample is not representative of the population: i.e. the respondents are only people who have an e-mail

address, or respondents are representative only of one category or, also, only who will receive the potential benefits of the system under investigation answer the questionnaire;

- not all sampled people will respond to the questionnaire;
- some respondent provides non-plausible answers or misunderstands some survey's questions.

Various aggregation methods are proposed in the literature; Koppelman (1975) [178] suggested five procedures:

- average individual: define an "average individual" and use him/her as representative of the entire population.
- classification: partition the population into homogeneous groups and estimate the choice probability of the average individual of each group. Respondents have to complete few specific questions on some of their characteristics, and the researcher must have precise information on the distribution of the same characteristics over the population and hence a source of data on the population is needed, e.g. census data or data from another questionnaire.

  People can be classified according to their socio-economic characteristics or thanks to some attitude questions [122] which evaluate people disposition towards specific issues (attachment to the car, time constraints, orientation toward innovation, et.): the objective is achieving groups with the differences within each member of the class as small as possible.
- statistical differentials: approximate the distribution of the attributes in the population and subsequent approximation of the function of the population choosing an alternative W(j) through mathematical techniques.
- explicit integration: solve the integral of the product of the distribution of the probability of an individual choosing an alternative j and the distribution of the attributes among the population $\tilde{p}(x)$:

(18) $$W(j) = \int P(j|x)\tilde{p}(x)dx$$

- sample enumeration: use a sample to represent the whole population. The share of the sample choosing alternative j is:

(19) $$W(j) = \frac{1}{N_s}\sum_{i=1}^{N_s} P(j|x_i)$$

  with N_s the number of individuals in the sample, "i" the decision-maker and x_i the attributes affecting the choice for an individual.

Sample enumeration can be applied in combination with the classification procedure,

(20) $$W(j) = \sum_{g=1}^{G}\left(\frac{N_g}{N_T}\right)\frac{1}{N_{sg}}\sum_{i=1}^{N_{sg}} P(j|x_i)$$

Where N_{sg} is the size of the sample for the g^{th} group, N_g is the size of the population of the g^{th} group, and N_T is the population size. According to Ben-Akiva and Lerman (1985) [160] sample enumeration is effective in forecasting the policies implication on different population groups.

2.3.3 Stated Preference Survey and Discrete Choice Model Summary

All the different approaches to define a stated preference survey and develop a random utility model have positive and negative aspects; the selection of one rather than the other depends on many factors such as money, time, accuracy, the purpose of the study, presence of supporting technologies. The algorithm developed to dimension a new car sharing service, embedded in the planning methodology (cf. Step 17), is based on multinomial or nested logit models which are closed-form models, very straightforward in measuring the effect of the new service introduction, allowing easy interpretation of the results. Sample enumeration with classification technique is employed to estimate the aggregated results since it is based on simple mathematical techniques and produce efficient results for the forecasting purpose and, the possibility of splitting the population into classes increases the accuracy of the results. In the case study, included in this dissertation, data is collected through both paper and internet surveys and choice experiment is the chosen response form. Attributes and attributes' levels are combined through the fractional factorial design.

3 Problem Statement

When planning a new car sharing service, the complexities which arise are numerous. During the research conducted in the course of the doctorate, the elements, which seems to most influence the success of a car sharing service, have been individuated in:

- the novelty for the citizens;
- the economic problem;
- the mutual relationship between demand and supply;
- the environmental issue;
- the relationship between car sharing and public transport.

In several cities, car sharing is quite a novelty, citizens are not always aware of it, or at least, they have never tried it. Choosing to adopt car sharing implicates a change in the lifestyle, a change in the mindset, respect to the private car usage. Therefore, people join a car sharing organisation only if they feel that the service is appropriate for them if it supports them in their daily mobility and in overcoming the barriers that they encountered with the actual supply system [179]. This leads to the fact that usually people are inclined to adopt the new service only after ensuring the well-functioning and the potentialities of the service [50]. Consequently, this is reflected in a postponement of revenues, for the service operator [7], and it is related to the economic problem for the service operators. Indeed, people demand a well-functioning supply system, for which high investment costs are necessary, particularly in the starting-up phase. Car sharing yields the best results with a high number of users [66], which are related to high revenues for the service operator but also to high expenses in order to provide them with an efficient service. The problem is related to the balance between the satisfaction of the people mobility needs and the resources, which are limited, both if the service is implemented by a private operator or a public one (who tap into collective resources). One of the main challenges when planning a new car sharing service is posed by the strong interaction between demand and supply [66]. Car sharing demand is difficult to predict because the supply elements, such as vehicle availability in terms of number and location, are directly linked to the

number of trips and vice versa [10]. It is not a problem by itself, but it becomes so in relation to the financial issue. The best scenario for the users is the one with vehicles always available when and where they are need; while, on the supply side, the company which manage the service aims to high profit, i.e. high revenues, which are related to the number users, who subscribe and use the service, and low costs which means low number of vehicles and stations [10].

Also, the environment plays a crucial role, since one of the reasons for the spread of this new service is related to the desire of decreasing the required parking area for the vehicles in favour of green area and diminish congestion and consequently improving the air quality, reducing pollutant and acoustic emissions as well as accidents [28]. All these aspects can be reached if car sharing replace a trip which would otherwise be done in a vehicle with a single occupant and not whether the replaced trip would be by bus, train, bicycle [50]. So, it emerges that the relationship of this new service with the already existent public transport services is a crucial aspect for achieving the definite environmental objectives [180]. Indeed, one of the main goals when implementing car sharing services is the reduction of private vehicle usage, and this can be achieved if the new service is planned jointly with the already existent public transport services (train, bus, metro), the other sharing mobility services (carpooling, bike sharing) and the greener alternatives (walking, bicycling) [180]. Only through the complementarity of these services, it is possible to offer an efficient solution for boosting inter-modality and multi-modality which make people experience a higher level of satisfaction and the convenience to change their habits in favour of a means of transport different from the private car [6].

So, it seems pivotal to carefully plan the service in order to take into account and balance all these aspects.

4 Methodology Proposal

Short Summary

The research mainly focuses on the car sharing planning process and, according to the findings of the literature analysis, it can be valuable to define a complete methodology taking into account all the different aspects of the issue. The suggested methodology aims to provide a practical tool for the planning of a new station-based car sharing service. It is a "multi-step" procedure composed of several stages, some of which based on already developed theories and tools, which are related and integrated to each other since the outputs of a step are the inputs of the following one. Moreover, an algorithm, embedded in a methodology step, is developed for the scenario's definition. The issue is vast and complex, and this leads to stress some aspects over others. The elements individuated as relevant and stressed in the suggested procedure, mainly concern the relationship between demand and supply, the integration of the new service with the already existent public transport and the importance, when assessing different alternatives, of taking into account revenues, costs and the environmental impacts.

In this thesis chapter, each step of the suggested methodology is described. After each step description, a table is reported, which summarises the leading relations of the considered stage with the other ones. Almost every previous step to the one under consideration produces information that is used in the following ones, so, in order to be precise but not repetitive, this will not be reported explicitly every time, e.g. the objectives definition influence almost all the planning process, but this is not stated in every step. The connections between stages can also be retroactive; indeed, some phases of the suggested methodology are repeated until reaching satisfactory results.

An overview of the methodology structure is set out in Figure 6, activities are reported in rectangular boxes, while outputs are identified through elements whit the rounded corners. The seven phases of the planning process reported in the scheme can be further split into several steps, as it is clear from Figure 7, Figure 8, Figure 9 and Figure 10: each phase outputs are inputs of the following one.

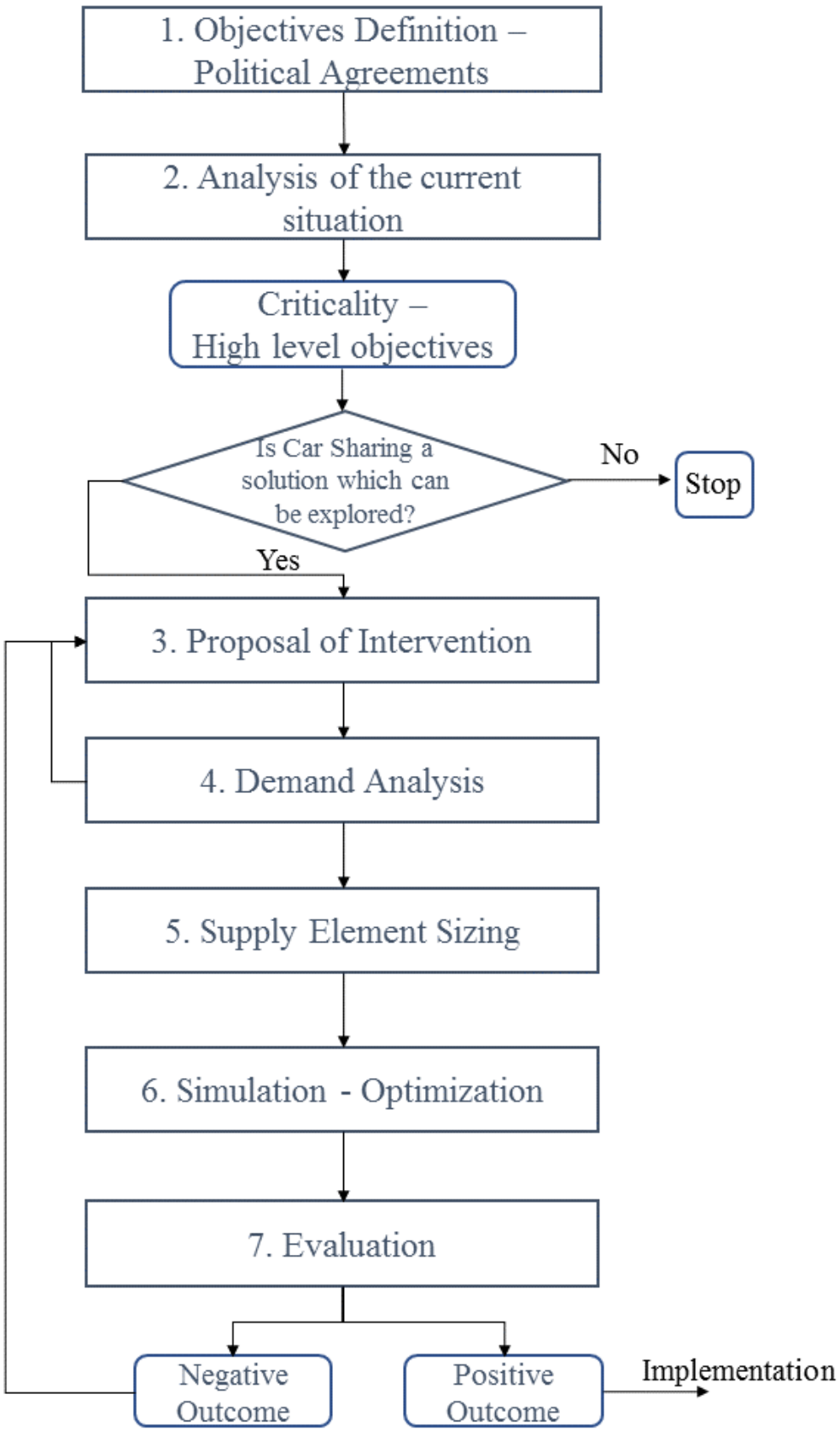


Figure 6: Planning Process

All the phases are related to the objectives' definition and the political agreements (phase 1), which set the purposes of the work. The analysis of the current situation (2) leads to the assessment of the necessity of exploiting the feasibility of a car sharing solution. If it is needed, then the following phases have to be pursued: the designer has to suggest a proposal of intervention (3), investigate the potential demand and develop the model which relates the potential demand to the supply (4). To size the service' elements (5), an algorithm, which embedded the model of the previous phase, has been developed: it allows the definition of the potential demand, costs and revenues for the service operator together with the environmental costs and the new modal split for each combination of supply' attributes. Finally, the designer establishes the scenario which better corresponds to the objectives through a process of simulation, optimization (6) and evaluation (7). The main actors involved are those who commissioned the study, the public authority, different partners and the designer (one or a group).

The steps are better explored in 4.1, however, from the schemes, it is possible to individuate the central relations between them and the presence of loop-procedure, i.e. activities which have to be repeated until finding an acceptable solution. At the end of the whole process, if the achieved solution is not satisfactory the designer should redefine the proposal of intervention and, sometimes, also the project's objectives. All the steps steps explained in 4.1 are listed in Table 4.

Some steps are not numerated with a progressive value, but they are marked as "Step#bis"; they represent two kinds of activities: those that do not necessarily have to follow the sequentially of the whole process and those that are not strictly necessary, i.e. they support the procedure, but can also be omitted. Moreover some steps are introduced in the first phases of the procedure, since from the really beginning the actors have to be aware of some crucial aspects (e.g. the financial one), but the proper activities would be carried on after the implementation of other stages of the procedure (e.g. funds can be requested after the definition of the service).

Table 4: Methodology's Steps

Multi-steps Methodology	
Step 1	Objective Definition – Political Agreements
Step 2	Analysis of Administrative and Legislative Issues
Step 3	Assessment of Financial Issues
Step 4	Study of the Planning Documents
Step 5	Context Definition and Assessment
Step 6	Identification of the Target Population
Step 7 - 8	Analysis of the Current Situation – Demand (7) and Supply (8) Side
Step 9	Interaction between Demand and Supply and Criticality Individuation
Step 10	Identification of the Car Sharing Typology – Proposal for Intervention
Step 10 bis	Side Businesses
Step 11	Detection of the Supply Elements
Step 12	Identification of Partners and Suppliers
Step 13	Potential Demand Estimation: Data Collection
Step 13 bis	Testing the Sample Answers
Step 14	Potential Demand Estimation: Model Development
Step 14bis	Elasticity Analysis
Step 15	Aggregation
Step 16	KPIs
Step 17	Supply Elements Sizing Algorithm
Step 18	Scenario Simulation
Step 19	Optimization

4.1 Steps Description

Step 1: Objective Definition – Political Agreements

Declaring that the objective definition is fundamental can be redundant, but it is also necessary: in order to define the best car sharing service and to investigate people reaction towards the new mobility initiative, the primary goals that the client aims to achieve must be very clear to the designer. The client is the one who is commissioning the project and can be a public entity, a private company, a car sharing operator, a university/a school, etc. and, depending on this, the objectives can be different.

The goals can be established by the results of political or private interest, can derive from a citizens' request, as well as they can be defined after the analysis of the current mobility behaviours, in order to try to overcome some encountered problems. The objectives can experience various changes after the analysis of the financial, administrative issues or after the partners' involvement and, furthermore they might be revised at the end of the planning process when assessing the outcomes.

There are some objectives which are most often pursued when planning a car sharing service; they can be split into:

- business goals, such as the maximisation of the service operator profit;
- customer service goals, such as the satisfaction of all the potential users, easiness to use, encouraging cooperative behaviours that benefit all users;
- environmental and social goals, like the reduction of harmful emissions, noise, shifting from private car usage, the complementarity with public transport, the reduction of parking requirements, the boosting of social inclusion.

The positive impacts of car sharing can be better reached if they fulfil the political objectives and car sharing can find fertile ground for its expansion when transport modes, which are alternative to private cars, are supported by politics [181]. In particular, when car sharing is not already known, the political support of a local council strengthens the potential users' favourable perspective towards the service. Furthermore, local political support is particularly constructive to prepare citizens for changes, encouraging them towards the adoption of new transport modes in order to improve their lifestyle, health and preserve the environment (cf. Step 12).

The support can be, not only at the local level but also at higher levels, regional, national or international; in Italy, car sharing is supported by "Iniziativa Car Sharing" (ICS) established by the Italian Environmental Ministry. Between 2007-2016, the Environment Ministry sustained car sharing also with bonuses: people who scraped a vehicle with pollution level Euro 0, Euro 1 or Euro 2 received a bonus to use for the car sharing adoption (2809 people benefited from the incentives) [182]. Nowadays (2019), ICS is supporting the, so-called, micro-carsharing initiatives, through a bonus for the car sharing serviced implemented on a small-scale (including municipalities with less than 200.000 citizens, companies or cooperatives with less than 50 employees and an annual revenues below than 10 million €, no- profit associations and public transport companies) with advance ICT technologies and innovative organizational models.

National governments are responsible for the promulgation of laws and regulations which support the realisation of car sharing projects and promote sustainable mobility measures.

Table 5: Relationship - Step 1

Related to:	Note:
Step 1 influences almost every other following step.	
Step 6 Identification of the Target Population	The definition of the target population can be imposed, directly by the project objectives, i.e. if the project aims to implement a new car sharing service for a specific target population (i.e. tourist, students, people with disabilities) the target population is straightforward established.
Step 9 Interaction between Demand and Supply and Criticality Individuation	Problems arise from the analysis of the current situation should be discussed among stakeholders and included in the project's objectives with the aim of overcoming them.
Step 16 KPIs	The KPIs are defined according to the project objectives
Step 18 Scenario Simulation	If the outcomes of the scenario simulation are not in line with the defined objective, it is possible to start the process again from the first step.
Step 19 Optimisation	The optimisation process leads to the maximisation/minimisation of the KPIs following the imposed objectives.

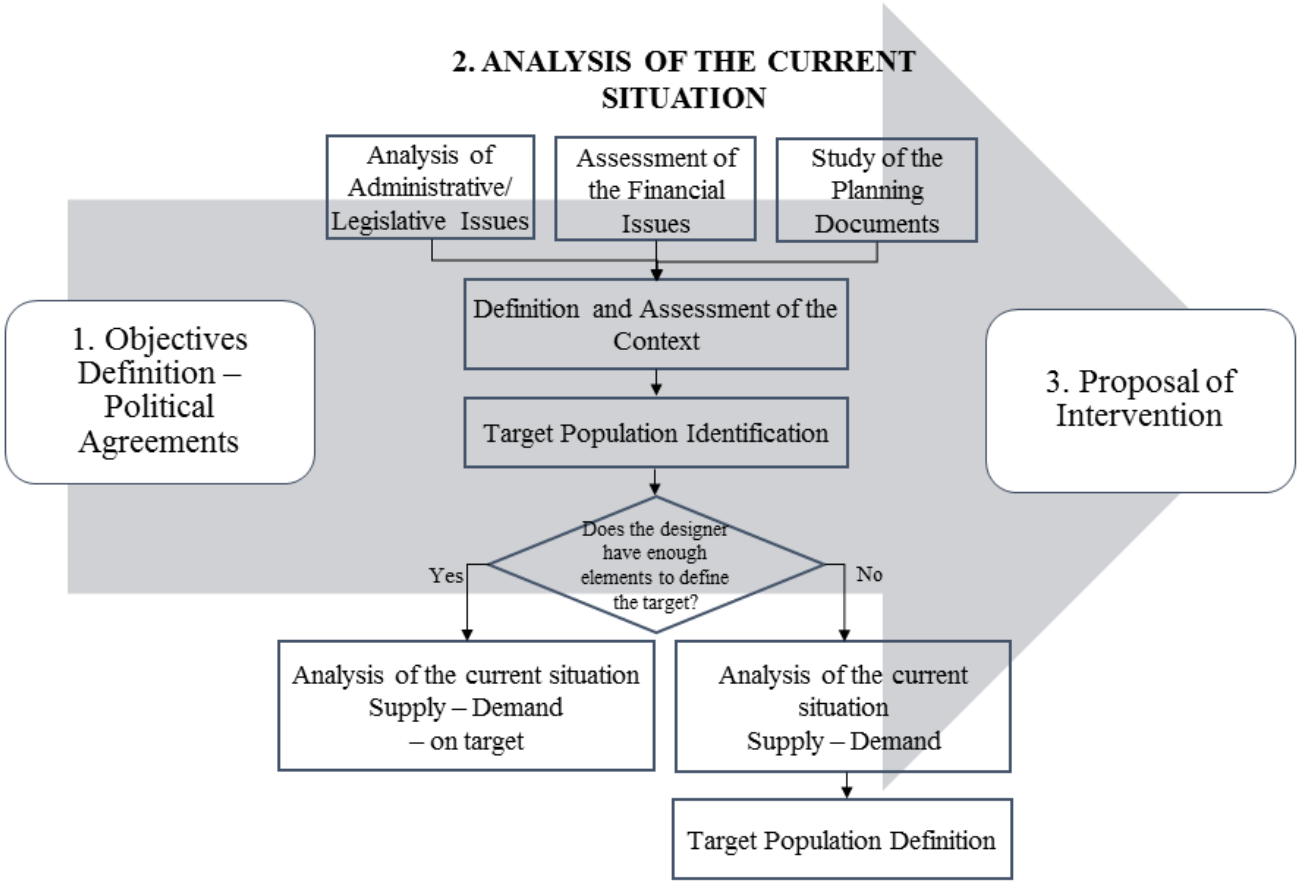


Figure 7: Phase 2 - Analysis of the Current Situation

Step 2: Analysis of Administrative and Legislative Issues

As already expressed in section 2.1.3.2, the car sharing organisational forms can be different; consequently, the initiative's operator can be a public authority, a private car sharing operator, a specific company, etc. and from this classification derives different contractual forms and required permissions (for starting the service, asking funds, parking management, and so on). Some laws and regulations mandate the designer to follow some procedure or ever the client to pursue some objectives, such as reduce pollution.

In a non-exhaustive manner, from an administrative point of view, to start a new service, a lawyer, a tax consultant and a notary have to be involved. The first couple to define the society's article of partnership, and the notary to execute the formal registration into the register of companies. Furthermore, the public authority provides the legal authorisation for the service starting up.

In Italy, car sharing finds support by the government, through the "Iniziativa Car Sharing", an agreement among municipalities in order to enable the development of this kind of service all around the country, guarantee a certain level of service and promote it.

The issue relates to data protection arises since car sharing companies manage several personal data, such as contact details, member socioeconomic characteristics (age, gender, address) and personal journey characteristics (origin, destination, time, duration, stops). Data must be managed according to the latest privacy laws.

Table 6: Relationship - Step 2

Related to:	Note:
Step 11 Detection of the Supply Elements	Administrative issues and, in particular, licences management, are directly related to two key service elements: enabling car sharing vehicles to access to LTZ and giving the permission to use the public parking areas to set the service stations.

Step 3: Assessment of Financial Issues

The financial issue is pivotal, since usually, the service requires high expenditures during the first phases, in order to establish a performing service also in the long term. Moreover, since adopting car sharing involves a change in the lifestyle, people usually seek for assurance in the well-functioning of the service and its potentialities, and it is unreasonable to think that they immediately adopt the service. This leads to a delay in revenues with respect to investments [7].

Financial issues are different according to the car sharing typology based on the capital source: for-profit, no-profit companies or cooperatives and also according to the operative typology: e.g. a corporate car sharing where the fleet is already existent experiences lower investment costs and, consequently, the funds required are diverse. In every case, the launch of a new car sharing service is expensive and, except in some cases, the operator has to raise finances, usually through agreements with banks, public authorities, other partners/sponsors or thanks to public funds and bonuses.

Aspects related to costs and revenues, from the service operator's point of view, are better explored when presenting the algorithm for the supply elements sizing, in Step 12 and Step 16.

Particular attention has to be paid to the taxes required for launching and managing a new service.

In this phase the designer has to be aware of the issue, but to achieve funds for the service implementation, it is essential to produce a financial report, stating all the cost and revenues components and explicating their value in the defined scenario, hence it is possible to define all these elements only at the end of the planning process. At the beginning of the procedure, the client has to assess the costs related to the design phase.

Table 7: Relationship - Step 3

Related to:	Note:
Step 12 Identification of Partners and Suppliers	Financial issues are related to the choice of partners and suppliers.
Step 17 Supply Elements Sizing Algorithm	The algorithm developed to size the car sharing is composed by several modules, two of them are related to costs and revenues for the service operator where the values of all the cost and revenues items are reported.

Step 4: Study of the Planning Documents

The urban mobility planning documents are the starting point for the development of transport policies in a joint process with urban, land-use and energy planning. These aspects are strongly related and reciprocally influence each other. Also car sharing is strongly related to the built environment, on the attractive nodes and infrastructure as well as, by the presence of pedestrian areas, limited traffic zones, by the parking availability and prices and also, by the existent public transport scheme. For example, it has been experienced that car sharing is boosted in car-free areas [84].

The primary documents related to transport planning are "Urban Traffic Plan", "Sustainable Urban Mobility Plan" and "Sustainable Energy and Climate Action Plan".

According to the Italian traffic law, the "Piano Urbano del Traffico" - Urban Traffic Plan (PUT) aims to enhance the traffic conditions, road safety, decrease the harmful emissions and energy consumption, together with the minimisation of the usage of the personal vehicles. It highlights several measures which aim to improve the urban traffic conditions without realising new infrastructures. It has to be consistent with the other urban plans and periodically updated.

SUMP "Sustainable Urban Mobility Plan" guidelines developed by the European Commission in 2014 have been incorporated in the Ministerial Decree of 4 August 2017 by the Italian Ministry of Infrastructure. They are strategic plans which aim of satisfying people and companies' urban mobility demand and improving the citizen quality of life [183]. They aim to achieve broader societal objectives related to economic, social and environmental sustainability, and they focus on integration, participation, monitoring and assessment. Sharing mobility measures are defined in almost all the SUMP adopted in Italy [6].

With the Covenant of Mayors for Climate and Energy, launched by the European Commission, the public authorities have committed to define and implement a SECAP "Sustainable Energy and Climate Action Plan", which is a document in which cities define measures to reduce CO_2 emissions and enhance the energy efficiency, according to the European targets. This document also involved transport issues (e-mobility) and has to be implemented before 2030 [184]. The joint planning of

energy and mobility systems maximises synergies and environmental benefits fostering the reaching of the vision goal, increasing the quality of life for citizens [185].

Table 8: Relationship - Step 4

Related to:	Note:
Step 5-7-8 Context Definition and Assessment Analysis of the Current Situation – Demand (7) and Supply (8) Side	The planning documents play an important role in the context assessment and in the analysis of the current situation: these documents can provide useful data or constraints that the designer has to consider in the service definition.
Step 11 Detection of the Supply Elements	The already existent planning documents regulate some supply elements (e.g. recharging infrastructure, LTZ).

Step 5: Context Definition and Assessment

The context definition and assessment involve the individuation of the study area, its characteristics, boundaries and constraints, together with the land-use. The study area is the territory which is implicated in the operation; it can be a site, a corridor, a network, the old downtown, a part of the urban area, the whole municipality, the regional area or a larger area. In addition to the study area, also the surrounded areas which have an influence on the study area must be considered in the context evaluation. In particular, the designer has to be aware of the area main characteristics like localization, extension, population density, the geographical distribution of the sociodemographic characteristics.

The boundaries can be spatial, social, temporal [137]. Spatial, refers to the geographical area and needs to be taken into account both in the identification of the car sharing typology (cf. Step 10) and in the target and sample definition (cf. Step 6 and Step 13). The geographical boundaries can be defined by natural discontinuities in the territory (rivers, lakes, sea, great difference in height) as well as men-made discontinuities (railways, metro, a street, a motorway, an LTZ). Social refers to the social dimension to be included in the project, the group of people who have some relation with the transport system presented, both the potential users, the non-users, who will benefit or will lose form the change, and it is firmly related to the target definition (cf. Step 6). Temporal dimension refers to the investigation in the short-term effects or medium-term or long-term. Different kinds of constraints can emerge, such as financial, political, operative, such as the number of professional staff and the time given to settle the study.

Another context element to assess for planning the new service is land-use: assessing land-use includes the evaluation of the management of the natural environment and built environment. Land-use, transport and energy planning (both the short and the long-time planning) must be pursued jointly in order to boost the efficiency of the resources usage and territory exploitation [186]. Only in this way, it is possible to improve the quality of life of the citizens (e.g. reducing stress, time-wasting, harmful health effects, noise, energy consumption) and enhance sustainability [187]. Several authors define as the most attractive areas for car sharing, those which are densely residential or mixed-used [188], with low vehicle ownership rate and where is available excellent public transport service, pedestrian and cycling paths [24] or areas closed to college/university [189] or where the park areas are limited [8]. Studying the land-use, it is possible to individuate the main attractive nodes (schools, universities, city centre, nightlife, economic centres as well as the train stations, airports) which must be taken into account when defining the service stations.

Table 9: Relationship - Step 5

Related to:	Note:
Step 6 Identification of the Target Population	Social barriers and the identification of the population to whom the new service is addressed are deeply related.
Step 7-8 Analysis of the Current Situation – Demand (7) and Supply (8) Side	The analysis of the current situation strongly depends on the context.
Step 10 Identification of the Car Sharing Typology	The identification of the car sharing typology is highly related to the context: e.g. free-floating car sharing is well suited for a metropolitan context.
Step 17 Supply Elements Sizing Algorithm	Study area and land-use characteristics are involved in the definition of the station location.

Step 6: Identification of the Target Population

The term target population refers to the people who are affected by the investigated system. These people will receive both benefits and costs [124].

First of all, when defining the target population, the designer has to consider the project objectives, i.e. if the project aims to implement a new car sharing service for tourist, for university students, for people who arrive at the airport, then the targets are straightforward established. Indications on the

target population are also provided when the service aims to some specific mobility pattern, e.g. it is designed for carrying large-sized objects, for moving into a new home, for the night trips, for weekend trips. Furthermore, the target is influenced by the organisational service form: if the operator is a company who is setting a car sharing service for its employees, the target population is, also, already defined.

If the target population is not readily apparent, it can be defined by expert judgments, by the interrogation of available databases (register of voters, households with telephone, all subscribers to a specific service, all the university students) and through the collection of new data (cf. Steps 7 - 8). Targeting the service to the "right" people is a very delicate task, indeed, to achieve positive effects, according to the defined objective, the new service has to be addressed to specific target people. For example, if shifting people away from private car is the key project goal, then it is important not to encourage people who are already using sustainable modes of transport to shift towards car sharing, but the service has to be implemented in such a manner that it results attractive to car users. To correctly assess the target, focus groups with the potential users can be carried out as well as private interviews with the main stakeholders and with people who represent some specific category. Section 2.1.3.5 reports the typical characteristics of the car sharing users, reported in the available literature.

Table 10: Relationship - Step 6

Related to:	Note:
Step 1 Objective Definition – Political Agreements	When defining the project objective, it is possible to include a specific target, e.g. if the project objective is related to the implementation of a new mobility service for the cruise tourist/ students, the target population is already defined.
Step 7-8 Analysis of the Current Situation – Demand (7) and Supply (8) Side	The analysis of the current situation has to be performed mainly on the target population.
Step 11 Detection of the Supply Elements	Some supply elements have to be defined differently according to the target population: to name but a few, the vehicle typology (city-car, luxury car), the presence of minivan with space for luggage and boxes, the establishment of a call-centre. Moreover, the adoption of a segmented price strategy according to the different targets is another example of the strong interaction between these two steps of the planning procedure.

Step 7 and 8: Analysis of the Current Situation – Demand (7) and Supply (8) Side

The main aim of these steps is the evaluation of the current situation regarding the population mobility behaviours, its transport needs and on the already existent transport supply. If already established, the analysis of the current situation must pay particular attention to the target population. From the knowledge of people current mobility behaviours and their transport problems, it is possible to determinate the reasons for some mobility choices and define the possibility of intervention.
According to Roe (2017) [179], who interviewed several experts in the sector, having a global comprehension of people daily life journey and mobility behaviours are necessary for service planning. In this way, the potential users can experience a higher level of trust towards the new service, together with the desire of trying a new service, which can be seen as useful and suitable to satisfy their needs. The service has to be designed in a "user-centric" perspective, in such a way that potential users experience the service like it was designed for them. To achieve this goal, involving the final users in the planning process is recommended.
Furthermore, the knowledge of the current situation allows the stated preference survey to be better formulated (cf. Step 13), since taking into account the real people behaviour increase the realism [190] and, moreover, these data can be exploited for the aggregation procedure in order to define classes (cf. Step 15).
The key elements to be collected concern:

- the current mobility behaviour (OD surveys): type of relevant trips (commuting, leisure, holidays, etc.) travel frequency, transport duration, time of depart/arrival, origin/destination, people current modal split and their intrinsic and extrinsic motivation towards these choices, kilometer travelled per year, multi-modal trips in relation to the single person and the whole households (number of family members);
- socio-economic characteristics, such as income, age, level of education, gender and, in particular, the owning of the driving licence, of one (or more) private car and of the public transport fee;
- specific mobility needs related to the households like trips with several stopovers, small children transport;
- individual attitudes towards private vehicle ownership and changing attitudes (influenced by the psychological ownership [191]);
- knowledge of the car sharing and usage of transport mode alternative to the private vehicle [57];
- opinions on the existing services and main limitation encountered when travelling.

Nowadays, this data can also be collected through tracker APPs since people always travel with their smartphones. These APPs can be used to automatically collect data on people's trips, since they record the distance travelled, the time spent, time of departure/arrival as well as the transport mode. Moreover, always through the APPs, several short-customised surveys can be administered in order to collect data on the socio-economic user's profile, his mobility habits, judgements on the quality service level. The same APP can also be an instrument to support the modal shift from private car, considering that they can suggest new alternative transport modes, showing the potential environmental and health benefits. Furthermore, these APPs can also integrate other services, such as ticket selling.

In order to provide a service as much as possible suitable for the targeted potential users, it is necessary to analyse the current situation not only of the transport demand but also of the already existent transport supply.

To plan the new car sharing service the designer has to be aware of the main characteristic elements of the service that he is intended to introduce (i.e. car sharing) but also of the currently available transport services. In particular, for the latter category, he has to be aware of services' availability, their utilisation rate, timetables, tickets' fee, frequency, physical accessibility. He has also to pay attention to the related aspects of the services. For example, considering the bus service, the designer does not only have to know its main technical characteristics (such as, capacity, number and location of the stops, the possibility to bring bicycles on the buses), but also, the quality of the bus service, people satisfaction towards them, the travel comfort, the presence of park and ride. Moreover, particular attention must be paid to the security level: people can avoid travelling with specific transport means because they do not feel secure on board or at the stations.

If one of the objectives of a new service implementation is the enhancement of the complementarity with public transport, other sharing mobility alternatives, soft transport mode (cycling or walking), the attention of the designer has to focus on these systems and on what they are currently offering to the users. In addition, the present supply for the private vehicle has to be assessed: the infrastructure, parking areas, electric recharging infrastructure, presence of limited traffic zones.

Table 11: Relationship - Steps 7 - 8

Related to:	Note:
Step 6 Identification of the Target Population	The analysis of the current situation has to be performed mainly on the target population or, if this letter is not known in advance, it can be defined after the analysis of the current situation.
Step 11 Detection of the Supply Elements	The analysis of the mobility behaviour and current transport supply helps the definition of the car sharing key supply elements, such as the presence of electric vehicles in the fleet, the presence of recharging infrastructure.

	In particular, the price strategy can be differentiated according to the current mobility behaviours of the users, e.g. price reduction for those who travel during the night.
Step 13 Potential Demand Estimation: Data Collection	Being aware of the current situation is essential for the definition of alternatives, attributes and levels in the stated preference survey; in order to enhance realism in the questionnaire, this latter should be designed with reference to the revealed data.
Step 15 Aggregation	Achieve data on the whole population is crucial for the aggregation process.
Step 16 KPIs	The designer can define some KPIs as values, related to the difference between the scenario with and without car sharing. These can be evaluated only when the data on the current situation is available; e.g. the losses or revenues of the public transport operator are related to their current supply.
Step 17 Supply Elements Sizing Algorithm	The current situation influences the sizing of the elements of the new service: OD data are pivotal to define the station locations correctly and to size the parking lots. Trips characteristics (time of vehicle usage, time of departure, kilometres travelled) are also pivotal for the service sizing.

Step 9: Interaction Between Demand and Supply and Criticality Individuation

Transport planning should allow transport supply to meet transport demand in order to satisfy the transport needs for mobility. The land-use analysis is pivotal since the distribution of the activities on the territory defines the movement generation, and the transport supply must support the demand for movement. Indeed, the transport supply would be worthless without the demand and demand without supply would be impossible. Furthermore, only analysing the interaction between demand and supply it is possible to individuate the critical elements which bring people to be dissatisfied by the current mobility situation.

Table 12: Relationship - Step 9

Related to:	Note:
Step 1 Objective Definition – Political Agreements	Overcome the problems arisen from the analysis of the current situation, both demand and supply side, can become an objective for a project.
Step 6 Identification of the Target Population	After the joint analysis of the current situation of supply and demand, the target population should be assessed again.

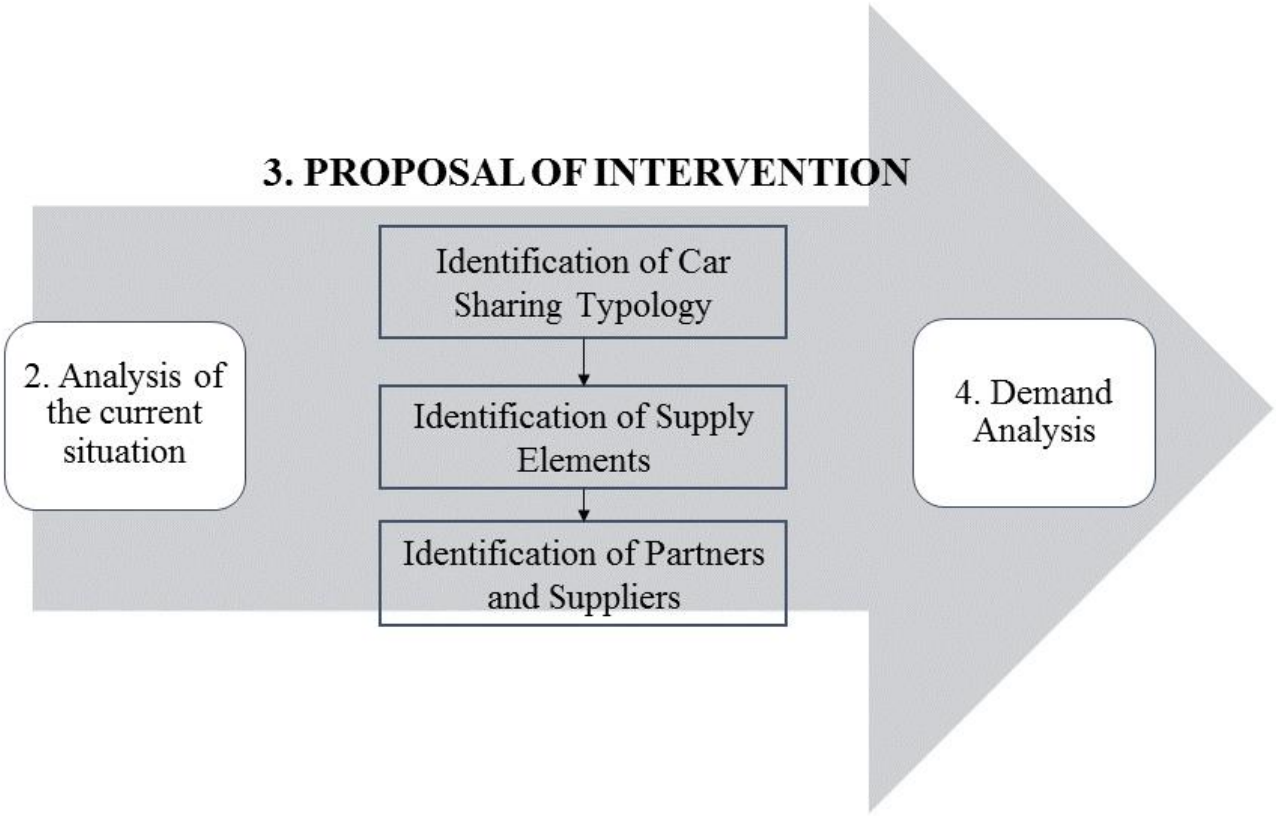


Figure 8: Phase 3 - Proposal of Intervention

Step 10: Identification of the Car Sharing Typology – Proposal for Intervention

As already reported in section 2.1.3.2, car sharing can be classified according to different parameters, such as organization forms, sources of capital, and also according to the depot presence: according to these latter parameter two are the principal car sharing typology: free-floating and station-based and this latter can also be split between round-trip and one-way.

Free-floating is characterised by the absence of fixed stations for the vehicles and limited to big cities. Nowadays, in Italy, there are more than 1,7 million of users of this kind of service, the 90% of the total number of car sharing members in the country, with more than 12 million of rentals in 2018 [6]. Since it is usually used for short trips and they do not have to be booked in advance, they are often used as a replacement for public transport, especially when there are some gaps in the network [87]. Free-floating services are very suited for metropolitan cities, with a high population density: the individuation of the most efficient car sharing typology is strictly related to the context assessment (cf. Step 5).

Station-based typology involves the presence of stations: one-way service allows the users to take the car from one station and to give it back to any other one, while users have to return the vehicle to the same station where they picked it up if the service is round-trip. One-way is suited when the potential users' flow is bidirectional, i.e. almost the same quantity of users moves from A to B and vice-versa, in big cities, with an efficient public transport service and in very densely populated areas [192]; indeed, if not, it would create a vehicle imbalance, and the service operator must relocate them.

Moreover, there are different business and operational models: car sharing can specifically be configured as a service for the first-last mile problem, for company's employees who, occasionally, have to move from two office places, for tourists who are attracted by the main cities points of interest, for businessman who needs to move quickly from and to the larger nodes. The identification of the car sharing typology can be performed only after having analysed the current situation and the emerging mobility problems. For example, if the citizens complain about the lack of an appropriate service to reach the airport (cf. Step 9) and the defined objective of the project (cf. Step 1) is to improve the connection between the city centre and the airport and vice-versa, the service will be station-based one-way and parking areas must be situated close to the airport. If there are no flights to/from the airport under consideration during the night, the service will be operative only during the daytime and the vehicle will be free for another usage during the hours of darkness.

Before starting the following activities, the designer has, also, to individuate the key questions which he aims to answer with his work, such as: "How many users new service will attract?", "Which features have to be enhanced in order to make it more attractive?", together with the questions related to the objectives such as "Will the service operator make a profit?".

Table 13: Relationship - Step 10

Related to:	Note:
Step 11-17 Detection of the Supply Elements Supply Elements Sizing Algorithm	Different car sharing typology also diverges for some supply elements, e.g. presence of stations, relocation strategy, and consequently, the algorithm, implemented for the sizing of the service is different.
Step 14 -18 -19 Potential Demand Estimation: Model Development Scenario Simulation Optimisation	The designer can be forced to re-define a new proposal of intervention if the results of the modelling estimation or the outcomes of the scenario simulation or, even, the results of the optimisation process are not satisfactory.

Step 10 bis: Side Businesses

Besides the aspects strictly related to the planning of the car sharing, there are some other issues, that can be called "side business", which can contribute to the development and the success of the new service.

Since, in some cities, car sharing is almost unknown and very unfamiliar, it is essential to conduct awareness-raising and information campaign to make the public know about the service [180]. Of course, people cannot start to use a new service if they do not even know about their existence. Indeed, Zheng et al. (2009) [76] state that people who are already familiar with car sharing are more inclined to the initiative adoption. In order to make a new service attractive, its success and benefits have to be made known to the population. Information should to be clear and easy to understand by everyone; its lack is one of the reasons for the failure of the first car sharing experiment in Istanbul [53]. The European Mobility Week is an event, carried out all around Europe (more than 2800 towns joined the event in 2018), to promote policies, initiatives and best practises related to sustainable mobility, to inform people on several related themes, emphasising the local commitment and launching new initiatives.

Marketing and advertising are also tools to inform people of the new service: TV, radio, posters, leaflets, web, promotional events are crucial. Brook (2004) [65] analyses the marketing issues from the point of view of who has to start a new service. He stated that particular attention has to be paid to:

- target the marketing campaign to the potential interested people (who lives/work near to the station location, young, people environmental aware, those who are living some particular life events which force them to rethink about their travel behaviour -changing of job, moving to a new city/house, having a baby);
- select the appropriate slogan;
- the "word of mouth" which is a powerful marketing approach (also, for this reason, the level of customer service has to be high) [193].

Innovative ways to promote car sharing are also the so-called, "car sharing parties", where the car sharing is presented to a small number of people in a living room [35], offering car sharing discounts or vouchers as rewards for the winning of some games or quiz (Enjoy and RDS [194]) or even through initiatives like "Bring a Friend" where free membership fee is given to who bring a friend to establish a new subscription [195].

People, usually, do not change their travel habits suddenly, neither their awareness towards environmental nor health issues and so campaigns to sensitise citizen are essential. In particular, it is not easy to change personal daily routines, even more, if it involves some familiar choices. Focus-

groups can be promoted to involve people in the planning process and make them feel more participative in the implementation of a service which can be experienced as useful for them.

Even if it depends on the cultural group and on people's age, adults are still considering the private car as a status symbol, a sign of prosperity and power (also supported by the car industry). Therefore it can be supportive addressing specific campaigns to children since several studies show that childhood and youth are periods where people internalize their values and establish their habits and lifestyle [196]. There are several publications of the European Union which provide the guideline for teachers to discuss the problem with students [197].

In addition, alongside with the sensitisation and information campaign, the benefits of the new service increase if the adoption of supportive policies is boosted: these policies have to enhance initiative to support mobility forms which substitute private vehicles. According to Van Malderen et al. (2012) [198], these initiatives can be split into two groups: the promotion of alternative mode of transport (carpooling, public transport, cycling, walking, car sharing) and the so-called pull-and-push measures which aim to make people renouncing to the private car. Pull measures reward who reduce the car use, e.g. the development of an efficient infrastructure for electric cars, the creation of park-and-rides, pedestrian areas and cycle paths, financial incentives or points which can be collected and transform into some prizes.

Furthermore, it is imperative to streamline the already existent public transport service [8], [19] increasing the frequency and the commercial speed (with actions which aims to give priority to PT). An efficient public transit network lessens the need of owning a car, and this makes the car sharing potential users already familiar with travel solutions different from the private vehicle [50]: people can forgo owning a private car, as long as the public transport system is efficient [81]. Indeed, otherwise, car sharing services can compete with public transit, as revealed by de Luca and Di Pace (2013) [52].

On the other side, the introduction of taxes for accessing the city centre (congestion charges), limited traffic zones (always together to an efficient public transport system to preserve the accessibility to the zones), higher prices for parking, can be defined as push initiatives because they disincentive citizens to private car use.

Finally, it can be supportive conducting researches on similar case study and project already developed, not only the ones which are having success, in order to understand their potentiality, but also those who failed, in order to learn from the errors [192].

Step 11: Individuation of the Supply Elements

The designer has to be aware of the main characteristic elements, of the service that he is intended to introduce (i.e. car sharing), when planning a new car sharing service. Even if, as express in section 2.1.3.2 and explained in Step 10, car sharing can be classified in several ways (station bases vs free-floating, peer-to-peer vs by provider, corporate vs private, etc.) and each of them has its specific characteristics, all of them share some key elements which have to be defined in order to implement a new service:

- the number of cars in the vehicle fleet: the fleet size strongly influences the demand, since a higher number of cars assures the presence of a vehicle available when members need it, but the same parameter also influence the operators since a higher number of vehicles means higher costs.
- The ratio of electric vehicles in the fleet: electric vehicle in the fleet brings benefits for the environment [61] since the local pollutant emissions, and acoustic emissions are lower towards ICEV, and they reduce dependence on imported petroleum. Furthermore, their presence in the car sharing fleet also allows users who cannot afford to buy a private electric vehicle due to its higher purchasing costs, to drive one. Additionally, from the operators' point of view, electric cars have lower operative costs, but higher purchasing cost and they introduce a factor of complexity in the service operation since they must be recharged before their usage. When selecting an electric vehicle, a pivotal criterion is its autonomy range, together with the battery charging time and the number of battery charging cycles [68].
- The number of stations (only for station-based services) influences the numerosity of the potential users since the higher the number of stations, the shorter the distance that they have to cover to reach a car. On the other hand, similarly to the number of vehicles, a higher number of stations means higher costs for the operators.
- The number of parking lots: a station with only one lot can be underperforming, since if the lot is already occupied by a car, a driver who wants to park there, will be forced to find another location, furthest from his destination.
- The extension of the area where the service will be operative: this is a crucial element which influences other ones (e.g. the distance among stations). It is related to some other service potentiality such as:
    - the integration with the public transport system;
    - the decision of the car sharing typology (cf. Step 10);
    - the individuation of the target people to whom address the service (e.g. if the area of interest is the university campus, probably the service will be predominantly used by students – cf. Step 6);

- the context analysis (high density and mixed-uses areas are more suitable for car sharing [123]).

- The distance among stations, which influence the decision of adopting car sharing or not, depends on the extension of the area of interest and the number of stations.
- Location of the stations influences the integration with public transport and the accessibility to some services (schools, hospitals). As express in section 2.1.3.4, if the car sharing stations are located close to interchange parking areas or the public transit stops, people can be encouraged towards them; this is even more important when dealing with extra-urban car sharing services. The agreements with the public authority and the parking managers also influence this aspect.

  In station-based round-trip car sharing the users have to leave the vehicle in the same stations where they picked it up. However, the car sharing designer can also define some stations reserved to the users of the service, near the most attractive nodes (e.g. shopping centres, hospitals), where the service members can temporarily park the vehicle, run their errands and pick up the car again to drop it off in the departing station.
- The number of recharging stations is vital for the electric fleets where the users should recharge the cars after the usage, assuring the availability of the vehicle for covering the desired travel distance. According to Galatoulas et al. (2019) [68], the charging stations must have high power capacity, provide good quality current and allow flexible load connection. The charging stations can be gathered together in a "central charging station" or can be dispersed around the study area.
- Definition of the pricing strategy: the most recurrent scheme consists of a membership fee (usually once a year) and a fee for the real hourly and kilometres usage of the car. However, several companies provide different fee schemes according to the user typology according to his transport behaviour (cf. Step 7 – 8) or socio-economic characteristics (cf. Step 6). For example, they can define a scheme for people who runs many kilometres, another one for those who use the car only once a week or even for the company who offers the service to its employees during the working time; besides, special discount for students, women, people with disabilities can be set. Perboli et al. (2018) [67] state that differentiates the pricing structure and models of service according to different users' segments is pivotal. For example, offering lower subscription fee and lower per-minute fee is attractive for younger members (from 18 to 25), special offers without the subscription cost can be set for occasional users or, also, special entry tariff can be defined to allow many people to try the service.

  In addition, in accordance with the public transport operator, the service can offer a special discount for the public transport season ticket owners and the usage of a unique ticket for

both the services. These factors can lead to a more higher degree of complementarity between services, since, as expressed in section 2.1.3.4, ticketing and fare integration is one of the key elements for the success of both the services.

Some services also request a membership deposit, fully or partially refundable if the member decides to leave the service; this quota, usable in case of car damage, is also very recommended by the insurance [66].

- Individuation of the car typology (city cars, luxury cars, vans): some companies offer only one brand cars making easier the association of the car to the operator and facilitating the driveability, reducing the maintenance costs and also facilitating the negotiation of the vehicles purchasing. Some other companies aim to a diversification of the vehicles in the fleet to satisfy different users' exigencies. Particular attention has to be also paid to the vehicles emissions level in order to provide benefits for the environment and the citizens' health. MOMO project [193] provides several practical criteria to take into account when purchasing vehicles for the new service, for instance, the driving visibility, the number of seats, the compatibility with technology, type of tyres, warning sounds.
- Allowing the possibility of sharing the trip with more users in order to split usage costs is particularly attractive for people who drive from closest origin and destination in the same time, e.g. for commuters or people who work in the same office. It brings the users to pay a reduced cost, but, on the other side, it limits users' independence and flexibility. This scheme has the potential for emissions and congestion reduction [199].
- Maximum days of consecutive reservation and cancellation policy: sometimes the service can be reserved for a certain number of consecutive days [8], guaranteeing the users the vehicle's availability when and where they need it. Several types of cancellation policies can be adopted: users can cancel their booking at any time, or within a certain number of hours, otherwise, the total or partial tariff is charged in any case.
- Unlocking modality: the designer has to define how the users can unlock the vehicle: the ways which are currently most used are through the membership smartcard (RFID), QR code or PIN. If the modality foresees the use of the smartphone, attention must be paid to the mobile phone signal coverage that may be compromised, for example, in underground parking areas.
- Defining the chance of driving in limited traffic zones or separate lines: this can be defined in accordance with the Municipality (cf. Step 12), but can be attractive for the users, especially for who travel during the peak time in a very congested city centre.
- Information: to boost complementarity among car sharing, public transport and the other services of sharing mobility, allowing the users to access contemporaneity to real-time information on all the services can be a great potential. Furthermore, in the first stage of the

service implementation, only people who are aware of the existence and the advantages of the service can use it and so the given information has to show the potentiality of the common usage of all the different services. This aspect must be planned in cooperation with the other transport operators.

- Reservation modality: defining the way in which the users can reserve the car is also critical: usually they can use an APP or/and a call centre service. The call centre service can be helpful when the service is targeted to a broad public which also includes people who are not very confident with smartphones and new technologies.
- Relocation strategy: when choosing a station based – one-way service, also the relocation strategy has to be set [83]: users can drop off the vehicles in a different station from where they take it on, and this can cause an imbalance among stations. Actually, the relocation strategies can be "operator-based" or "users-based". In the first one, the imbalance of the network is dealt thanks to operators (maybe, in the future, the relocation can be experienced with autonomous road vehicles [19]) who manually move vehicles among stations. The real challenge consists of being reactive to the actual demand variation and initiate the relocation activities between depots before the shortage occurs in order to ensure the customer satisfaction level. Static relocation refers to this activity carried out only once a day with the purpose of resetting the initial car balance. The operator-based relocation can be performed differently: according to de Almeida Correia and Antunes (2012) [97], it can be done under three distinct scenarios: (i) the operators can decide whether to accept or decline trips, (ii) they accept all the requested trips, (iii) they are not obligated to satisfy all trips between existing depots but they can only reject trips when there are no vehicles available in the pick-up station. The rebalancing of the vehicles among the stations means higher costs for the operator. In "user-based" policy, the users themselves perform relocation: for example, with dynamic pricing [84], i.e. the usage fees vary according to the vehicle availability. If there are numerous vehicles in the depots, the trips will be offered for lower prices or for free in order to encourage them, considering that otherwise, a company operator would have to do the redistribution.

Table 14 lists some of the contributes from the literature on this issue: these authors also provide numerical contributions to the topics: e.g. distance among station is recurrently defined to be smaller than 1 kilometre, preferably 500 m.

Table 14: Service Elements - Literature Review

N. of Vehicles	Brook D. (2004) [65]; Rickenberg T.A.A. et al. (2013) [98]; de Almeia Correia G.H. and Antunes A.P. (2012) [97]; Shaheen S.A. and Cohen A.P. (2007) [34]; Valenti G. and Mastretta M. (1999) [200]; Shaheen S.A. and Cohen A.P. (2013) [189]

N. of Stations and Lots	Brook D. (2004) [65]; Rickenberg T.A.A. et al. (2013) [98] ; Valenti G. and Mastretta M. (1999) [200]; Kumar V.P. and Bierlaire M. (2012) [54]; Nakayama S. et al. (2002) [96]
Extension of the Area of Interest	Shaheen S.A. and Cohen A.P. (2007) [201]; Lightfoot G. (2011) [202]; Shaheen S.A. and Cohen A.P. (2013) [189]; Juschten et al. (2017) [8];
Stations' location	Brook D. (2004) [65]; de Almeia Correia G.H. and Antunes A.P. (2012) [97]; Kumar V.P. and Bierlaire M. (2012) [54]; Awasthi A. et al (2007) [203]; Valenti G. and Mastretta M. (1999) [200]; Burlando C. and Mastretta M. (2007) [204], Celsor and Millar-Ball (2007) [123]; Gavalas et al. (2016) [205]
N. of Recharging Stations	Kumar V.P. and Bierlaire M. (2012) [54]; Cocca et al. (2019) [89]
Definition of the Tariff scheme	Brook D. (2004) [65]; Jorge et al. (2015) [110]; Kumar V.P. and Bierlaire M. (2012) [54]; Burlando C. and Mastretta M. (2007) [204]; Valenti G. and Mastretta M. (1999) [200]
Definition of the Car brand/typology	Brook D. (2004) [65]; Burlando C. and Mastretta M. (2007) [204]; Lightfoot G. (2011) [202]; Kumar V.P. and Bierlaire M. (2012) [54]; Valenti G. and Mastretta M. (1999) [200]; Shaheen S.A. and Cohen A.P. (2013) [189]

Every year (since 2016) "Osservatorio Nazionale Sharing Mobility" provide a national report on state of the art and the evolution of the Italian Sharing Mobility, analysing the current situation and assessing the already developed services. These documents are very reliable to identify the dimensional ranges of the service parameters in Italy.

Table 15: Relationship - Step 11

Related to:	Note:
Step 12 Identification of Partners and Suppliers	Considering the objective of making car sharing and public transport complementary to each other, the supply elements such as depot location, information providing, price and ticketing have to be determined alongside with the public transport's operators. The definition of the supply elements and the agreements with the suppliers are intrinsically related.
Step 13 Potential Demand Estimation: Data Collection	The supply elements are the attributes of the stated preference survey: the respondents express their opinion considering the variation of the characteristics of the supply elements (attributes' levels).
Step 14 Potential Demand Estimation: Model Development	The model can highlight some attributes which are not significative, i.e. after the development of the discrete choice model, some attributes can result not to contribute to the respondents' choice process. So, the designer can "return" to step 11 and individuate a different set of key supply elements: it is a cyclic process.

Step 12: Identification of Partners and Suppliers

Car sharing partners and service suppliers should be identified before assessing the potential service demand, but the related activities, i.e. the negotiation with partners and the agreements with suppliers, can be conducted after the estimation of the service market share, in order to be able to provide validated data to the potential partners. Agreements with suppliers are pivotal because the designer has to be aware of the cost per unit of each item needed for the service (cf. Step 11) for estimate costs and revenues and the partners' involvement strongly influences the car sharing objectives' achievement [182].

Partners

In the following list are reported the most important partners and the reasons why making a deal with them can be beneficial:

- local authorities are crucial in boosting the achieving of the defined objectives (cf. Step 1). They can introduce other potential partners, being a matchmaker with the already existent public transport/innovative transport companies or offer expert support from other cities where car sharing is already implemented. Furthermore, their involvement can be beneficial also in numerous practical items, to name but a few, electric charging infrastructure [19], marketing issues, financial issues [35], for allowing the access to separate traffic lines and for the parking concessions. This latter aspect is crucial, since locating the car sharing stations on the street can be problematic for the few available areas, and the high rental costs. The scarcity of space is particularly problematic for stations situated near the central nodes for multi-modality, such as train stations, final bus stops. For example, in Alto Adige, car sharing is supported by Municipalities who offer free parking lots for the service [192].
- As detailed in section 2.1.3.4 and expressed by Huwer (2004) [50], making a deal with public transport operators emerges as a strategic point; car sharing and public transport cannot only coexist but also, they can boost each other. This result can be obtained only if their operators define a joint plan and suggest a unified offer to enhance physical, information, ticketing and prices integration between the services.
- As stated in the "3° Rapporto Sharing Mobility" [6], only through spatial and temporal integrations of the new service and the already existent sharing mobility services, the users can benefit from an efficient supply and shift from the private car use. What emerges from a "what if" scenario analysis carried out in the city of Lisbon is that, if all the private vehicles were substituted by shared vehicles (self-driving shared vehicles, electric vehicles, shared

taxis and shared buses) integrated to each other, congestions, CO_2 emissions, parking spaces and car requested would decrease substantially [206].

- Other car sharing providers: in big cities, there are more than one car sharing providers for the same service or for different typologies (regional/urban, station-bases/free-floating, corporate/public) and, in other to benefit jointly, the operators have to define a common plan.
- Making an agreement with parking managers are indispensable to define the parking strategy for the new service. Car sharing vehicles can be drop-off on the surface parking areas, as well in the in multi-storey buildings. The first ones are usually managed by the municipality, while the second ones by private managers.
- It is crucial to concur with taxi companies in order to avoid conflicts of interests and, furthermore, to joint efforts in achieving better fleet assistance, e.g., refuelling, maintenance or vehicle cleaning [9].
- Press and media are also important partners to make people know about the new service.
- Since the car sharing fleet is quite large, making an agreement with car manufacturers can be pivotal. Of course, it also depends on the marketing strategy and the choice of car typology (cf. Step 11)
- Usually, the vehicles are equipped with a fuel card that the members can use in specific stations to refuel the cars and so agreements with gas stations' chains are fundamental.

Suppliers

To assess the financial issue, the cost per unit of each item needed for the service have to be negotiated with the suppliers. Most of the time, prices have to be discussed because, considering that the requested amounts are elevated, the final price can benefit from a discount. If the suppliers are not already established, the designer can define the elements' costs leveraging the data available in literature or in the catalogues.

According to Brooke (2004) [65], since the costs for technologies and vehicles are high, the car sharing company can develop "franchise", outsourcing specific services (back office, call-centre, billing, web reservation), and even vehicle can be lease instead of purchase. In this way, the car sharing company can be supported by a company which is expert in that specific services, and they can concentrate their efforts on their central business.

The principal service costs/revenues items which have to be negotiated with suppliers are:

- vehicles: usually the ones used for car sharing are new models which have low emissions of pollutant, noise and fuel consumption; designers have to be aware of the purchasing cost, maintenance cost, depreciation (related to years and kilometres travelled) and vehicle's lifetime;

- parking areas: their price has to be concurred with parking managers or with the Municipality;
- electric vehicle recharging columns: this aspect can be managed in accordance with the local energy provider and the Municipality since some recharging columns can be added for free; the companies which produce the recharging columns provide both costs and lifetime values;
- call-centre: car sharing company can adopt this service in order to allow its members to book a vehicle through the telephone or to ask for information; call-centre can be shared among different car sharing companies in order to mitigate its elevated cost;
- software/APP/technical equipment: vehicles are equipped with an ICT device which records the hours and km travelled, a technological system which allows the access to the vehicle [24] and Global Positioning System (GPS) which allows the operators to know the position of the vehicle in every situation. The operators also need administrative, billing and reservation software which must be compatible with each other; designers have to be aware of the purchasing cost, management cost and products lifetime;
- headquarter rental: this expense item varies depending on the operator type, whether he is a private one or a company/public entity who already have a headquarter;
- sponsor: the designer has to be aware of the presence of some sponsors and their funding (for example an automobile company can give discounts for the purchasing of their cars in exchange of the brand association with the service);
- public funds: some country can provide public concessions/funding to car sharing company, or the Municipalities can allow the company to use the public parking spaces or the reserved lines;
- advertising/marketing campaigns: leaflets, posters, web advertisings, publicity campaigns, press releases.

Table 16: Relationship - Step 12

Related to:	Note:
Step 10 Identification of the Car Sharing Typology – Proposal of Intervention	The definition of the car sharing typology is influenced by the agreements among partners, especially concerning the presence of other sharing mobility/car sharing services on the territory.
Step 11 Individuation of the Supply Elements	Partners accordance is crucial for the definition of the supply elements, such as in the individuation of the car typology, parking areas, study area, technical aspects. Furthermore, in order to make the new service complementary to the currently available public transport system, it is necessary to make a deal with the public transport operator in order to achieve:

	▪ Cost integration: e.g. providing an integrated tariff scheme with some discounts for the owners of the PT fee and a unique ticket; ▪ Physical integration: e.g. providing dedicated parking lots for the car sharing vehicles in walking distance from public transport stops and stations; ▪ Information integration: e.g. providing join (real-time) information on all the different services on the same platform. The agreements with suppliers have to be carried out based on the supply elements.

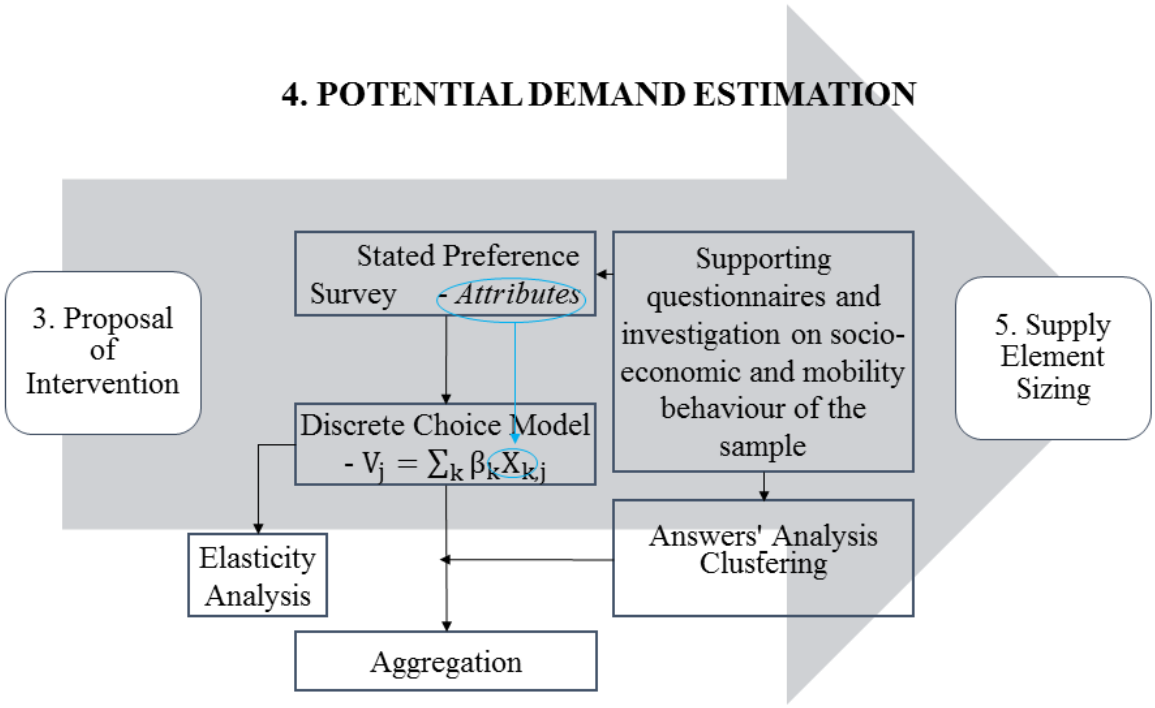


Figure 9: Phase 4 - Potential Demand Estimation

Step 13: Potential Demand Estimation: Data Collection

The main aim of Step 13 and 14 is the estimation of the potential demand for the new service. The potential demand is, also, a function of the supply performances and, to plan a new car sharing system, i.e. to size its key elements, it is pivotal to simulate the potential demand when varying the supply characteristics. Mathematical models are applied to reach this objective. In order to plan a car sharing service, random utility models (cf. section 2.3.2) are very suitable since they allow the designer to modify the supply characteristics and evaluate the resulting probability of adopting the new service. The model for the estimation of future demand requires to be specified (definition of the functional form), calibrated (estimation of the coefficient) and validated (the ability to reproduce different data from those utilised for the calibration). Step 14 of the suggested procedure details these activities, but, preliminarily, disaggregate information on the travel behaviour of the potential users have to be collected.

Since in this phase, the new service is not available yet, the information on transport behaviour has to be collected in a hypothetical context. In the suggested procedure, the applied method is the stated preference survey (better described in section 2.3.1); it is essential to underline that the attributes' set must include the supply elements.

To design a stated preference survey the data gained in the previous steps of the suggested methodology are necessary: the designer has to have already established the key elements of the service alternatives, included the elements which boost the integration with the existent public transport service, and has to be aware of the potential users and their mobility patterns.

In this step, the stated preference survey has to be conducted, according to the procedure reported in section 2.3.1. In order to increase realism, all the information, collected through the analysis of the current transport behaviour of the previous phase, can be important for alternatives, attributes and levels definition. In particular, concerning the costs attributes, it is important to provide the respondents with the "instrument" to compare them accurately with the private car costs. Indeed, car owners are not always aware of the private car costs per year (aside from the purchasing costs), they tend to underestimate them [39], and fuel is the only cost that people usually take into account [182]. Of course, this can cause a not proper evaluation of the cost parameter; it can be partially alleviated suggesting the respondents all the cost items (annual depreciation, tax, assurance, garage, fuel, maintenance, oil, tires, cleaning, etc.) of a car ownership, together with their estimation through mean values.

Usually, the SP survey is split into two, or more, parts, one reserved to the stated preferences investigation and another one to examine the socio-economic characteristics of the respondents, their current travel habits together with the information whether they own a driving licence and a public transport seasonal ticket. This information is pivotal to define classes for the aggregation procedure (cf. Step 15) and to design a more efficient service. For example, it is crucial to investigate the trips origin and destination sites to plan the service in a more targeted way.

Sometime, over these two parts, also some other short and specific surveys are needed to explore particular elements requested for the planning of the service, for example, to take into account the public transport interaction, it could be useful to investigate the potential change of habits of the respondents who declare to be interested in car sharing. Furthermore, it is crucial to investigate the current transport mode used by the target people in order to define, in the future scenario with the car sharing service, how the new service influence the modal split.

For those who choose the car sharing alternative, the designer also has to ask them to express the frequency with which they would use the service (once per week/month).

The adoption of a new transport system is not always so immediate, and some psychological and strategical aspect can influence the goodness of the collected data and, consequently, the model estimation capability. An important issue, when analysing SP responses regards the fact that often SP responses do not reflect people true preferences [207]. This especially occurs when people feel that they could benefit from the realisation of the initiative (or when they, however, do not have any disadvantage in not implementing it) and so they try to influence policymakers. Another source of bias can arise when the focus is on environmental problems: sometimes people demonstrate their

attention to the issue, but this not always correspond to and actual change of their habits in favour of the cause. Moreover, the bias can also be caused by the lack of realism in the SP options or by the lack of familiarity in the suggested alternative. According to Lu et al. (2006) [207] in the transport field, this is true and, especially when people are asked to express their intention on using a new transport mode, SP overpredicts the reality, even three times more than the observed demand after the service realisation [208]. Lu et al. (2006) suggest two principal methods to avoid incentive to bias: the first consists in increasing the complexity by adding some attributes in order to shift respondents' attention by the purpose of the questionnaire in order to avoid strategic answers. The latter suggest including "cheap talk" which is a script that warns respondents on the effect of their answers on the real market setting and asking them not to overestimate their preferences [209]. Jacquemet et al. (2013) [210] ask the respondents to sign an oath to induce higher honesty when answering the questionnaire. An ex-post method to reduce the bias is suggested by Champ et al. (1997) [211] who introduce a final question which asks how much the respondent is sure about his answers on the SP options and if he indicates a value minor of seven in a 1 to 10 scale or less than "definitely sure" his answer is equivalent to a "no" answer. Several studies demonstrate that using the follow-up certainty scale can be valuable at reducing the gap between the actual and the stated behaviour [212].

From the SP survey, the designer achieves input data for discrete choice model (DCM) calibration and some information on the respondents which are better explored in Step 13bis.

Table 17: Relationship - Step 13

Related to:	Note:
Step 11 Detection of the Supply Elements	The supply elements are the attributes of the stated preference survey: the respondents express their opinion considering the variation of the characteristics of the supply elements (attributes' levels).
Step 14 Potential Demand Estimation: Model Development	The discrete choice model is calibrated thanks to the data collected by the stated preference survey.
Step 15 Aggregation	Aggregation is based on the data of the target population and of the sample.

Step 13 bis: Testing the Sample's Answers

The review of the second part of the SP questionnaire, i.e. the one which investigates the socio-economic characteristics of the respondents, leads to the acquisition of valuable information for the service implementation.

The answers can be organized in a database, reporting (i) the main socio-economic characteristics of the respondents, which are useful for the aggregation procedure (cf. Step 15) and for the analysis of the sample characteristics based on their choices. Moreover, analysing the surveys' answers the designer can assess (ii) the mobility behaviour of both the sample portions, who have chosen the suggested alternative and who have not. This information is worthwhile to define the stations' location and to assess the modal split variation with and without the new service.
Besides, it is possible to explore the answers related to (iii) the potential type of the new service use (frequency, duration) of people who declared themselves interested in car sharing, which are data necessary for planning the new service. If this data is not available, the designer has to estimate them from literature.

Step 14: Potential Demand Estimation: Model Development

The main aim of this step of the suggested planning methodology is the development of a mathematical model able to simulate the changing in demand when varying several supply elements. Model estimation consists in a series of operations, called formulation, calibration and validation in which the functional form is defined, the parameters are estimated, and it is verified that the model also runs in different data context and also assessing the statistical quality of data. It is a recursive process of trial and error, controlled by the modeller, in which these three phases are repeated several times until obtaining a satisfactory solution. The process is based on the output data of the previous phase of the planning procedure. Since data is disaggregated, the approach is known as disaggregate estimation of demand model [85] and each scenario presented to the respondent can be considered as an element of the sample of observation of the choice behaviour.
The model specification consists of the definition of the functional form and the attributes used. The functional form of a discrete choice model (cf. section 2.3.2) is determined by the assumptions on the error components of the utility function for each alternative:

(21) $U_{ij} = V_{ij} + \varepsilon_{ij}$

(22) $V_j(X_j) = \sum_k \beta_k X_{k,j}$

(23) $p(j) = \frac{e^{V_j}}{\sum_{h=1}^{m} e^{V_h}}$

With p(j) the probability of an individual to choose alternative j.
Where V_{ij} is the systematic component of the utility function of the decision-maker "i", regarding alternative "j", ε_{ij} is the error component, β_k are the parameters of "k" attribute and $X_{k,j}$ the vector of the attributes of the alternative "j". The attributes are the same as the stated preference survey, i.e. the supply's elements. The error component can be represented by a wide range of distributions,

as already described in section 2.3.2, for example in the Multinomial Logit formulation the error components are Gumbel distributed, and they are identically and independently distributed among alternatives and individuals. Multinomial Logit (MNL) is one of the numerous functional forms of a discrete choice model, but there are several others such as Nested Logit, Multinomial Probit. The choice among them depends on many elements such as a priori expectation on the correlation of error components, the mathematical complexity, the result obtained in similar cases, expert suggestions. The attributes are identified according to the service under investigation, and they must not be linearly dependent on each other. Socio-economic attributes are constant over all the alternatives, and this can violet the dependence principle and so can be introduced in the systematic utility function V_{ij} of all alternatives excepted one.

Sometimes it is not possible to state that there is equal competition between all pairs of alternatives, which is one of the hypotheses of the MNL. For example when the alternatives are car, bus or metro, these last two are more similar to each other than they are towards car for a series of attributes which cannot be explicated in the functional form of the systematic utility function (e.g. the lack of privacy, the fact that they do not provide a door-to-door solution, the sharing of the trips with unknown people). This fact leads to a correlation between the errors of these alternatives. This cause a violation of the hypothesis which underlies the derivation of the MNL leading to the necessity of adopting different formulation forms of the model and one, very widely used is the Nested Logit (NL) formulation. In this formulation, some similar alternatives are clustered together in nests. The alternatives in the same nest share some common components of the error term. When analysing innovative transport modes, an option is to group the "already known" alternatives and the "innovative" ones (e.g. bus and car together and car sharing in a different nest).

The data collected through the SP survey in step 13 are used to calibrate the discrete choice model, i.e. estimate the vector β from the choices made by the respondents of the survey. The method most widely used to infer β is the Maximum Likelihood [85] (see section 2.3.2.1). Each scenario or choice set can be seen as an element of a sample of observations and, consequently, the final size of the SP sample is equal to the product of the number of choice-sets and the survey's respondents. The maximum likelihood can be computed thanks to many software; one of them is Biogeme [213], an opensource Python software appropriately designed for this function.

Finally, the model has to be validated, i.e. the designer must assess the statistical quality of the estimated parameters, the assumption underlying the model specification and the model capability of reproducing the behaviour, in choices terms, of a sample of users. These operations can be done through statistical tests better detailed in section 2.3.2.2.

Table 18: Relationship - Step 14

Related to:	Note:
Step 13 Potential Demand Estimation: Data Collection	Both step 13 and 14 contribute to define the potential demand on the new service and step 13 provide the data to calibrate the model.
Step 17 Supply Elements Sizing Algorithm	Discrete choice model is the "engine" for dimensioning of the service.

Step 14 bis: Elasticity Analysis

Elasticity analysis is an optional step in the planning process: it is not indispensable in the procedure application, but it can be valuable in order to analyse the model results better.

To anticipate the effects of the change of the independent variable value associated to an alternative on the choice of an individual and, consequently, on the probability of being chosen of the concerned alternative, elasticity can be evaluated [214]. It is useful to understand deeply which the consequences of the independent parameters' variation are.

Direct elasticity measures the effects of the variation of the attribute of alternative i, on the choice probability of the same alternative. Cross elasticity measures the effect of the variation of the attribute of alternative i, on the choice probability of another alternative [85].

Elasticity can be estimated referring to a specific individual (disaggregate), but also aggregate elasticity can be computed through the same methodology applied for the choices' aggregation (cf. Step 15). Furthermore, when considering infinitesimal changes, the elasticity is called "point", while "arc elasticity" refers to changes which are not infinitesimal [214].

Step 15: Aggregation

Up to this point, it has been debated on data collected among a sample of people, but the designer is interested in the whole target population behaviour and, furthermore, he is interested in the aggregate demand more than the individual probability of behaving in a certain way. As already express in section 2.3.2.3, there are various techniques to make aggregate forecasts with disaggregate models. In the developed tool, the chosen procedure is "sample enumeration", suggested by Koppelman (1975) [178], which consider the random sample as representative of the whole population. It is a very flexible approach, which allows the designer not to be forced to make prior assumptions about the distribution of the attributes among the population, but, on the other way, this procedure is not

very suited for situation where there are some attributes which are non-homogeneously distributed among the population (i.e. commuters and residents). To deal with unrepresentative sample (i.e. when the sample is not perfectly random and not all the member of the population has an equal probability of being included in the sample), the designer can follow the combined method "sample enumeration and classification". This procedure is based on the population partition into homogeneous clusters and on the introduction of an analytical weight w_i. It is the inverse of the probability of being in the sample: its value is higher for observations which have a low probability of being in the sample and vice-versa.

(24) $$w_i = \frac{N_g}{n_g}$$

With N_g the number of population individuals in class g and n_g the number of people in the sample in class g.

To apply the classification approach, knowing the distribution of the attributes over the population is fundamental; the most often adopted classification criteria are gender, professional status, income, age, geographic zones.

Table 19: Relationship - Step 15

Related to:	Note:
Step 7 – 8 – 9 – 13 Analysis of the Current Situation – Demand (7) and Supply (8) Side Interaction between Demand and Supply and Criticality Individuation Potential Demand Estimation: Data Collection	Aggregation is based on the data of the target population and of the sample.

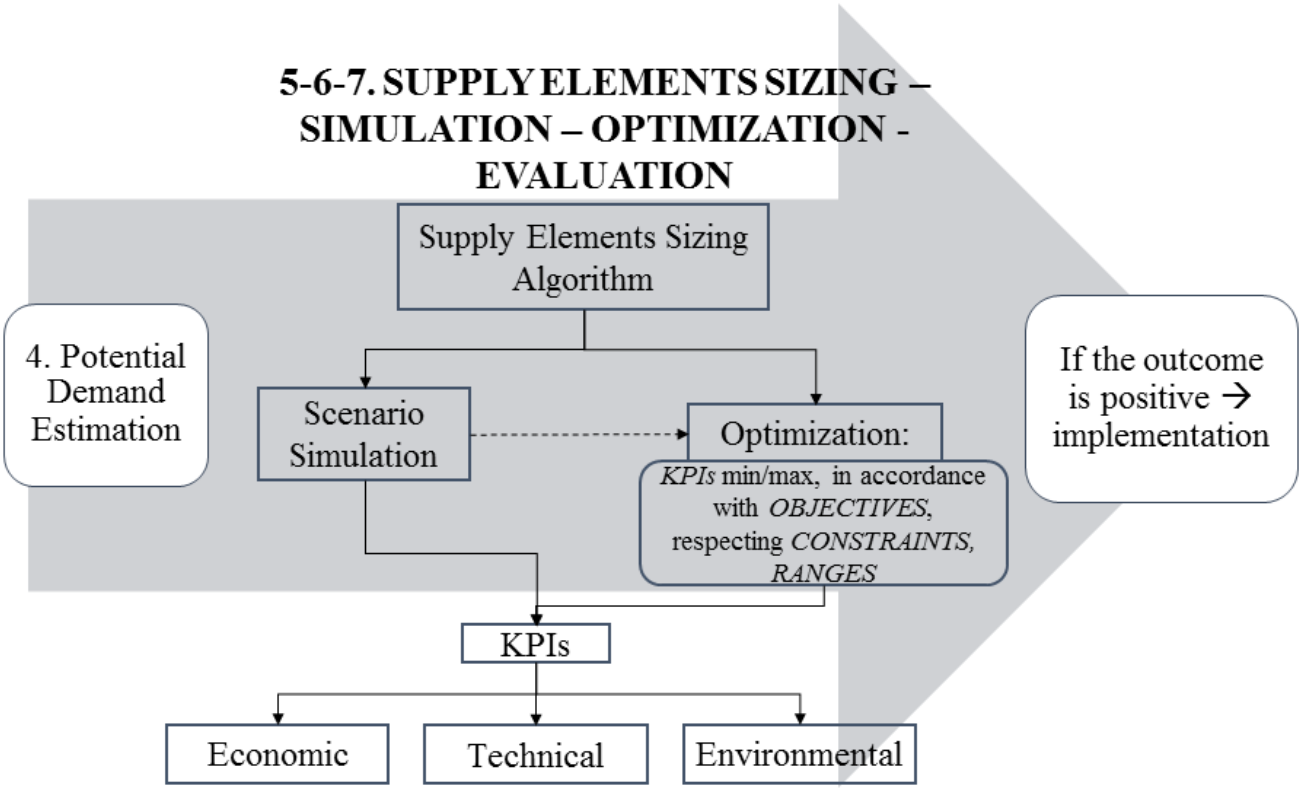


Figure 10: Phases 5-6-7 - Supply Element Sizing, Simulation, Optimization, Evaluation

Step 16: KPIs

Key performance indicators are pivotal to outline, with few data of immediate comprehension, the results of the planning procedure, as well as for the following optimisation process. The designer has to define the indicators which quantify the project objectives (cf. Step 1) and describe the dimension of the main supply's elements. The selection of the indicators is a crucial phase, and they must be validated by the key stakeholders. First of all, it is necessary to identify the objectives, the impacts and the outcomes that are to be achieved, cluster them into groups and then, for each group, it is possible to define the indicators. Several procedures can be followed for the KPIs definition, to name one, the European project CIVITAS WIKI provides a well-functioning, already tasted, set of indicators, clustered according to the impact area (economy, energy, environment, society, transport, and government) [215]. For the implemented methodology, the indicators can be grouped into three clusters, which seems to be most relevant: economic, technical and environmental.

For instance, some economic KPIs are costs/revenues per year or cost/revenues per member, losses or revenues for the public transport operators, technical indicators can be individuated, for example, in the ratio between ICEV and EV, number of rentals per day/per year, number of relocations (for one-way car sharing) [84], ratio between the number of station and of vehicles, and between the

number of members and vehicles; additionally, some environmental indicators are the area required for parking, emissions costs, the modal shift with the new service, or better, the number of actual car users and bus users who intend to join a car sharing organisation.
KPIs has to be identified before dimensioning the supply' elements (cf. Step 17), but their values are gathered after the activities of Step 17 and 18 whose outcomes can influence the KPIs selection, forcing the designer to change them again.

Table 20: Relationship - Step 16

Related to:	Note:
Step 1 Objective Definition – Political Agreements	The KPIs are set in accordance with the objectives.
Step 13 Potential Demand Estimation: Data Collection	Data collected among the sample on their current mobility behaviour are the baseline for the determination of some KPIs value. In particular for those KPIs which refers to variation after the introduction of the new service (e.g. modal shift).
Step 18 – [1-10] Scenario Simulation	KPIs definition, together with and Scenario Simulation (step 18), are necessary tools for the project evaluation. Planning is a cyclic process, i.e. if the outputs, the KPIs, emerging from the scenario simulation are not satisfactory, the designer should take into consideration the setting of a new proposal of intervention (Step 10) and repeating all the other steps, until achieving a satisfactory output. In some cases, the designer is also forced to define the project objective (Step 1) again and re-start the whole process once.
Step 19 Optimisation	The KPIs are the elements to be optimised.

Step 17: Supply Elements Dimensioning Algorithm

A spreadsheet model has been developed to support the designer to define different scenarios and find out the best solutions for the new service planning (cf. Steps 18, 19). Essentially it is a sample enumeration tool (which also allows sample enumeration with classification), implemented on the model achieve in Step 14. It has been created in order to deal with new estimations of the planning outputs when changing inputs and variable, which are under the designer control, iteratively. The spreadsheet is composed of several modules (Figure 11), connected by an algorithm:

- the so-called "control panel" which is the sheet where the planner enters the input values, together with some parameters, and the principal technical outputs are reported;

- the "summary" where the main outputs are summarised, and a graph is reported for the assessment of the modal split with and without the introduction of a car sharing service;
- two separate sheets with revenues and expenditures;
- the "environment" module where are calculated the parameters and indexes related to the modal shift and the environmental cost (in terms of CO_2 emissions and fuel consumption);
- two supporting databases: one with the data collected by previous similar services by the "Osservatorio Nazionale Sharing Mobility" and one with the data related to purchasing, operative and reselling costs for the chosen vehicles' types;
- O-D module which reports the Origin-Destination matrix;
- a sheet reporting the discrete choice model created in Step 14 of the planning strategy;

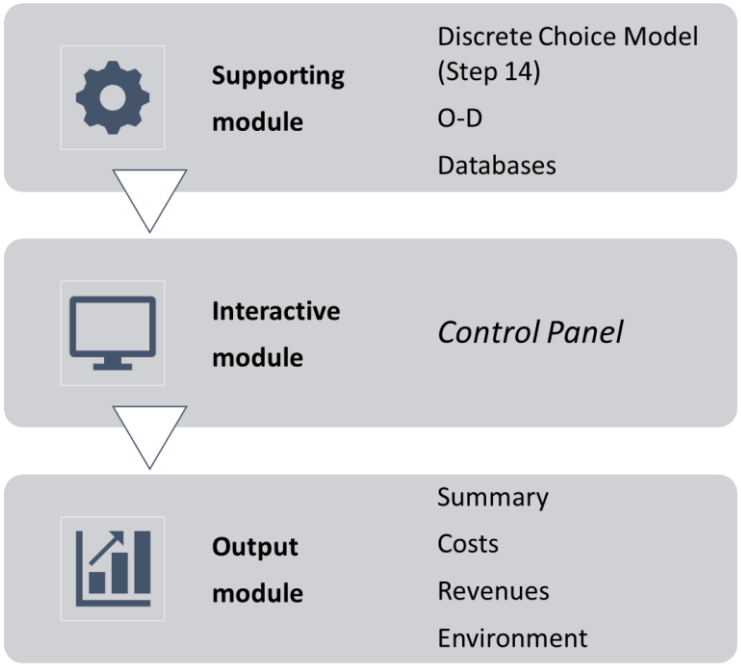


Figure 11: Spreadsheet Modules

Control Panel

The control panel can be seen as the primary interface with the designer since it provides all the elements to plan the service and reports the main outputs.

The sheet is composed of four main parts: inputs, parameters, constraints and outputs.

Input includes all the elements which are under the designer control and influence the decision of the potential users in adopting the car sharing service, i.e. these elements are the attributes of the car sharing alternative in the utility function, the principal inputs are:

- subscription cost [€];
- cost per km / per hour [€/km, €/hour];

- number of vehicles and stations;
- number of lots;
- electric vehicle rate [%].

Some parameters and some fixed cost items have to be defined before the planning of the service (cf. Step 12); all these values have to be confirmed by the car sharing operator and by the external suppliers. The following three parameters can be achieved from the data provided by the questionnaire answers (cf. Step 13bis) or in literature, e.g. from the "National Report on Sharing Mobility" [14], [17], [6]. They can be fixed values, or the designer can make them change, according to the project objectives:

- mean travel time [min];
- mean travel kilometres [km];
- time from the vehicle pickup to its drop-off [min];

There are other parameters related to the unit costs, fixed annual costs and technical issues:

- study area [km2];
- on foot speed [m/sec];
- maximum number of years for the vehicles' utilisation [years];
- technological system lifetime and costs [years; €];
- recharging columns lifetime and costs [years; €];
- call-centre [€/year];
- headquarter rental [€/year];
- sponsor [€/year];
- public funds [€/year];
- advertising/ marketing [€/year];
- Municipality fees [€/year].

In relation to public transport, there are some parameters, which are useful when planning a service which includes cost reductions for those who own a public transport season ticket in order to encourage different soft mobility solutions, for example:

- % of people who own a public transport season ticket.

Among parameters, there are also those related to the level of service; the developed algorithm considers the level of service as a constraint, i.e., are accepted only the solutions which guarantee, at least, an acceptable level:

- the number of vehicles has to be greater or equal than the number of stations in order to assure the hypothetical presence of, at least, one vehicle per station; otherwise, the input parameter "distance to the nearest stations" is non-sense, since it would define the distance among empty stations resulting useless;

- the number of vehicles has to be greater or equal than the number of trips per day divided by the ratio between the number of service hours and the mean travel time (A/R for the round-trip service). This value is reduced if service members are allowed to use the same vehicle at the same time;
- the ratio between members and vehicles has to be among a specific range to assure an efficient service;
- the number of parking lots has to be fixed up to values higher than the number of stations and vehicles.

In additions to these parameters the designer has to identify the vehicle typology and brand in order to be able to define the purchasing costs, the maintenance costs (in Italy these costs are reported by: "Tabelle ACI per i rimborsi chilometrici") and the resale prices (related to the kilometres travelled and the time past from their purchase). All these data are reported in a supporting module of the spreadsheet.

The outputs' values derive from the sample enumeration (with classification) procedure based on the discrete choice model, which is a function of the input data and parameters mentioned above; the main outputs are:

- number of vehicles, split per type (electric and internal combustion engine);
- mean of the maximum distance that users have to cover to reach the nearest stations [km] – also expressed as the time on foot spent to cover the distance [min];
- number of potential members;
- ratio rental/year;
- ratio rental/day (for some services the ratio rental/hour can be more useful);
- number of people who take advantages from the conjoint ticket "car sharing – public transport" if this option is available.
- number of frequent users: analysing data from the already existent services it is possible to notice that, in Italy, there is a large percentage of people who subscribe car sharing, but they only try the service once [14]. The "frequent users" are the members who rent the car sharing vehicle, at least two times per year: there are several people who are interested in the service and want to try it since it is a novelty, but they do not really use it. According to Kumar and Bierlaire (2012) [54], 55% of the members contribute to over 93% of all the vehicle pickups. Another research [200] reports that in Germany 48% of subscribers utilise the car sharing service less than once a month, 34% use the car two or three times per month, 13% four or five and only 5% of the members utilise the cars more than five times per month. According to what reported by Juschten et al. (2017) the car sharing members, on average, use the service less than three times per month. If the subscription fee is free the rate of frequent users can be sensitively lower. Figure 12 shows the ratio between members and vehicles and

between frequent users and vehicles for each city, according to the data reported on the "National Report of Sharing Mobility" (2016) [14].[1]

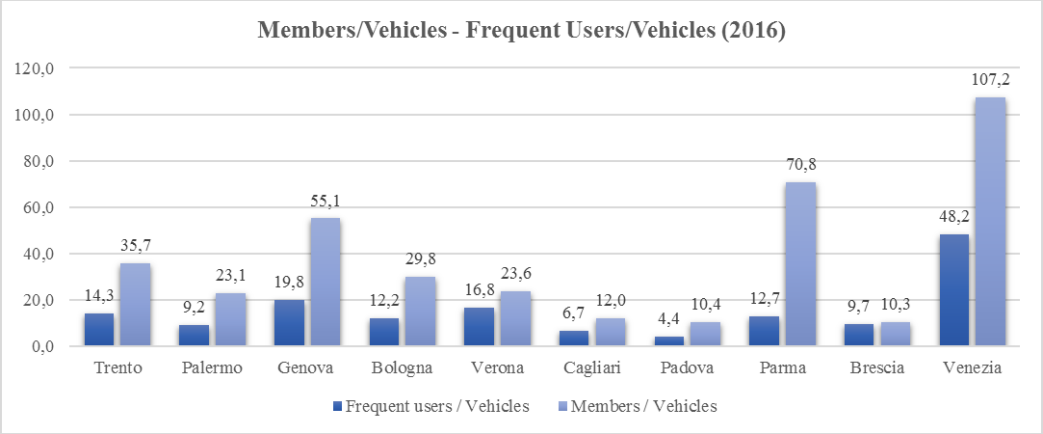


Figure 12: Members-Frequent Users/ Vehicles (2016)

The main aspects to consider when starting the design phase of a new car sharing system pertain to the location of the car sharing stations, the station capacity (i.e. the number of vehicle's lots), the individuation of the initial number of vehicles and the payment system. Before choosing the ranges of the inputs and defining the parameters, it is necessary to analyse the O-D matrix (built thanks to data collected in step 7-8-13) in order to pinpoint the sites where car sharing stations can be beneficial for the potential users. All the mathematical approaches to define the location of the car sharing stations have to be supported by in-depth knowledge of the local businesses, geographical conformations and citizens mobility habits. Defining stations is different for car sharing round-trip and one-way: for the first one, the service only assures a parking lot at the origin, when picking up the car, since then the user can drive (almost) everywhere and then drop off the vehicle in the same station of departure. Differently, for the one-way car sharing, the designer has to analyse also destination nodes since the user can leave the car in a different station all around the study area.
In Table 21 are reported the relations among input, output and parameters:

[1] The histogram refers only to station-based car sharing; data for free-floating is very different. For Venice, the ratio is evidently different from the other Italian data, but it is due to the fact that Venice presents some characteristics unique in the world. It is dutiful to declare that from 2016 to 2018 data has rapidly changed since the total number of car sharing members in Italy is grown of more than 40.000 units in one year, regrettably, however, for 2018 data reported on the National Report presents a different level of detail.

Table 21: Mathematical Relations among Input, Output and Parameters

		Notes
Stations required =	Derived from the O-D investigations	
Stations =	Defined by the planner: it can be the same value of "stations required" or lower if the designer decides not to set a station in areas where the demand results very low, from the O-D analysis	
% not allowed rentals =	From the O-D matrix and the designer decisions on the number of stations, can result that a % of people would not be served by the new service	
N° Potential members =	Derived from the discrete choice model defined in step 14 of the planning procedure; it is related to the chosen attributes. The achieved value is decreased by not allowed rentals.	
N° Frequent Users =	[n. potential members] x [mean value of the rate of frequent users taken from already existent services]	*According to data reported in "National Report on Sharing Mobility"* [14]*: mean value in =43%;*
N° Rentals/day =	<u>If it is NOT allowed to share the trips among users:</u> [n. frequent users] x [mean value of the declared frequency of service use] <u>If it is allowed to share the trips among users:</u> [[n. frequent users] x [mean value of the declared frequency of service use] x % of people who do not share the trip]+ [[n. frequent users] x [mean value of the declared frequency of service use] x % of people who share the trip / n° of people per vehicle]	*The value can be split among classes.*
N° Rentals/Year =	[n. frequent users] x [mean value of the ratio of rental and frequent users taken from already existent services]	*Mean value rental/frequent users* [14] = *14 per year*

	<u>If it is allowed to share the trips among users,</u> this value is split between people who exploit the service and who does not, considering the n° of people per vehicle.	
Distance on foot [km]=	$\sqrt{\frac{\text{area of interest}}{\frac{\text{n° stations}}{\pi}}}$	
Distance on foot [min]=	$\frac{[\text{Distance on foot (km)}] \text{ x1000}}{\text{speed on foot } \left[\frac{\text{m}}{\text{sec}}\right] \text{ x 60}}$	
Z=	<u>Station-based – round-trip</u> $\frac{\text{service time}}{\text{mean travel time A/R}}$	
Lots =	<u>Station-based – round-trip</u> Distribution of n° rentals/day on the O-D matrix → for each location [l], n° of trips/day (called m). lots = $\sum_l$ rounded up$(\frac{m_l}{z})$ If lots <= n° stations OR n° vehicles → lots= MAX (n° stations, n° vehicles) Lots should be calculated considering the origin location; if there are some locations which are both origin and destination node, then the designer has to choose the one with the higher value for m. For the round-trip services, a lot is guaranteed at the origin, but then, during the vehicle using the members can park the car everywhere. However, if there is a destination node which is very popular, then the designer can decide to add there another station and lots. <u>Station-based – one-way</u> Distribution of n° rentals/day on the O-D matrix → for each location [l], n° of trips/day (called m).	*According to Brook (2004)* [65], *in the start-up phase, the lots can be one per station.*

	lots = $\sum_l$ rounded up$\left(\frac{m_l}{\text{n° relocations}+1}\right)$ If lots <= n° stations AND n° vehicles → lots= MAX (n° stations, n° vehicles) For the one-way service, the designer has to take into account both the origin and destination node.	
N° fleet relocations =	Station based – one way $\frac{\text{n° rentals/day} - \text{n° vehicles}}{\text{n° vehicles}}$	
N° vehicles (CONSTRAINTS) =	If it is NOT allowed to share the trips among users: $= \frac{\text{n° rentals /day}}{Z}$ If it is allowed to share the trips among users: $= \frac{\text{n° rentals /day}}{Z} \text{x (\% of people who travel alone)} + \frac{\frac{\text{n° rentals/day}}{Z} \text{x (\% of people who share the trip)}}{\text{n° of people per vehicle}}$	*Rounded up to the nearest integer*
N° vehicles =	Defined by the designer but in respect of the following constraints: n° vehicle > MAX (n° stations, n° vehicles (CONSTRAINTS)) n° vehicle s.t. $\frac{\text{n° members}}{\text{n° vehicles}} < \text{constant } C$	*From literature* [65], [98], [97], [201], [200], [189], [66], *and from the analysis of the data of the services which have already been implemented* [14], $C \approx 30$. *The ratio members to vehicles is higher when starting a new service* [68].

Expected Revenues

The revenues sheet is a report of all the revenues items, their values and graphic visualisation in other to allow the designer to, rapidly, individuate the most consistent items.

The revenues items are:

- annual fees [€/year];
- kilometric fees [€/year];
- hourly fees [€/year];
- reselling ICEV [€/year] – not for the first year of operation;
- reselling EV [€/year] – not for the first year of operation;
- sponsor [€/year];
- public funds [€/year];

Their values are strictly related to the parameters' value chosen by the designer, and they are calculated according to the model output: e.g. kilometric fee = tariff per km [€/km] * mean travelled kilometre [km] * number of rentals per year.

Expected Costs

Similarly, from the revenues' items, also the costs items are reported, and the consistency of the value is highlighted in a coloured way. They can be split into investment costs, i.e. the capital costs in which the car sharing operator incurs at the service launch, and operating costs, related to the service management per year.

The principal investment cost considered are:

- ICEV purchasing [€];
- EV purchasing [€];
- software/APP/technical equipment purchasing [€];
- EV charging columns [€];
- overheads (e.g. planning costs) [€].

The operating costs are:

- ICEV maintenance [€/year];
- EV maintenance [€/year];
- employees [€/year];
- employees for relocation [€/year] – only for one-way services;
- technical equipment management [€/year];
- parks [€/year];
- advertising/marketing [€/year];
- fee to the Municipality [€/year];
- call-centre [€/year];

- headquarter rental [€/year];
- relocations [€/year] – only for one-way services;
- overheads [€/year].

Each item can be further split into more detailed cost items, such as maintenance cost includes fuelling, cleaning, oil change, tire change, taxes, assurance, reparations, etc. Most of these costs' items have already been discussed in Step 12 and in the "Control Panel", where the costs per unit for every single element are reported. In this module, the total costs are calculated on the basis of the real number of cars/ people/ lifetimes. For example, cost for ICEV purchasing = unitary cost for purchasing an ICEV [€] * number of ICEV / number of years for the vehicles' utilization [year]; cost for EV maintenance = unitary management cost for the chosen type of vehicle [€/km] * number of rental/year * mean travel kilometres [km]* electric vehicle rate [%] /100.

The employees cost mainly affects the total expenses; the number of requested staff mainly depends on the number of vehicles in the fleet [36]. However, the minimum staff required to manage a car sharing company is: the unit manager, the secretary, who handle also billing issues, and the fleet manager who deals with the vehicle purchasing, management (installing onboard technology, administering fuel cards, tracking vehicle usage, managing the cars' reparations), reselling and with the management of parking lots [9]. According to Brooke [65] if it is a small company the unit manager, who provide the overall direction of the service, can also fulfil duties related to marketing/sales, together with the finance issues. Furthermore, if car sharing service disposes of a small number of vehicles and is integrated into a firm (i.e. corporate car sharing), a general manager and a handyman are sufficient [36]. Finally, if the company is of no-profit form, the employees can be volunteer [195];

In this module, the financial aspects are taken into consideration in a simplified way, through the method of the profit comparison, a non-discount method of investment appraisal, which does not take into account the time value of money [216]. Moreover, the non-discounted methods do not consider all the project life, but only an average value of a representative period and they do not ponder taxation, uncertainty and capital scarcity. In addition, the applied method assumes that the operator has an adequate amount of needed money to undertake the investment. However, in real situations, an operator who wants to start the service can already hold the initial capital or receive the funds from different possible sourcing, such as a bank, a European project, public funding.

This method is not precise, but useful to achieve a quick general appraisal of the scenario under consideration.

The profit comparison method allows the designer to compare the different implemented scenarios, considering the average total cost per year. First of all, it is indispensable to define the project reference time, which, not necessarily, coincide with the items' economic lifetime. In this module, the car average life is taken into account as the reference time period. Then, all the costs and revenues

items have to be defined, together with the residual value, i.e. the value of an asset when its economic life is not completely exhausted at the end of the reference time period.

Starting a car sharing business, some investments must be done, vehicle purchasing, technological system purchasing and, if the fleet is composed also by electric vehicles, it is fundamental to set the appropriate infrastructure for charging the vehicles. Investment expenses are related to the purchasing cost of the item under consideration and capital cost can be straight-line computed as:

$$(25) \quad C_{cap} = \frac{I_o}{n}$$

With I_o the initial expenses and n the average life.

The interest cost is given by:

$$(26) \quad C_{int} = \frac{I_o}{2}\, i$$

Where i is the interest rate, the ratio of the interest amount and the capital amount and depends on several factors, such as the risk, economic condition, time frame, security [217]. Interest can be considered both what the operator pays to the bank for the loan or the missed opportunity to put the capital for another investment.

These values are reduced when also considering the possibility of reselling the vehicles at the end of a defined period at a certain value, called salvage value (sv).

$$(27) \quad C_{cap} = \frac{I_o - sv}{n}$$

$$(28) \quad C_{int} = \frac{I_o + sv}{2}\, i$$

The same formula can also be applied when considering items with an economic lifetime (el) higher than the reference time period (n): at the end of this latter, some items will have a residual value (rv), computed as:

$$(29) \quad rv = (el - n)\frac{I_o}{el}$$

Annual costs are computed as the sum of the investment costs (included interests) and the running costs. Furthermore, also revenues have to be included in the analysis:

$$(30) \quad Average\ annual\ profit = Annual\ Revenues - Annual\ Costs$$

Moreover, the payback method can be easily applied to compute of time necessary to recover the initial investments. Faster a measure reaches the payback (PB), less risky is the measure.

$$(31) \quad PB = \frac{I_o}{F_m}$$

With F_m is the average annual cash flow, i.e. the difference between annual incomes and average annual outflow; this method considers F_m as a constant value over the years.

The non-discounting methods are satisfying for the purpose of this module, but they provide only approximations since they do not take into account the time value of money, which is instead considered through the discounting method, such as the net present value method. They are based on the economic axiom of the time value of money, i.e. that capital available at the present time is worth

more than the same amount of money in the future [217]. Hence, it is pivotal to balance present and future expenses and incomes: all the cash flows disbursed or collected at a diverse time have to be converted to a common moment.

Environment

The environment module mainly deals with the modal shift, which is often considered a transport indicator [215], but the means of transport are strictly related to the energy consumption and emissions, and so, it can be stated that, indirectly, the modal split influences the environment. Analysing the collected data (Step 13 and 13bis), it is possible to assess the current transport mode used by the people who declared to be interested in car sharing. So, the designer can define a vector with the percentage of substitution of the car sharing with other transport modes (e.g. a certain percentage of people who would use car sharing if available, currently are bus users). With this vector, for each scenario, calculated the number of potential users of car sharing, the new modal split can be defined.

Moreover, it is possible to conduct an environment costs estimation, analysing the impacts of the new fleet introduction. First of all, the designer has to identify the external effects of the new service: they are external to the users, related to the impact of the service on human environment and nature [218] and are reflected on the whole society. There is no market for those effects. In the case of a fleet of car sharing, they can be individuated in the change in emissions, noise and accidents.

In order to calculate the external costs, in €, the inputs needed are:

- change in modal split (vehicle km);
- marginal external costs for different vehicle types.

Marginal external costs can be calculated in two ways:

- through the default values directly related to vehicle/ km;
- from the default values for emissions, accidents and noise together with the prior calculation of the change in fuel/energy consumption, change in emissions/emissions factors, change in accident risk, change in noise level.

Marginal external emissions costs (€/vkm) are reported in tables [218], which take into account only the direct emissions or both direct and indirect (also the ones from the fuel production).

Summary

This sheet reports the primary information, to sum up the achieved results (costs, revenues, number of members, etc.), and a histogram which represents the variation in the modal split before and after the introduction of the new car sharing system. Furthermore, the summary allows the designer to notice the ratio between costs and revenues for the service operator.

O-D

The Origin-Destination (O-D) matrix is crucial for the individuation of the station location. Trough the leverage of the collected data it is possible to estimate the number of trips made from origin "O" to destination "D". Furthermore, for each trip, it is possible to estimate the distance and the time spent to reach "D", starting from "O".

Model

The "engine" of the spreadsheet is the model developed in Step 14. It is based on the Bi/Multinomial Logit model (*23*) which is function of the systematic utilities (*22*) of the alternatives with the parameters (β) calculated through the loglikelihood estimation. The attributes of the utility function (*22*) are varied through the modification that the designer can introduce in the control panel. The model allows the designer to forecast the aggregate demand of the alternative under investigation (car sharing) of the target population, also considering the personal characteristics by clustering people into classes (g) and weighting each of them according to the ratio of the spread of that determinate characteristic over the target population and over the sample. To forecast the aggregate demand starting from the disaggregate model it is necessary to estimate the target population size N_T. Of course, the designer does not know the attributes related to the individual character of everyone in the population, and so the total number of people choosing the alternative under investigation cannot be calculated as the sum of the single probabilities. The procedures applied in the developed tool are sample enumeration/sample enumeration with classification (cf. section 2.3.2.3).

Table 22: Relationship - Step 17

Related to:	
Input data for the structure and values of the algorithms are provided by:	
Step 5- 7- 8 Context Definition and Assessment Analysis of the Current Situation – Demand (7) and Supply (8) Side	The sizing of the elements of the new service is influenced by the current situation and the context analysis: OD data are essential to define the station locations correctly and to size the parking lots. Trips characteristics (time of vehicle usage, time of departure, kilometres travelled) are also useful for the service sizing.
Step 13 – 13 bis Potential Demand Estimation: Data Collection Testing the Sample Answers	Determination of the stations' numbers, parking lots number, frequency of service usage, travel time and travel duration, etc. are based on the sample's answers to the questionnaire.

Step 14 Potential Demand Estimation: Model Development	N. of potential members; The discrete choice model is the "engine" of the algorithm.
From the algorithm, it is possible to compute:	
Step 16 KPIs	KPI values.
Step 18 Scenario Simulation	Different scenarios.
Step 19 Optimization	Efficient solutions.

Step 18: Scenario Simulation

Scenario simulation is very often applied to assess the impacts of each scenario, to analyse future environments and, hence, support decision-makers on their task. It is a powerful instrument to deal with uncertainty which characterises forecasting of future or not yet implemented activities/events and can be very supportive for the evaluation of the introduction of some changes in the system.
Forecasting is intrinsically tricky because it is not based on real experiences but hypothesis. Moreover, when forecasting involves new transport modes, it is essential to underline that customers are required to conduct behavioural changes that are very poorly predictable by the designer, as well as there are several elements (e.g. stakeholders' participation, political strategies, laws, policies, and social issues) that affect the new service adoption which are not under the designer control. Scenario simulation can be done jointly to the research of the optimised scenario [61].
The developed algorithm allows the designer to set different inputs, changing them manually, and assess the resulting outputs. Varying the input parameters, which are under the designer control (e.g. service costs, n° of stations, allowing price reduction for the public transport season ticket owners) the designer can achieve, analyse and compare the different values of the KPIs. These indicators are related to the project objectives (e.g. maximisation of the operator's profit, minimisation of the number of people shifting away from bus) in respect of the imposed constraints (e.g. the minimum number of parking lots, ratio members/vehicles).
The spreadsheet allows the designer to use the "solver" function, which defines the values of the input parameters (number of vehicles, of stations, service cost) for the optimal (minimum and maximum) value for an objective function subjected to constrains.
Scenario simulation is useful for gathering KPIs and for a preliminary investigation on the possible solutions since the scenarios have to be built one by one by the designer and only one objective at a

time can be investigated. A more powerful instrument can be used to achieve better solutions and to set the final value of the variables: optimization is explored in the next paragraph.

Table 23: Relationship - Step 18

Related to:	
Scenario simulation can be carried out parallelly to the optimisation process, but, otherwise, it can also be performed before in order to define the dimensional ranges of the input, required for the optimisation. At the end of the scenario simulation, the outcomes can be positive or negative: in this latter case, if no one scenario is satisfactory, the designer should take into consideration the setting of a new proposal of intervention (Step 10) and repeating all the other steps, until achieving a satisfactory output. In some cases, the designer is also forced to define the project objective (Step 1) again and re-start the whole process.	

Step 19: Optimisation

To achieve a successful configuration of car sharing service, the designer has to evaluate how the changes in the supply elements (e.g. the number of vehicles, the distance between stations, fees), i.e. elements which are under the designer control, results in the users' choices (e.g. subscribe to car sharing service). The dimensioning of the supply elements is related to the impacts on the environment and to costs and revenues. The designer must search for the most efficient solution considering the objectives defined in step 1, which are often contrasting.

The objective function is related to the KPIs (cf. Step 16) and it is subjected to some constraints (cf. Step 17) which assure the sufficient level of service.

As already stated in 2.2.2.2, an efficient optimisation process is the application of the Design of Experiment -DoE- methodology which crates the population for the next application of the Genetic Algorithms and the exploration of the Pareto solutions, i.e., those solutions which cannot be improved in one dimension without being worsened in another [105]. The representation of these solutions is the Pareto front [219].

The suggested software for the optimisation process is ModeFrontier, which is developed by ESTECO S.p.A. [102] and is a GUI driven software written in Java, which performs the optimisation by varying the input values and assessing the outputs, both in terms of objectives and constraints of the design problem.

ModeFrontier is made up of three platform environments, which develop the process in three steps:

- Workflow Editor: the definition of the problem's elements, of the DoE strategy and the optimisation strategy;
- Run Analysis: for the design evaluation;
- Design Space: the environment for the data analysis and the visualisation of the results.

The software allows to explore the Pareto solutions and, among them, by prioritising the objectives, the designer can identify the best service configuration.

Table 24: Relationship - Step 19

Related to:	Note:
Step 1 Objective Definition – Political Agreements	The elements to be optimised are defined following the objectives.
Step 16 KPIs	The KPIs are the elements to be optimised.
Step 18 Scenario Simulation	Thanks to the scenario simulation, it is possible to assess the ranges of the input values.
Planning is a cyclic process, i.e. if the solutions obtained by the optimisation process are not satisfactory, the designer should take into consideration the setting of a new proposal of intervention (Step 10) and repeating all the other steps, until achieving a satisfactory output. In some cases, the designer is also forced to define the project objective (Step 1) again and re-start the whole process.	

5 Case Study: Car Sharing for University Students

Short Summary

With the aim of highlighting the potentiality of the developed methodology, presented in the previous chapter, this section presents the case of study used as a test.
The case study aims to implement a car sharing service for university students and has been tested at the beginning of 2019 at the University of Trieste. Before suggesting a new car sharing service, the current situation is analysed, in order to suggest a realistic and potentially useful car sharing which encounters their mobility needs and try to present a possible alternative solution to overcome the mobility weaknesses of the current services. High attention has been paid to the potential complementary of the new suggested service to the already existent bus service. Finally, the possible solutions for intervention are not only assessed from a financial point of view but also considering the possible presence of environmental objectives.
This chapter structure tries to follow the sequence of the steps of the developed methodology: for each step, are reported the considerations, analysis, results and the discussion on this latter, together with the potential future improvements. Some steps are not taken into account in the reported case study since it is not a real application and no one commissioned the study, so, to avoid further deepen discussions about items out of transport engineering, some qualitative aspects are only hypothesised, and some simplifications are assumed. Furthermore, the methodology is tested under different conditions, in order to prove its flexibility.

5.1 Objectives

The final objective of this case study is the assessment of the developed methodology, reported in Chapter 4. The study's primary goal is the evaluation of the potential interest in the innovative car

sharing system by the University students both qualitatively and quantitatively. Furthermore, the study aims to better understand how the students would use the service if it was available and the potential synergies between the car sharing service and public transport. Since, as also Danielis et al. (2015) [59] stated, the car non-availability often constrained students mobility options, and, consequently, their lifestyle is already set on a sustainable approach, for example, they rent a home which is close to the university where they attend classes and/or to the city centre, leading them to move on foot or by bus. The key research questions are: "How many users will the new service attract?" "Which features have to be enhanced in order to make it more attractive?" "How would the service be used (in terms of frequency of usage/purpose of the trips/destinations to be reached)?", "Would the students shift to car sharing from the private vehicle or from other soft mobility modes?" and, finally, "Will the service operator make a profit?".

In order to reach these objectives, the developed methodology, reported in Chapter 4, has been tested and implemented in this specific case study, highlighting the following aspects:

- demand and supply mutual influence: it is a crucial aspect to be considered when planning this kind of services which increases their efficiency when there is a considerable number of people who use them, and, in turn, more people use the service if the supply is adequate. In the reported case demand is function of the supply characteristics, so, when varying the latter, also demand change;
- public transport integration: "physical location integration", "information and data integration" and "ticketing and fare integration" are the main elements taken into consideration to enhance the relationship between public transport and car sharing. In the scenario with car sharing suggested to the student through the administered survey it is assumed that the owners of the urban bus or train seasonal ticket do not have to pay the annual car sharing fee;
- specific target population: the study has been developed for a particular target, very different from the whole city population and this aspect profoundly influence the study: the student target segment has specific socio-economic and transport demand characteristics, quite homogeneous among the segment itself;
- identification of the actual mobility system criticality and suggestion of the car sharing solutions able to mitigate these findings: only analysing the current situation properly it is possible to understand people mobility behaviours and suggest a potentially attractive alternative service. This also improves the stated preference design: Rose and Hensher (2006) [220] highlight the importance of constructing experiments in which the alternatives/services are respondent specific: respondents have different mobility needs that have to be reflected in the experiment. Furthermore, it is not productive to show all the alternatives/services to everybody since for someone, some of them would never be feasible.

The survey built in the present case study is not an adaptive survey or even an SP pivoting survey, but it borrows some characteristic features from both: there are different questionnaires according to the data on actual students mobility choices, and the attributes are better specified through examples taken from their real experience. Potential users are much more enticed by using the new service if they experience it as designed for them and able to satisfy their real mobility needs. In order to adopt this approach in paragraph 5.3 is reported a framework study which has been conducted to analyse the present mobility situation and to be able to suggest proper solutions.

In the present work some steps of the suggested methodology have not been explored, in particular, are omitted or only briefly mentioned:

- the analysis of administrative and legislative issues;
- the assessment of financial issues;
- the negotiations with partners;
- the agreements with suppliers;
- the study of the planning documents.

5.2 Context Definition and Target Identification

The study area is the city of Trieste, in particular, the city centre and the areas closed to the main university sites. Trieste is the capital of the region Friuli-Venezia Giulia in the north-east of Italy, located on the border between Italy and Slovenia. The latest estimation of Trieste's population (2018) is 204.338 (97.685 male; 106.653 female) [221] and it is the Italian city with the lowest geographical extension (84 km^2), also caused by Trieste particular configuration: a narrow strip of land that covers 30 km north to south and 5-10 km east to west, surrounded by the Adriatic sea, the Gorizia province, the Karst Plateau and Slovenia.

Its university includes ten departments and offers a wide range of university courses.

The target population, defined by the study objective, is composed of university students, and, after the investigation on the current demand and supply situation, the target is better identified, splitting them into different categories which correspond to different mobility needs and behaviours.

According to the MIUR register, in the academic year 2017-2018, the students are 15.240 (6.747 male and 8.493 female), of which 13.724 attend classes in Trieste. The university students have some specific features, already known and supported by the analysis of the current situation: their age is almost homogenous (between 20-26), usually, do not have a high personal income and, for this reason, they pay special attention to the economic aspect and so, often, they choose to move on foot.

Most of them do not have a private vehicle and live in the city centre or near the main university sites which are located about 10 minutes by bus from the city centre.

The main sites of interest for the university students are the university buildings where they attend classes, together with the areas where students who are not resident in the city are typically accommodated, the university sport centres, the principal (public and university) libraries and the city centre where are located numerous bars, restaurants, shops and several attractions for the nightlife.

The University of Trieste main site is in Piazzale Europa 1, but several offices and classrooms are located in different part of the city (Figure 13): San Giovanni, Cattinara Hospital, Maggiore Hospital (closed to Manzoni and Pascoli), Piazzale Valmaura, via Filzi, and "Polo Umanistico included the Department of Economics, Business, Mathematical and Statistical Sciences – DEAMS –" (via dell'Università, Via Tigor, Borgo Giuseppino, Campo Marzio e San Vito).

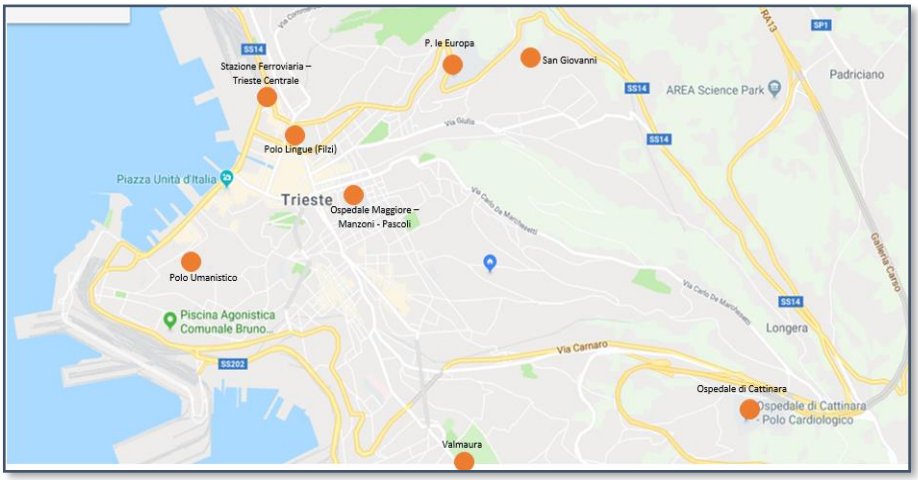


Figure 13: Trieste City Map and Classes Location

5.3 Analysis of the Current Situation – Demand and Supply Side and Criticality Individuation

Every year the University of Trieste promotes a survey to all its students on the global satisfaction level. The survey is composed of several sections (lessons, homestay, Ardiss services, food services) and one of which concerns the transport behaviour. Specifically, the analysed survey (2018) investigates the urban public transport (PT) and the access mode to the city of Trieste for all those students who are not resident in Trieste. The survey is administered online: everyone who have to log in to the online university services, from August 2018 to September 2018, is forced to complete the questionnaire. Eight thousand nine hundred ninety-four students complete the transport section,

57,5 % of the total. Participants are asked whether they are users of urban public transport, and which is their access mode to Trieste, their trip's characteristics and their satisfaction level.

5.3.1 Survey Description

The survey includes demographic status questions: nationality, residency, gender, university department, degree course, and enrollment status. Furthermore, students indicate the location where they usually have classes and if they are: "resident in Trieste", "resident in a Municipality in the Province of Trieste", "commuters", "not resident in Trieste but with accommodation in the city".
In the urban public transport section, respondents are asked whether they use the service and their opinion on the adequacy of bus timetables, punctuality, stops location, vehicles' capacity, comfort, and cleaning. For each aspect, respondents can opt for a four-grade scale of satisfaction from "Absolutely not" to "Absolutely yes". Moreover, the answer "I prefer not to answer" is available. Referring to the same four-grade scale, respondents have to express their global satisfaction towards the urban public transport service.
The access mode section enquires into the number of times students access to Trieste, the means of transport they use, how long is their travel (both in terms of time and kilometres) and the service frequency. Furthermore, respondents have to identify the accessibility most critical aspects among: "travel comfort", "travel time", "integration with urban transport services", "number of connections", "other" and the alternative "I prefer not to answer" is also available. At the end of this questionnaire section, respondents must express their global satisfaction towards the access services.

5.3.2 Profiling the Survey Respondents

Among the total of 8994 respondents, 8318 are Italian, while the remaining 676 students come from different counties around the world, predominantly from: Croatia (159 respondents), Lebanon (69), Romania (47), Albania (46), Serbia (43), Slovenia (35), Cameroon (34), Togo (31), Moldavia (19) and Ukraine (18). Female (4996) response rate is higher than male (3998), and the most represented study courses are: "Department of Medical, Surgical and Health Sciences", "Department of Engineering and Architecture" and "Department of Legal, Language, Interpreting and Translation Studies".
Figure 14 and Figure 15 summarise the response rate concerning classes location and the residences classification.

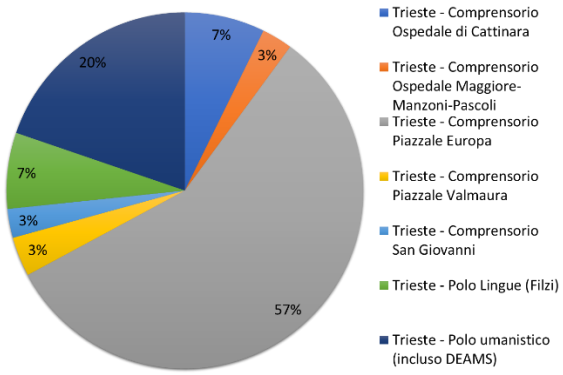


Figure 14: Classes Location

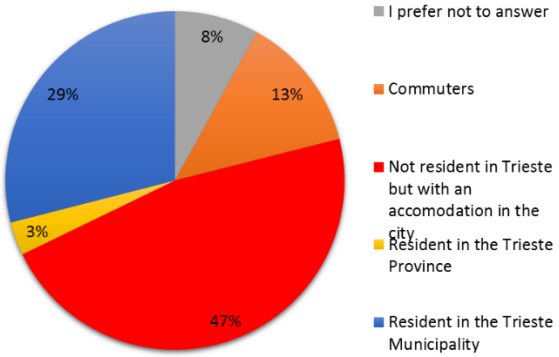


Figure 15: Residences Classification

5.3.3 Data Evaluation

Data has been evaluated separately based on the investigation topic: urban public transport (5.3.3.1) and Trieste accessibility (5.3.3.2). Furthermore, in order to evaluate Trieste accessibility, it is necessary to disaggregate students in different categories: "commuters" (5.3.3.3), "people who are not resident in Trieste but have an accommodation in the city" (5.3.3.4) and "people who are resident in a Municipality belonging to the Province of Trieste" (5.3.3.5). Each of these categories has different travel needs and habits, and so, it seems to be profitable to analyse them separately.

5.3.3.1 Urban Public Transport

Currently, the University of Trieste is well served by several bus routes:

- the principal site - Piazzale Europa- can be reached, from the city centre, by route 17, 17/: 17/ runs every 5 minutes from the Trieste train station and route 17 every 7 minutes from Piazza Tommaseo, their final stops are near the main building and close to San Giovanni as well; routes 3, 39, 42, 51 pass by the principal site but their final destination is not the university itself;
- San Giovanni is located at a distance of only two bus stops after Piazzale Europa and can be reached by routes 17 and 17/ (it is the final destination). After the bus trips, students must continue their journey on foot in the San Giovanni park;
- Valmaura is connected with the city centre by routes 8, 10, 20, 29;
- Maggiore Hospital (Manzoni and Pascoli) and via Filzi sites are in the city centre, a vast number of buses reach these locations or arrive in the proximity;

- students can arrive at Cattinara Hospital, from the city centre, with routes 22, 25, 26, 26/ (night and weekend), 37, 48 (not very frequent) and some other routes from different part of the city;
- the "polo umanistico" consists in many adjacent buildings. Via dell' Università can be reached by routes 8 and 9, while via Tigor is served by route 30. However, these sites are located near the city centre, and many other buses can serve the students in the neighbourhood.

Figure 16 shows the stated modal split to reach the classes locations: 53% of the students use urban public transport, 30% walk to the university, and 17% drive (car or motorcycle).

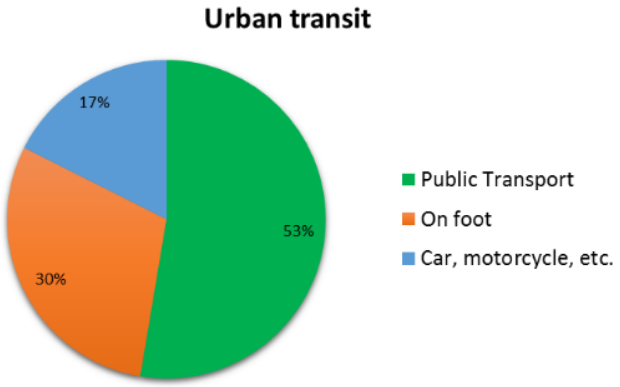


Figure 16: Urban Transit

Results are in line with other studies on mobility students' behaviour: Miralles-Guasch and Domene (2010) [77] detail the modal split to and from the Autonomous University of Barcelona and evidence that the majority of the trips are made walking (45%), followed by public transport and private mode (both 35,8%) and only 0,9% of the trips are made by bicycle. In Canada, Whalen et al. (2013) [69] analyse the students' travel behaviour at the McMaster University through a web-survey: most of the student reach the university on foot (51,7%), 24,4% of the sample use public transport, 20,4% drive to the university and 3,5% use the bicycle.

From a mobility survey conducted at the Pavia University (Italy, 2013) [222] emerges that 23% of the students reach the university on foot, 10% by bicycle, 45% by public transport (including urban bus service -25% -, extra-urban bus service - 7% - and train -13% -), 1% with the motorcycle and 20% by car (as diver -14% - or passenger - 6% -).

Clearly, it is not possible to export these rates to other situations without considering several factors: the geographical position of the university, the different cultural inclinations around the world, the city orography and the students' social status, as well as many other factors like subsidies, accessibility and infrastructure condition by mode.

Furthermore, a previous survey, conducted by our research team, on the University of Trieste on students' mobility behaviours for the night trips (cf. Annexe 5.1), shows similar results: 45% of the

respondent move on foot at the night and 23% on the bus, highlighting the inclination of the students towards mobility modalities which are not private vehicles.

A more in-depth analysis has been conducted on the relationship between the students' classification based on their residence vs modal split and classes location vs modal split. It emerges that students who are not resident in Trieste but have an accommodation in the city are more inclined to walk and use public transport, while the majority of those who drive to university are resident in the Municipality of Trieste or the Trieste Province (Figure 17).

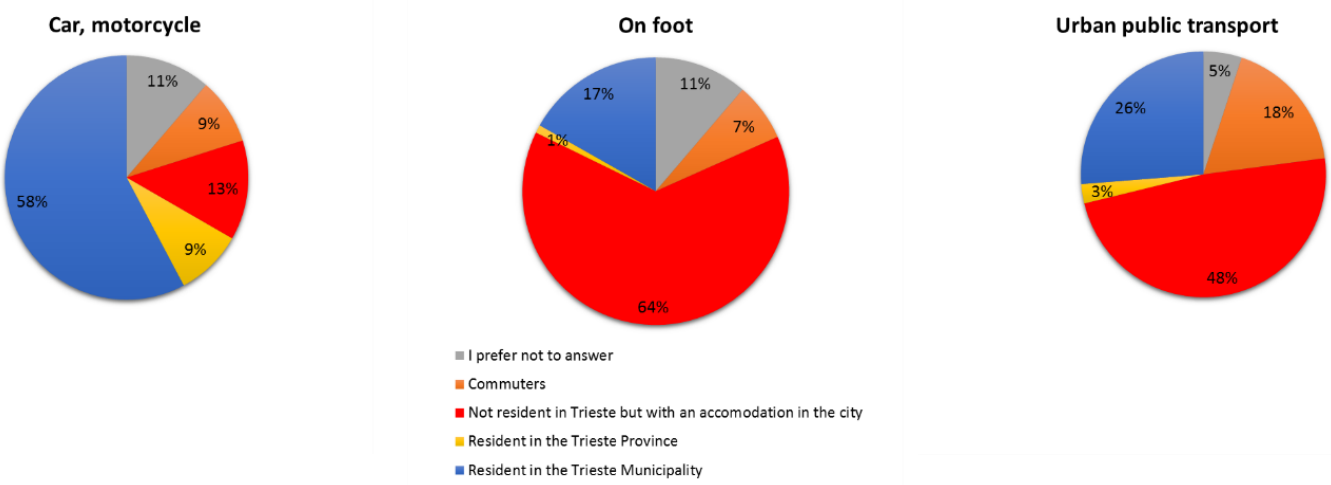


Figure 17: Relationship Between Residence Status and Modal Split

Students who have lessons in the city centre (via Filzi and Maggiore Hospital) mostly reach the university on foot (73% and 43%) or by public transport (24% and 37%). The classrooms which are far from the city centre (Valmaura and Cattinara Hospital) are mainly reached by public transport (69% and 63%) and by private vehicles (25% and 33%). Other university sites are reached by almost half of the student by public transport (San Giovanni 57%, Piazzale Europa 55%, polo umanistico 51%).

Overall, most of the students are satisfied by the urban public transport service (Figure 18).

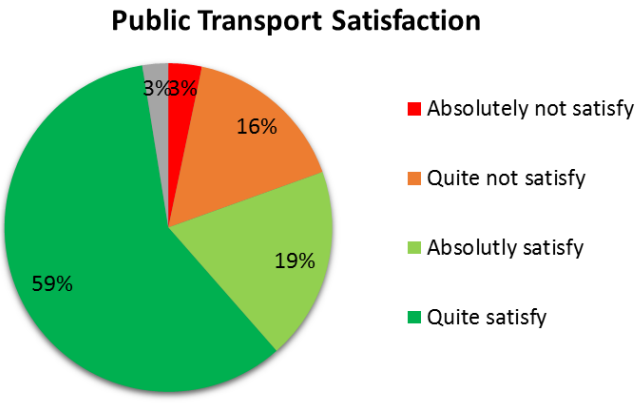


Figure 18: Public Transport Satisfaction – "Are you satisfied with the urban public transport service?"

Figure 19 reports the satisfaction levels towards different urban public transport characteristics: "bus timetables", "stop locations" are the bus service characteristics which more satisfy the students, while "capacity" and "comfort" are those which frustrate more. This is caused by the fact that the principal buses which connect the city centre to the main university building (route 17 and 17/) are always very crowded during the peak-time (8:30-9:30), even though they are very frequent (17/: every 5 minutes, 17: every 7 minutes) and there are also other buses with different final destination but which skirt the university: route 3, 39, 51, etc.

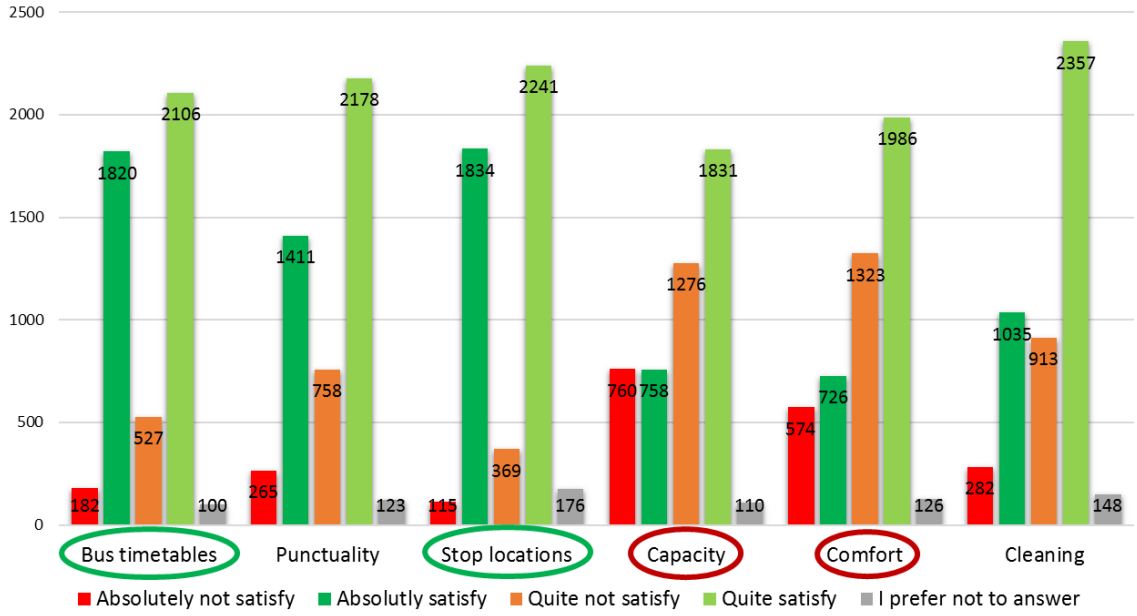


Figure 19: Public Transport Characteristics and Satisfaction – "Which is your satisfaction level with regard to the bus service characteristics?"

Also, the night transport service is a very critical issue (in particular for students who are not resident in the city but accommodate in Trieste), and many students complain about the lack of appropriate service. During the night four bus routes are available with a frequency of two or three runs per hour, from 9 p.m. to midnight. Similar results have also been observed through another research (cf. Annexe 5.1), which reports that almost 80% of the students complain about the night urban bus service.

5.3.3.2 Trieste Accessibility

Trieste is a border city, and this aspect strongly characterises its accessibility. Students who come from other Italian Regions (or also from other countries) can reach the city through:

Figure 20: Direct Flights (March 2018)

- Trieste Airport (Ronchi dei Legionari) which is connected with Trieste city centre (33 km) by extra-urban bus and by train: unfortunately, however, the airport assures a very low number of direct flights with another city in Italy or Europe (Figure 20).

- Treviso/Venezia airports: they assure direct flights to a higher number of cities all around Europe, but they are about two-hour drive off Trieste. Extra-urban bus services and trains provide the connection with Trieste.

Figure 21: Friuli-Venezia Giulia Train Lines

- Train: lines Trieste – Venice (by way of Cervignano) and Trieste – Udine – Tarvisio/Venezia (Figure 21).

- Extra-urban bus: they assure both the connection between Trieste and other regional cities and Trieste with cities in different Italian and European regions (to name the principal: Ljubljana, Rijeka, Pula, Zagreb). The first ones are provided by two routes: 21 (Trieste-Grado: infrequent in winter) and 51 (Trieste-Udine, by way of Trieste airport), while the latter by Flixbus, EuroLines, and Buscenter.it.

A significant proportion of the sample complains the lack of an appropriate connection between Trieste and other Italian cities, together with the high prices of trains' ticket.

5.3.3.3 Commuters

The survey investigates Trieste access mode of the commuters and, as it is possible to notice in Figure 22, 80% of the students reach the city by train.

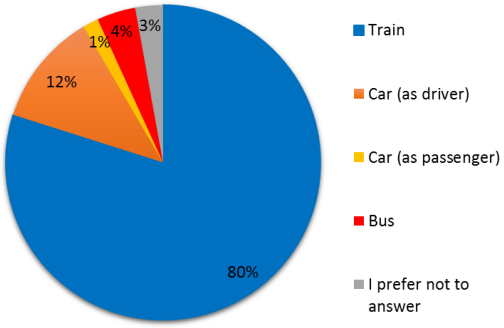


Figure 22: Commuters Access Mode

Figure 23 shows the different commuters modal split in the urban area, clustered according to their access mode.

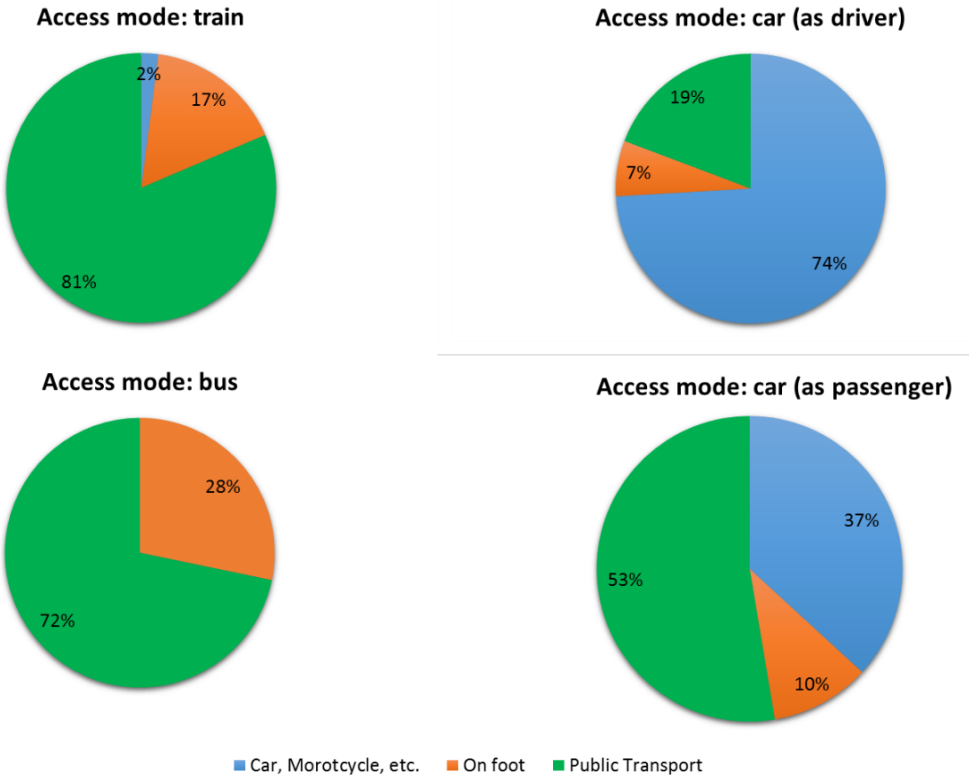


Figure 23: Access Mode and Urban Transport

People who have access to the city by private car and continue the journey with the same means of transport are an interesting target to whom suggest a more sustainable transport mode.
Usually, their travel distance lies between 30 to 75 kilometres and the travel time between 30 to 60 minutes and precisely the travel time is the most critical aspect that they identify for the accessibility.

Almost 30% of the commuters who access to Trieste by car and use the same mean of transport for urban trips are not completely satisfied with Trieste accessibility.

5.3.3.4 Students who are not resident in Trieste but have accommodation in the city

Non-residents students who accommodate in the city is the largest category and, furthermore, it is also very inhomogeneous: some students come from a foreign country or from the south or west of Italy and come back home only a few times a year, other students instead, come back home one or more times per week.
Like the commuters, most of them access to Trieste by train, but there is also a considerable portion of whom arrive by plane and bus – cf. Figure 24 – (the travel time of whom arrive by bus is more than 90 minutes for 37% of the sample).

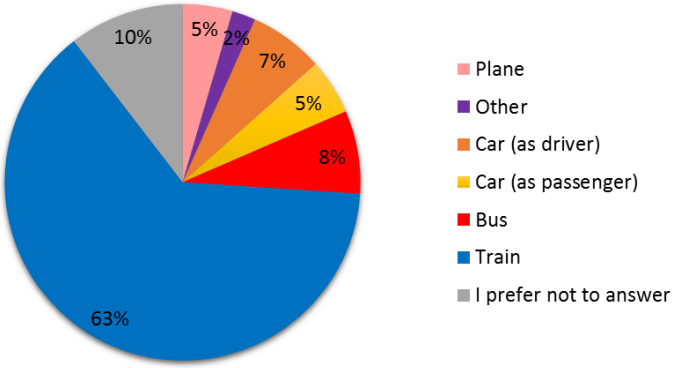


Figure 24: Non-Residents Access Mode

5.3.3.5 Students who are resident in a municipality of the Trieste province

Trieste is the smallest Province in Italy, and it has only six Municipalities: Trieste, Duino-Aurisina, Monrupino, Muggia, San Dorligo Della Valle and Sgnico (Figure 25). Students from the Province are a minority (3%), and most of them drive to the university (Figure 26).

Figure 25: Trieste Province

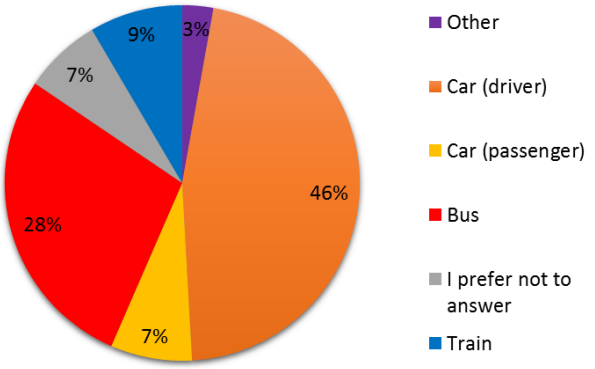


Figure 26: Resident in Trieste Province Access Mode

Students who drive to the university, usually cover a distance fewer than 30 kilometres, in less than 30 minutes. Like for the commuters, they identify as the accessibility's biggest barrier the travel time, accompanied by the integration with the urban travel services and the number of available connections.

5.4 Proposal for Intervention

The main problems raised by respondents in the global mobility survey (cf. 5.3.3) have been taken into consideration in order to plan the best possible strategies to overcome these problems. For this reason, students have been split into four categories:

- commuters;
- residents in Trieste;
- resident in a Municipality of the Trieste Province;
- not resident in Trieste, but with accommodation in the city.

Each category presents different travel habits and encounters different transport necessities.

By defining different proposals of intervention, it is possible to capture specific exigencies and investigate students' interest regarding a service calibrated on their mobility needs. E.g. it is a non-sense to suggest to commuters the usage of a night service since they come back home every day after lessons, as well as suggest a service to move between different university buildings is a problem that does not interest all the students, but only a limited portion.

A common feature of all the suggested services is that they are of station-based typology, i.e. people have to leave the car in a well-defined station. This choice seemed to be mandatory since free-floating systems are well-performing in the metropolis, and usually, they are operated by big enterprises [84].

In the following sections, for each students' category are highlighted:

- their declared mobility problems;
- the description of a possible solution to satisfy their transport exigencies;
- the description of a proposal of intervention which has been submitted to the students through the surveys, described in 5.6, for investigating on their propensity to adhering on a car sharing service with the specified configuration.

5.4.1 Commuters

- Main problems for the commuters in the access trips to the university sites:

Commuters arise the problem that the buses which leave the train station to the main university sites are too crowded and sometimes it is difficult to get into the bus. Moreover, they complain about the lack of appropriate direct connections between the train station and some sites where they have classes.

- Description of one of the possible solutions:

One possible solution is the introduction of a specific car sharing service with cars available in a depot near the train station (as well as the extra-urban bus station) which they can use to reach the university and park the vehicles in specific parking lots reserved for the scope. Furthermore, the vehicles can be shared among up to four/five students who arrive in the same time in the train station and have to reach the same place: in this way fewer cars are requested (less congestion, fewer emissions) and the service cost can be split over several people. Integration to this service targeted to students would permit the usage of the same vehicles to the university employees who could use the vehicles for their work activities and drop off the vehicle in the same parking lot ready for the commuters to come back to the train station. In the same way, the usage of the vehicle can be done by other company employees during their working time (especially for the university sites which are located close to the city centre) or by private citizens with the requirement that the vehicle has to be dropped off in the same place in time for the commuter who reserved it.

- Proposal for intervention:

In the questionnaire, the scheme suggested (Figure 27) for commuters presents the chance to access the car sharing service with the same train, or extra-urban bus, subscription and to take a car located in a park close to the train station and drive to their university site for their classes. It is supposed that near the university site there are some available free parking lots for car sharer. People can reserve a vehicle through an APP, up to one hour before use. The relocation of the vehicle fleet is "operator-based" (cf. section 4.1 - Step 11).

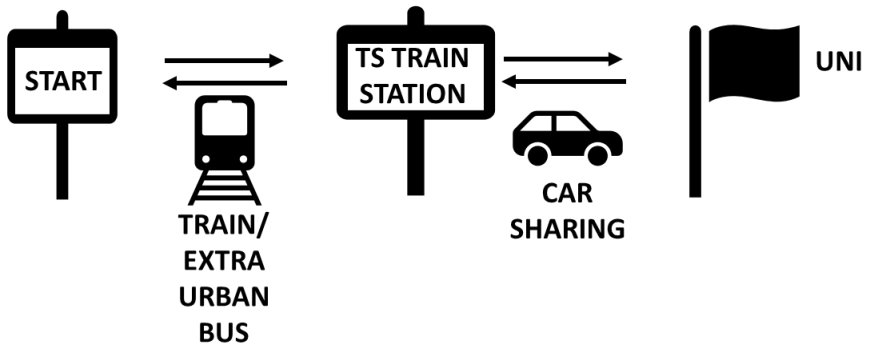


Figure 27: Service for Commuters

5.4.2 Students who are resident in a municipality of the Trieste province

- Main problems for students who are resident in Trieste Province when coming to the university sites:

One of the main problems arisen by students who arrive at the university from the Trieste Province in the lack of parking spaces close to the main university sites.

- Description of one of the possible solutions:

Considering that in the university area there is not enough space for parking too numerous cars, a possible solution is to introduce some dedicated parking areas and connect them with the university sites through a shuttle buses service. From the Province to the reserved parking area, more users can share the trip, saving money and adverse car usage effects. Like for commuters during the classes time, some companies' employees or private citizens can use vehicles with the requirement to drop it off in time for the students who reserved it.

- Proposal for intervention:

People who are resident in the Trieste Province are asked to imagine to be able to access a car sharing service and use it for the systematic trips home - reserved park - university and the other way around. They can access to a combined service: use the car sharing from home to an appropriate parking area where it is possible to take a shuttle bus to the university site with a unique subscription; the same for coming back home. People can reserve a vehicle through an APP, up to one hour before use (Figure 28).

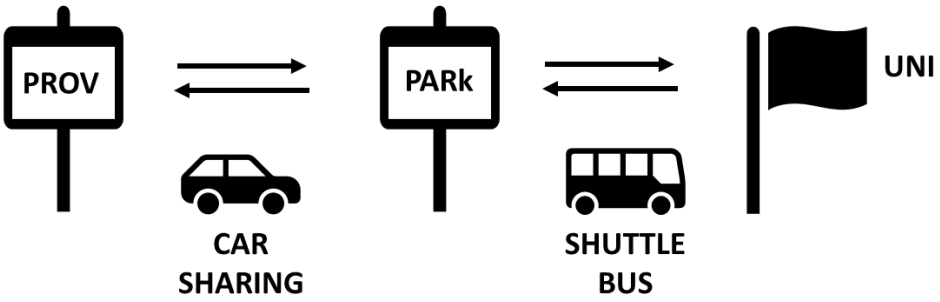


Figure 28: Service for Residents in Trieste Province

5.4.4 Students who are not resident in Trieste but have accommodation in the city

- Main problems for students who are not resident in Trieste but have accommodation in the city:

The main problems raised by them is the lack of an appropriate service when they come back to Trieste on Sunday night, after spending the weekend in their residential town: most of the time there is not the bus service anymore, or the buses do not go through the train station. Another problem is the lack of a night bus service during the weekday: indeed, the last bus route is at 24:00 or 00:30 and the bus frequency is rather inadequate (usually, 30 minutes).

- Description of one of the possible solutions:

One possible solution is the realisation of a car sharing service accessible by students with the same train fee, which guarantees the presence of cars in a station located near the train station (extra-urban bus station) on Sunday night. Furthermore, the vehicles can be shared among up to four/five students who arrive in the same time in the train station and have to reach close destinations: in this way fewer cars are requested (less congestion, fewer emissions) and the tariff can be split over several people. In this scenario, the shared mode substitutes public transport in a time interval in which the latter is not available/efficient. For the second problem, night trips, the description of the possible solution is reported in section 5.4.5.

- Proposal for intervention:

In the questionnaire targeted to whom is not resident in Trieste but have an accommodation in the city, the car sharing service suggested aims to solve the lack of public transport service when they arrive in Trieste, by train, the Sunday night (Figure 29). So, the suggested system consists of a car sharing service which is accessible to students with the same train/extra-urban bus subscription and with a car station located near the train station: they can reserve a vehicle through an APP, up to one hour before use it to reach their home from the station. The respondents are also asked to express their interest in a possible service during the night time for urban trips.

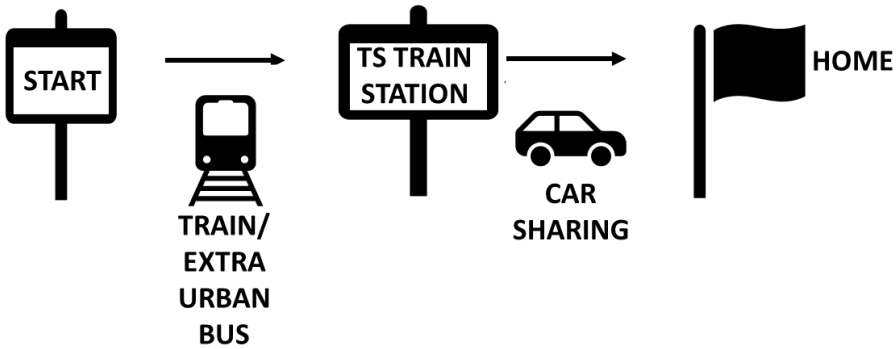


Figure 29: Services for Non-Residents

5.4.5 Residents in Trieste

- Main problems for students who are resident in Trieste for their night trips:

The lack of an appropriate night public transport service is one of the main issues raised by the university students who are resident in Trieste, together with students who are not resident in the city but are accommodated in the city during the week of the term time. Currently, the service is infrequent and finishes at midnight.

- Description of one of the possible solutions:

The suggested solution is the establishment of a car sharing service available during the night time. Students can take up the vehicles in one of the stations located all around the city centre, use it for their private affair and drop off the vehicle in the same station from where they left. During the day, the same vehicles could serve commuters, as well as citizens, university or company employees.

- Service description:

Residents are enquired to think about their night or weekend trips and hypothesize to be able to access a car sharing service (Figure 30). They can reserve a vehicle through an APP, up to one hour before use and, at the end of the trip, they must drop off the vehicle in the same station from where they picked it up (car sharing station-based round-trip).

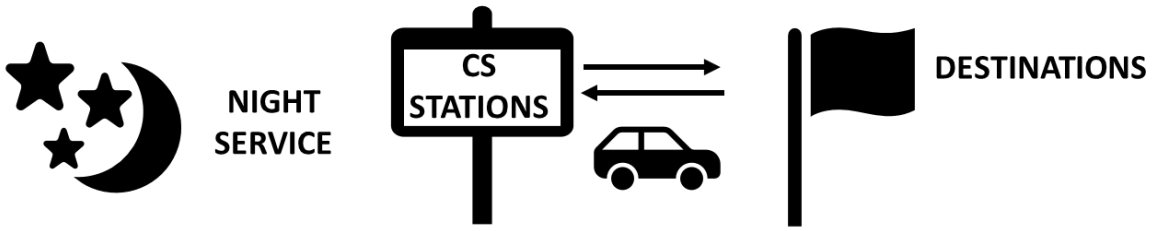


Figure 30: Service for Residents in Trieste

5.5 Individuation of the Supply Elements

There are some supply elements which are essential for the car sharing service of type station based, such as, vehicles, stations, parking lots, recharging columns in the case of a fleet also composed by electric vehicle.

Referring to the state of the art, the current practice and the common sense, other elements are identified as pivotal. Their influence on the alternative's choice is assessed through the survey reported in section 5.6. It is essential to underline the fact that the planning methodology is a continuous loop, i.e. some elements which are recognized as influent on the car sharing adoption could reveal to be insignificant after the model development (cf. 5.8).

The critical supply elements are of boolean type, i.e. they are present or not, or defined by numeric values or strategy description. For example, belongs to the first category the possibility of sharing the trip with more users in order to split usage costs and the chance of driving in separate lines. While, belongs to the second one: the pricing strategy, the definition of the car typology, the maximum days of consecutive reservation and cancellation policy, the unlocking modality, the reservation modality.
Furthermore, other elements are defined only after the data collection and the examination of the answers, such as the extension of the study area and the relocation strategy.
The following sections better describe all the supply elements.

5.6 Potential Demand Estimation: Data Collection

5.6.1 The Survey

Stated preference (SP) survey is applied to collect data on the demand estimation of the not already implemented car sharing service. Indeed, at the present moment, there is not any car sharing (CS) in Trieste Municipality, so the service is a complete novelty for the interviewed. The global questionnaire (cf. 5.3) on students mobility behaviour has been indispensable: in fact, to promote a more sustainable transport mode, such as car sharing, it is crucial to propose a new urban mobility scheme which is realistic and also potentially attractive for students. In order to have these qualifications, it is fundamental to study people needs and their current attitude and be able to suggest solutions which are suitable for them, as also suggested by Politis et al. (2012) [75].
The aim of the SP survey is to collect data, which is useful to calibrate a model able to reproduce university students' choice behaviours when introducing a new car sharing service and to understand the way in which the students would use the service, if available. Moreover, the research points to the evaluation of the potential positive relationship between public transport and car sharing.

5.6.2 Individuation of the Sample

The sample is an appropriate subset of the target population, and it is chosen according to the simple random sampling technique which permits the use of statistic theory to derive the properties of the sample estimators and, every element of the targeted population have equal and non-zero, probability of being chosen [124] (cf. Chapter 4). Choosing the sample size is a balance between costs versus precision. The bigger is the sample, the better is the accuracy of the collected information, but the

cost is higher. It is not intuitively, however, the sample size is little affected by the size of the population, but it is profoundly affected by the variability over the population of the parameters which have to be estimated [137]. There are several approaches to sample size definition, Johnson and Orme [141] propose a rule of thumb to estimate the minimum sample. They suggest that the sample size is affected by the number of choice tasks (t), the number of alternatives (a) and by the largest number of levels for any of the attribute (c) or, when considering, also, the two-way interactions (c) is equal to the largest product between the levels of any two attributes.

(21) $N > \frac{500\ c}{t\ a}$

As it will be better detailed in next section, in this case study, N has to be greater than 125 since c= 2 (only main effects are considered with the fractional factorial design); t= 4; a= 2.

5.6.3 The Survey Structures

Since the proposals for intervention are different for each student category, also four surveys have been developed, respectively targeted to:

- commuters;
- residents in Trieste;
- resident in a Municipality of the Trieste Province;
- not resident in Trieste, but with accommodation in the city.

Developing four different surveys, seemed to be an efficient strategy: actually, for the online version, the four surveys are integrated into only one, but to each of the respondents, after having declared to which category they belong to, the questionnaire is automatically configured with only the questions addressed to himself.

Questionnaires are split into two sections: the first deals with respondents' socio-economic characteristics and their current transport behaviour (e.g. age, gender, driving license, knowledge of the car sharing system, owning of a private vehicle, owning of an urban bus fee). The second section consists of four specific stated choice questions: each of them presents a situation in which a car sharing service is described according to the defined attributes and levels, reported in the following sections, 5.6.4. For each situation, respondents have to explicit if they would choose car sharing or not. Only for the online questionnaires, a final question which asks how much the respondents are sure about their answers on the SP options is introduced, to reduce the bias of responses which do not reflect people true preferences, as better explored in section 5.7.8.

The following subsections better details the car sharing service suggested to each students' category, the attributes and levels of the SP questions.

The questionnaires may be designed in a more extensive and detailed way, and they may investigate on numerous other specific elements as reported in Chapter 7.3. However, it has been experienced, through other case studies and pilot surveys, that respondents do not complete the questionnaire, or they assign casual answers if the surveys are too long or present too many alternatives or attributes which rise the respondents' burden. Indeed, an unrepresentative test has been done, administering SP pivoting questionnaires (cf. section 2.3.1.1), but they resulted in being too long and complicated, and students were not able to cope with them and complained about the too high burden required (and time spent on the compilation).

5.6.4 Alternatives, Service Attributes and Levels Definition

5.6.4.1 Commuters

Each choice set has five attributes with two levels, reported and described in Table 25:

Table 25: Attributes and Levels - Commuters

Attributes	**Attribute's description**	**Levels**
Electric vehicles	Presence of electric vehicle in the fleet.	Yes
		No
Service cost	The service cost includes the hourly cost, the kilometric cost, and the subscription fee. Since one of the main objectives is to plan and offer to students a service which is complementary to the public transport service, the cost scheme reflects this aim and the subscription fee is free for all those who own a train (extra-urban bus) subscription. This wish to promote Trieste accessing by train or extra-urban bus also among those who commute to the city by private vehicle.	3* €/hour + 0,5 €/km Subscription fee: free for all those who own a train (or extra-urban bus) subscription, otherwise 5 €/month
		2 €/hour + 0,5 €/km Subscription fee: free for all those who own a train (or extra-urban bus) subscription, otherwise 5 €/month
Maximum days of continuous reservation	This attribute represents the number of consecutive days of usage for which the vehicle can be reserved: this can be very useful in order to guarantee the presence of a vehicle near the train station for all those who commute to the city.	2 days
		5 days
		Yes

Access to priority lines	Commuters usually arrive in the city during the peak-hour, and so, the accessibility to priority line can be an added benefit to speed up their trip.	No
Vehicles' simultaneous use	Allowing the chance to share the journey with other students and split the service costs: this aspect can be relevant for students, who often keep an eye on the budget but can be attracted by keeping in touch with other students and, furthermore, can be quite safe to share the trip with students who are not entirely strangers. In the APP where people can reserve the car sharing vehicle, they can also find other people with whom share the trip and provide feedback on them.	Yes: the subscription fee is individual for each user, while the service cost is split over all those who share the trip.
		No

* 2,5 €/hour (day time) is the mean value reported in the report "Ricerca sulla convenienza economica del Car Sharing" [39]

Even if station location is a crucial attribute for the car sharing planning, in this case, it is not a stated preference question since it is specified in the service presentation that the stations will be located close to the train station (as well as extra-urban bus station) and near to the university sites.

5.6.4.2 Students who are resident in a municipality of the Trieste province

Each choice set has five attributes, with two levels (Table 26):

Table 26: Attributes and Levels - Residents in Trieste Province

Attributes	**Attribute's description**	**Levels**
Electric vehicles	Presence of electric vehicle in the fleet.	Yes
		No
Service cost	The service cost includes the hourly cost, the kilometric cost, and the subscription fee.	3,5 €/hour + 0,5 €/km Subscription fee: 60 €/year
		2,5 €/hour + 0,5 €/km Subscription fee: 60 €/year
Time on the shuttle bus	Time spent on the shuttle bus from the dedicated parking area to the university: this parameter is essential to define the maximum distance of the parking area from the main university sites.	About 10 minutes
		About 18 minutes
	This attribute is specific to encourage the integration between car sharing and public transport. The	Yes, for the owner of an urban bus pass the car

Service cost reduction for the owners of an urban bus pass	service cost reduction for the owners of the urban bus subscription can be a driver for reducing the car-usage and enhance public transport service.	sharing subscription fee is free
		No
Vehicles' simultaneous use	Allowing the chance to share the journey with other students and split the service costs: this aspect can be relevant for students, who often keep an eye on the budget but can be attracted by keeping in touch with other students and, furthermore, can be quite safe to share the trip with students who are not entirely strangers. In the APP where people can reserve the car sharing vehicle, they can also find other people with whom share the trip and provide feedback on them.	Yes: the subscription fee is individual for each user, while the service cost is split over all those who share the trip.
		No

Like for the survey addressed to commuters, the distance among stations is not a stated preference attribute since it is specified in the service presentation that the stations will be located in their Municipality and in a specific parking area from where they can benefit from a shuttle bus service to the university.

Differently from commuters, the priority lines are not supposed to be a significant attribute since most of the time students from the Province come to the university without going through the city centre where the priority lines are concentrated.

Moreover, unlike commuters who come to Trieste only when they have lessons (few months a year), resident in the Trieste Province can use the service throughout the year and so, an annual subscription can be appropriate.

5.6.4.3 Students who are not resident in Trieste but have accommodation in the city

Each choice set has five attributes, with two levels (Table 27):

Table 27: Attributes and Levels - Non-Residents

Attributes	**Attribute's description**	**Levels**
Electric vehicles	Presence of electric vehicle in the fleet.	Yes
		No
Service cost	The service cost includes the hourly cost, the kilometric cost, and the subscription fee. Since one of the main objectives is to plan and offer to students a service which is complementary to the public	3 €/hour + 0,5 €/km Subscription fee: free for all those who own a train (or extra-urban bus)

	transport service, the cost scheme reflects this aim and the subscription fee is free for all those who own a train (extra-urban bus) subscription. This wish to promote Trieste accessing by train or extra-urban bus also among those who commute to the city by private vehicle.	subscription, otherwise 5 €/month
		2 €/hour + 0,5 €/km Subscription fee: free for all those who own a train (or extra-urban bus) subscription, otherwise 5 €/month
Distance from the car sharing parking station to their accommodation	Distance from the car sharing station to the final destination and vice-versa is a crucial element for the service planning: from this attribute, it is possible to estimate the number of stations requested to satisfy the potential users.	About 5 minutes walk
		About 8 minutes walk
Service cost reduction for the owners of an urban bus pass	This attribute is specific to encourage the integration between car sharing and public transport. The service cost reduction for the owners of the urban bus pass can be a driver for reducing the car-usage and enhance public transport service.	Yes, for the owner of an urban bus pass the car sharing subscription fee is free
		No
Vehicles' simultaneous use	Allowing the chance to share the journey with other students and split the service costs: this aspect can be relevant for students, who often keep an eye on the budget but can be attracted by keeping in touch with other students and, furthermore, can be quite safe to share the trip with students who are not entirely strangers. In the APP where people can reserve the car sharing vehicle, they can also find other people with whom share the trip and provide feedback on them.	Yes: the subscription fee is individual for each user, while the service cost is split over all those who share the trip.
		No

To this student category is also asked them to indicate whether they would choose the service for the night trip (cf. 5.6.4.4), considering that they express the lack of urban public transport service during the weekdays. This part of the survey corresponds to that administered to residents (cf. 5.6.4.4).

5.6.4.4 Residents in Trieste

Each scenario has five attributes, with two levels (Table 28):

Table 28: Attributes and Levels - Residents in Trieste

Attributes	Attribute's description	Levels
Electric vehicles	Presence of electric vehicle in the fleet.	Yes
		No
Service cost	The service cost includes the hourly cost, the kilometric cost, and the subscription fee.	3 €/hour + 0,5 €/km Subscription fee: 60€/year
		2 €/hour + 0,5 €/km Subscription fee: 60€/year
Distance to reach the nearest car sharing parking station	Distance to and from the car sharing station from the place of departure or to the final destination is a crucial element for the service planning: from this attribute, it is possible to estimate the number of stations requested to satisfy the potential users.	About 5 minutes on foot
		About 8 minutes on foot
Service cost reduction for the owners of an urban bus pass	This attribute is specific to encourage the integration between car sharing and public transport. The service cost reduction for the owners of the urban bus pass can be a driver for reducing the car-usage and enhance public transport service.	Yes, for the owner of an urban bus pass the car sharing subscription fee is free
		No
Station-based – one-way car sharing	Allowing the chance to use the car only to a route can be attractive, in particular users can leave home when the bus service is still available and come back home after 24:00 when the bus service is not available anymore or, vice-versa, they can leave home with the car sharing service and have a lift to come back. This attribute guarantees more flexibility in the service, even if for the car sharing operator this kind of service introduces more complexity, such as the vehicle imbalance in the stations or the relocation's costs.	Yes, but the service cost for users who drop off the vehicle in a different station from where they take off it is: 3 €/hour + 1 €/km. The subscription fee remains unchanged: 60 €/year.
		No

If they answered positively to, at least, one scenario, they are asked to answer several questions which investigate the characteristic of their night trips.

5.6.5 Discrete Choice Experiment Design and Choice Set Creation

The so-called design of the experiment aims to optimise a process or system by performing each experiment and drawing conclusions about the significant behaviour of the studied objects from the experiment's results. Of course, making choices among all the possible combinations of attribute

levels is impossible for a single respondent. The choice experiment design for the present study has been built thanks to arrays' tables: a fractional factorial design was generated, using table oa.8.5.2.2. where oa.N.k.s.t stands for an orthogonal array with N runs (8), k attributes (5), s levels (2) and strength t (2). The orthogonal array has been taken from a library of more than 200 arrays provided by Sloane N.J.A. et al. [223]. Since eight scenarios constitute a significant burden for the respondents, it seemed to be necessary to split the total number of choice tasks into two different subsets and allocate them to different respondents. The blocks are allocated in order to avoid presenting in one block all the high cost/long distance, scenarios. So, at the end of the design process results in eight questionnaires: two for each category of students: each of them presents four scenarios with five attributes and two levels (which are very realistic and acceptable by respondents). The alternative is given by choice of whether or not to adhere to the suggested car sharing service.

5.6.6 The Surveys' Administration

The first data-collecting campaign was executed as face to face interviews, with pen and paper surveys, in fact, previous tests have brought to light the barriers of the informatic survey sent by e-mail, in particular, the main problem encountered with the informatic survey was that only people who are interested in the subject (e.g. car sharing) complete the questionnaire. Therefore, in order to overcome this issue, the present survey was administered to students before their classes, ensuring that everyone completes the questionnaire, no matter they are interested in the suggested strategies or not. On the other side, this strategy makes data analysis more complicated and laborious considering that all the answers where "paper-based" and not organised in an excel, or other informatic support, requested for the following data elaboration and moreover the sample results reduced (145). The survey was administered on February 26th, 2019 to the engineering students in the main building of Piazzale Europa (18 respondents), on March 5th, 2019 to the medical students in Cattinara Hospital (80 respondents), on March 19th to speech and language therapist's students in Cattinara (22 respondents) and finally to the physiotherapy students in via Pascoli in ITIS on March 21st (25 respondents). Hence, globally, the produced cases for model estimation are 580 [145 x 4]., The survey has also been distributed online, to overcome the aforementioned limits of the paper-based survey, in particular in order to sample a larger number of students. The link and QR code to the survey have been printed on some leaflets, and these have been spread among the university buildings, canteens, libraries, students' home during April and May 2019. Considering both pen-and-paper and online surveys, 635 students filled out the questionnaire, 10% commuters, 3% from Trieste Province, 31% are resident in the city, and 56% are not resident but have an accommodation in the city. This data has been used to collect information on the actual transport mode and to plan the car sharing service.

5.7 Analysis of the Answers

The data collected from the pen-and-paper survey and online survey has been analysed separately and also jointly. In the following figures and tables, different statistics are reported, and the data from the surveys has been compared with the data of the population, considering the global mobility survey (cf. 5.3.1) data as population data. Students rate for each category is reported in Figure 31:

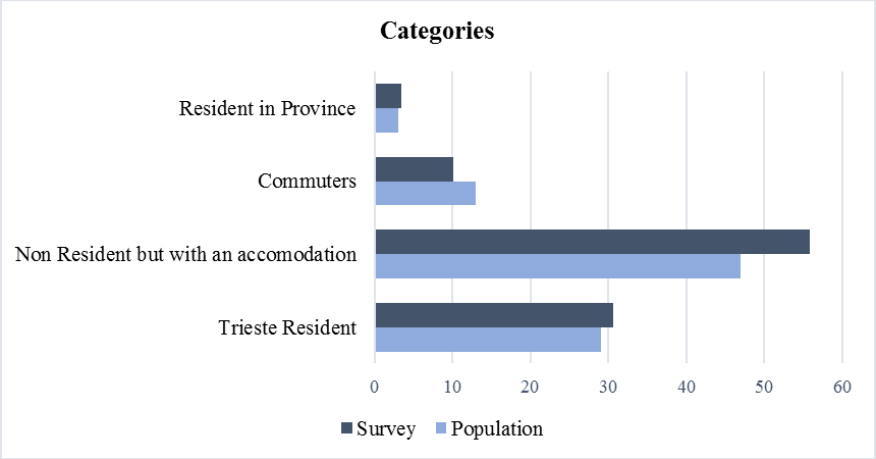


Figure 31: Students Rate for Each Category - Surveys and Population Data

Totally the respondents are 635: 370 females and 265 males. They are almost uniform in terms of age (average age: 22,1); 90% have a driving license, 45% have a bus fee and 56% already know about car sharing (Figure 32).

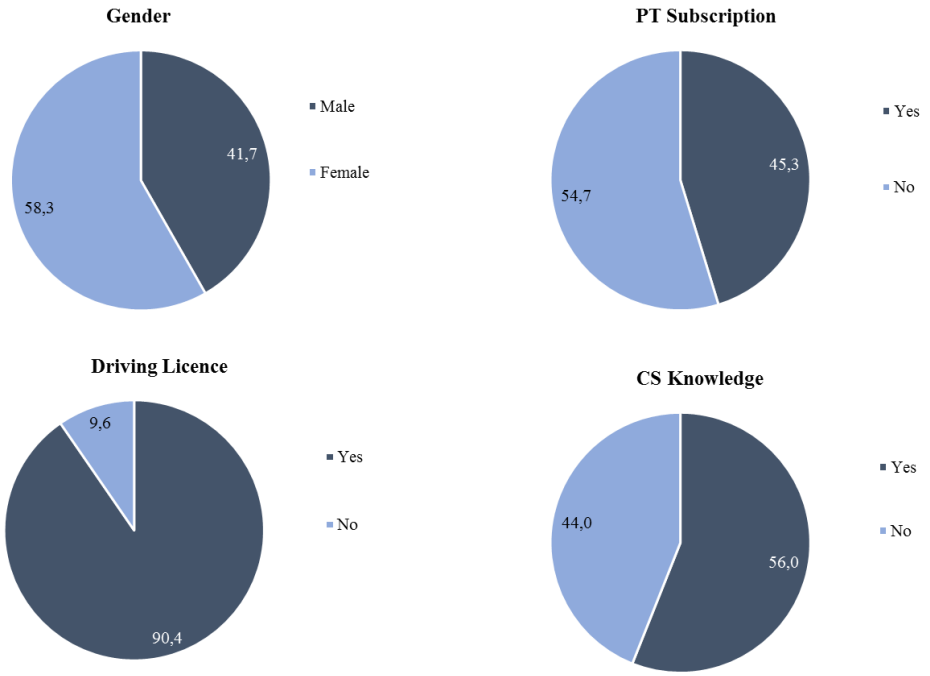


Figure 32: Global Results - Gender, PT season ticket, Driving License, CS Knowledge

Figure 33 reports the comparison of the male-female rate among population, online survey, pen-and-paper survey: females are always more numerous.

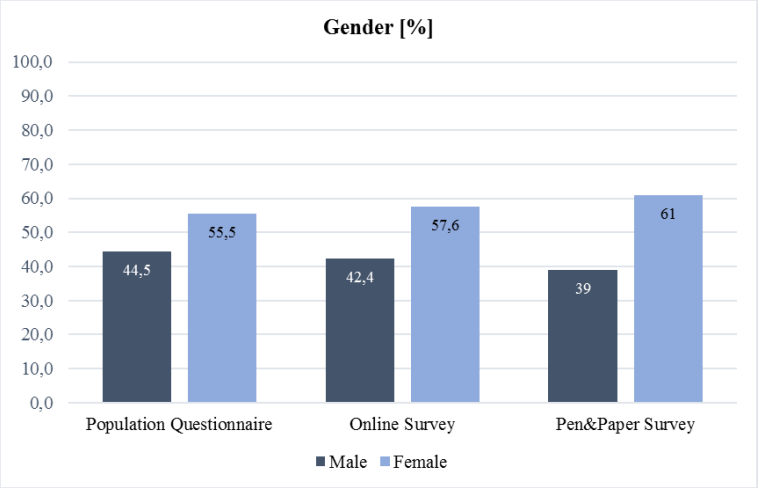


Figure 33: Gender - Surveys and Population Data

Most of the interviewed attend classes in the main university buildings, i.e. Piazzale Europa; the interviewed distribution on the university sites follow the population distribution, except for Cattinara: the survey sample over-represent people who frequent Cattinara Hospital (cf. Figure 34).

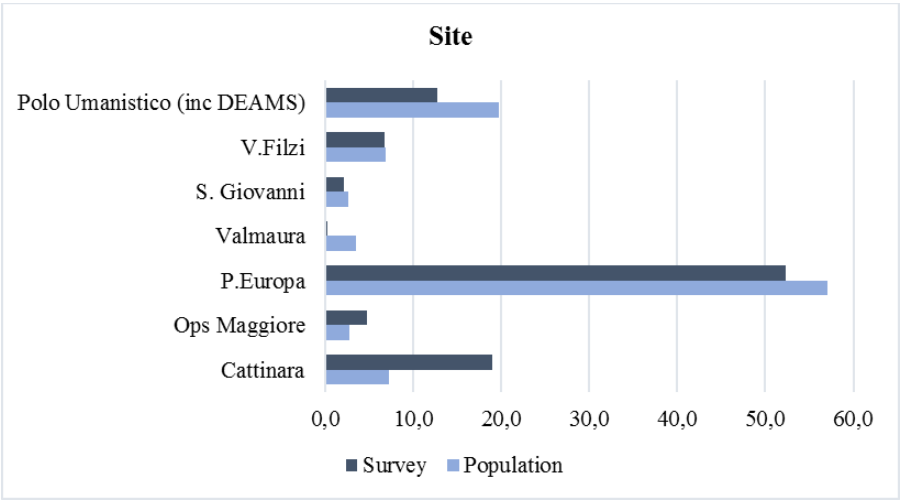


Figure 34: Site Distribution - Surveys and Population Data

Since one of the main objectives of the car sharing service introduction is the limitation of private car usage, the collected data has been elaborated to understand the student current transport behaviour better.

In the following discussion, when naming "non-residents", it is referring to the category of students who do not reside in Trieste but have a home in the city.

A significative difference emerges between resident and non-resident in Trieste in the vehicle ownership (Figure 35): 86% of the non-resident does not have a vehicle for the trips in Trieste, vs

31% of students resident in the city. Only 6,5% of the non-residents own a car, vs the 54% of the residents (or have access to household one). However, non-residents usually live near the university site where they attend classes or near the city centre, in order to overcome the difficulties caused by vehicle absence. Again, for this reason, the rate of non-residents who own a public transport season ticket (39%) is slightly lower compared to the residents (41%).

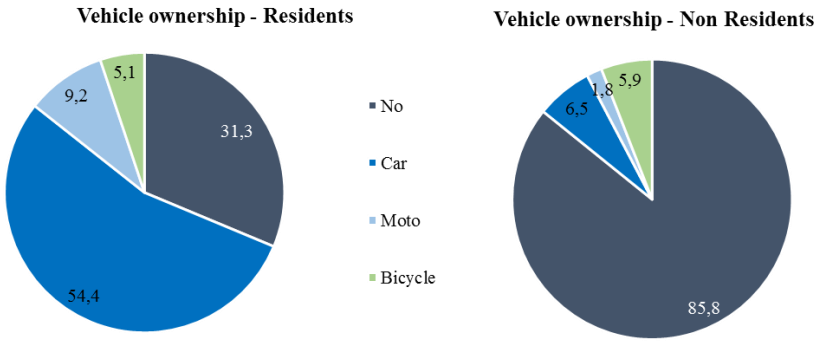


Figure 35: Vehicle Ownership - Residents and Non-Residents

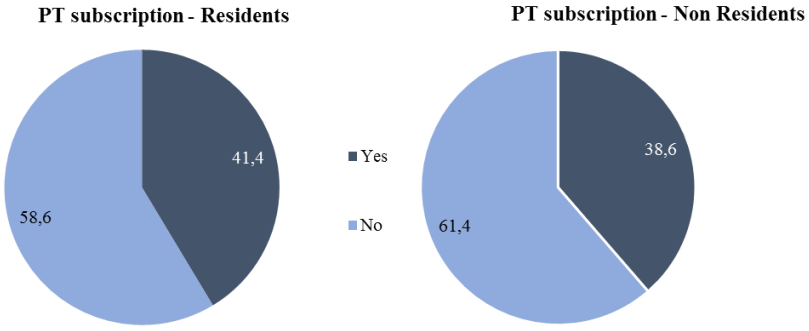


Figure 36: Public Transport Season Ticket - Residents and Non-Residents

5.7.1 Commuters

The commuters are a minority: only 61 interviewed students belong to this category, they come from Friuli-Venezia Giulia Region, mostly from the province of Gorizia, which is bordered by Trieste. Almost the 30% declares to be interested in car sharing, more of 65% owns a train's fee (16% the annual subscription and 84% a monthly one) and a public transport season ticket, but this information cannot be considered statistically-based since the poor numerosity of the sample. Among the collected data, more than half the people states to departure from home, between 6:30 – 7:30 (min: 6:30, max: 9:30) and their travel lasts, in 60% of cases, less than one hour. Instead, the time of departure from Trieste does not have a peak, but the values are evenly among the afternoon (Figure 37). More than 70% of the commuters arrive at Trieste by train, as reported in Figure 38, and this

characterises their mobility behaviour since, after arriving at Trieste train station, they take a bus (or go on foot if they attend classes within a reasonable walking distance). Since their arrival in the city and their destinations are quite homogeneous, the bus crowding is increased.

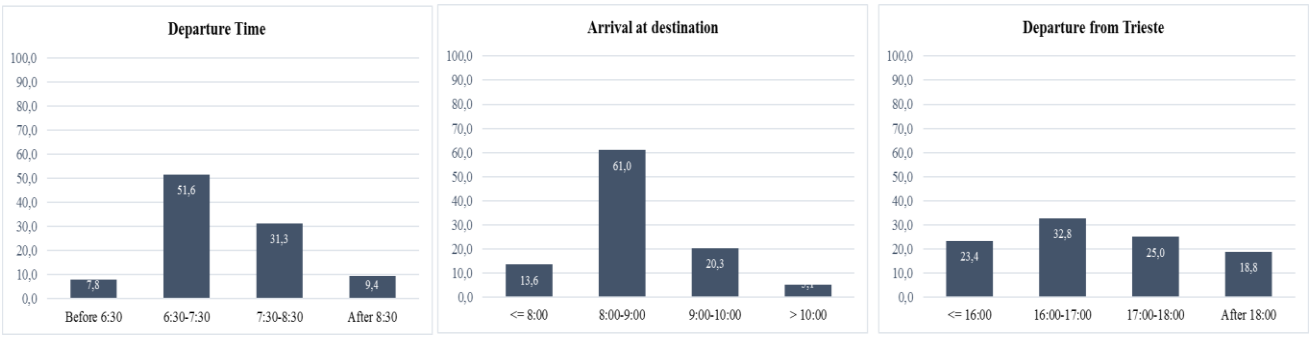


Figure 37: Commuters Schedule

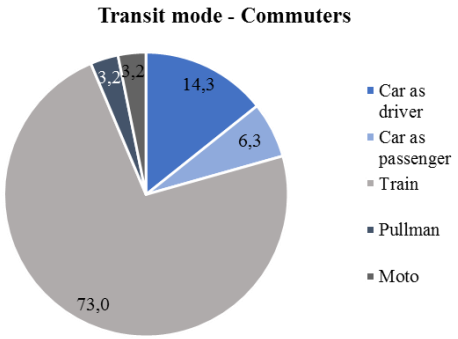


Figure 38: Transit Mode – Commuters

5.7.2 Students who are resident in a municipality of the Trieste province

The sample is irrelevant: only 22 students belong to this category, and so the collected data are useless for any statistical analysis.
However, all the students who do not own a private vehicle, have a public transport season ticket and 28% of the students who belong to this category express their favour towards the car sharing.

5.7.3 Students who are not resident in Trieste but have accommodation in the city

The category of students who are not resident in Trieste but have accommodation in the city is the most represented.

Considering the revealed preferences towards the transport mode for accessing to Trieste, the most used means of transport is the train [73%] (Figure 39), in the same line with what emerges analysing the population data, followed by plane and extra-urban bus. Only 0,4% of the non-residents own a train subscription, and most of them come back home less than 1 per month or 2/3 times per month.

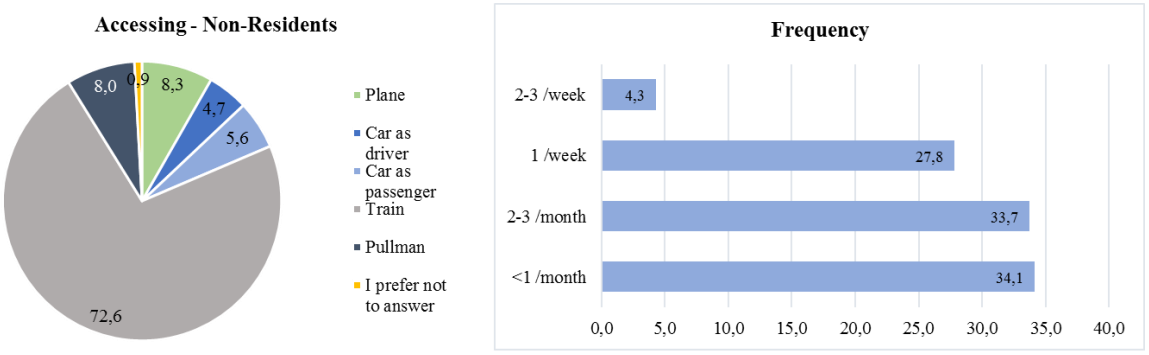


Figure 39: Access to Trieste and Frequency - Non-Residents

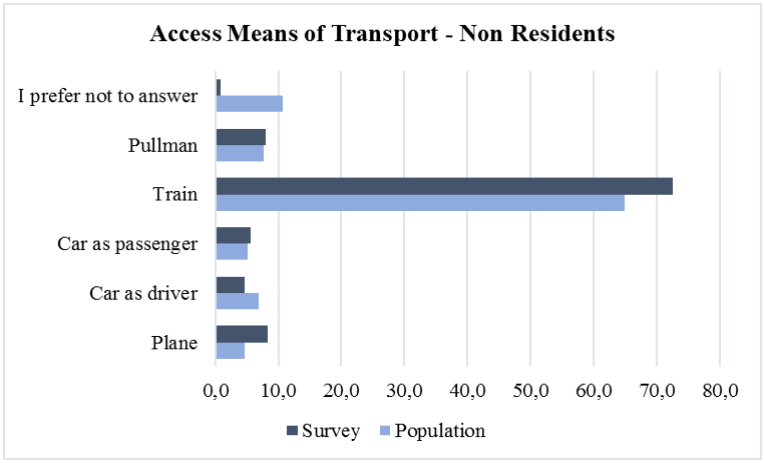


Figure 40: Access Means of Transport, Non-Residents - Surveys and Population Data

Most of the interviewed are resident in Friuli Venezia Giulia and Veneto, and the age is almost homogenous among the sample.

Still processing the collected data, it has been possible to define the main areas of Trieste where these students live (Figure 41) and defining the origin/destination matrix (which reports the number of trips from one node -origin- to another -destination- in a specific period of time) and the distance, from the train station (red triangle on the map in Figure 41).

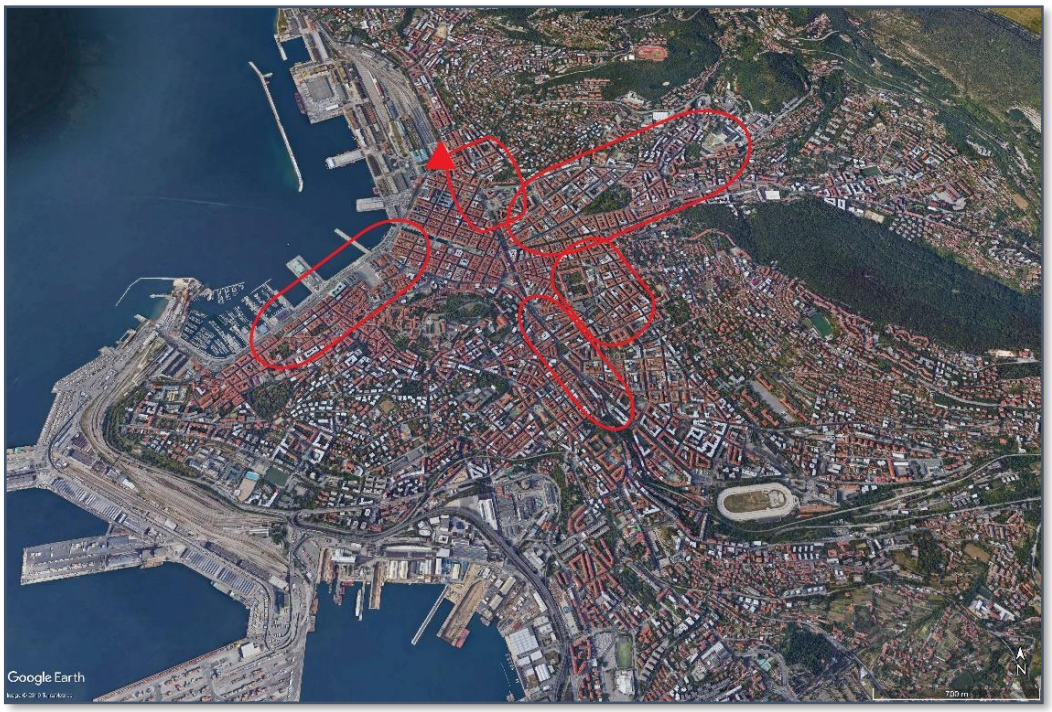


Figure 41: Trieste Map - Non-Residents

Distance in kilometres and minutes have been calculated thanks to Google maps, considering, for each street, an intermediate point. The weighted average value of the kilometres travelled is 2,9, and the weighted average value of the time is 11 minutes. The histogram, in Figure 42, reports the central Trieste locations where the students live and, as expected, the most frequently mentioned are halfway between the main university buildings and the city centre.

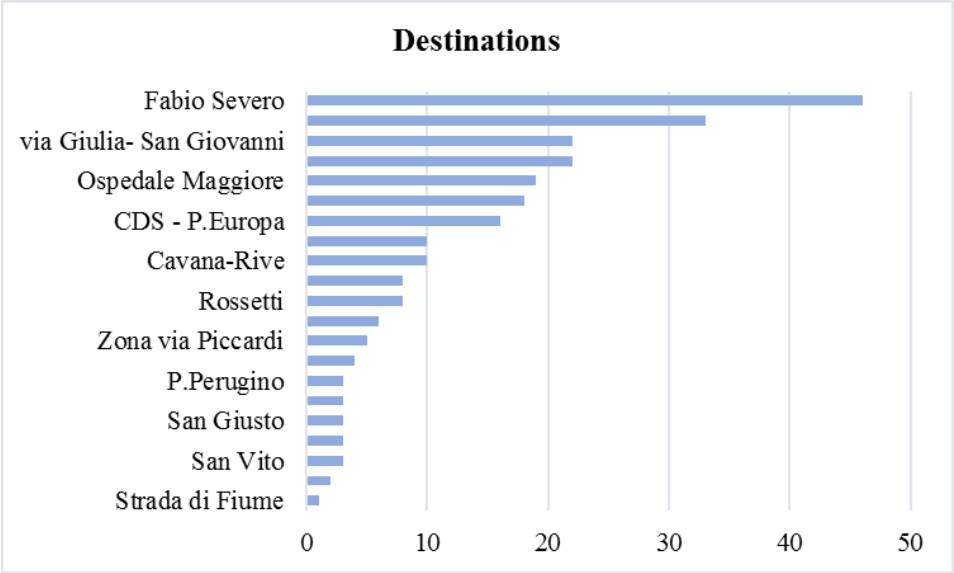


Figure 42: Destinations - Non-Residents

5.7.4 Residents in Trieste

One hundred ninety-four students among the interviewed declare to be resident in Trieste. No specific enquiries have been submitted to the students who belong to this category, excluding the general questions already analysed. Since the service suggested for residents is designed to be also used by non-residents, the answers are analysed together for the two categories and explored in the next section (5.7.5).

5.7.5 Night Trips

To acquire data for the service planning, both residents and non-residents have been asked to declare the means of transport that they are using for the night trips. Figure 43 shows the current modal split and emerges that more than half of the interviewed currently move on foot during the night, followed by bus (19%) and car as a driver (17%). However, exploring separately the modal split for residents and non-residents considerable differences emerge between the two groups: residents prefers moving by car (34%) and in the 26 % of the cases travel on foot, while, much as 74% of the non-resident move on foot and only the 2% choose the private car for their night trips (cf. Figure 44). This fact reflects the rate of private car ownership, as already discussed (cf. Figure 35). Differences in the modal split, also, emerge from the analysis of the almost 3000 answers of a questionnaire administered in November 2019 to all the students of the University of Trieste concerning night mobility.

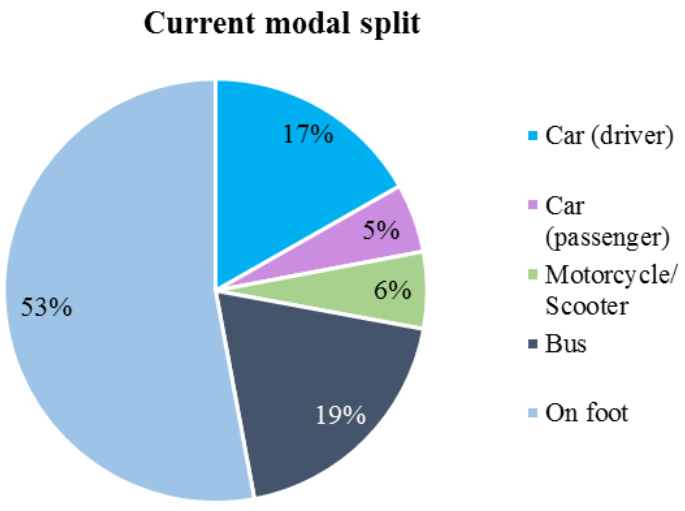


Figure 43: Current Modal Split - Night Trips

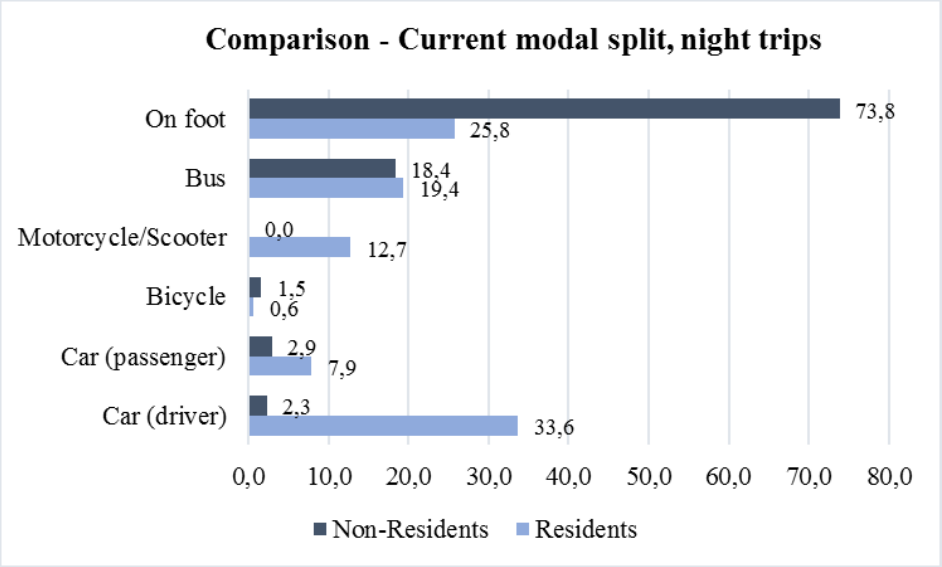


Figure 44: Current Modal Split, Night Trips - Residents and Non-Residents

Since one of the main objectives of the car sharing initiative introduction is the limitation of the private car usage, like for commuters, the collected data has been elaborated to understand better the current transport mode of people who state their interest towards car sharing. Since the results are very different for the two categories, the modal split has been inspected separately for residents and non-residents. It appears that for residents the car sharing enterprise can be a valid substitute of the private car for almost the half of the residents who express their favour towards the new modality, while for the non-resident car sharing will substitute walking in the 68% of the cases. Table 29 reports the repartition of the means of transport currently used by the students who declare to be interested in car sharing for the night trips.

Table 29: Current Transport Mode of Students Interested in CS, Night Trips

	Residents	Non-Residents
	People who declare to be interested in CS currently are using:	
Car (driver)	44,8 %	5,3 %
Car (passenger)	6,0 %	5,3 %
Taxi	0	2,2 %
Bicycle	0	0
Motorcycle/Scooter	7,5 %	0
Bus	26,9 %	19,4 %
On foot	14,9 %	67,8 %

To better inspect night trips, the time in which they would leave and return if the service was available, has been investigated. The achieved results are reported in Figure 45, and the average time, they declare that they would use the service, is almost 2:30 hours.

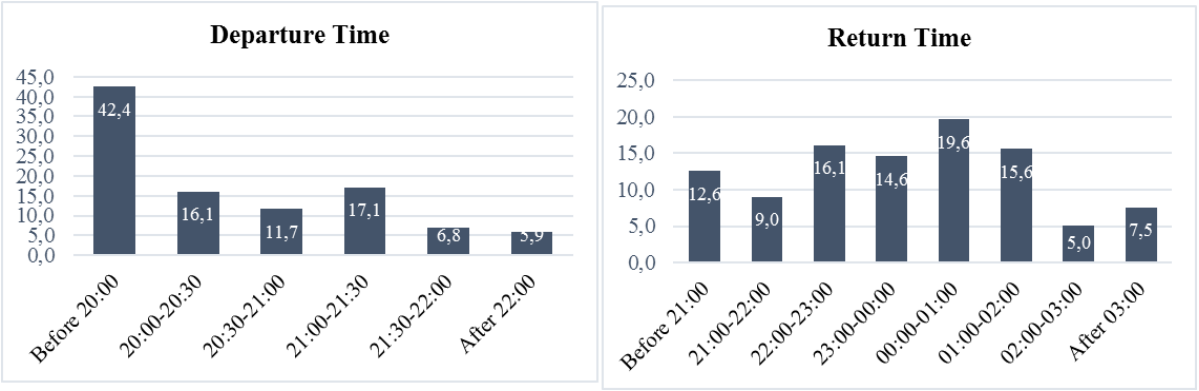


Figure 45: Departure and Return Time - Residents

To better comprehend the reasons behind the choice of the car sharing alternative, also the aims of the hypothetical trip which will be travelled with the innovative service are investigated and it emerges that most of the respondents choose car sharing when they travel for entertainment or dinner (Figure 46).

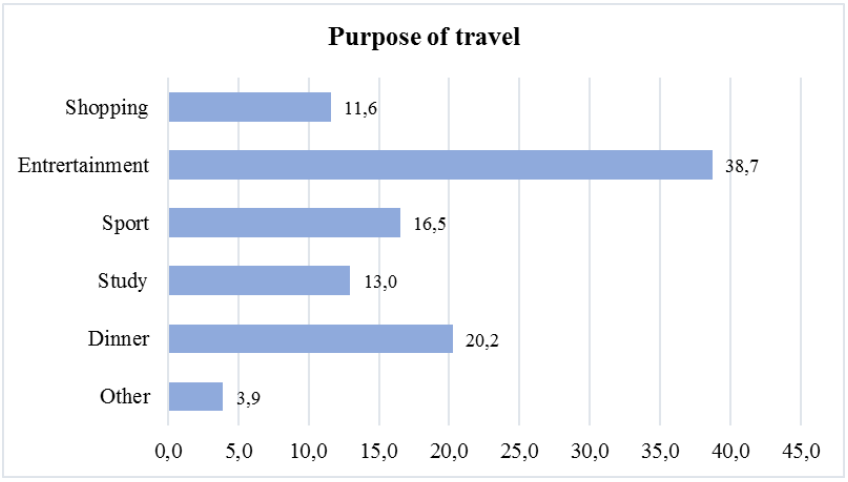


Figure 46: Night Trips - Purpose of Travel

The origin/destination matrix for the night trips has been developed (cf. Annexe 5.2) and, like for the non-residents who travel from the train station to their final destination, for the most chosen O-D couples the distance has been calculated as well as the time spent. Similar results emerge also from the almost 3000 answers of a questionnaire administered in November 2019 to all the students of the University of Trieste.

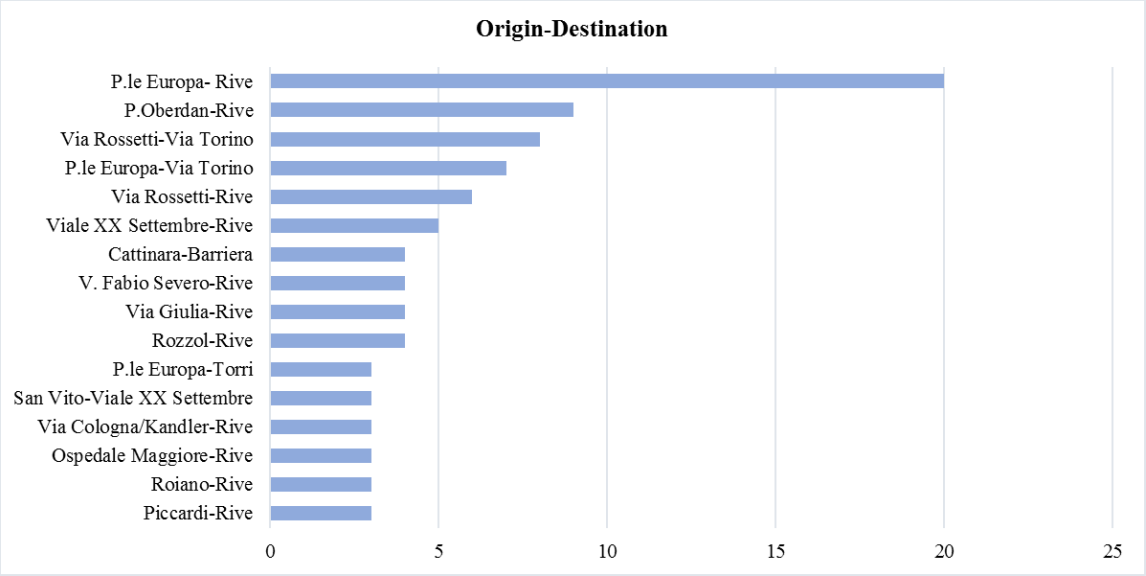


Figure 47: Origins and Destinations - Night Trips

5.7.6 Public Transport and Car Sharing

The relationship between car sharing and public transport has been investigated, taking into account three main aspects:

- physical location integration: this aspect has a low influence on the choice of the car sharing since in the area of interest, i.e. Trieste centre, the buses' stops are very close to each other [mean 250 m];
- information and data integration: this issue is crucial in harmonising the two services (buses and car sharing), but it will be better detailed and discussed in the operative phase: clearly, an agreement between the two operators of the services is crucial;
- ticketing and fare integration: this aspect is explored thanks to the questionnaire, from which emerges that, for the night trips, the possibility of benefit of a price reduction for those who own a public transport season ticket influence the car sharing alternative selection, since car sharing is chosen, in the 70% of the cases, when this possibility is allowed. Furthermore, it is possible to state that, after cost, it is the second parameter which has more influence on the car sharing choice. Since the night car sharing service is designed to overcome the lack/the low efficiency of public transport during the night, the suggested initiative has the potentiality for being complementary to buses. Very different is the situation for commuters, since in this case the car sharing service is designed to bring relief to the overcrowded buses of the morning peak hour, and so, it is intrinsically in competition with public transport.

5.7.7 Declared Interest in Car Sharing

In the questionnaire, the direct question "Would you like to use the car sharing service (according to the declared conditions)?" is asked to students. In Table 30, their choices, expressed in the surveys, are reported:

Table 30: Declared Interest in CS

		I am interested in Car Sharing [%]	I am not interested in Car Sharing [%]
Non-Resident (Sunday night service)		23,2 %	76,8 %
Commuters		31,1%	68,9%
Night trips	Resident	18,5 %	81,5 %
	Non-Resident	30,8 %	69,2 %
	Jointly	25,5 %	74,5 %

5.7.8 Answers Confidence

As accounted in section 4.1 - Step 13, when analysing SP responses an important issue regards the fact that often SP responses do not always reflect people true preferences [207]. The ex-post method to reduce the bias, suggested by Champ et al. (1997) [211], has been tested on the online survey, by introducing a final question which asks how much the respondents are sure about their answers on the SP options. From this test emerges that 0,7 % of the respondents declare "to be definitely not confident", 17,6% "not very confident", 63,6% "quite confident" and 18,1 % "absolutely confident". Regarding the online survey and the answers of both categories for the night trips, it emerges that people who declared to be interested in car sharing are almost 22,2%, while, only considering who declared to be absolutely confident and quite confident the rate decreases to 19,7%. Table 31 reports the rate of interest in the car sharing service, as declared in the surveys, together with the preventive service knowledge rate in relation to the level of confidence about the answers. It emerges that people who are absolutely confident in what they stated are already aware of the system.

Table 31: Confidence in the Answers

	Interest in Car Sharing	Non-interest in Car Sharing	Car Sharing Knowledge
absolutely confident	3,9 %	96,1 %	70 %
quite confident	25 %	75 %	49 %
not very confident	33,8 %	66,2 %	52 %
definitely not confident	0	0	/

5.8 Potential Demand Estimation: Model Development

Several models have been developed:

- Model NR: related to the service for students who are not resident in Trieste but accommodate in the city: they often spend the weekend at home, and, on Sunday night, they came back to the city to attend classes during the weekdays. The suggested car sharing initiative would allow them to use a car to reach their lodging from the Trieste train station.
- Model COM: related to the service studied for commuters who arrive in Trieste by train every weekday. Car sharing would help them to reach university sites.
- Model NIGHT: this model is related to the night car sharing service, and it has been calibrated with all the available data collected through the pen-and-paper and the online surveys both among resident and non-resident. The model has also been compared with the ones calibrated through the pen-and-paper database (resident and non-resident) – NIGHT_PAPER – and trough the online survey data (resident and non-resident as well) – NIGHT_ONLINE –.

Several model specifications were tested with the binomial logit (BNL) structure, and the software package Biogeme [213] is used to perform discrete choice analysis based on the maximum likelihood estimation techniques. The goodness of the fit of the different model specifications was compared through the analysis of the software outputs. The main statistical tests performed are t-test, ρ^2 test, Akaike Information Criterion, Bayesian Information Criterion, and the Likelihood Ratio Test, in addition to an informal sign test of the different coefficient (see 2.3.2.2).

The following sections present Model NR (cf. 5.8.1), Model NIGHT (cf. 5.8.2) and Model COM (cf. 5.8.4) in their formulation, calibration and validation; in order of not being repetitive some analysis have been reported only once, such as for elasticity (cf. 5.9).

5.8.1 Model NR

After a long "trial and error" process, the following expression best describes the utility function:

$$V_{CS-nr} = \beta_c \cdot cost + \beta_{dis} \cdot \text{dist} + \beta_{rtp} \cdot \text{rtp} + \beta_{cp} \cdot \text{cp} + \beta_{age} \cdot \text{age} + \beta_{ptfee} \cdot \text{ptfee}$$

$$V_{NO-nr} = \alpha_{no} + \beta_{veh} \cdot \text{vehicle}$$

With:

V = Systematic utility

CS = car sharing alternative

NO = status quo alternative

β_x = parameters

cost = cost [€/h]

dist = distance from the CS station to the final destination [min] on foot

rtp = price reduction for those who have a public transport fee [binary]

cp = availablity of sharing the trip [binary]

age = respondent age

ptfee = respondent owning a public transport fee [binary]

α_{no} = alternative specific constant

vehicle = respondent owning a vehicle for the trips in Trieste [binary]

The parameters are reported in Table 32 and Table 33:

Table 32: Model's Parameters - NR

Parameter:	ASC_{no}	β_{ptfee}	β_c	β_{cp}	β_{dis}	β_{veh}	β_{age}	β_{rtp}
	3,46	-1,07	-0,879	1,23	-1,45	1,18	2,08	1,31

Table 33: Model's Parameters from Biogeme – NR

	Value	**Std err**	**t-test**	**p-value**
ASC_NO	3.46	1.64	2.11	0.03
BETA_PTFEE	-1.07	0.338	-3.15	0.00
BETA_COST	-0.879	0.301	-2.92	0.00
BETA_CP	1.23	0.309	3.96	0.00
BETA_DIST	-1.45	0.989	-1.47	0.14*
BETA_AGE	2.08	0.539	3.86	0.00
BETA_VEHICLE	1.18	0.440	2.68	0.01
BETA_RIDTPL	1.31	0.312	4.21	0.00

The ASC for the Car Sharing alternative is zero because the ASCs are estimated relative to each other because in the BNL models the choice probabilities of the alternatives are related to the differences of the systematic utilities of different alternatives [224].

Through the analysis of the model formulation, it is possible to notice that gender and knowledge do not have any influence on the choice of the car sharing alternative. As well as the presence of electric vehicles in the fleet does not influence the final respondents' choice: it seems that students who demonstrate to be interested in the service itself more than the type of available cars. It is an interesting result since from a previous survey, conducted among 399 university students in 2018 (cf. Annexe 5.1), emerges that they identify the presence of electric vehicles in the fleet as an important factor especially in order to reduce the air pollution. However, in this previous research, the question on electric vehicles was laid down in "general terms", i.e. without connecting this aspect to their

behaviours. It was directly asked students "on a scale of one to ten, how much do you define as indispensable that the fleet would include electric vehicles? (one = absolutely not indispensable, ten = Absolutely indispensable)". Considering the supply's factors, the probability of being a car sharing member decreases with the distance among stations and the cost, while it increases if the service can be used without paying the annual fee for who possess a bus season ticket and members are allowed to carpool. Age is the individual characteristics which increase the probability of joining the new service, while the owning of a public transport fee reduces it. This can be explained since this form of car sharing initiative provide a mobility service when the public transport is not available, and hence students do not consider the owning of public transport as an influent factor for the choice of car sharing. Moreover, it could be possible that the non-residents who own an urban bus season ticket are prevalently those who do not come back home very frequently during the weekend and, consequently, they are not interested in this kind of service. The personally owned car decreases the probability of being a car sharing member.

Once the model has been estimated, its capability in reproducing the collected data has been verified through a developed excel spreadsheet and also trough the software Biogeme [213], and the results coincide.

The model is able to reproduce the collected data: in the collected data the 23,2 % of the interviewed declare to be interested in the car sharing alternative, and the same value is obtained with the model developed in the spreadsheet and with Biogeme.

The model fits very well the data and the statistic tests carried out are schematically reported in Table 34, whereas it is essential to underline that these tests cannot be used as the unique criteria for model acceptance or rejection [160]:

Table 34: Statistic Tests - model NR

Statistic test	Result	Comment
Sign test	Informal test	The signs of the parameters are all in line with what was expected. The owning of a public transport season ticket is a negative value.
Standard Error	Higher values for β_{dis} (0,989)	This test is related to the t-test; it measures the accuracy with which the sample represents the population: it will influence the confidence interval of the market share (bigger the standard error, bigger the interval of the market share). A possible and plausible reason for a high standard error is that the data collected is not a sufficient amount and that the variability of data is not sufficient (maybe the chosen levels, even if plausible, do not present very different values). Collecting more data would be useful.
T-test	Always > |1,96| (CI 97,5%)	The critical value for the t-test is chosen by the designer and is 97,5%, but, as declared by Bierlaire (2016) [225], the statement "remove

	except for β_{dis} (-1,47).	coefficients that have a t-test less than 1.96 (in absolute value) is not necessarily correct" has been assumed as valid [224]. In this situation it has been chosen not to reject the parameters since in literature there is evidence that distance to be covered on foot from the station to the final destination influences the decision towards car sharing and so the null hypothesis [β=0] does not make sense. Moreover, it has been evaluated that the potential damage in including an irrelevant variable (Type I error) is smaller than omitted a relevant one (Type II error) since in the first case the model will lose efficiency, i.e. the estimates have large variance, while in the second it will produce a specification error.
p-value	Always < |0,05| except for β_{dis} (0,14).	the p-value is calculated as 2(1-Φ(t)) where Φ is the cumulative density function of the standard normal distribution and t is the t statistic of the previously described test. The threshold, alpha, is set 0,05. The values higher than 0,05 represent a potential lack of statistical significance, however, as already express for the t-test, β_{dis} is considered a relevant variable.
Likelihood Ratio Test	To compare two models	It has been performed to compare two models when one of them is the restricted version of the other, e.g. when removing some parameters which have a low t-value. This test is carried out in combination with the assessment of the AIC (Akaike Information Criterion – 303,7) and BIC (Bayesian Information Criterion – 334,1): the best model is the one with these two values lower.
ρ^2	0,375	As stated by Bhat and Koppelman (2006) [224] there is not a reference value for a "good" ρ^2; however, it is an acceptable value in literature.

5.8.2 Model NIGHT

The night model has been calibrated through the data collected the answers of resident and non-residents to both the pen and paper and the online questionnaires since the joint database was broader (1538 choice sets) and the resulting model better fits data. Nevertheless, section 5.8.3 reports also the models which have been formulated and calibrated using the split databases (pen-and-paper and online) and further considering the database with only the online responses of the students who declared to be "definitely sure" or "quite sure" in their answers (cf. 5.7.8).

Several formulations have been tested and through Biogeme software [213] has been possible to identify the best functional form of the utility function and to estimate the parameters.

Some variables are defined as the product of the variable's value and the binary term "type" which stands for "student typology/category" and is set as equal to one for resident and two for non-

residents. The idea behind this is that some variables are differently perceived by the two students' categories under investigation.

$$V_{CS} = \beta_{cost} * cost * type + \beta_{dis} * dist * mosp + \beta_{rtp} * rtp * type + \beta_{ow} * ow + \beta_{type} * type$$
$$V_{NO} = \alpha_{no} + \beta_{male} * male$$

With:

V = Systematic utility

β_x = parameters

cost = cost [€/h]

type = resident [1], non − resident [2]

dist = time [min] to reach the CS station on foot

mosp = modal split: bus [0]; car, taxi, moto [0,5]; on foot, bicycle [1]

rtp = price reduction for those who have a public transport fee [binary]

ow = allowing vehicle drop − off in a station different from that of departure [binary]

α_{no} = alternative specific constant

male = male [1], female [0]

The estimated parameters' values are (Table 35):

Table 35: Model's Parameters - NIGHT

Parameter:	ASC_{no}	β_{cost}	β_{dist}	β_{rtp}	β_{ow}	β_{typ}	β_{male}
	2,26	-1,58	-0,641	0,537	0,676	0,883	0,400
Std Error	0,240	0,718	0,225	0,075	0,125	0,226	0,126
T-test	9,40	-2,21	-2,85	7,18	5,33	3,91	5,40
p-value	0,00	0,03	0,00	0,00	0,00	0,00	0,00

It is noteworthy that distance is influenced by the means of transport which is most frequently used for the night trips. People who are already used to walk or cycle differently perceive the distance to cover to reach the station/final destination: a possible explanation is that if the distance is too long, they do not experience any benefits from using the shared system instead of walk. The probability of being car sharing member will increase if the annual fee is free from the possessor of a bus season ticket and it is possible to leave the vehicle in a station different from where it was picked-up. Distance and cost decrease this probability. Non-residents are more likely to become member of the new initiative, and, even among the individual characteristics, gender influences the choice of the car sharing alternative, in particular women are slightly more attracted by the service, perhaps this can be justified considering that using car sharing instead of walking can be perceived as safer for a girl in the night. The model reproduces the collected data (1538 choice sets) and, with the 90% of

confidence, it is possible to state that the students interested in this kind of car sharing service lies between 21% and 30%.

Table 36: Statistic Tests - Model NIGHT

Statistic test	Result	Comment
Sign test	Informal test	The signs of the parameters are all in line with what was expected. The parameters for cost and distance have negative values since their increment is perceived as a disadvantage towards the car sharing alternative.
Standard Error and T-test	T-test always > |1,96| (CI 97,5%)	The alternative specific constant is immaterial since the constant includes all the effects of all the not included variable. The t-test is always higher than 1,96, and for several parameters, it is higher than 2,58 which correspond to a confidence interval of 99%.
Likelihood Ratio Test	To compare two models	It has been done to compare two models when one of them is the restricted version of the other, e.g. when removing some parameters which have a low t-value. This test is carried out in combination with the assessment of the AIC (Akaike Information Criterion – 1631,9) and BIC (Bayesian Information Criterion – 1669): the best model is the one with these two values lower. The test has been used to define the best model, as reported in 5.8.3.
ρ^2	0,241	As stated by Bhat and Koppelman (2006) [224] there is not a reference value for a "good" ρ^2; however, it is an acceptable value in literature.

5.8.3 Models NIGHT - Comparison

The model NIGHT has been compared to those calibrated only with the separate database collected through pen-and-paper and the online survey. As express by Efthymiou and Antoniou (2016) [73], the two surveys' results are different, especially in terms of responses' honesty and issue's understanding. First of all, the same model formulation is tested for all the different databases, and then a new formulation is tested, in order to define the one which best fits the collected data. The likelihood ratio test has been used to compare the models when one is a restricted version of the other. The null hypothesis is that the restricted model is better than the other: this hypothesis is rejected if $\chi^2(conv) > critical\ value$. The critical value is related to the level of confidence desired and is also influences by the number of restrictions.

The definition of the best formulation is a labour-intensive "trial-and-error" process, only as an example here two formulations are reported and compared:

Formulation A (joint formulation):

$V_{CS} = \beta_c * cost * type + \beta_{dis} * dist * mosp + \beta_{rtp} * rtp * type + \beta_{ow} * OW + \beta_{type} * type$

$V_{NO} = \alpha_{no}$

Formulation B: extends specification A by adding gender variable

$V_{CS} = \beta_c * cost * type + \beta_{dis} * dist * mosp + \beta_{rtp} * rtp * type + \beta_{ow} * OW + \beta_{type} * type$

$V_{NO} = \alpha_{no} + \boldsymbol{\beta_{male}} * \boldsymbol{male}$

Table 37: Model's Parameters – Comparison

Parameter:	ASC_{no}	β_c	β_{dis}	β_{rtp}	β_{ow}	β_{type}	
	2,41	-1,61	-0,621	0,542	0,661	0,876	
t-test	10,20	-2,25	-2,78	7,27	5,30	3,89	
Parameter:	ASC_{no}	β_c	β_{dis}	β_{rtp}	β_{ow}	β_{type}	β_{male}
	2,26	-1,58	-0,641	0,537	0,676	0,883	0,400
t-test	9,40	-2,21	-2,85	7,18	5,40	3,91	3,18

Table 38: Likelihood Ratio Test

	LL (conv)	N. of parameters
Formulation A	-814,1	6
Formulation B	-808,9	7

$|-2\,[\mathcal{L}_R - \mathcal{L}_U]|$ = -2 (-814,1+808,9) = 10,4 > 3,84 (95%)

It emerges that the best model is the last one, the one which includes the gender characteristic which is a positive value for not to choose the car sharing option, i.e. being male influence negatively the car sharing adoption.

Below are reported the different formulations of the utility functions when considering only separate fractions of the whole database:

- the database with the answers obtained by the pen-and-paper survey called PAPER;
- the database with the answers obtained by the online survey called ONLINE;
- the database with only people who declare to be confident (quite and absolutely) when completing the questionnaire, called CONFIDENCE.

PAPER:

Formulation:

$V_{CS} = \beta_c * cost * type + \beta_{dis} * dist * mosp + \beta_{rtp} * rtp * type + \beta_{ow} * OW + \beta_{type} * type$

$V_{NO} = \alpha_{no}$

Choice set: 283

Table 39: Model's Parameters - Paper Database

PAPER database						
Parameter:	ASC_{no}	β_c	β_{dis}	β_{rtp}	β_{ow}	β_{type}
	2,37	-6,02	-0,304	1,53	0,848	1,62
t-test	3,84	-2,91	-0,92	4,20	2,44	2,06

Percentage of respondents who chose car sharing alternative: 38%

ONLINE

Formulation:

$$V_{CS} = \beta_c * cost * type + \beta_{dis} * dist * mosp + \beta_{rtp} * rtp * type + \beta_{ow} * OW + \beta_{type} * type$$

$$V_{NO} = \alpha_{no}$$

Choice set: 1136

Table 40: Model's Parameters - Online Database

ONLINE database						
Parameter:	ASC_{no}	β_c	β_{dis}	β_{rtp}	β_{ow}	β_{type}
	2,79	-1,10	-0,507	0,287	1,08	0,847
t-test	8,81	-1,33	-2,73	3,48	6,93	3,11

Percentage of respondents who chose car sharing alternative: 22%

Paper and online databases differ not only for the modality of data acquisition but also for the sample size, and this leads to some difficulties in comparing the results. Moreover, from a psychological point of view, people who are asked to complete the paper surveys are enrolled before lessons at the presence of their professor and, before the survey administration, a brief introduction on car sharing and sustainable mobility is made. These factors lead them to pay more attention when filling out the questionnaires and make them feel more inclined to answer positively towards the car sharing adoption.

CONFIDENCE

Formulation:

$$V_{CS} = \beta_c * cost * type + \beta_{dis} * dist * mosp + \beta_{rtp} * rtp * type + \beta_{ow} * OW + \beta_{type} * type$$

$$V_{NO} = \alpha_{no}$$

Choice set: 920

Table 41: Model's Parameters - Confidence Database

CONFIDENCE database						
Parameter:	ASC_{no}	β_c	β_{dis}	β_{rtp}	β_{ow}	β_{type}
	2,80	-1,41	-0,596	0,283	0,922	0,866
t-test	7,76	-1,46	-1,96	2,93	5,13	2,77

The percentage of respondents who chose car sharing alternative is 19,6 %.
This model formulation and calibration has been used for dimensioning the car sharing and testing different service solutions, as reported in 5.13.

5.8.4 Model COM

The model has been calibrated, taking into account all the data collected through different surveys (pen-and-paper and online).

$$V_{CS} = pat * (\beta_{cost} * cost * abbtpl + \beta_{bloc} * bloc + \beta_{cp} * cp) + \beta_{train} * train$$
$$V_{NO} = \alpha_{no}$$

With
$V = Systematic\ utility$
$\beta_x =$ parameters
cost = cost [€/h]
abbtpl = owning an urban public transport season ticket [binary]
bloc = maximum days of continuous reservation [2; 5]
cp = possibility of sharing the trip with another student, splitting the usage costs [binary]
train = owning a train subscription [binary]
α_{no} = alternative specific constant

Table 42: Model's Parameters - COM

Parameter:	ASC_{no}	β_{cost}	β_{bloc}	β_{cp}	β_{train}
	1,97	-0,261	0,213	1,32	0,267
Std Error	0,448	0,132	0,094	0,301	0,352
T-test	4,39	-1,98	2,27	4,39	0,76
p-value	0,00	0,05	0,02	0,00	0,45

5.9 Elasticity

In order to anticipate the effects of the change of the value of the independent variable on the choice of an individual and, consequently, on the market share of the concerned alternative, elasticity can be evaluated. Direct elasticity is the percentage variation of the demand relative to the choice probability of the alternative investigated, divided by the percentage variation of the attribute, relative to the attribute itself [85]. In Figure 48 is reported the car sharing choice probability curve (Model NR) in relation to the "cost" attribute; for cost values higher than 4 €/hour the curve tends to be anaelasic (circled in red).

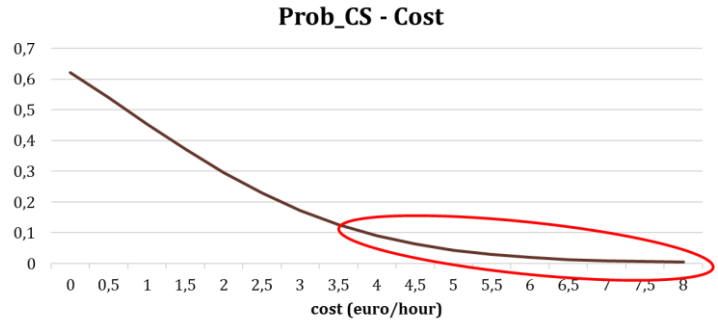


Figure 48: Car Sharing Elasticity - Cost

Figure 49 reports the Logit Model probability curve: the Cumulative Distribution Function (values on the right) and Probability Density Function (on the left) for car sharing in relation to cost for one standard respondent are plotted. On the abscissa are reported the values of the systematic utility V_{ij} considering fixed all the attributes and variating only the cost attribute. It is possible to observe that there is a graph portion over the negative cost values, which are unrealistic since it means that people are paid to use the service and not vice versa.

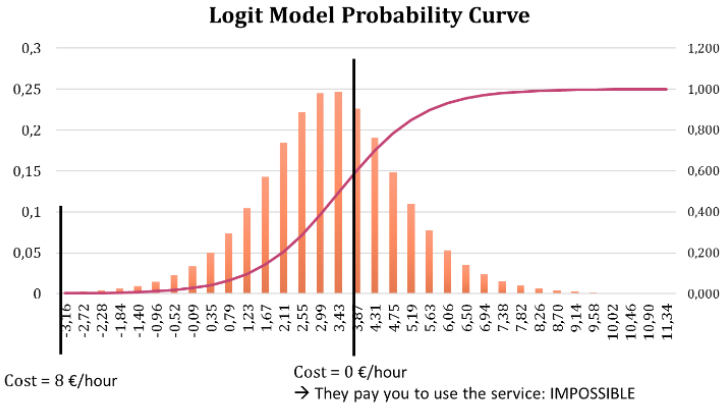


Figure 49: Logit Model Probability Curve - Cost

5.10 Loop Procedure

As highlighted in Figure 6 the planning process is not linear, but the designer has to adapt his choices based on feedback from the previous steps, also changing decisions which were already established, on the basis of the new outcomes.

In this case study, after data collection and the model development, it emerges that some modifications in the proposal of intervention have to be done.

As already reported in the sections dedicated to the model (cf. 5.8), some supply attributes, e.g. the presence of electric vehicles in the fleet, seem not to influence the service adoption.

Moreover, modelling brings out clearly that the service suggested for commuters does not satisfy the project objective of implementing an initiative complementary to the bus and that does not increase the traffic congestion. Indeed, after the model formulation, calibration and validation several scenarios have been developed and assessed (varying the supply elements), but in each of them the level of congestion would be significantly increased and the number of bus users reduced with high losses of money for the public transport operator. In Figure 50 is reported the current modal split for the commuters urban trips together with the potential modal split in the scenario with car sharing, as declared by the survey's respondents.

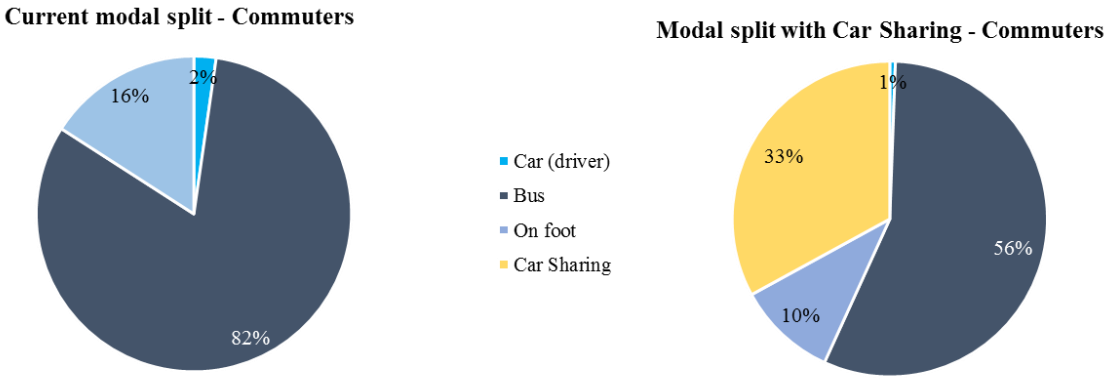


Figure 50: Commuters Modal Split

Moreover, the commuters' flow is strongly unidirectional, i.e. in the morning all of them depart from the train station to reach the main university sites and vice versa in the evening and, consequently, vehicles would be parked for almost all day in the university parks. This would be unsustainable since the service implementation aims to reach the opposite effect (i.e. reducing the number of cars parked) and, what is more, the parking areas near the university sites are already very scarce compared to the number of vehicles, and it would not be possible to allocate new areas for this purpose. For the university sites which are located in the city centre, the feasibility of allowing the usage of these vehicles to employees of a company located near the university, while students attend

classes could be studied to try to overcome the barrier of the vehicles stationary in the parking areas. However, the problem of rising the traffic level during the morning-peak will keep remaining.
So, only one service is dimensioned, the night one, considering different scenarios, one of which also integrate the Sunday night service. The service dimensioned is of type station-bases round-trip. The demand and supply's elements considered are reported in Table 45.

5.11 Aggregation

Data collected refers to the single individual of the sample, so, in order to expand the results to the whole target population the sample enumeration with classification is the aggregation procedure followed (cf. Aggregation 2.3.2.3).
The night mobility problem is very similar for both residents and non-residents in Trieste, nevertheless, the two categories present some differences, and, moreover, the rate between the two categories in the sample do not perfectly correspond to the population. So, to overcome these issues, each individual has been associated with a weight. The sum of the weights is equal to the number of individuals in the sample. The computed weights are reported in Table 43. The total number of students has been achieved from the "Osservatorio Studenti Didattica" [226] considering only the students of the University of Trieste enrolled in the Trieste site, i.e. without taking into account the students enrolled in Pordenone, Portogruaro e Gorizia (approx. 10%).

Table 43: Weights

	Residents (29%)	Non-Residents (47%)
Target population	3980	6450
Sample	660	878
% target population	38,2	61,8
% sample	42,9	57,1
Weight	0,89	1,08
Tot students	13.724(year 2017/2018 in Trieste, [226])	

Aggregation process is included in the tool for the dimensioning of the supply's elements (cf. section 4.1 - Step 17 and 5.13).

5.12 KPIs Definition

Since the goal of the case study implementation is to test the developed methodology, and it is a hypothetical case since no one committed it properly, some assumptions have been made on the objectives and the client typology.

The car sharing service aims to overcome the problem arisen by the students, both resident and non-resident: the lack of proper service for the night trips. It is assumed to be a station based round-trip car sharing, targeted on students and available during the night-time (7 P.M. – 3 A.M.). Vehicles can be reserved through an APP, at least one hour before the car usage. Users can share the trip with another member and split the travel costs. Stations are located all around the city. The operator is supposed to be a for-profit company.

The service goals are:

- satisfy the potential users' needs for mobility;
- bring economic profit for the operator of the service;
- minimising the parking area required;
- minimising the number of potential users who are currently bus users and maximising the shifting from private cars;

The main KPIs, which capture these objectives, are reported in Table 44: for each of the previous objectives are indicated the corresponding indicators and, for each of them, is reported the optimization process (cf. 5.14):

Table 44: KPIs

Goals	KPIs	Optimization
Satisfy the potential users' needs for mobility	Number of members;	Maximisation of the KPI;
	Members/Vehicles; Rentals per day/Vehicles; Vehicles/Stations;	In the optimization process these indicators are considered as constraints (cf. section 4.1– Step 17 and Table 21). Lower values for the first two ratios indicate a higher level of service, while for the last one higher value stands for a better level of service.
Bring economic profit for the operator of the service	Revenues per year [€/year]; Costs per year [€/year];	Maximization of the difference between KPIs;
Minimising the parking area required	Square meter intended for parking area [m^2];	Minimisation of the KPI
Minimising the number of potential users who are currently bus users	Number of people shifting from bus;	Minimisation of the KPI.

5.13 Supply Elements Dimensioning and Scenario Simulation

The developed spreadsheet model, presented in Chapter 4, has been applied to define different scenarios and find out the best solutions for the planning of the new service.

The process which brings to the definition of the best scenario is comprehensive also of the optimization phase, i.e. the various steps (elements' dimensioning - aggregation, scenario simulation, optimization) are repeated in a loop until reaching a satisfactory scheme.

To ease the understanding, the optimisation results are reported in a separate section (cf. 5.14).

The implemented tool manages the interaction between demand and supply, analysing the effects produced by the variation of the supply elements over the likelihood that people adopt car sharing. The discrete choice model (cf. 5.8), calibrated based on the stated preference data (cf. 5.6), is applied to estimate the market share by varying the different system's characteristics (walking time to reach the car sharing station, cost, etc.). The probability of choosing the car sharing alternative is related, thanks to the estimated utility function, to the supply's attributes and so the number of potential users is not a unique value but varying with the service modifications.

The case study implementation goal is to test the developed methodology, and so, for this reason, it has also been tested for purposes which would not have been necessary if the methodology had been applied for a real case. The best scenario for the night service has been researched under different conditions of:

- objectives: maximisation of the operator profit, maximisation of the number of members, minimisation of the area requested for parking the vehicles or minimisation of the number of bus users who shift to car sharing or even some combinations of these goals;
- input parameters: making varying some parameters which, in real cases are known (e.g. costs of office renting) or parameters which are defined by the average value of the information collected through the questionnaires (e.g. potential users travel time);
- vehicle typology: considering different car manufacturers.

Moreover, a scenario is also post-evaluated, considering two different situations:

- the case where the service is expanded to overcome the problem of the non-residents who reach Trieste on Sunday night. Differently from the "night service", which is a station-based round-trip service, this new one, is of type station-based one-way. The algorithm has been applied in reversed way compared to the original scenario, i.e. have been deployed the service supply data (like the number of cars, stations, parking lots) which results from the previously defined night service, and, then, the number of potential members, revenues and costs for the operator have been re-computed and assessed through the application of the so-called NR model (cf. 5.8.1);

- the case in which the urban public transport operator strengthens its service also during the night.

This dissertation presents only these scenarios; however, of course, there are other latent potentialities: e.g. during the day, the vehicles could be used by a company for its employees' trips or a city-wide car sharing service from the morning till 7 P.M. can be started with the same fleet. Another alternative is that the University itself (or another public authority) makes available its fleet. Furthermore, the students themselves could start the service (peer-to-peer car sharing – cf. 2.1.3.2) or by the public transport city company and, in these cases the costs items, as well as the objectives, would be different. Finally, a further option can be the implementation of a car sharing service, usable not only by the students but also by the university staff and professors. These proposals should be managed with the collection of more new data, and, in some cases, starting the planning procedure again from the beginning.

Figure 51 represents the scheme of the process implemented to define the potential number of members (through sample enumeration technique), rentals on the peak-day, modal shift, operator's costs and revenues according to factors such as the number of stations, vehicles, kilometric costs, sharing trips possibility and the required number of parking lots.

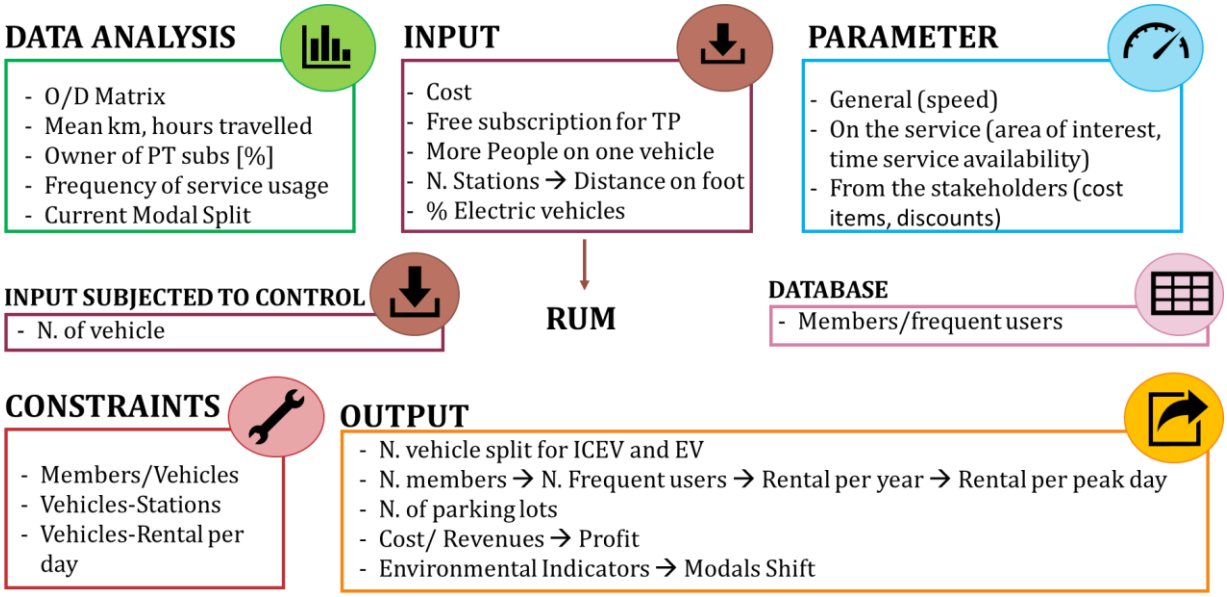


Figure 51: Planning Scheme

The tool for dimensioning the supply's elements is composed by several modules, which have already been detailed in Chapter 5 and here are reported in an applicative perspective: to make the explanation clearer, the discussion on the case study follows the structure of the developed spreadsheet modules:

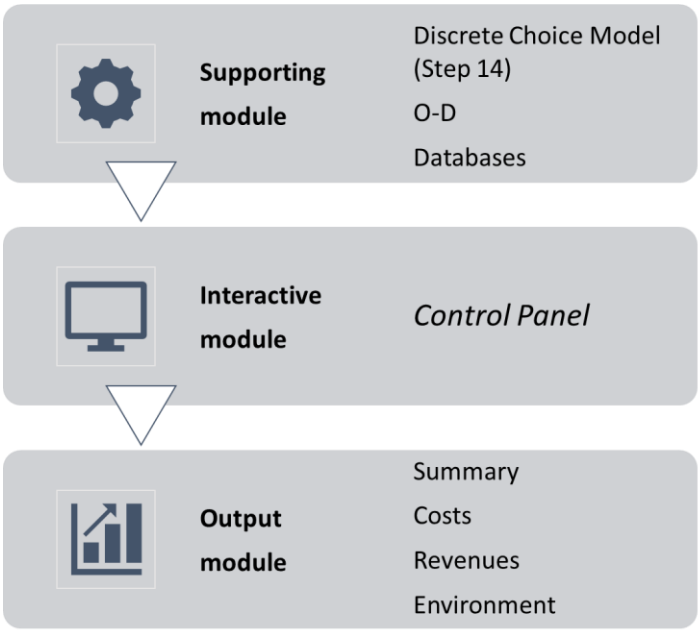


Figure 52: Spreadsheet Modules

Supporting module

- In the first module, the developed model (cf. 5.8.3) is reported. The model is adapted for the forecasting purpose, and the attributes can be varied through the "control panel module". The sample enumeration (with classification – resident and non-resident for the NIGHT service, weights reported in Table 43) is implemented to define the number of students who are potentially interested in the service. The University global survey data (cf. 5.3) is taken as reference for the population data.
- The O-D module presents the O-D matrix, mentioned in 5.7.5., and reported in Annexe 5.2; data on trips origin and destination are taken from what explicit on the questionnaires by students who declared to be interested in car sharing. The matrix does not report the real number of trips made in the reference period, but only the number of trips of the sample; to overcome this issue the collected number of trips are included into the O-D module as percentage value. Each of the origin zones (for the NIGHT service - roundtrip) and destination zone (for NR service – one-way) is considered as a station for the service. From these values, alongside the study of the area of interest and the land use, the designer can define the required stations' number.
- Two supporting databases: one with the data collected by previous similar services by the "Osservatorio Nazionale Sharing Mobility" and one with the data related to purchasing, operative and reselling costs for the chosen vehicle types: the vehicles taken into consideration for the case study implementation are (Figure 53):
  - Renault Twingo: gasoline, city-car, 110CV, Euro 6, 4 seats, vel max 151 km/h;
  - Renault Zoe: electric, 58CV, 5 seats, vel max 135 km/h;

Figure 53: Renault Twingo and Zoe

Their purchasing costs have been taken from "quattroruote" [227], the resale prices are taken from an online service [228] and the maintenance costs are taken from the "Tabella ACI: tariffe rimborso chilometrico" [229]. The database on the Italian car sharing services is taken as reference for the indicators "rentals/vehicles" and "members/frequent users".

In order to test the procedure, a scenario is developed with a different vehicle typology: the Renault Twizy Life (Figure 54) which is an electric quadricycle: 4 kW, max 45 km/h, two seats, battery 12 V, 7 kWh. It can be charged to a 220 V power outlet and is fully charged in 3,5 hours [230].

Figure 54: Renault Twizy

Outputs

- Two separate sheets with the annual budget: revenues and expenditures with the items expressed in section 4.1 - Step 17. The one-way service differs from the round-trip also the cost structures: for the first typology the costs for the employees who are dedicated to the vehicle relocation and the km travelled are included, and relative maintenance costs, are doubled.
- The "summary" with the main outputs and a graph, which facilitate the modal split comparison in the situations with and without the car sharing. The screen of this module is reported in the result section (cf. 5.15) to schematize the main outcomes;
- In the "environment module" the new modal shift is computed based on the data collected by the surveys and reported in Figure 43 and Table 29.

The parameters used to define the utility function and hence the number of potential car sharing members are cost per hour [€/h], free subscription for the owner of a public transport fee [binary],

walking distance to reach the car sharing station/ from the car sharing station to the final destination [min] and [km]. The letter parameter is strongly related to the number of stations implemented on the territory of interest.

Key service elements and parameters

The principal demand and supply elements considered are reported in Table 45.

Table 45: Elements for Service Planning – NIGHT

Demand	N. of potential members
	N. of potential members split over residents and non-residents
	N. of frequent users
	N. of frequent users split over residents and non-residents
	N. of trips per day
	N. of trips per year
	N. of trips per year split over residents and non-residents
	N. of people who subscribe to the service for free (PT or train fees owners)
Supply	N. of stations → walking distance Possibility of not considering specific zones → deriving effect in terms of people not served by the service
	N. of vehicles
	N. of parking lots
	% of electric vehicle in the fleet
	Free subscription for the owners of a PT fee
	Carpooling availability
	Costs [subscription, per km, per hour]

These elements are correlated through mathematical equations reported in Chapter 4, Table 21; some parameters and constraints have also been defined in order to shape the service (Table 46).

Table 46: Parameters - NIGHT Service

Parameters	**Value**	**Comment**
Travel time [mean]	10 min	The administered questionnaires (March 2019) investigate, also, on the students' final destinations from which it is possible to calculate the distance (both in terms of time and km) from the Trieste train station to them. Google map has been used for the purpose.
Travel distance [mean]	3,5 km	
Time A/R [mean]	156 min (ca. 2:30 hours)	
Owner of a public transport season ticket	40 %	Collected from the administered questionnaires (March 2019).

Time of service	19:00-03:00	From the data collected through the questionnaires (March 2019) and from the data collected through the survey reported in Annexe 5.1.
N. of people per vehicle (when carpooling is available)	2	Minimum number
% of people interested in sharing the trip with other students	70%	From the analysis of the data collected with the questionnaires
Months of subscription	12 months: residents 6 months: non-residents	Usually, students who are not resident in Trieste stay in the city only during term time.
Δ years for fleet renewal	5 years	Estimation
Technical Equipment lifetime	15 years	Estimation
Recharging columns lifetime	15 years	Estimation
Costs/revenues to be agreed with external stakeholders		Some items (sponsor, public funds, advertising/marketing, fees to the Municipality) are set at 0 € since their estimation is not possible a priori; call-centre is set to 0 € since, during the operative phase, the decision of allowing only the App as reservation system is possible considering that the service is targeted to students. Software are estimated to cost 30.000 € (value taken from a feasibility study [231]) and that their management costs 8.500 € per year. Charging columns are estimated to be 2.800 €, according to a service provider site [232]. The number of charging columns is equal to the number of stations if the number of electric cars is lower than the number of stations; otherwise, the number of recharging columns is considered as equal to those of the electric vehicles (it is a simplification). The expenses for the office are set equal to 8.000 € per year. Finally, considering the fact that the project developed in the case of study takes into account the start-up phase, as reported in Chapter 4, a manager (50.000 €/year), a secretary (30.000 €/year) and a fleet manager (30.000 €/year) are sufficient, but, however, some tests have been done linearizing the data reported in [36]. Parking lots are assumed to cost 600 €/year, presuming a small discount on the renal cost applied by the main Trieste parking managers.

On foot speed	1 m/s	Lowest value due to the presence of ascending steep slope in Trieste.
Study Area	20 km^2	Cf. Figure 55

Figure 55: Study Area - NIGHT service

Computing

Here are briefly reported the main procedure for the definition of:

- stations location;
- number of parking lots;
- number of potential uses;
- number of frequent users;
- number of trips per day.

In section 4.1 – Step 17, the algorithm for their computing is better detailed: it allows the estimation of the output and to simulate different scenarios making varying the elements which are under the designer control.

Stations are pinpointed according to the O-D investigation carried out through questionnaires summarised in Figure 47 and Annexe 5.2. A set of candidate stations is provided by all the origin zones, together with the points which, analysing the land-use, emerges to be a very frequently chosen destination node, such as "via Torino". The developed spreadsheet offers the designer the possibility of removing some stations, such as "Melara", "Opicina", "Strada di Fiume" since the flow from these nodes were very low, and the costs for stations would be too expensive for their scarce usage. By simplifying, when the designer opted for a reduced number of stations, the percentage of not satisfy

trips (considering the O-D matrix) is subtracted from the total number of trips and members. In the considered area of interest, without opting for any reduction, the total number of stations required is 34, as reported in Figure 56.

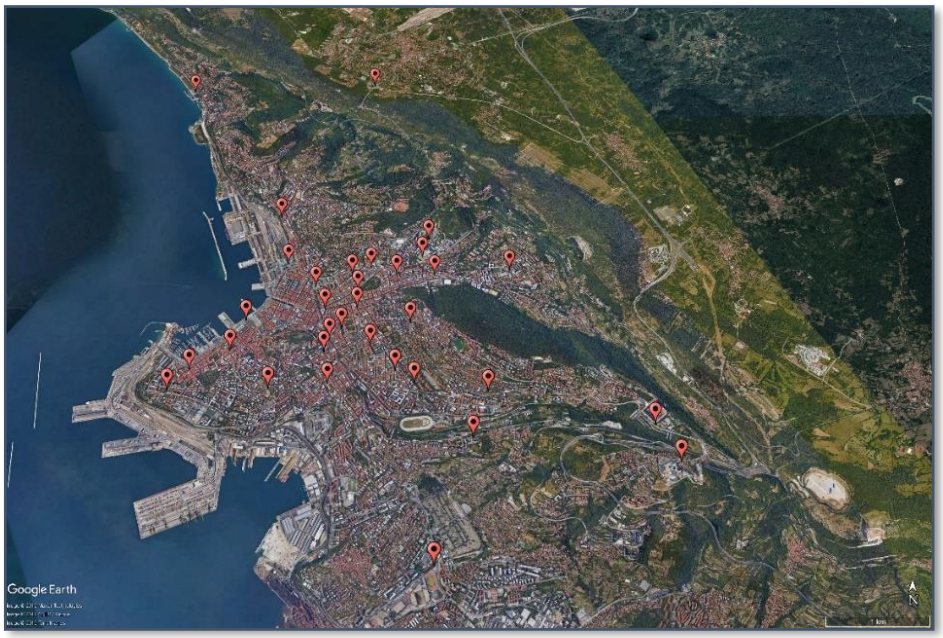


Figure 56: Stations Location

Parking lots are defined according to the algorithm: the total trips per day are distributed according to the rate resulting from in the O-D matrix. These values are divided by the number of trips during the service time and in this way, rounded up the obtained values, it is possible to achieve the number of parking lots needed for each station.

Potential users are estimated through the sample enumeration with classification method, considering two classes "residents" and "non-residents". For each class is computed the weight, reported in Table 43 and the expansion factor, i.e. the ratio between N_g, the number of people in the population, belonging to class g and N_{sg} the number of people of the sample, belonging to class g.

The number of trips during the service time is ganged from the ratio between the hours when the service is available, and the mean of the vehicle time usage expressed by the interviewed students.

In the stated preference survey, for those who choose car sharing, there are also some questions on the type of use they were going to do, such as the frequency with which they would use the service; it emerges that residents would use the service 0,16 times per day and the non-resident 0,15. Figure 57 reports the rates of the declared frequency expressed in times per week.

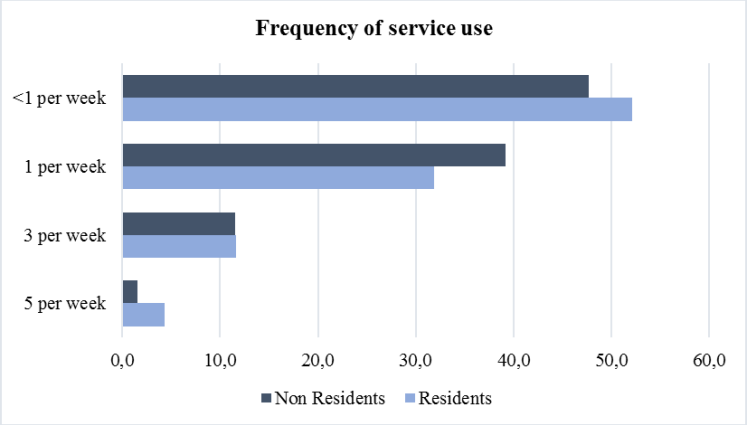


Figure 57: Service Use Frequency

The results of the implemented scenarios are reported after the optimisation process, in order of not being repetitive.

5.14 Optimisation

The research of the right trade-off between the different objectives (maximum profit for the operator, maximum number of users, minimum area required for the vehicle parking and maximum positive cooperation with the bus) results in a multi-objective problem. These objectives are often conflicting, since, for example, demand increases with the service fee reduction and with the number of stations increase, but, at the same time, these factors lead to a decrease of the revenues by the car sharing operator. The optimisation process is carried on to define the best possible car sharing service solution.

As suggested in section 4.1 – Step 19, the optimisation process is implemented through the software ModeFrontier, which is developed by ESTECO S.p.A. [102]. In the analysed case study, the software is utilised for the elaboration of several steps, recursively, until finding the balanced solutions between the contrasting objectives. The balanced solution leads to the definition of the main characteristics of the car sharing service. The feasible combinations among the parameters (within the imposed constraint) are countless and, manually it is almost impossible to calculate them; for this reason, the process implemented thanks to ModeFrontier is essential to elaborate a set of efficient solutions, known as Pareto solutions. As already anticipated in 2.2.2.2, the DoE methodology applied in the case study is Sobol, a deterministic algorithm which aims to obtain a uniform sampling of the design space, while the applied genetic optimisation algorithm is M.O.G.A. II (Multi-Objective Genetic Algorithm II), which allows defining an array in which, for every solution, there are the supply's elements.

Firstly, it is necessary to define objective functions:

$Max\ (Profit) = Max\ (Revenues - Costs)$

$Max\ (Members)$

$Min\ (Parking\ Area)$

$Min\ (Shifting\ from\ Bus)$

With costs and revenues computed as reported in section 4.1 – Step 17.

Revenues are a function of the number of rental per year, the number of members, cost per hour, per km, annual cost, travel time, travel distance and rental duration, percentage of students who are owners of a public transport fee, the vehicle reselling costs, money achieved by sponsors/funds.

Costs are a function of the unitary costs per item (and eventually their discounts and the lifetime) and the number of vehicles, stations, parking lots, recharging columns, rental per year, km travelled, vehicle management cost per km.

Members derive from the implementation of the discrete choice model, and their value is a function of the number of stations (from which the distance to cover on foot to reach the nearest car sharing station is computed), cost per hour, the possibility of carpool, target population (split into residents and non-residents).

The area requested for parking is computed as a function of the number of parking lots.

The number of people who adopt car sharing, being bus users at present, is defined considering the current modal split and the number of car sharing members.

The objective functions are implemented in ModeFrontier through a logical flowchart (Figure 58) which constitutes the logical scheme of the optimization process and is composed of nodes connected with each other. The green elements are the input and parameters: percentage of the electric vehicles, number of removed stations, cost per hour, number of stations, and number of vehicles: the last one is also partially an output since it is limited by constraints which also depends by the outputs. Each input can vary within defined ranges. The parameters, circled in orange, are annual cost, cost per km, unitary cost per software, office rental, employees' costs, discount from the car manufacturer for the vehicle purchasing and the mean travel time, distance, travel duration, percentage of members who shares the trip. The parameters have been considered fixed values for each test, except for Tests 4 and 5, which aim to assess their influence on the final results.

In blue are the output: number of members, costs, revenues, parking area, number of people shifting from the bus, from the car, number of parking lots, ratio between members and vehicles and the number of rentals per day.

In the yellow square are the objectives and, finally, there are the constraints (cf. section 4.1 - Step 17): the ratio between members and vehicles, the relation between vehicles and stations, and those among vehicles, trips per day, service hours and the mean travel time (A/R for the round-trip service). Objective nodes need specifying wheater the target has to be maximized or minimized.

The core of the logical flowchart is the excel node, consisting of the algorithm described in 4.1 – Step 17 and in section 5.13).

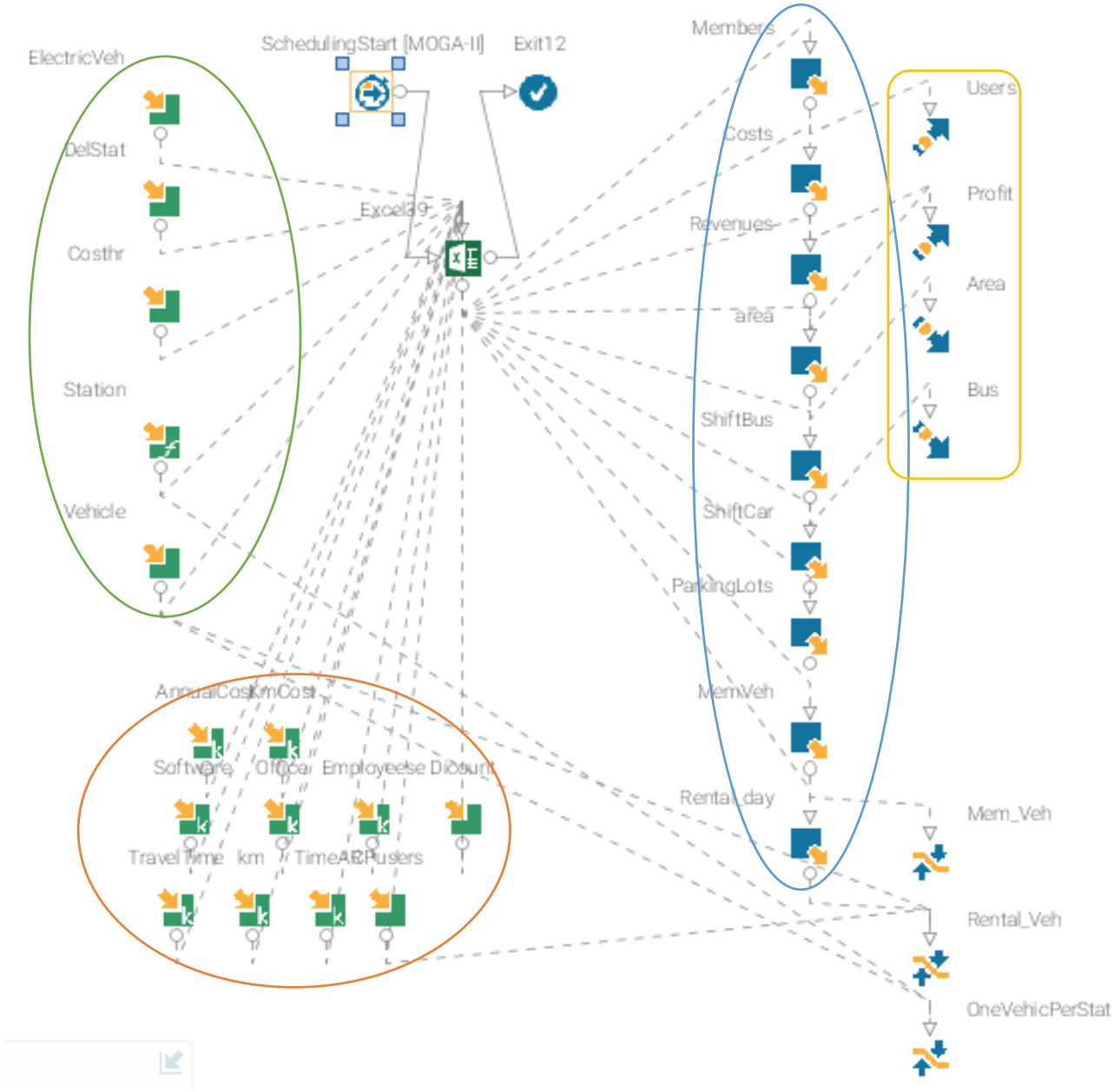


Figure 58: Model Logical Flowchart

The software provides several analysis tools, and one very powerful is called "Parallel coordinates" (Figure 59), where all the possible combinations are plotted. It is, easily, possible to define the ranges of the input variables and the desired outputs, since their size rages are defined through vertical lines and the feasible combinations are reported by transversal continuum lines that move through the vertical lines.

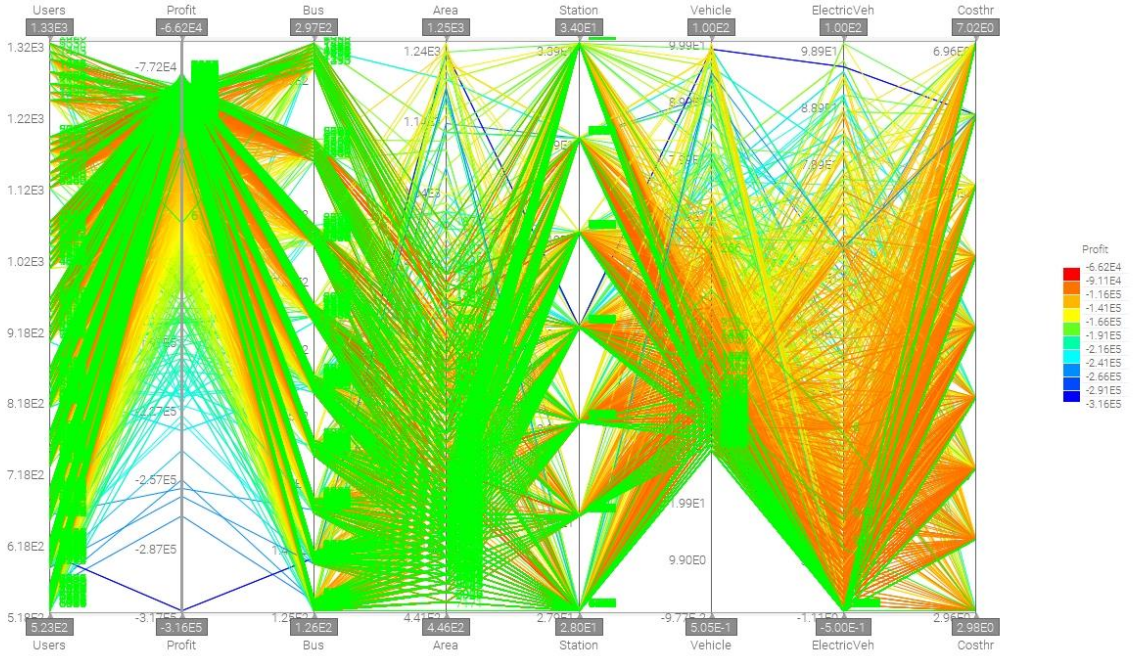


Figure 59: Parallel Coordinates

The intersection between vertical lines and transversal lines determinates the value of the inputs and outputs for that specific combination. Furthermore, different colours allow to identify the behaviour of inputs/outputs and the combinations which do not respect the imposed constraints, and moreover, in bright green are plotted the Pareto solutions. It is, also possible to impose new constraints to limit the solutions, until reaching the most efficient one. Considering that the purpose of this case study is to apply the developed methodology and assess its potentiality, this tool is particularly powerful, since it enables the designer to test different situations in which a hypothetical client defines diverse objectives. In this way, adding new constraints, it is possible to identify, among all the Pareto solutions, the one which describes the best car sharing service solution. For example, it is possible to reduce the number of solution among those which bring the maximum profit for the operator and then, among this latter group of solutions those which minimise the area requested for the vehicle parking (Figure 60). Otherwise, it is possible to define the solutions which minimise the number of people shifting away from public transport and, among them, those with the highest number of electric vehicles.

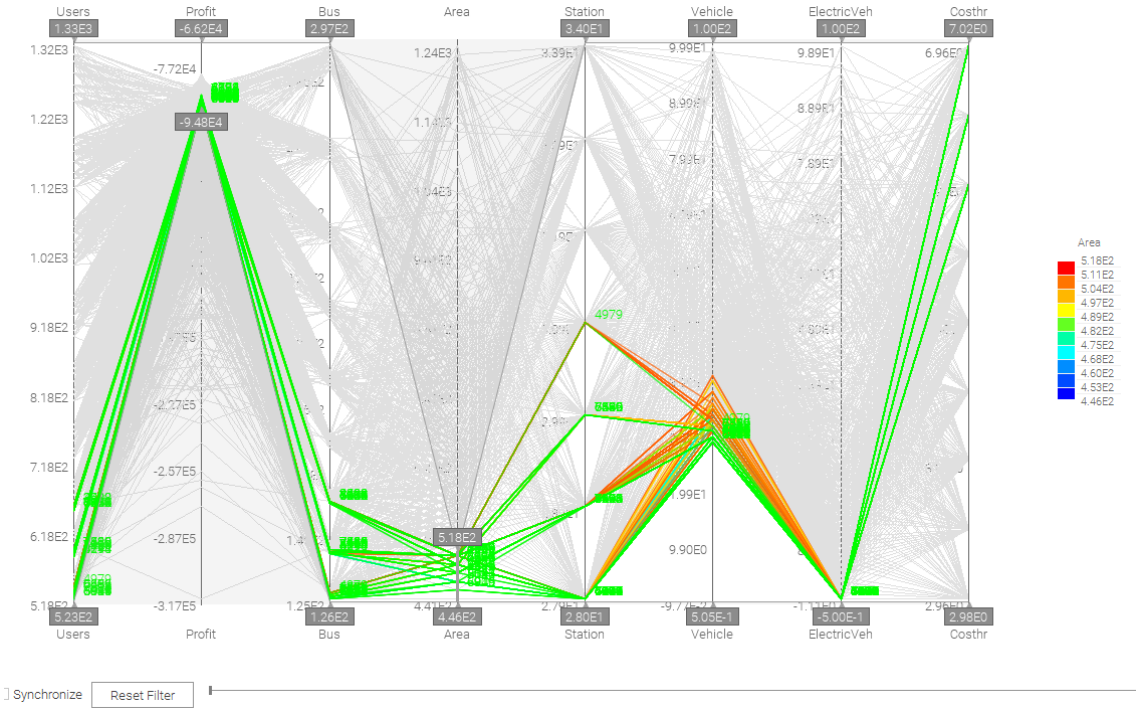


Figure 60: Parallel Coordinates - Constrained

Then these solutions are post-evaluated thanks to the spreadsheet (cf. section 4.1 - Step 17) used for the scenario simulation, in order to compute all the KPIs, assess them and, eventually, considering the possibility of defining new proposals of intervention.

In the case of study implemented, the most significative tests are:

- Test 1: in this scenario, the members who own a public transport season ticket do not have to pay the car sharing annual fee and the vehicle chosen for the fleet are both ICEV (Twingo) and EV (Zoe). The parameters related to the users' behaviour are the mean value of what they declare in the surveys, and the unitary costs are considered as constant values. Test 1 is used as a reference scenario for the other ones, i.e. they are always compared to this first one.
- Test 2: differs from Test 1 because all the members have to pay the annual fee;
- Test 3: differs from Test 1 because the vehicles of the fleet are the Twizy Life electric quadricycle;
- Test 4: differs from Test 1 because the users' behaviours (travel time, travel distance and rental duration) are varied;
- Test 5: differs from Test 1 because the unitary costs related to the employees, the office rental, the software as well as the annual fee and the kilometric fee are varied.
- Test 6: Test 1 is re-elaborated also considering the possibility of using the service to overcome the problem arisen by the non-resident of the lack of an efficient transport service when they come back to Trieste on Sunday night.

- Test 7: Test 1 is taken into account imagining that, due to the introduction of car sharing, the urban public transport operator reacts, extending the coverage of bus service during the night. For this experiment, many other assumptions have been made, based on the results of a survey conducted among the student in 2018 (cf. Annexe 5.1). Of course, for more precise results, this alternative should be investigated in a new stated preference survey, together with the car sharing.

5.15 Results

For each test, several graphical outputs have been elaborated thanks to ModeFrontier, and several designs have been assessed but, for not being redundant, some outputs and results are reported only for the first test.

5.15.1 Test 1

In this scenario, the annual fee is free for those who own a bus season ticket and the automobiles chosen for the fleet are Renauld Twingo and Zoe (electric). Users behaviours (travel time, distance, etc.) are characterised by constant values (the average value of what students declared in the surveys), and the unitary prices of the supply elements (e.g. office rental, employees) are considered established and fixed value.

Figure 61 shows the Pareto Front (in bright green) when considering three objectives, the maximisation of the service users, the maximisation of the profit and the minimisation of the bus users who join a car sharing organisation. As it is possible to assess, the solutions are discontinued since the input is made change among a finite number of solutions (i.e. hourly cost varying of steps of 0,5 € between 3€ to 7€).

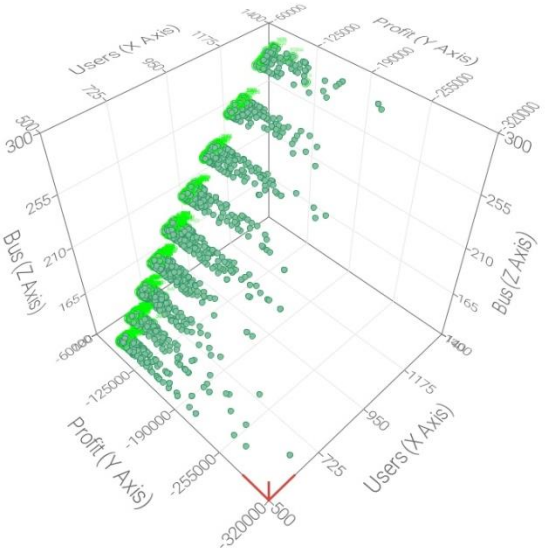


Figure 61: Test1 - Pareto Front

Figure 62 shows the relation between users (x-axis), profit (y-axis) and the number of people shifting from the bus (colour), while in Figure 63 also the required area for parking is included, expressed as the diameter of the dots.

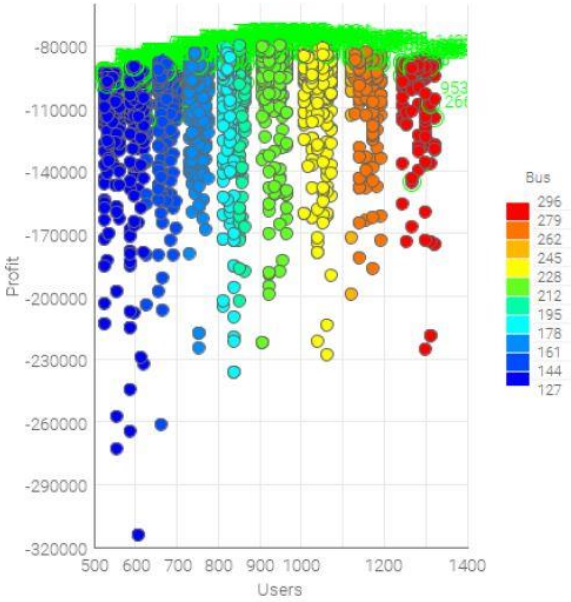


Figure 62: Test1 - Users, Profit, Bus

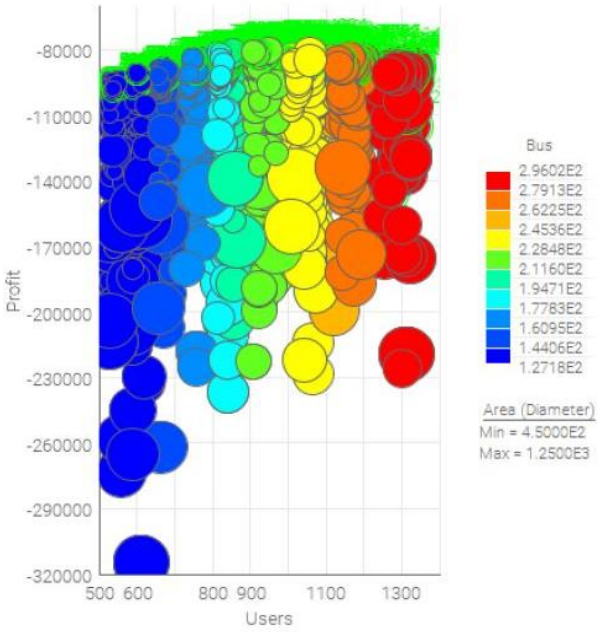


Figure 63: Test 1 - Users, Profit, Bus and Area

Another useful software output is a table with all the input, parameter and output reporting their ranges, mean and standard deviation. The number of vehicles varying between 1 to 100, the mean value is 37, and the standard deviation is 9,2.

The unfeasible solutions in relation to the broken constraints are 10,13%. The 60,8% of times that the solution results unfeasible is due to the violation of the constraints which related the number of vehicles to the number of stations, the 33,6% is due to the ratio member/ vehicles and only in the 5,5% of the cases it is about the number of rental per day (Figure 64).

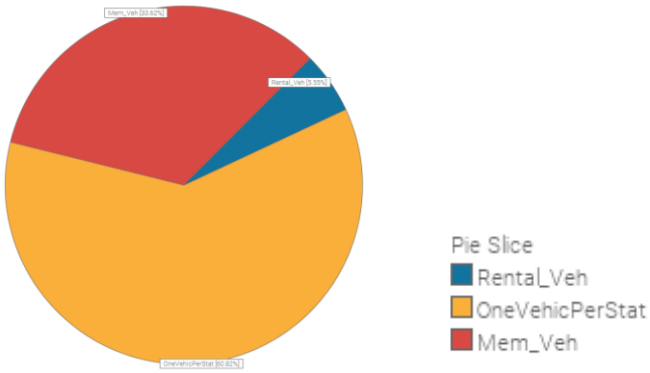


Figure 64: Broken Constraints

For each test, the number of Pareto solutions is quite high and so, to define the best one, the client has to define some more specific constraints. In this case study, which is used to validate the developed planning methodology, the objectives are chosen time to time and discussed.

Firstly, the designs with the maximum profit have been selected and, among all those scenarios, it has been chosen the one which also minimises the area required for parking and the number of people who shift away from bus. Table 47 and Figure 65 report the main outputs.

As anticipated, in Test 1 people who own a public transport season ticket do not pay the car sharing annual fee, so it is supposed that people continue to buy the bus travel card. Hence, the lost revenues for the public transport operator are computed considering only the proportion of people who do not own a public transport season ticket and considering the bus ticket price equal to 1,3 €.

Table 47: Test 1 - Objective: Max Profit – Min Area and People Shifting from Bus

Test 1 **Objective: maximum profit – minimum area and people shifting from bus**			
Annual fee [€/year]	60	Members/Vehicles	22,6
Cost per hr [€/hr]	6	Rentals per day/Vehicles	1,97
Stations	28	Vehicles/Stations	1,04
Parking Lots	42	Discount for car purchasing [%]	25
Vehicles	29	Revenues [€/year]	98.540
Electric vehicles [%]	0	Costs [€/year]	185.506
ICEV	29	Profit [€/year]	- 86.966
EV	0	Shifting from car	124
Members	655	Shifting from bus	144
Frequent Users	283	Area [m^2]	525
Rental/year	3487	Lost revenues for the PT [€/peak day]	112
People who share the trips [%]	30		

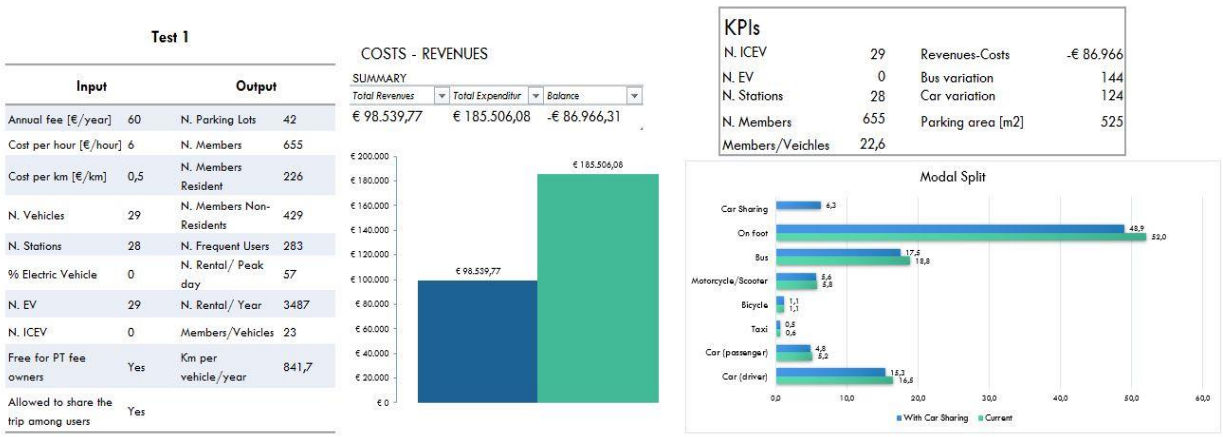


Figure 65: Test 1- Objective: Max Profit – Min Area and People Shifting from Bus

The 28 stations are located all around the city, as it is represented by the map in Figure 66:

Figure 66: Test 1 - Stations Location

Under these conditions, the rate of residents interested in car sharing is 5,7 % and 6,6% among non-residents. The modal split is strongly different between the two categories as it is possible to be inferred from Figure 67 and Figure 68.

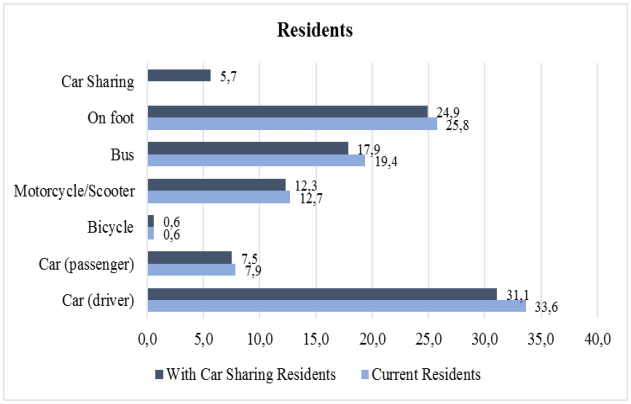


Figure 67: Test1 - Modal Spit, Residents

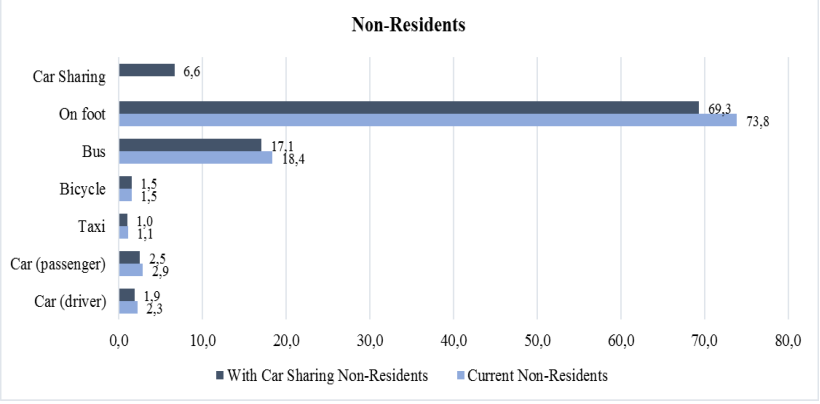


Figure 68: Test1 - Modal Spit, Non-Residents

It does not constitute scientific proof of the goodness of the achieved results, but, in the business plan developed by Scott for the car sharing of Portland, Oregon [66], for 480 members the required number of vehicles is 43 and for 150 members it is equal to 20. Consequently, linearizing their statements and considering the number of frequent users, i.e. those who use the service more than one time, it possible to gange the number of members who can be served by introducing a fleet of 29 vehicles, which correspond to 289 members, closed to 283, which is the amount of frequent users defined through the implemented algorithm.

Differently, if the main goal is to maximise the number of car sharing members and then, among these solutions identify the one which also maximises the profit, the best result is reported in Table 48 and Figure 69

Table 48: Test 1 - Objective: Max Members – Max profit

Test 1 **Objective: maximum members – maximum profit**			
Annual cost [€/year]	60	Members/Vehicles	30,7
Cost per hr [€/hr]	3	Rentals per day/Vehicles	2,65
Stations	34	Vehicles/Stations	1,26
Parking Lots	79	Discount for car purchasing [%]	25
Vehicles	43	Revenues [€/year]	135.702
Electric vehicles [%]	0	Costs [€/year]	223.885
ICEV	43	Profit [€/year]	-88.183
EV	0	Shifting from car	209
Members	1322	Shifting from bus	283
Frequent Users	572	Area [m^2]	988
Rental/year	7048	Lost revenues for the PT [€/peak day]	221
People who share the trips [%]	30		

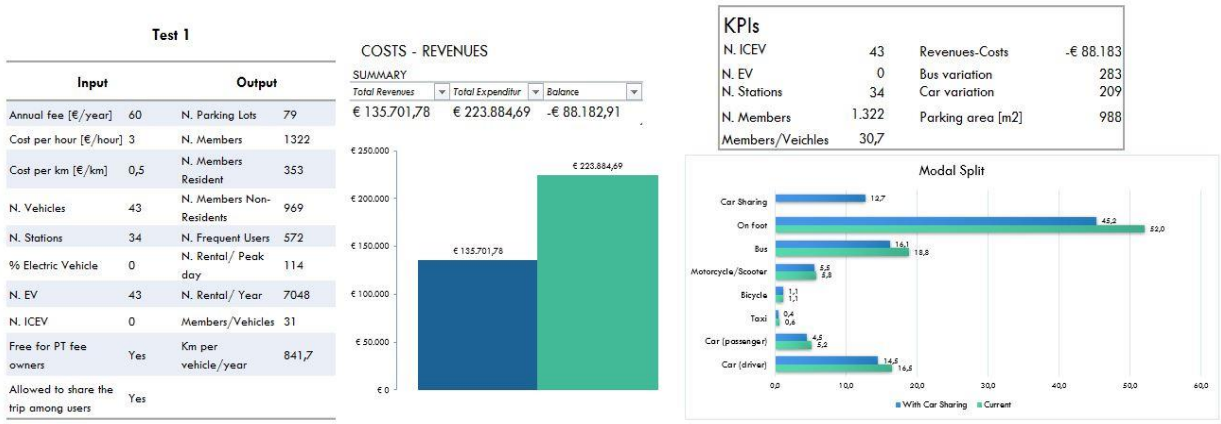


Figure 69: Test 1 - Objective: Max Members – Max profit

Comparing this design with the first one, it is possible to notice that revenues are higher but also costs are more elevated, leading to even more negatives profit. The client should assess if the difference of little more than 1.000 €, worth the implementation of the first scheme respect this other one, since the number of members is almost twice in this second case. Always with respect to the imposed constraints, in this scenario, the number of members for each vehicle is substantially higher, and this could lead to a lower level of service.

Instead, if the client aims only to reduce the number of bus users who would adopt the new car sharing service and minimise the area requested for parking, then the best result is reported in Table 49 and Figure 70. In this situation, the lost revenues for the public transport operator are lower, but the minimisation of the area for parking entails a diminution of the parking lots and, consequently, of the number of people interested in the new service and the operator's revenues.

Table 49: Test 1 - Objective: Min Shift from Bus – Min Area

Test 1 **Objective: minimum shift from the bus – minimum area required**			
Annual cost [€/year]	60	Members/Vehicles	17,6
Cost per hr [€/hr]	7	Rentals per day/Vehicles	1,5
Stations	28	Vehicles/Stations	1,07
Parking Lots	37	Discount for car purchasing [%]	25
Vehicles	30	Revenues [€/year]	85.674
Electric vehicles [%]	0	Costs [€/year]	180.593
ICEV	30	Profit [€/year]	-94.919
EV	0	Shifting from car	106
Members	527	Shifting from bus	117
Frequent Users	229	Area [m^2]	463
Rental/year	2722	Lost revenues for the PT [€/peak day]	91
People who share the trips [%]	36		

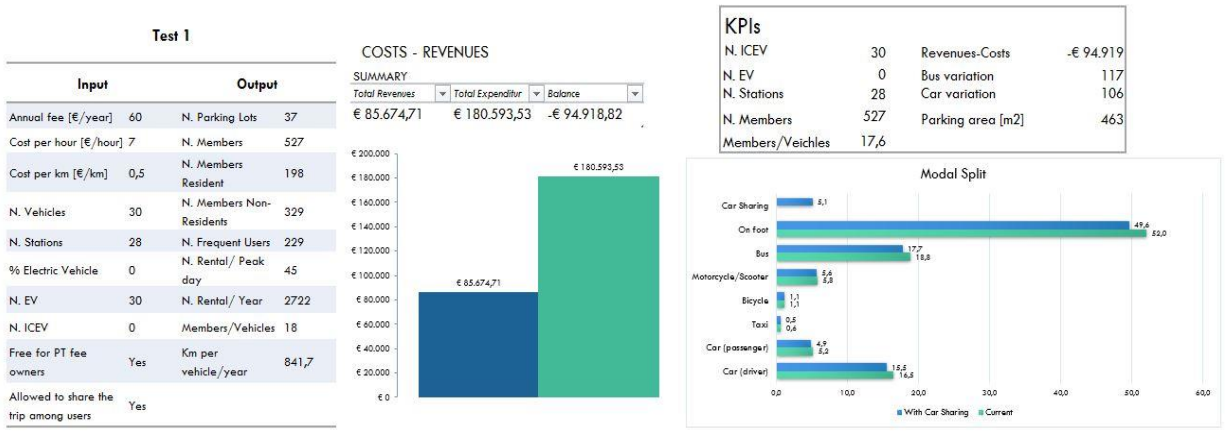


Figure 70: Test 1 - Objective: Min Shift from Bus – Min Area

Finally, it is reported the case in which the objective is the maximisation of the electric vehicles in the fleet. The design is chosen among all the Pareto solutions, and no one of them includes a percentage of electric vehicle in the fleet equal to 100% (cf. - Table 50).

Table 50: Test 1 - Objective: Max Electric Vehicles in the Fleet

Test 1 **Objective: maximisation of the electric vehicles in the fleet**			
Annual cost [€/a year]	60	Members/Vehicles	18,3
Cost per hr [€/hr]	6	Rentals per day/Vehicles	1,37
Stations	34	Vehicles/Stations	1,12
Parking Lots	47	Discount for car purchasing [%]	20
Vehicles	38	Revenues [€/year]	93.338
Electric vehicles [%]	16	Costs [€/year]	206.436
ICEV	31	Profit [€/year]	-113.098
EV	7	Shifting from car	131
Members	697	Shifting from bus	153
Frequent Users	302	Area [m^2]	588
Rental/year	3174	Lost revenues for the PT [€/peak day]	119
People who share the trips [%]	55		

In this situation, a quick assessment of the external effects related to this design is possible. Assuming that the ICE car chosen for the case study emits 99 g CO_2 per km [233] and that Ricardo-AEA (2014) suggest a value of 90 €/t CO_2 eq., the following conclusions are possible (Table 51):

Table 51: Test 1 - Emissions

CO_2 emissions if all the vehicles would be ICEV	41.791,4	kg CO2
CO_2 emissions for the real fleet composition	34.093,0	kg CO2
CO_2 saved	7.698,4	kg CO2
€ saved thanks to the presence of EV in the fleet	692,9	€/year

5.15.2 Test 2

This test differs from the first one since all the potential members have to pay the annual fee, without any discounts for those who own a public transport fee.

As in Test 1, different objectives have been tested.

Table 52 and Figure 71 report the output related to the best design in terms of profit maximisation and, among all these solutions, in terms of minimisation of the requested area for parking and minimisation of the number of bus users who would become car sharing member.

Table 52: Test 2

Test 2 **Objective: maximum profit – minimum area and people shifting from bus**			
Annual cost [€/year]	60	Members/Vehicles	22,5
Cost per hr [€/hr]	4	Rentals per day/Vehicles	1,97
Stations	28	Vehicles/Stations	1,04
Parking Lots	42	Discount for car purchasing [%]	25
Vehicles	29	Revenues [€/year]	93.268
Electric vehicles [%]	0	Costs [€/year]	185.506
ICEV	29	Profit [€/year]	- 92.237
EV	0	Shifting from car	125
Members	654	Shifting from bus	109
Frequent Users	283	Area [m^2]	525
Rental/year	3487	Lost revenues for the PT [€/peak day]	1.692
People who share the trips [%]	30		

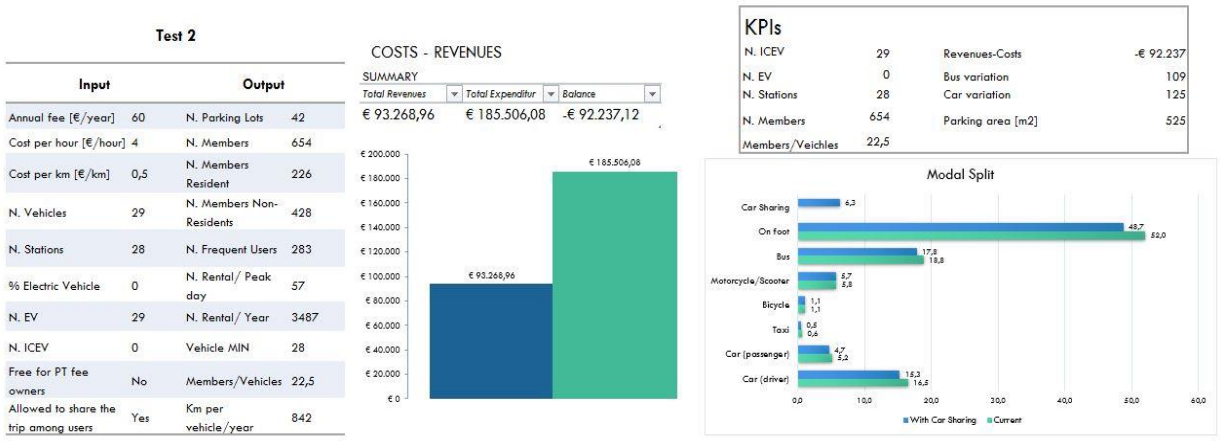


Figure 71: Test 2

This test is interesting since the main outputs (number of stations, parking lots, vehicles, member and rentals per year) correspond to those of Test 1, and also the parameters have the same value (discount, people who share the trips, electric vehicles). Nevertheless, these results are obtained in front of an hourly cost reduction which makes the service more attractive. Consequently the revenues are reduced: analysing in detail the revenues items for the two tests it is possible to notice that, even if in Test 2, revenues from the annual fee are higher, since all the members pay the fee, the revenues from the usage are lower due to the fact that the unitary cost per hour is inferior. In order to ensure the revenues higher or equal to those in Test 1, leaving the cost per hour unchanged, the annual fee would have to cost 68 €, but, per sure, this will lead to a reduction of the people interested in the service. Another aspect is related to the number of bus users who would choose the car sharing,

which is lower in Test 2 since the cancellation of the free annual fee for who owns a bus season ticket makes the service lesser attractive for the bus users. However, on the other hand, it is not possible, anymore, to assume that people who join the car sharing would maintain their bus season ticket and so, this causes massive losses of gain for the urban bus operator, considering that the monthly bus travel card cost is 34,85 €.

5.15.3 Test 3

This test has been conducting, leaving unchanged the structure of Test 1, but changing the vehicle typology. The new one is the Renault Twizy Life electric quadricycle, smaller than the other cars chosen for the case study. So, for the same number of parking lots, this service requires a smaller area (the Twizy dimensions are 2,34 x 1,19 m), moreover, also the purchasing costs are inferior to those of the previously chosen vehicles. Furthermore, it is opted to include only electric vehicles in the fleet, and this causes a slight difference in the modal split; in fact, students who declare to be interested in electric car sharing usually are scooter/moto drivers among residents and car drivers among non-residents. Other things being equal, in particular for the same number of members, the introduction of this kind of service slightly reduce the usage of car (14,7% - 15%), moto (5,5% - 5,6%) and marginally increase the bus passengers (17,2% - 17%) compared to the service of Test 1. Table 53 and Figure 72 report the main outputs of the design chosen among the Pareto solutions which maximise the profit and, among these designs, the one which also minimises the number of bus users who adopt the car sharing and the required parking area.

Table 53: Test 3

Test 3 **Objective: maximum profit – minimum area and people shifting from bus**			
Annual cost [€/year]	60	Members/Vehicles	31,2
Cost per hr [€/hr]	4,5	Rentals per day/Vehicles	2,69
Stations	28	Vehicles/Stations	1,04
Parking Lots	52	Discount for car purchasing [%]	25
Vehicles	29	Revenues [€/year]	114.474
Electric vehicles [%]	100	Costs [€/year]	187.594
ICEV	0	Profit [€/year]	-73.120
EV	29	Shifting from car	184
Members	905	Shifting from bus	170
Frequent Users	391	Area [m^2]	208
Rental/year	4818	Lost revenues for the PT [€/peak day]	220
People who share the trips [%]	30		

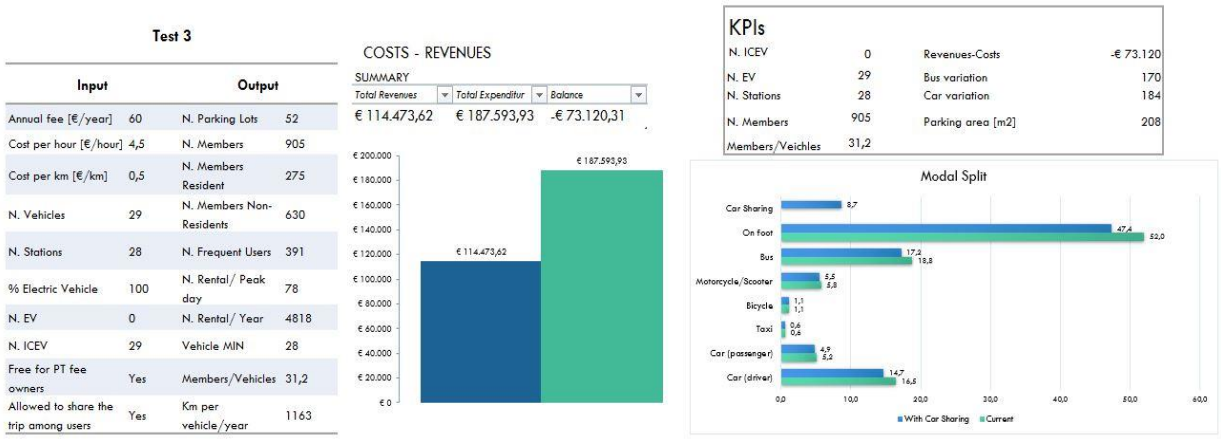


Figure 72: Test 3

5.15.4 Test 4 and Test 5

Test 4 and 5 share the same goal, i.e. stressing the input variable and parameters in order to assess their effects on outputs.

In an attempt to investigate the effects of the parameters related to the potential users' behaviour on the output, Test 4 is conducted. The parameters under investigation and their ranges of variation are:

- travel time ranges from 7 to 25 minutes;
- distance driven (2,5 – 6 km);
- rental duration (30 minutes – 5 hours).

Distance driven and travel time are correlated, but their relationship also depends on the traffic conditions and by other external factors (e.g. the driving style, the road travelled, the time of the night)

Instead, Test 5 stresses the parameters related to the unitary costs also considering the case in which a company/ public entity implements the car sharing, i.e. the case in which the employees' costs, the office rental's costs are zero or lower (since these costs are included in other cost items of the company). Even the annual fee and the cost for the software are varied.

Therefore, it is possible to assess how the parameters related to the users' behaviour influence the objectives (cf. Figure 73).

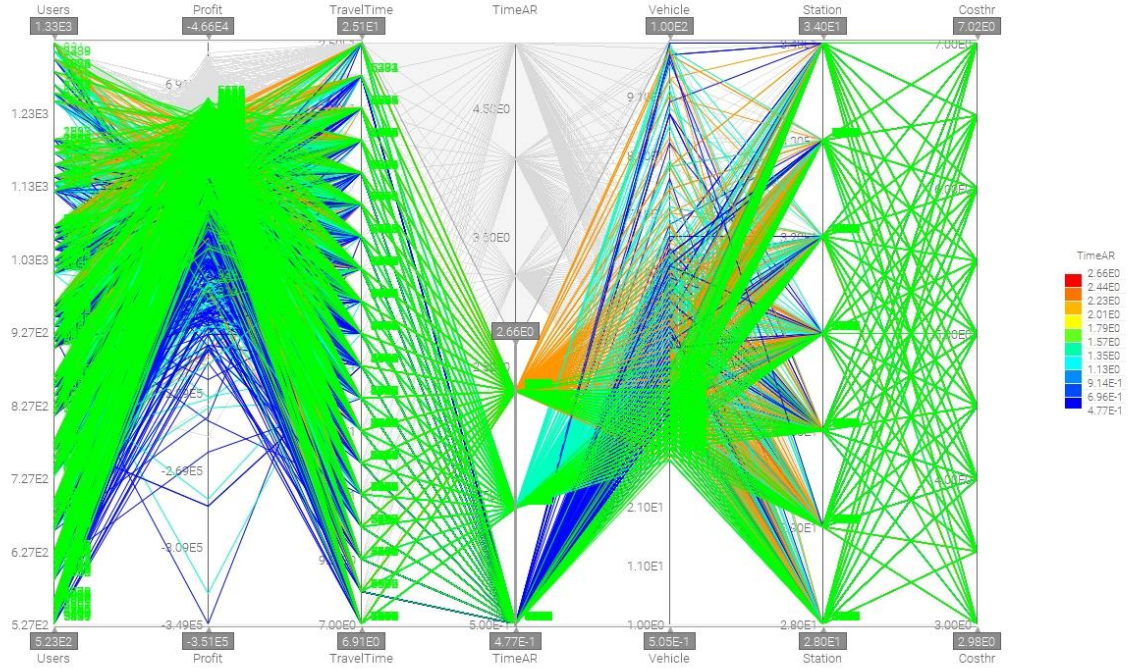


Figure 73: Test 4 - Parallel Coordinates

The design which maximises the profit is the one with the distance travelled equal to 5 km, and the rental duration 4,1 hours (246 min); Table 54 reports the main outputs.

Table 54: Test 4

Test 4 **Objective: maximum profit**			
Annual cost [€/year]	60	Members/Vehicles	22,8
Cost per hr [€/hr]	5,5	Rentals per day/Vehicles	2
Stations	31	Vehicles/Stations	1,06
Parking Lots	71	Discount for car purchasing [%]	25
Vehicles	33	Revenues [€/year]	157.677
Electric vehicles [%]	0	Costs [€/year]	211.243
ICEV	33	Profit [€/year]	-53.566
EV	0	Shifting from car	138
Members	754	Shifting from bus	165
Frequent Users	326	Area [m^2]	888
Rental/year	4017	Lost revenues for the PT [€/peak day]	128
People who share the trips [%]	30	Travel distance [km]	5
		Rental duration [hr]	4,1

Test 5 is the only one, among all the ones defined so far, which leads to positive values for the profit.

As it is possible to notice in Figure 74, the variation of the costs for employees and the office rentals lead to significant shifts in the response variable. This difference is higher for the employees' cost as it is possible to evince from the slope of the connecting line. The dot in the middle of each box represents the mean value of the profit calculated for that level of the parameter. The box itself is the standard error of the mean, computed as the standard deviation (the line above and below the boxes) divided with the square root of the number of designs. The dashed line is the output mean value.

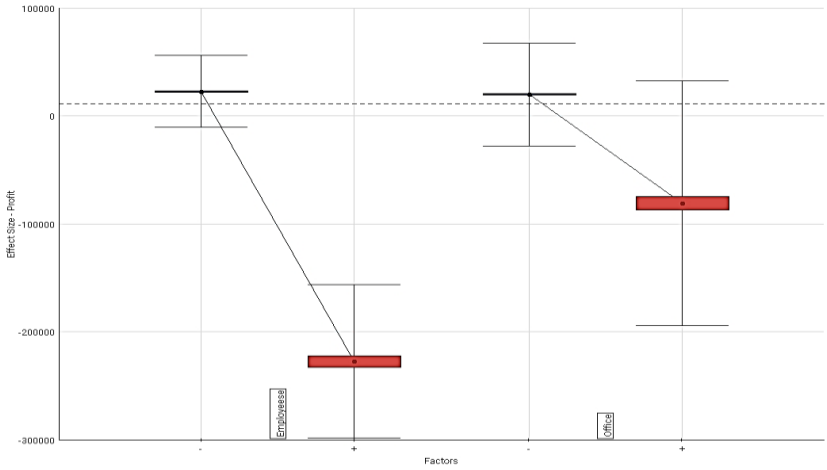


Figure 74: Test 5 - Profit (Y) - Office and Employees (X)

Considering the rate of an annual fee in a rage of 60±5, since higher variation would have a consequence on the number of people joining the service, Table 55 and Figure 75 report the design which maximises the profit.

Table 55: Test 5

Test 5 **Objective: maximum profit**			
Annual cost [€/year]	65	Members/Vehicles	19,9
Cost per hr [€/hr]	6	Rentals per day/Vehicles	1,74
Stations	34	Vehicles/Stations	1,03
Parking Lots	49	Revenues [€/year]	107.195
Vehicles	35	Costs [€/year]	63.879
Electric vehicles [%]	0	Profit [€/year]	43.315
ICEV	35	Shifting from car	131
EV	0	Shifting from bus	153
Members	697	Area [m^2]	613
Rental/year	3721	Lost revenues for the PT [€/peak day]	119
Frequent Users	302	Software purchasing [€/year]	10.000
People who share the trips [%]	30	Office rental [€/year]	0
Discount for car purchasing [%]	25	Employees [€/year]	0

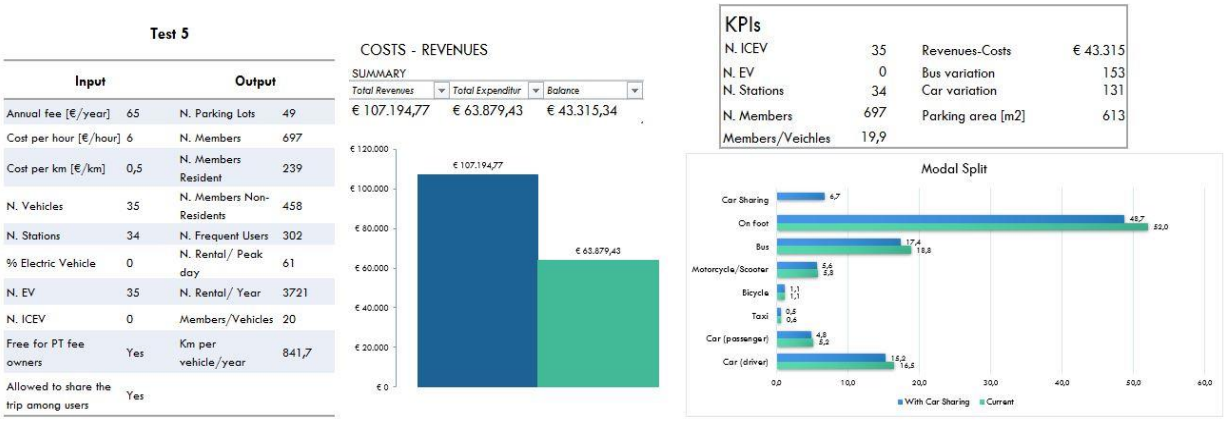


Figure 75: Test 5 - Objective: Max Profit

The case in which the employees and the office rental are not onerous may appear if the car sharing is implemented by a corporate or a public entity; in this way, it is possible that who is responsible for the service management is already employed in the company and also the spaces for the offices are already owned. Maybe, after the car sharing start-up phase, the company can need to hire new staff members, specifically, for service management. The discount for the software can be obtained by the company/public entity thanks to its importance and influence on the market.

5.15.5 Test 6

Test 6 is an attempt to define a service which overcomes both the problem arisen by the students: the night lack of means of transport and the lack of an efficient service on Sunday night when non-residents students come back to Trieste after spending the weekend in their hometown.

It has been assumed that no vehicles are introduced for this expansion with respect to Test 1 (Table 47), but that only from 6 P.M. to 11 P.M. of Sunday night the service is of type one-way. In this way, non-residents students who arrive in Trieste can reach their homes in the city. Travel time [average value 11 min] and distance [average value 2 km] are defined on the basis of what they declare in the survey (cf. 5.7.3). The service is available six months per year, since, usually, when there are no classes, the students who are not resident in Trieste arrive in the city only for the examination days.

The same algorithm reported in section 4.1 - Step 17, and applied to the previous tests, is implemented for this simulation, but it is not used to estimate the number of vehicle/stations required but, inversely, starting from the supply elements defined in Test 1, the number of potential members for the Sunday night service is computed. Finally, costs and revenues related to the service expansion are determined.

The following assumptions are made:

- students can access the service only paying the annual fee, even if they are already a member of the (night) service;
- tariff scheme, number of stations, parking lots and vehicles are the same as the night service;
- people can share the trips with other students in order to reduce the usage costs;
- one station is added close to the train station, with a number of parking lots equal to the number of vehicles minus one which is already considered for the night service. For this case of study, it has been supposed that the station is located in "Park Saba" a multi-storey car park closed to the railway station, which hourly fee is equal to 1,5 € and which has sufficient network coverage for using the APP for unlocking vehicles and booking trips;
- costs for relocations are computed considering the number of needed relocation (cf. Table 21) together with the hourly cost for the staff requested for the vehicles' movement and the expenses for the vehicles' consumption; The number of relocations is given by the difference between the number of trips per day and the number of vehicles, split by the number of vehicles. It is the number of relocations of the whole fleet.
- sample enumeration is the technique applied to estimate the aggregate probability of choosing car sharing. i.e. it is assumed that the whole population, chosen with the random sample technique, is represented by the sample. It is applied to the outcomes of the binomial logit model, "Model NR", reported in section 5.8.1. The parameters used to define the utility function and hence the number of potential car sharing members for the service are cost per hour [€/h], free subscription for the owner of a public transport fee, the possibility of sharing the trip with other users, walking distance from the car sharing station to the final destination. No cost reduction for the owners of the train subscription is adopted since only 1% of the non-residents who stay in Trieste owns it. The total population is 13.724 (year 2017/2018 in Trieste, [19]), the percentage of students who are not resident in Trieste but have a home in the city is 47% (cf. Figure 3): the rate of the ones who arrive in the city by flight is not considered for the service planning. The number of people per day is computed considering what they declare on the Trieste access trip frequency (Figure 39).
- Level of service is taken into account with the imposed constraints which guarantee, at least, an acceptable level (cf. section 4.1 - Step 17).

reports the main outputs of the defined solution:

Table 56: Test 6

Test 6 One-way car sharing			
Annual cost [€/year]	60	N. rentals/ year	1072
Cost per hr [€/hr]	6	Members/vehicles	6,9
Stations	28	Rentals per day/Vehicles	1,79
Parking Lots	42	Vehicles/Stations	1,04
Vehicles	29	Revenues [€/year]	15.006
Electric vehicles [%]	0	Costs [€/year]	11.368
Members of the one-way car sharing	201	Profit [€/year]	3.638
N. rentals/ Sunday	52	N. relocations [cars/Sunday]	23 cars

Profit results positive but, of course, this value has to be calculated globally to the whole night service (e.g. total profit -83.328 €/year). In the case that all the students who join this service are already members of the (night) service and they do not have to pay the annual subscription (60 €), the profit becomes negative (-3.704 €/year).

5.15.6 Test 7

Similarly to Test 6, in this case, Test 1 is re-elaborated assuming that, due to the introduction of the car sharing, the urban public transport operator reacts, adding two bus routes operating every night until 4 A.M. This test is based on several assumptions since, for precise planning, the possibility of modifying the bus time coverage would have been emerged in the context definition (cf. 5.2), in the first phases of this methodology application, and it should be investigated as an alternative in the stated preference survey, together with car sharing and status-quo. However, this test could be seen as a check of the suggested methodology to validate its flexibility and its capacity to adapt in different contexts.

The results obtained in Test 1 are post-evaluate, assuming that if a bus operates until 4 A.M. and connect the main points of interest for the students, they will use this service, instead of the car sharing. This is stated on the basis the results of a survey conducted among the student in 2018 (see Annexe 5.1 for a brief survey description) form which emerges that, under these conditions, the vast majority prefer the bus. Moreover, it is supposed that the public transport operator puts in service two bus routes covering the most travelled itineraries, i.e. the couple origin-destination with the higher values in the O-D matrix (Annexe 5.2).

The bus ***route 1*** has the following itinerary (cf. Figure 76):

Piazzale Europa – Via Cologna – Giardino Pubblico – Via Battisti (parallel to Viale XX Settembre) – Piazza Oberdan – Stazione – Rive – Piazza Unità – Via Torino

(and coming back following the same itinerary)

Route 2 (cf. Figure 76):

Piazzale Europa – Via Fabio Severo – Piazza Oberdan – Stazione – Rive – Piazza Unità – Via Torino

(and coming back following the same itinerary)

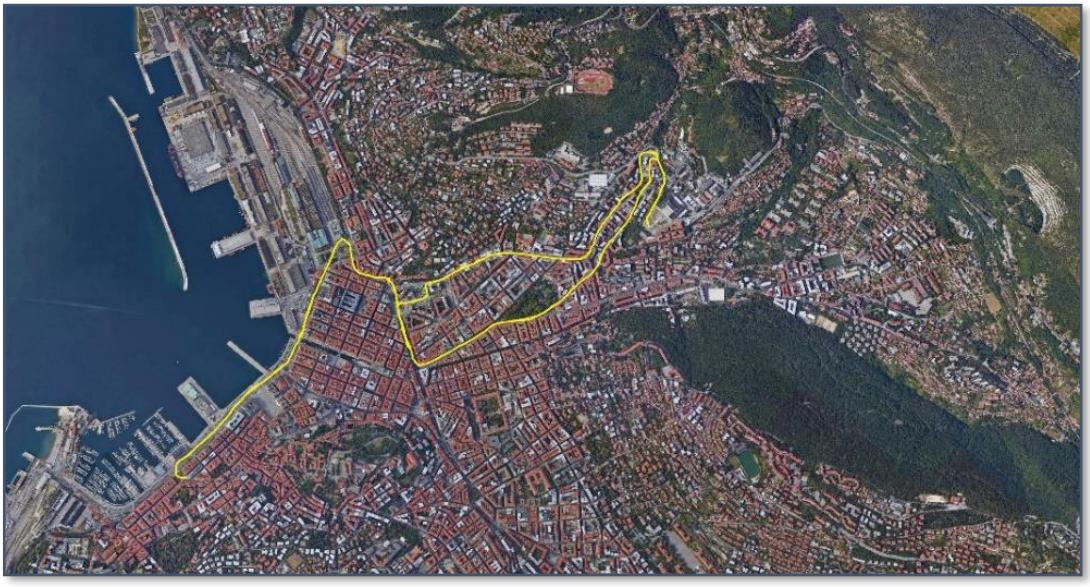


Figure 76: Bus Routes

Analysing the O-D matrix, it is possible to state that these bus routes serve the 30% of those who affirm that would use the car sharing and so, the new number of potential car sharing members is computed and the number of parking lots is, consequently, resized. Considering the cost per hour, the number of stations and vehicles defined in Test 1, it emerges that the car sharing service would face fewer expenditures but also fewer revenues since the number of adopters would be sensitively reduced. Table 57 reports the main outputs and the comparison with the design of Test 1. Of course, on the other hand, this service would increase bus users.

Table 57: Test 7

Test 7 **Bus extension and car sharing**			
Annual cost [€/year]	60	N. rentals/ year	2427 → 3487 in Test 1
Cost per hr [€/hr]	6	N. rentals/ day	40→ 57
Stations	28	Members/vehicles	15,7 → 22,6
Parking Lots	33 → 42 in Test 1	Rentals per day/Vehicles	1,42
Vehicles	29	Vehicles/Stations	1,04
Electric vehicles [%]	0	Revenues [€/year]	68.608 → 98.540
Members of the car sharing	456 → 655	Costs [€/year]	176.916 → 185.506
Members of the new bus service	199	Profit [€/year]	-108.308 → -86.966

It is possible to notice that the percentage of members' reduction is different (higher) than the rate of variation of the parking lots. This because the number of stations is undiminished since they are still in use for reaching destinations which are not served by the bus routes.

Annexe 5.1

Survey on the Students' Night Mobility Behaviour – Purpose and Data Collection

The study on night mobility was conducted in May 2018 among the students of the University of Trieste; it firstly aims to understand the target night transport behaviours (Why do they move in the night? Where do they usually go? With which means of transport?) and their satisfaction of the actual public transport service and, also, to identify the main characteristics of a potential new sustainable transport system.

A stated preference survey has been conducted for this research, inspecting alternatives such as car sharing, demand responsive transit service, carpooling and, also, a modification of the existing bus service. The suggested bus modification, investigated with the survey, consider two principal attributes: fee and extension of the operating time. All the alternatives have two attributes with three levels, except carpooling which has one attribute with two levels (cf. Table 58). Furthermore, the "none" answer is included. The choice experiment design for the present study has been built through the R software: firstly, a full factorial design was generated and, then, an optimal factorial design was generated using a modified Federov's algorithm [234]. Starting points are chosen randomly and the D-criterion is used for optimisation [235].

Table 58: Alternatives, Attributes and Levels

Alternatives	Attributes	Levels
Car Sharing [CS]	Cost [c]	10 (€/month)
		15 (€/month)
		20 (€/month)
	Extra time (to reach the car sharing station on foot) [t]	4 (min)
		6 (min)
		10 (min)
Demand Responsive Transit Service [DRT]	Cost [c]	1,25 €
		2 €
		5 €
	Extra time (comprehensive of the waiting time with respect to the desired time and the time spent onboard, due to the deviation along the way) [t]	10 min
		15 min
		20 min
Modification of the existing bus services [MB]	Cost [c]	Free during the night
		1,25 € (the present cost)
		3 €
	Hours of service operation [h]	21 - 24 (the present hours of service operation)
		21 – 02
		21 - 04
Carpooling [CP]	Free park lots [p]	Yes
		No

The survey was executed as a computer interview in which each respondent answered four stated choice situations, choosing among four different alternatives. The survey was conducted on May 2018, a total of 399 interviews were undertaken, but only 338 respondents completed the whole questionnaire and 14 are commuters (who are not a Trieste during the night time), and, so, the produced cases for model estimation are 1296 [(338-14) x 4].

The sample is almost homogeneous, and it is interesting to detect that 79,9% of the respondent is not satisfied with the present public transport service, especially (79,8% of them) because the night service is available, only, until midnight.

What emerges from the collected data is that if all the other alternatives were available, the students would primarily prefer the bus if it was in service for more hours during the night and if it was less expensive (cf. Figure 77):

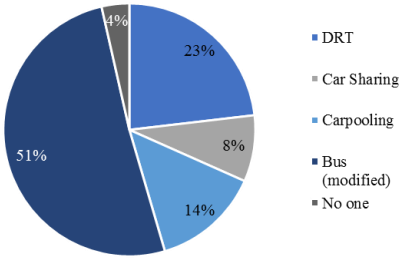


Figure 77: Choices - Student Night Mobility Behaviour

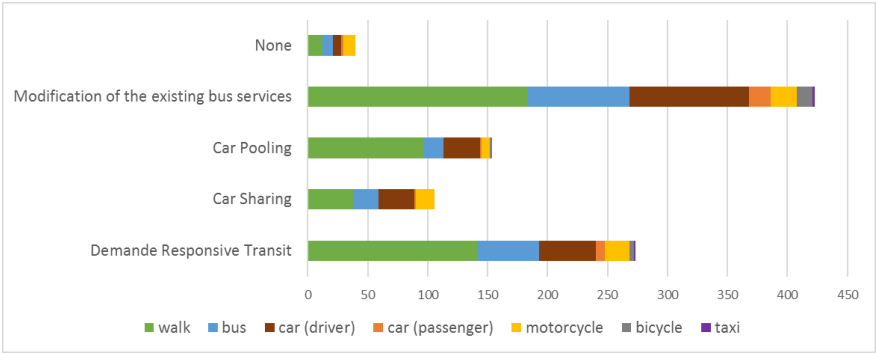
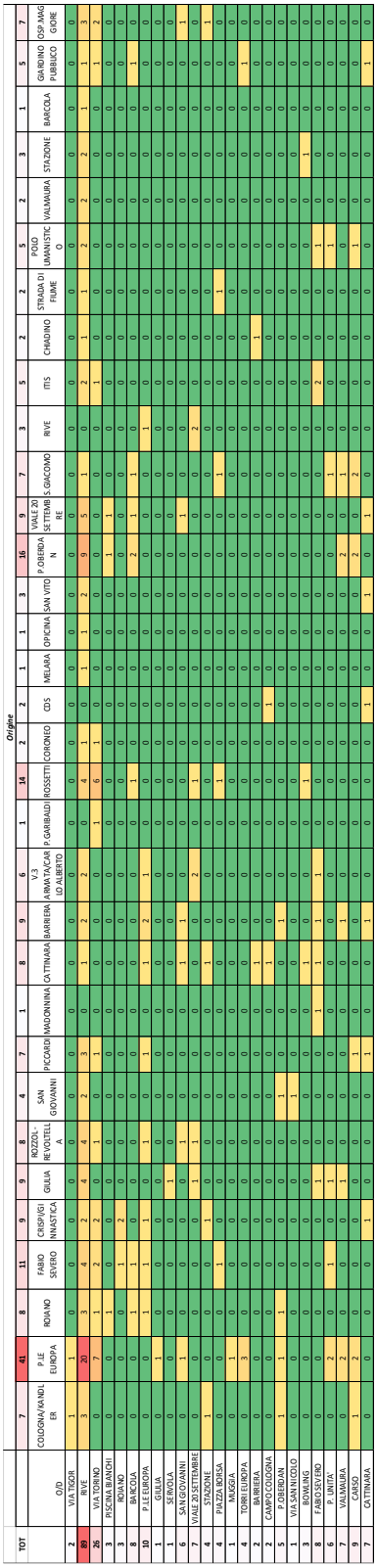


Figure 78: Preferred Alternative with Respect to the Present Modal Split

Furthermore, there are also two final questions on electric vehicles and emerges that people consider that it is important (7 on a scale from 1 to 10) that the public transport fleet includes electric vehicles, in particular, because they believe that this will effect on the environment, helping to reduce harmful pollution.

Annexe 5.2

O-D Matrix – Night Trips



6 Discussion on the Case Study Results

Short Summary

This section discusses the achievements of the case study, highlighting the potentiality of the developed methodology. The chapter is split into two sections: the first one resumes the tests described in 5.15 and compares their results, while the second one discusses the whole case study reported in chapter 5, emphasizing the elements which emerge as pivotal for the success of a car sharing planning process.

6.1 Tests comparison

In the Trieste case study reported in Chapter 5, several design options are tested in order to assess the developed methodology and define different service scenarios. As already stated, the first test is used as a reference scenario for the other ones, i.e. they are always compared to Test 1. In the first case, the members who own a public transport season ticket do not have to pay the car sharing annual fee and the vehicle chosen for the fleet are both ICEV (Twingo) and EV (Zoe). The parameters related to the users' behaviour are the mean value of what they declare in the surveys, and the unitary costs of the supply elements are considered as constant values. For the other tests some variations have been introduced on the annual subscription mode for the owners of a public transport season ticket, the cars' typologies, as well as on the users travel time, travel distance, rental duration and also on the costs' items for the service operators. Table 59 reports the key elements which distinguish the tests reported in 5.15. The final two tests differ from Test 1 because they present some extension and modification to the service itself. Test 6 introduces a station based one-way service available for non-residents students on Sunday night connecting Trieste train station to the main areas where

student live. While Test 7 assumes that also the urban bus operator improves its service, extending it during the night-time.

Table 59: Tests' key elements

	PT season ticket – free annual CS fee	Vehicles' typology	Users' behaviour	Unitary cost items	
Test 1	Free annual CS fee for the owners of a PT season ticket	ICEV (Twingo) EV (Zoe)	Data from surveys	Constant values	
Test 2	*All the members have to pay the annual fee*	ICEV (Twingo) EV (Zoe)	Data from surveys	Constant values	
Test 3	Free annual CS fee for the owners of a PT season ticket	*Only EV (Twizy)*	Data from surveys	Constant values	
Test 4	Free annual CS fee for the owners of a PT season ticket	ICEV (Twingo) EV (Zoe)	*Travel time (from 7 to 25 minutes); Distance driven (2,5 – 6 km); Rental duration (30 minutes – 5 hours)*	Constant values	
Test 5	Free annual CS fee for the owners of a PT season ticket	ICEV (Twingo) EV (Zoe)	Data from surveys	*Unitary costs (employees, office rental, software, etc.) are varied*	
Test 6	Free annual CS fee for the owners of a PT season ticket	ICEV (Twingo) EV (Zoe)	Data from surveys	Constant values	*Sunday night – one way*
Test 7	Free annual CS fee for the owners of a PT season ticket	ICEV (Twingo) EV (Zoe)	Data from surveys	Constant values	*Bus extending the coverage*

Among all the Pareto solutions of Test 1, on a case-by-case basis, different constraints have been introduced in order to define a final solution which better corresponds to the objectives. The first case, called with the abbreviation "Ob1", aims to determinate the solutions which maximise the operator profit and, among them, is defined the one which minimises the area required for parking the vehicles and the number of people who were bus users before adopting car sharing. In the case, "Ob2", within the Pareto solutions are determined those which maximise the number of potential members and, among them, the solution with the highest profit for the operator is established. The third case "Ob3" sets all the solutions which minimise the number of bus users choosing car sharing and, in these, the one which simultaneously minimises the area requested for parking the vehicles. The final one "Ob4" considers, among all the Pareto solutions, the one which maximises the percentage of electric vehicles in the fleet. Table 60 expresses the main outputs for each analysed case and Figure 79 shows them graphically in an easily identifiable way.

Table 60: Test 1 – Design Options Comparison

	Profit [€/year]	Members	Parking Area [m²]	Students shifting from Bus	EV in the fleet [%]		
Ob1	-86.966	655	525	144	0		
Ob2	-88.183	1355	988	283	0		
Ob3	-94.919	527	463	117	0		
Ob4	-113.098	697	588	153	16	*CO2 saved – € saved thanks to the presence of EV in the fleet*	7698,4 kg CO_2 – 692,9 €/year

Figure 79: Test 1 - Design Options Comparison

From Figure 79, it is possible to notice that the presence of electric vehicles in the fleet implies a reduction of the profit for the service operator. The value of profits is comparable for the first two solutions: the second one entails a slight profit decrease (-1.200 €/year ca) but a considerable increase of the number of people who are potentially attracted by the service (+700 ca). However, in the second design option "Ob2" the square meters required for the parking lots are higher (+450 m² ca), as well as the number of bus users who would shift from the bus to the new car sharing service (+140 ca). It is interesting to notice that, for each additional person of the second case, the ratio costs/members and revenues/members are almost equal.

It is not possible to a priori compare these cases among them since the best scenario depends on the client's key service implementation purposes.

It is possible to compare Test1 to the other tests 2 and 3, considering the same priorities for the achievement of the objectives (maximum profit and, among these solutions, minimum parking area and people shifting from the bus). Figure 80 reports the comparison of the main outputs for each test. Of course, the presence of cars which are, not only, less parking space requesting due to their compact

size, but also less expensive (Test 3), allows the exploration of solutions with lower hourly price (4,5 € instead of 6 €) and the presence of more parking lots, which are very attractive factors for the potential users. The situation in which all the users, included those who own a bus season ticket, have to pay the annual car sharing fee (Test 2) is less enticing for students and, consequently, the operator is forced to decrease the prices for the service usage, to maintain the service appealing. This fact also implies the decrease in revenues and consequently lower profit.

Figure 80: Tests 1 - 2 - 3 – Comparison

The fourth test assesses the impact of some elements which are not completely under the designer control, i.e., it tests the variation of the output when changing the potential users' behaviour. The best scenario is obtained for distance travelled equal to 5 km, and the rental duration 4,1 hours. The changes in the outputs allow underlining the importance of collecting these data in the most accurate possible way in the pre-implementation phase since they prove to crucially influence the supply elements' definition.

Test 6 proves that expanding the service, allowing also the usage of the vehicles for the one-way car sharing on Sunday night for the trips from the train station to the students home in Trieste, is positive since it increases the car usage, adding positive profit (+ 3.600 €/year ca). But this is only the case if the number of rentals per year is moderate. Indeed, the number of relocations needed, and their costs, especially in term of staff and vehicle maintenance, grows with the number of required trips.

Test 7 explores a hypothetical situation where the urban bus service is available until 4 A.M. This scenario deserves to be analysed with a new stated preference survey and a new model, as declared in section 7.3. However, through the implemented algorithm and the data collected and reported in Annexe 5.1, it is possible to declare that the number of potential members (- 200 ca) and the profit (- 21.300 € ca) are sensibly reduced in comparison to Test 1.

The design option, for a car sharing service addressed to the university students' night trips, which better balance the different objectives seems to be the first case explored in Test 1. In this scenario,

the key supply elements are the presence of 28 stations all around the city (cf. map in Figure 66), with 42 parking lots and the availability of 29 ICEVs. This would attract about 655 interested people, for a total of more than 280 frequent users. Nevertheless, it is important to state that, from the point of view of the operator of the new service the profit (cf. Table 47) would be negative.

All these designs tested have negative profit, due to the significant starting-up expenses and the small operational scale of the outset. An aspect which influences this results is that university students usually drive for few kilometres, since all their attractive nodes are quite close (university sites, homes, libraries, fitness centres, amusement places, shops), usually in the city-centre, besides the fact that Trieste is a low-extended city. This fact leads to reduced revenues for the operators from the usage fee. The lack of profit in the first years of a new car sharing service implementation is an already discussed issue. According to Scott et al. (1997) [66] who developed a car sharing business plan for car sharing mobility services in Portland, Oregon, profit margins for this kind of services are small. High expenses and low revenues characterise the outset, since the number of members is still reduced and, like for other business, it requires time to increase. Nevertheless, he continues, on a broader scale and more long operating time, a car sharing is supposed to provide a profit to its owners and shareholders, if it is operated and managed appropriately. The profit is strongly related to the scale of the service, its size influences the profitability, but usually, the growth is slow, often taking many years. This can be particularly crucial for small companies, which do not own the initial capital for purchasing a high number of vehicles and affords all the initial expenses. It is worthy to assess also solutions in which the cars are leased, and some activities are outsourcing or franchise. In addition, different car sharing operators can agree and share some functions (e.g. call-centre), splitting the costs. Again for the considerable initial capital required for starting a new service, in an interview [236], Iacovini, who support the development of the car sharing in Australia, declares that car sharing can be profitable as long as it is promoted by large company (with significant capital). He also affirms that the break-even of this kind of enterprise requires very long times since it is a service at a very low economic marginality.

Only in Test 5, which considers reduced costs, the profit presents a positive value, in line with what reported by Brook (2004) [65], who examined a small service in which some operations have an eased cost, and the profit appears to be positive at the beginning of the second year. Costs can be reduced for several reasons, such as for these hypothetical situations reported as non-exhaustive examples:

- car sharing is entrusted by a private company or a public entity which already own offices and employees;
- administrative tasks are performed by volunteer, e.g. when a non-profit organization supports the service;

- service is commissioned by a car manufacturer or by car parking managers and consequently the vehicles/ parking lots are for free.

In Italy, at the present moment and until the beginning of 2020, "Iniziativa Car Sharing", an umbrella organisation of the Italian car sharing network, thanks to the support of the Italian Environment Ministry, allocated funds for "micro car sharing", i.e. services implemented on a small-scale. The funds cover the costs related to service planning, the IT platform and the activities related to communication and service promotion. For the public entity, the funds also support the purchasing of electric vehicles.

To assess the diverse tests can be useful to introduce a financial analysis to declare if a design option is financially viable from the standpoint of the operator [218]. This analysis is also suitable to realize whether the service implementation needs some economical supports which can be provided by a private or by a public fund. In the latter case, a social cost-benefit analysis would be very supportive, as reported in section 7.3.

Through the financial analysis, it is possible to calculate an indicator, called Net Present Value (NPV) which is the sum of the net discounted cash flows. Assuming a discount rate of 3,5% and a period of 5 years, which correspond to the interval of vehicles replacement, a financial analysis is performed for each test reported in section 5.15. To avoid distracting the reader from the central issue, only the analyses for test 1 and test 4 are discussed in this dissertation and reported in Annexe 6.1. For each design option the investment costs, the operating annual costs and revenues and the residual values are determined. As it is possible to notice in the tables reported in Annexe 6.1 the NPV is negative unless considering a cost reduction (e.g. the adoption of less expensive cars or if the Municipality would grant free parking lots) or assuming that the members would use the vehicle for travelling more km and for longer-lasting. Indeed, car sharing is a service which better performs if its members are varied in terms of transport habits, in order to exploit the service more intensively and effectively. Moreover, the computation of the rate of costs coverage in relation to the revenues is an interesting index for the design option assessment. Indeed, this index can be significant to compare the new car sharing to existent urban bus service and, consequently, supporting the public authority in the choice of the best investment for the community. From the financial statement 2018 of the Trieste public transport company this index is almost 35%, while for car sharing it is always higher than 70% considering a mean value of the first five year of operation (cf. tables in Annexe 6.1).

6.2 Discussion on the case study achievements

The case of study aims to show the developed methodology's potentialities, in relation to both quantitative and qualitative aspects. As already affirmed, since not a real client commissioned the

work, several hypothesis and assumptions have been done, which lead to results that could be different in other situations.

As emerging from literature, university students demonstrate to be interested in joining the car sharing service. This is also related to specific characteristics, which are typical of this target and certain features of the Trieste mobility: usually, university students do not own a vehicle or do not have prior access to household vehicles, they have a low (or null) income, and they are inclined to try new services/experiences. Furthermore, Trieste orography does not allow bicycle usage.

Various supply and demand factors that influence the probability of adopting car sharing have been examined. Besides cost and distance to cover on foot before reaching the first car sharing station, the possibility of sharing the trip among users in order to split costs seems a relevant element, as well as the possibility of dropping off the vehicle in a station different from the departure one. From the demand perspective, over the others, the student category influences the final choice towards the service: non-residents are more likely to adopt it.

In the implemented case of study, car sharing seems to be an attractive solution for the unsystematic trips (night trips or when accessing the city). This occurrence can be explained considering that students who are not resident in the city usually rent a home close to the university and the city centre and, furthermore, that the city can boast of an efficient public transport service which very well supports systematic trips.

Analysing students' answers to the administered questionnaire, they would prevalently use car sharing during the night-time, i.e. when the public transport service is not available or not efficient. It thereby can lead to express that the new service will, only partially, compete with the bus, but, mostly, they can be perceived as complementary services. In fact, during the night, the mobility demand is characterised by discontinuity, variability in terms of origin, destinations, times, weekdays, and car sharing with its flexibility, well perform in these situations.

Stated preferences survey is a powerful tool for collecting data on a service which has not been implemented yet, even if it is based on people statement about what they would do in hypothetical situations and not on their real behaviour. This fact can lead to some distortions between the declared and the real observation, and these distortions are more significant if the service under investigation is unfamiliar to the respondents. As already highlighted in the literature, including only those who declare to be "absolutely confident" on their answers as positive responses toward the new alternative adoption, reduce the gap between the real and the stated behaviour. From the case study implementation emerges that people who declare to be "absolutely sure" on their answers are principally those who already know car sharing. Hence, there is a correlation between the new service awareness level and the reduction of the SP bias related to the gap between declared and real people behaviour. Meanwhile, it is worthwhile underlining that car sharing knowledge does not influence the propensity towards service adoption.

The utility function for the car sharing alternative in the NIGHT model is formulated taking into account the influence of the actual modal split on the distance. Indeed, people who are already used to walk or cycle differently perceive the distance to cover to reach the nearest car sharing station: a possible explanation is that if the distance is too long they do not experience any benefit from the car sharing adoption instead of walk.

The developed random utility models can relate the probability of joining a car sharing organisation to the characteristics of this service, i.e. to relate demand and supply. Consequently, retracing one of the key research questions, it is not possible to define a fixed value on the number of people attracted by the new service, but it depends on the service characteristics and by the objectives that the commissioner intends to pursuit. In these tests, the number of potential users ranges between 500-1350 ca, but many other scenarios could be explored, and different outcomes would have been obtained.

Moreover, it is worth reporting that predict is intrinsically difficult and risky and it is also true for car sharing demand prediction since it is related to the supply elements of the service under examination, as also to external factors related to people behaviour and personal characteristics. Besides, as emerges in Test 7, demand also varies according to the other mobility services offered. Consequently, these latter have to be considered from the first stages of the planning procedure in order to be included as another hypothetical alternative in the stated preference questionnaire.

As explicated by Juschten et al. (2017) [8] joining a car sharing organisation is not only an economic decision but also a choice driven by a lifestyle which aims to be more sustainable, healthier and environmentally-friendly. Hence, performance trade-offs cannot be measured only in terms of money. For example, electric vehicles will not be selected if the service performances are analysed only in reference to the starting-up phase with the objective of cost minimisation since they are still considerably more expensive than the ICE ones. Moreover, the choice of including electric vehicles in the fleet is also influenced by the fact that they are still not very spread, that their market is constantly changing and also that the supporting infrastructure is in continuous expansion. Notwithstanding, EV can be advantageous if considering longer time and external effects since their maintenance costs are lower [61] as well as the local emissions [19]. Hence, these vehicles would not be considered if the only objective is the initial cost minimization, but EVs result attractive when considering different factors like the zero local emissions, the noise reduction, the positive company return of image [237], as well as, the attractively for people who would like to experience this kind of vehicle before purchasing one [217].

Generally, assessing objectives, which are not related to the profit maximisation, it is possible to notice that other solutions can conduct to the best performance of the service under different points of view, such as the reduction of the parking area or the number of people shifting away from public transport.

The latter can only be estimated if there are sufficient data on the current modal split and on how this change according to the service modification. In the case of the Trieste University students, it emerges that the car sharing adopters among residents are prevalently private car users, while among non-residents, people who shift to the shared mode are primarily walkers. The alternatives in which the students who have a public transport season ticket do not have to pay the annual fee for car sharing seem to be more attractive, and this makes suppose that people would join car sharing preserving the bus season ticket, using both the services.

Finally, the methodology appears to be a flexible tool, capable of adapting to different situations, as tested in the case study. In particular, as assessed in Test 6, the implemented algorithm, also, allows defining the number of potential members when the service attributes are already known.

Annexe 6.1

Discussion on the NPV

To compare the diverse tests of section 5.15 and assess various growth options and subsidy policy a simplified spreadsheet model is developed. The items modified for the assessment and shown in this Annex are those which do not influence the service demand, otherwise, it would be necessary to re-apply the whole process: demand analysis, supply element sizing, simulation and optimization.
In Table 61 and Table 64 the cash flow for test 1 and test 4 is reported, together with the percentage of cost coverage in relation to revenues [% C/R] and the NPV:

(32) $NPV = \sum_n \frac{S_n}{(1+i)^n}$

With S_n is the cash flow at year *n* and *i* is the financial discount rate.
The primary assumptions are a financial discount rate of 3,5%, a period of 5 years and a growth rate of 10% per annum.
All the unitary costs are reported in section 5.13. The items are split into investment costs, operating annual costs, operating annual revenues and residual value (cf. section 4.1 – Step 17). Specifically, investment costs include:

- vehicles purchasing [€];
- software/APP/Technical Equipment Purchasing [€];

The operating costs are:

- vehicles maintenance [€/year];
- employees [€/year];
- technical equipment management [€/year];
- parks [€/year];
- headquarter rental [€/year];

The revenues items encompass:

- annual fees [€/year];
- kilometric fees [€/year];
- hourly fees [€/year];

For vehicles and software are also included the residual values.

Table 61: Test 1 - Performance Over Five Years

Test 1 (growth rate 10% per annum, discount rate 3,5%)							
Year	*0*	*1*	*2*	*3*	*4*	*5*	
Members	655	721	793	872	959	1.055	
Rental/year	3.487	3.836	4.219	4.641	5.105	5.616	
Members/vehicles	22,6	24,8	27,3	30,1	33,1	36,4	
Investment costs	260.550	0	0	0	0	0	
Annual Revenues	98.552	108.407	119.248	131.173	144.290	158.719	
Annual Costs	172.196	173.246	174.400	175.670	177.067	178.604	
Annual Cash Flow (R-C)	-73.644	-64.838	-55.152	-44.498	-32.777	-19.885	Mean: -48.466
Residual Value	0	0	0	0	0	194.000	
NPS (including investment costs)	-334.194	-62.646	-51.485	-40.134	-28.564	146.600	**Sum: -370.423**
% C/R	57	63	68	75	81	89	
% C/R (including investments costs)	23	63	68	75	81	197	Mean: 85%

To facilitate the reading, the main supply elements of the design option, better described in section 5.15.1, are here reported in Table 62 and Table 65.

Table 62: Test 1 – Key Outputs

Test 1			
N. vehicles	29	Annual fee	60 €/year
N. parking lots	42	Km driven	3,5 km
N. Stations	28	Rental duration	2,6 hours
Fee per km	0,5 €/km	Students with PT season ticket	40%
Fee per hour	6 €/hour		

Moreover, a sensitivity analysis is conducted in order to assess the new value of the NPV when some parameters change and the main outcomes are reported in Table 63 and Table 66, respectively for test 1 and test 4.

Table 63: Test 1 – Assessment of Various Growth Options and Subsidy Policy

Test 1				
Parameter	Changed value	New NPV [€]	New %C/R (mean value) – including investments costs	Note
Growth rate	15%	-290.260	93%	In the fifth year the annual operating cash flow is positive (15.412 €), i.e. revenues are higher than costs, but the ratio members/vehicles is almost 45, meaning that to maintain a sufficient

				level of service some new vehicles should be purchased
Growth rate	0%	-503.358	70%	
Software/APP /Technical Equipment Purchasing Cost	0 €	-357.262	83%	This can be accomplished, for example, by taking advantage of some funding
Residual value (vehicle)	3000 €	-443.675	76%	Residual value (cf. section 5.13) is intrinsically uncertain, since it depends by numerous factors and will define only after 5 years
Parking Lots	free	-231.444	98%	It can be a reality if the Municipality grants the parking lots for free. In the fifth year the annual operating cash flow is positive (5.315 €).

Table 64: Test 4 - Performance Over Five Years

Test 4 (growth rate 10% per annum, discount rate 3,5%)							
Year	*0*	*1*	*2*	*3*	*4*	*5*	
Members	754	829	912	1.004	1.104	1.214	
Rental/year	4.017	4.419	4.861	5.347	5.881	6.469	
Members/vehicles	22,8	25,1	27,6	30,4	33,5	36,8	
Investment costs	292.350	0	0	0	0	0	
Annual Revenues	157.697	173.466	190.813	209.894	230.883	253.972	
Annual Costs	196.373	198.100	200.000	202.090	204.390	206.919	
Annual Cash Flow (R-C)	-38.677	-24.634	-9.188	7.804	26.494	47.053	Mean: 1.475
Residual Value	0	0	0	0	0	218.000	
NPS (including investment costs)	-331.027	-23.801	-8.577	7.038	23.088	223.168	**Sum: -110.111**
% C/R	80	88	95	104	113	123	
% C/R (including investments costs)	32	88	95	104	113	123	Mean: 92%

Table 65: Test 4 – Key Outputs

Test 4			
N. vehicles	33	Annual fee	60 €/year
N. parking lots	71	Km driven	5 km
N. Stations	31	Rental duration	4,1 hours
Fee per km	0,5 €/km	Student with PT season ticket	40%
Fee per hour	5,5 €/hour		

Table 66: Test 4 – Assessment of Various Growth Options and Subsidy Policy

Test 4				
Parameter	Changed value	New NPV [€]	New %C/R (mean value) – including investments costs	Note
Growth rate	15%	**17.726**	104%	In this situation the NPV is positive and the annual operating cash flow is positive from the second year, however from the fourth year the ratio members/vehicles is too high, leading to a lower level of service. So, it seems to be indispensable to re-evaluate the test, considering the purchasing of new vehicles: the results are reported in Table 67.
Parking Lots	free	**124.831**	116%	The annual operating cash flow is positive from the first year (3.923 €).

Table 67: Test 4 – Purchasing of New Cars Over the Years

Test 4 (growth rate 15% per annum, discount rate 3,5%)							
Year	*0*	*1*	*2*	*3*	*4*	*5*	
Members	754	867	997	1.147	1.319	1.517	
Rental/year	4.017	4.620	5.312	6.109	7.026	8.080	
Members/vehicles	22,8	26,3	30,2	34,7	34,7 Adding 5 new vehicles	35,3 Adding 5 new vehicles	
Investment costs	292.350	0	0	0	39.750	39.750	
Annual Revenues	157.697	181.351	208.554	239.837	275.812	317.184	
Annual Costs	196.373	198.964	201.944	205.370	209.311	213.842	
Annual Cash Flow (R-C)	-38.677	-17.613	6.610	34.466	66.501	103.342	Mean: 25.772
Residual Value	0	0	0	0	0	218.000	
NPS (including investment costs)	-331.027	-17.017	6.170	31.087	23.312	237.093	**Sum: -50.382**
% C/R	80	91	103	117	132	148	
% C/R (including investments costs)	32	91	103	117	111	125	Mean: 97%

If considering zero the cost for parking lots, the NPV of this last scenario is positive (**184.559** €)

7 Conclusions

Short Summary

The PhD thesis focuses on the development of a methodology to support car sharing planning and, in this section, the main topics of the thesis are summarised, retracing the dissertation structure. Furthermore, this last chapter reports the milestones of the research work and the main achievements, together with the prospective future developments and work improvements.

7.1 Summary

This PhD thesis focuses on car sharing and the planning of this service, before its implementation; the research work aims to develop a methodology which can be a supportive tool for the designer of a new car sharing service.

As emerges in *Chapter 2, section 2.1.* the service is strongly related to the principles of the sharing economy and of the sharing mobility and, as stated in *section 2.2.*, the planning methodology is necessary since, until now, the researches have been mainly focused on separate aspects of car sharing planning and arise the lack of a structured car sharing planning procedure. This dissertation aims to fill this gap. *Chapter 3* reports the crucial elements which should be taken into account and balanced when planning a new service.

The developed methodology is of type "multi-step": it is composed by several stages, which are analysed, in *Chapter 4*, both in qualitative and quantitative terms, including the implementation of methods already discussed in literature (*Chapter 2 – section 2.3.*) as well as an algorithm, developed explicitly for the purpose of dimensioning the critical supply's elements and the application of the optimisation procedure. The steps are related to each other since the outputs of a step are the inputs of the following one, but the connections between steps can also be retroactive; indeed, some phases

are feed-back loops, hence, until reaching satisfactory results, the same activities should be repeated. The combination of several methodologies reduces the disadvantages of a single method and boosts the significance of results. The different tools complete each other. This planning methodology focus on aspects related to marketing, policy, documental analysis, as well as technical aspects of the service's dimensioning. As *Chapter 4* reports, the methodology leads the designer, jointly with other stakeholders, such as the client, politics, public transport operators, to define a proposal of intervention only after a series of crucial preliminary activities such as, the objective definition, the context analyses, the target population individuation and the delineation of the current situation both supply and demand side. The methodology guides the designer to dimension the proposal of intervention, thanks to an optimisation process which determine the efficient solutions in relations to all the objectives referred to the economic goals, environmental goals together with the satisfaction of the mobility demand. Supply and demand are related by means of the discrete choice model (explored in *Chapter 2 – section 2.3.*), which is calibrated through stated preference survey data (*Chapter 2 – section 2.3.*) and is applied to forecast people behaviour, in different conditions of supply attributes variation.

The approach leads to identify a bundle of efficient solutions for the design of the new service: among these solutions, the client has to choose the best one according to specific constraints and objectives. The implementation of a case study, related to the planning of a car sharing service among the students of the University of Trieste, and reported in *Chapter 5*, aims to prove the potentialities of the developed methodology.

7.2 Achievements

The research activities on literature and the implemented services, as well as the application of the developed methodology to the case study, allow highlighting some aspects which appear pivotal for the subsequent implementation of a successful service. The achievements related to the case of study are reported, separately, in *Chapter 6*.

Concerning the developed methodology, the preliminary study of the context and of the current situation plays a crucial role, principally for two reasons:

- nowadays there is a high demand for flexible and efficient transport solutions, and, whilst private cars can satisfy these requests, at the same time, they imply some disadvantages, especially in urban areas [1]. Consequently, people are shifting towards different means of transport and car sharing can be a satisfactory alternative, if it is planned in accordance with all the transport system (e.g. bus, metro, train, bicycle, carpooling) [9]. Indeed, each of these services must be efficient and well-integrated with the others (from the physical, economic

and data information points of view) in order to allow users to experience an inter/multy-modality travel solution comparable to that offered by the cars [6]. In this framework, the preliminary study of the context, of the already existent services and the coordination/agreement with the other services' operators are pivotal.

- The second reason is related to the fact that, in order to accept and adopt a new mobility solution, often unfamiliar, people have to perceive it as potentially useful to overcome what they are currently experiencing as a criticality in their travelling: only in this situation they will be encouraged in making a significant change in their lifestyle. So, it is crucial to individuate the elements which characterise the current mobility service, its strengths and weaknesses, in order to be able to suggest a service which fits the target population needs. For the same reason, the target definition is also significant in order to reach a successful service.

Furthermore, the developed algorithm and the optimisation procedure allow the designer to balance between:

- the definition of efficient service for the users, since people seek assurance that the new service is well functioning, efficient and convenient, before adopting it and hence the service has to be implemented in order to meet these requirements [50];
- the achievement of positive profit for the service operator: since the supply dimensioning problem exists in relation to the fact that the economic resources are not infinite and that the service must be profitable or, at least non-loss making (even if the operator is a public entity since it taps into collective resources);
- the maximisation of the environmental objectives: there are several environmental benefits which can be achieved by the implementation of a well-planned car sharing. Most of them are related to private car reduction. In order to achieve this result, people have to experience that the new travel solutions are efficient, flexible, in one word, comparable to the private car; it is possible only when all the diverse transport modes are efficient and integrated [25]. The presence of a unique ticket, of preferential tariff schemes, of an information platform which gathers all the real-time data on the different services, other than the physical connection among stations, are elements which mainly boost the integration among mobility services [53].

The first two aspects are, particularly, related since the service can be improved only with a high number of users, but it is difficult to attract them with a just implemented service, not yet well-operative, i.e. without significative investments. The suggested methodology supports the designer to well dimension the service, in order to make people experience that it is efficient, and it is worthy of trying and adopting and at the same time, analyse costs and revenues for the operator.

The suggested methodology permits to pursue different objectives, summarising them into KPIs and defining the optimised solutions, also considering environmental goals.
The developed algorithm is easy to use, thanks to the "Control Panel" and the "Summary", respectively a sheet where input data and parameters are entered, and the main outputs are reported both in numerical and graphical form.
Besides the considerations already reported in Chapter 6, it is possible to assert that the procedure is widely applicable; the tool is capable of adapting to different situations and provide support to the designer for the planning of a new station-based car sharing service in different context and situations.

7.3 Limitations and Future Development

Different future research items can be further pursuit both to expand the work and also to overcome the encountered limitations. The list of the aspects which belongs to the first typology is quite broad since the continuous research on all the aspects discussed in the thesis, to name but a few:

- although vehicle relocation can be classified as an operational issue, it also influences the design of one-way car sharing, since the service, the number of vehicles, in particular, is strongly related to the type of relocation. For this reason, the developed algorithm may be enhanced if it will be integrated with a relocation module;
- similarly, the algorithm may also be improved by incorporating a module for the dimensioning and location of the charging columns, in the case of a fleet also composed of electric vehicles;
- a collaboration with economic science can be performing for better detail the financial scheme instead of using the profit comparison, a non-discount method of investment appraisal, which does not take into account the time value of money;
- in order to make easier to check the trade-off among the different effects it could be helpful to put all the impacts to the same nominator (money), i.e. performing a social cost benefit analysis. This analysis considers the whole society, including direct, indirect and external effects which includes the impact on environment and society, like air pollution, use of space, noise, accidents, time, social value of work, land use, etc.

From the limitations encountered in the implemented case report, the main recommendations and suggestions for future researchers are:

- increase the number of collected questionnaires; in the case study, the model has been calibrated based on the answers to 635 questionnaires, with a total of 1538 choice sets for the night model. Extending the sample of interviewed students will increase the precision of

the estimated model parameters, can prevent from the omission of relevant variables [160], and provide more information, in particular, on the modal split, O/D matrix;

- ensure data on numerous other specific elements, such as psychological aspects [191], attitude to transport policies [8], transport behaviour under different weather situations [118]. For example, it could be useful to ask students who are propense to adhere to the car sharing whether they would stop their bus subscription. This data may be collected through specific questionnaires, noting that it is central not to increase the burden of the respondents since it has been experienced that too many questions lead people not to complete the survey.
- design a new stated preference survey, including also hypothetical scenarios with different public transport services or different types of car sharing service. The introduction of the alternative "bus modification", besides car sharing and status-quo alternatives, will be worthwhile to define the service in the scenario which consider the joint implementation of car sharing with a more efficient bus service (Test 7) and, only through the collection of new data, it will be possible to define the modal shift accurately;
- still, on the questionnaires it may be preferable to introduce the final question which asks how much the respondents are sure about their answers on the SP options [211] on all the surveys;
- car sharing services are more effective when the users' travel demands are diverse and spread across the entire day, since, this increases the vehicle utilisation rates, the numbers of members and the ability to satisfy users' needs effectively [7]. For these reasons a new proposal of intervention may be interesting: a service dedicated to students in the night time and accessible to university staff, or residents, during the rest of the day, as suggested in 5.4;
- finally, it can be valuable to apply the methodology to a real case.

In conclusion, it can be asserted that the methodological results, together with the key points which emerge from the case study, can be a solid foundation for future researches, and the suggested methodology can be a valuable tool to approach the planning of a car sharing service in a structured and holistic way.

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