Car-sharing services: An annotated review

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Car-sharing services: an annotated review

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Abstract

The growth of car-sharing services as a new and more sustainable way of transportation is shifting the private mobility from ownership to service use. Despite the emerging importance of this type of mobility and the large number of papers present in the scientific literature, to the best of our knowledge no extensive and structured analysis has been performed to classify the research and determine the mainstreams. Aim of this study is to introduce a taxonomy and analyze the different aspects of car-sharing, including the different car-sharing services and the research questions considered in the papers. We analyze and classify 137 papers, covering the last fifteen years of research and deriving an insight of the mainstreams. Finally, we deeply study the trends and research perspectives of the literature, showing the unbalancing between the literature related to the operational level and the economic, business development and customer validation aspects.

Keywords: Car-sharing, Taxonomy, Optimization, Business models.

1. Introduction

In the last years the growth of car-sharing services as a new and more sustainable way of transportation is shifting the private mobility from ownership to service use. The basic idea of car-sharing is quite simple: share the usage of a vehicle fleet by members for trip making on a per trip basis. Although the first shared used vehicles system can be traced back to 1948 in the city of Zurich (Switzerland), motivated by economic reasons, in the following years other attempts of public car-sharing systems were not successful. In the 1980s, several successful car-sharing programs were started, with a consolidation in the early 1990s, thanks to a new awareness of the citizens and a real burst due to a more pervasive diffusion of ICT and mobile services in 2000s. Car-sharing increases mobility for community members to reach destinations otherwise inaccessible by public transit, walking or biking, while increasing the citizens' awareness about the social and environmental impact of using private cars. It encourages and supports multi-modal communities by providing an additional transportation option. From the point of view of building a sustainable city, the vehicles used in car-sharing are typically fuel efficient and lead to positive effects in reduction of urban emissions and city congestion [111].

Recently, also car producers started to enter directly in the market, as Daimler, BMW and FCA group, are directly involved in car-sharing operations with the scope of finding new channels to market the produced cars [9, 147, 144, 146, 145]. Presently, some large companies start to exist Worldwide, as Zipcar with over 900,000 members and 11,000 vehicles [167] and Car2Go with 2,000,000 members and 14,000 cars in several countries, including China [162, 68]. So, the market is growing fast and with this increasing demand also the demand of better understanding and control of the system increases. In fact, car-sharing is not just a matter of business or fleet optimization, but creates a complex system made by different actors, including citizens, public authorities and municipalities, companies. The system becomes complex for the strong links between the actors, as well as for the implications on the governance of a city when a large car-sharing service is introduced, as the integration with the existing public transport network and the policies for letting different companies to compete in the same urban area.

Despite the emerging importance of this type of mobility and the large number of papers present in the scientific literature, to the best of our knowledge no extensive and structured analysis has been performed to classify the whole research field and determine its mainstreams. In fact, partial visions and state of the art reviews of car-sharing exist, but there is a lack in terms of global vision. Existing works can be mainly split in two groups: reviews considering the technical and modeling aspects [80, 95] and papers dealing with the business perspectives of car-sharing obtained by surveys [145, 143]. Thus, just a little has been done to give a holistic vision of the topic and to classify in a more general way the literature.

Aim of this study is to fulfill this gap, presenting a taxonomy considering all the multi-facet aspects of car-sharing. Our taxonomy provides a framework for classifying papers published in the various academic disciplines and it becomes a guide for the researcher who chooses to study car-sharing with an interdisciplinary view, providing numerical analysis and a way for characterizing the papers in the literature. The educator can use this taxonomy to introduce the subject in a comprehensive way, letting a newcomer to have a depiction of the wide spectrum of possible research lines. Finally, institutional managers and stakeholders can use it in developing strategies for sharing mobility.

More in detail, in this paper we want to answer to the following questions:

- Can we find a series of keywords/axes such that we can categorize any paper dealing with car-sharing services?
- Can we organize the papers in a taxonomy and, by means of that taxonomy, highlight the research mainstreams and future directions?
- Can we see any lack in current frameworks in the literature, in terms of global view of the car-sharing service, current trends and future paths?

To answer to our research questions, we structured this paper as follows. We first introduce a taxonomy for papers dealing with car-sharing services, considering in it the different aspects, including the specifications of the different car-sharing services and the research questions considered in the papers (Section 2). Second, we analyze and classify 137 papers appeared in the last fifteen years, giving an insight of the mainstreams (Section 3) and making our study based on the largest database of works from the literature. Third, we deeply study the trends and research perspectives of the literature (Section 4), with a specific focus on four issues related to car-sharing services: the analysis of the user behaviors (Section 4.1), the forecast of the service demand (Section 4.2), the use of optimization tools for the design and the management of the service (Section 4.3) and the business development and its effect in driving the research (4.4). We demonstrate that there is an imbalance between the literature related to the operational level and the user behaviors and business development.

2. Search methodology

To build the taxonomy we followed the three-steps method described by Bailey [5, 4]. We begin with the empirical analysis of a database of papers. Then, the second stage clusters the information obtained by the first stage, while, the third stage envisions in a mental concept of the cluster by generating a name or label for the cluster. We first looked to the best practices defined by other taxonomies in the literature [12, 126, 58]. To select the papers, we used scientific refereed journals and refereed conference proceedings as a source for the car-sharing literature. To retrieve the papers, we used the Scopus database because, concerning the transportation field, this bibliographic database contains articles from all major journals dealing with transportation and management. Furthermore, the largest part of these journals are also listed in the Excellence in Research for Australia (ERA) 2012 Journal List by the Australian Research Council [52], a known list of scientific journals.
We restricted our search to the papers dated from 2001 until the end of 2016 to consider the most recent papers (last extraction of the database, March 2017). After a screening consisted of an in-depth analysis of abstracts, main topics, and results of papers, we selected 137 of these. This additional phase was needed to remove, for example, the papers that considered specific aspects as the technologies for the charging stations of electric vehicles, powertrains optimization and other technical features used in the car-sharing services, but not pertinent with a topology of car-sharing services. We also decided to not consider peer-to-peer papers, because we want to focus on the core car-sharing business, where the fleet

is owned by the car-sharing company. Moreover, we focused our analysis on car-sharing services based on urban areas because they represent the most settled business model and they cover the mostly part of the literature.

2.1. Taxonomy dimensions

We organized our taxonomy according to a double level classification. This choice is due to our willingness to limit the complexity of the overall classification. Due to the large number of factors affecting the car-sharing, our taxonomy does not meant to be jointly exhaustive and mutually exclusive in its axes and subcategories. For example, a methodology can be applied to different problems and specifications. However, our analysis intended to give an overview of literature patterns and trends in this field. In fact it is known that classifications too much refined becomes difficult to use and to maintain, preventing a practical usage of them [133]. Thus, we organized the information by axes, splitting each axis in categories when needed (see Figure 1).

The taxonomy describes articles according to five main axes, which constitute the first level of our taxonomy: *Mode*, *Engine*, *Optimization objective*, *Time Horizon* and *Methodologies*. The first two axes concern the car-sharing service specifications, while the remaining three inform on the research problem and the role of the research in the paper under consideration. Then, each axis is organized in a set of categories (second level of the taxonomy). This section presents each axis in turn, briefly describing its object and scope.

Service specifications	
Mode	Engine
Two-way (station based)	*Fully thermic*
One-way (station based)	*Green*
Free floating	
Not Applicable	

Research problem		
Optimization objectives	Time horizon	Methodologies
Business and Service	*Design*	*Simulation*
Infrastructure	*Planning*	*Stochastic optimization*
Fleet management	*Operational and real time*	*Combinatorial optimization*
		Statistical analysis

Figure 1: Resume of the taxonomy axes

2.1.1. Mode

Mode identifies the different ways in which a car-sharing service can be provided.

- **Two-way (station based)**: in the *Two-way* [120] mode the available cars are parked in pick-up stations, which are defined parking lots by the service provider or local administration and the journey must start and finish in the same space. Thus, this operational model does not consider the intermediate parking, which are the stops that the customer may plan for personal needs. The set of parking lots is predefined.

- **One-way (station based)**: the *One-way* [120] mode is similar to the previous one, but in the one-way case the parking lot in which the journey finish can be different from the parking lot in which it started. The set of parking lots is predefined.

- **Free-floating**: the *Free-floating* [60] mode is the last one came to the market; the cars are freely parked in public spaces within the operational area (i.e., the area served by the car-sharing company), and the journey can start and finish in any point in this area.

- **Not Applicable**: This section considers the papers analyzing car-sharing services without reference to any specific mode.

2.1.2. Engine

This dimension is used to classify the engine type of the cars involved in the car-sharing service.

- **Fully thermic**: in this section are contained papers that analyze fleets with fully thermic engines. Thus, these fleets are composed by vehicles powered by traditional (i.e., fossil derived) fuels such as gasoline or diesel.
- **Green**: in this section are contained papers that analyze fleets of green vehicles adopted by car-sharing companies, environmentally aware. In particular, these vehicles has less-polluting engines, as electrical, hybrid, plug-in, natural gas, liquefied petroleum gas (LPG), as well as hybrid.

2.1.3. Optimization objectives

The *Optimization objectives* dimension classifies the analyzed papers according to the component of the car-sharing service (i.e., technical management of the physical assets as infrastructure and fleets as well as the business management) that is subjected to optimization. This dimension does not consider the specific objective function in the operating model.

- **Business and service**: papers in this category deals with the identification of service features. In details, we consider here all the papers dealing with the business models and the definition of the car-sharing service, including the identification of the user behaviors and the demand estimation.
- **Infrastructure**: papers analyzing the optimal design and location of the car-sharing facilities , as the parking stations and, for electrical vehicles, the charging stations.
- **Fleet management**: papers analyzing the operations for the management of the fleet, as determining the fleet size and defining the car relocation strategies.

2.1.4. Time horizon

This axis considers the interval of time for which the decisions remain valid.

- **Design (strategic)**: strategic decisions that players (i.e., car-sharing company management) must keep in account in the designing of the service, including fleet type definition, user behavior, pricing policies, market place (green fields and urban areas) and demand identification.
- **Planning (tactical)**: this category considers all the papers dealing with service planning decisions, including fleet size definition, location of facilities (parking stations, e-charging stations, car maintenance facilities), urban areas boundaries, management of uncertainty of local demand.
- **Operational and real time**: operational and day-by-day decisions related to the service provided: operative car maintenance, refueling, car washing, relocation strategies to balance the system, avoiding stations with an excess of vehicles, or empty stations.

2.1.5. Methodologies

The *Methodologies* axis groups the papers according to the scientific approach used by the authors.

- **Simulation**: *simulation* aims to imitate the operation of the real-world processes. These methodologies are adopted to estimate the demand of the service to help the decision making process for new operators. Simulations are mainly based on real data referring the transport behavior of the dwellers of a specific area.
- **Combinatorial optimization**: *combinatorial optimization* consists in modeling, analyzing and solving a decision problem finding the optimal objective function according to a set of constraints when the data involved in the problem under study can be considered as deterministic. It is used in car-sharing services for the management of the fleet (e.g., relocation of cars) as well as for the design and the planning of the service.

- **Stochastic optimization**: *stochastic optimization* methods are used to solve decision problems where the data are affected by uncertainty. In the car-sharing services case, uncertainty often affects the service demand or the flows of vehicles between different parking stations or within the service area.

- **Statistical analysis**: *statistical analysis* methods are mainly adopted for analyzing data sets deriving from real observation (such as data sets provided by operators) or from surveys and focus groups; these methods are used to analyze the state of the art in context where at least one operator is working.

3. Literature analysis

In the following, we apply our taxonomy to the 137 selected papers and we use it to derive a first numerical analysis by grouping these papers in two categories: Journals (94 papers) and Proceedings (43 papers).

Although the plethora of journals that cover topics on car-sharing services is quite broad, it is interesting to note that more representative ones are Transportation Research Record and Transportation Research Part A-F. Indeed, they contain 46% of papers collected in journals and 31% of the total. Moreover, a large part of literature derives from proceedings (e.g. IEEE international conferences, Procedia - Social and Behavioral Sciences and Transportation research Procedia). 31% of papers refer to this category and they are usually papers describing real projects and applications of car-sharing services. Thus, the proceedings remain the main sources to have a better insight of the real-world projects, while journals mainly present the more theoretical and general results. In contrast, 28 journals are present with one and four with two works only. This unbalance is due, in our opinion, to the multidisciplinarity of the research studies in car-sharing. For more details, the interested reader can refer to [57].

3.1. Mode analysis

The results of the mode analysis are shown in Figure 2. Almost 50% of the analyzed papers are referred to one way mode, 19% are referred to free floating mode and 19% are referred to two way mode, while 15% of the papers have not been classified according to this dimension. Furthermore, in recent years there has been a growing interest in the electric car-sharing. In particular, one can notice how the research is moving from the infrastructure design of the first papers to a majority of the papers dealing with the customer behaviors and the customer acceptance. This shift in terms of papers' topic is mainly due to the change of maturity level of the electric car-sharing solutions, which are presently considered as the most promising business line of the next decade [159, 62].

Recently, [79] proposed a hybrid car-sharing system, which combines two-way and one-way modes. The authors applied it to the case study of Boston and showed the benefits and the profitability of the system. The improvement of existing station-based mode with free floating mode has been recently studied in [35]. Due to the limited usage of the hybrid systems, they are not considered as a separate category.

Figure 3 shows how the focus of the papers have changed during the last years. The chart shows an increasing of the interest in car-sharing in the recent years, since 79% of the selected papers were published from 2011 to 2016. The first result is that the one way mode was the first to be analyzed by the selected papers, while free floating mode was analyzed from 2011 with a peak in 2014. Since free floating mode has been studied to meet the growing demand for flexibility from the users of the service, the development of this service was made possible thanks to new IT infrastructures and services such as car positioning in the service area, mapping of the available cars and applications for the final users. Thus, this type of car-sharing mode started to be considered by researchers and practitioners only when the related IT technologies reached a sufficient maturity level.

3.2. Engine analysis

56% of the analyzed papers are related to fully thermic engines. Further analysis (Figure 4) show that the interest in green engines (mainly in electric or hybrid vehicles) increased in the recent years.

The chart shows also an increase in recent years of the number of publications related to fully thermic engines, due to the increased development of free floating car-sharing mode.

According to chart in Figure 5, fully thermic and green engines have been studied mainly referred to one way mode, while free floating mode with green engines (25% of overall green engines publications) are mainly referred to hybrid vehicles. Accordingly to the increasing awareness of public stakeholders to low-emission and eco-friendly solutions, there are more publications related to green engines than publications referred to fully thermic ones in the one way and free floating modes, which are also the most recently introduced modes.

3.3. Optimization objectives analysis

According to Figure 6, 60% of the papers are related to business and service optimization, 28% are related to fleet management optimization and 12% are related to infrastructure optimization. The chart in Figure 7 shows an increased interest in business and service optimization in the last years, with 45% of the papers published from 2011, and 22% of these were published in 2013 and 2014. Infrastructure and fleet management optimization were investigated in the recent years because of their importance for green car-sharing services (infrastructure) and free floating car-sharing services (fleet management). Business and service optimization has been analyzed for all the different service modes, but predominantly for one-way mode, with 51% of the papers analyzing business (see Figure 8). In this case, the analysis is referred to behavioral and demand estimation issues. Furthermore, infrastructure and fleet management optimization is mainly referred to the one way car-sharing mode. In fact, for this mode is very important to plan the correct location of the stations (in particular for electric/hybrid vehicles) and the relocation and maintenance strategies to balance the number of cars in the different stations and cope the users' needs. Finally, Figure 9 presents the relation between optimization objectives and engine type. Business and service optimization is mainly referred to fully thermic engines, while infrastructure optimization is an important aspect for the green vehicles, with the focus on the optimal location for the charging stations.

3.4. Time horizon analysis

59% of the selected papers are related to the design of a car-sharing service, while planning and operational and real time analysis represent respectively the 16% and the 25% of papers selected (see Figure 10). Analyzing the trend over time of publications (see Figure 11), an increased interest in the design and strategical planning emerges from 2011, with many papers analyzing the user's behavior and the demand estimation to identify the market places. One way mode is the mostly analyzed, with a prevalence of operational and real time analysis (see Figure 12). In particular, the interest in operational and real time matters is justified by the need of solid relocation strategies and accurate location of the parking stations. Finally, concerning the relationship between time horizon and engine type (Figure 13), all the issues in the time horizon dimension are mostly investigated with fully thermic engine vehicles. Furthermore, green engine vehicles are more analyzed according to the service design aspects (e.g. user behavior). This is logic by considering the recent introduction of green car fleets in commercial car-sharing solutions.

3.5. Methodologies analysis

As shown in Figure 14, 61% of the analyzed papers use a statistical analysis tool, while combinatorial optimization and stochastic programming method have a limited diffusion. This trend seems to be in contrast with the general need of limiting the costs of the service operations. It may be linked to a more general lack of linking between business models, business development, customer discovery and validation, and operational models (see Subsection 4.4). In recent years, the use of statistical analysis tools increased, accordingly to the increase of the number of publications (see Figure 15). Crossing methodologies with the service mode (see Figure 16), statistical analysis is used for all the different service modes, while simulation and optimization (both stochastic and combinatorial one) are mainly used for one way car-sharing service. Simulation tools are largely used in studies related to fully thermic engines, while green engines are mainly analyzed using optimization tools (see Figure 17). This behavior can be explained with the need, in the case of electric cars, of a more accurate phase of design of the service and planning of the infrastructures location due to the need of charging stations. Considering methodologies and optimization objectives (Figure 18), while statistical analysis is mainly used in studies related to business and service optimization (usually based on time series data collection), infrastructure optimization is largely analyzed using stochastic optimization tools. Fleet management optimization is mainly analyzed with both simulation and optimization tools. Finally, design issues are mainly faced with statistical analysis tools; stochastic optimization is largely used for planning issues, while simulation is the main tool for the analysis of operational and real time problems (Figure 19).

4. General trends and research perspectives

The aim of this section is to present a picture of the general trends and the research perspectives emerging from the literature. In Subsection 4.1 the focus is on the users behavior analysis, used mainly to determine how a car-sharing service could meet the customers mobility needs or the changes in users behavior consequent the introduction of a car-sharing service in a specific area. These studies are mainly aimed to quantify or at least estimate the positive effects (on environment, quality of life, land usage and traffic congestion) of the car-sharing services. Sub-section 4.2 presents the situation of the analysis of the demand, a key factor for the car-sharing operators to estimate the potential demand of the service in a specific area necessary to justify investments. For addressing this issue, it is important to accurately collect the primary data (Subsection 4.2.1); the two data collection methods mainly used are time series (in which historical data were analyzed to understand the underlying structure of the phenomenon) and qualitative and quantitative surveys (also including direct interviews, focus groups, brain storming sessions). The collected data are then analyzed (Subsection 4.2.2), most commonly by Logit models (used in estimating the parameters of a qualitative response model) and logistic regression. Sub-section 4.3 analyzes the papers according to their optimization objectives: business and service optimization, infrastructure optimization and fleet management. Finally, sub-section 4.4 focuses on one of the biggest lacks in the literature: the absence of studies related to the business models linked to car-sharing services, their business development process, as well as the value proposition and customer segmentation.

4.1. Users behaviors and factors affecting the adoption

Since the early years car-sharing has entered in the market, several researches are focusing on the impact of car-sharing on the urban mobility. They investigate mainly the characteristics of the services and the impact on users travel patterns an behaviors to estimate the potential demand and to investigate the main drivers of adoption [7, 8, 49, 62, 93, 104, 114, 168].

In [8, 100, 104, 119] the authors carry on an overview of the car-sharing service (through experts interviews), focusing on the main involved actors and drivers of adoption. The most relevant factors impacting the growth of the system are related to parking policies, technology, vehicles, fuels and insurance.

Several publications examine mobility behavior of members and potential members of car-sharing services. In different studies [39, 109, 110, 116, 144, 152, 165] the authors use stated preference methods to investigate the awareness and the acceptance of the service among car-sharing members. Then, by regression models, they identify the correlations between membership and social and demographic factors. Similarly, in [41] a binomial regression is used to model a spatial diffusion of car-sharing membership in Quebec City from 1996 to 2008, discovering how socio-economic factors such as education, motorization and family structure affect heavily the membership rate in the covered area.

Cohen et al. show how the adoption of car-sharing services is greater in high-density neighborhoods, where public transportation is more efficient and the usage of the private car is less frequent due to City regulations and restrictions [40]. In [116] Morency et al. estimate the factors affecting awareness and acceptance using both linear and logistic regression models, focusing on multimodal mobility patterns. Shaheen and Cohen present a method for the estimation of the potential market in Germany, analyzing potential users with objective and subjective criteria [144]. Unlike other studies, they focus on the satisfaction level towards other transportation means. Using a Logit model, the study reveals that bus travelers are more attracted from car-sharing models, while people traveling with high frequency and through longer distances are less interested. In [3] the authors introduce an innovative transportation concept in which personalized services are provided in real time to the customers, allowing them to select the best one from a list of travel options. A more recent study individuates the presence of a latent demand for car-sharing in a specific area, with the consequence that the increase of the number of supplied vehicles combined with a marketing campaign could lead to an increase of car-sharing membership [152]. In [109] and [110] users are asked about their willingness to adopt different hypothetical service plans, with different pricing policies and vehicle distribution, examining the service characteristics and evaluating the economic utility of each plan. In the last years, the growth of the performances of electric vehicles, the need of an electric mobility trajectory [46] and the increased attention to environmental issues shift the attention towards studies related to electric car-sharing systems, mainly focusing on propensity of the users and barriers to adopt these vehicles [43, 46, 51, 65, 69, 91, 94, 112, 137, 141]. Kumar and Bierlaire investigate the potential demand of these type of services in an academic community, with the result that electric vehicles could be chosen for short distances [94]. Furthermore, the research shows that the main factors of adoption of car-sharing services are related to cost reduction and traffic congestion, and respondents are willing to pay an additional cost for the use of an electric vehicle. Some studies, including [137], consider a specific age target, using factor analysis and ordered Logit models to investigate their satisfaction about current travel patterns and to evaluate the willingness to join electric car-sharing services. In [69] the authors employ surveys on expectation and attitudes of users before and after using the services, and then use qualitative methods to identify the motivations leading to successful adoption of hybrid and electric car-sharing services. The results show that electric car-sharing is perceived as part of an integrated transport system for short trips, with the consequence that the issue of range (also called Range Anxiety) have low relevance. In [109] and [110], and more recently in [43], authors investigate about economic utility of round-trip car-sharing services (which include also electric vehicles) employing both multinomial Logit and mixed Logit. The result is a reluctance to adopt fully electric vehicles, particularly for long distances, even if the distance is lower than the range of the vehicle, maybe because of uncertainty in predicting travel patterns. Similar studies, considering on the impact of electric vehicles in free floating car-sharing services, are presented in [106, 150].

Several studies [42, 48, 50, 66, 85, 89, 96, 108, 132, 135] focus on the behavior of current users of car-sharing services all over the world, mainly investigating on drivers of usage, changes in travel behavior before and after joining the service and membership duration. These papers analyze datasets from car-sharing operators or surveys. In [25, 42, 45, 48, 66, 85] and [115] the authors tried to predict the optimal location for the stations to maximize the integration of car-sharing service with other public transportation means. Genikomsakis et al., through a Geographic Information System (GIS), analyze regions already covered by the service, correlating factors like parking pressures, population density, age of the neighborhoods and car-sharing service level (defined as the vehicle availability) with census data [66]. A similar methodology is recently used in [25]. A GIS-based analysis carried on in several regions of the US finds that transportation characteristics are stronger than demographic information as indicators for car-sharing success. The aim of the study is to present a tool to identify neighborhoods and factors, as low vehicle ownership and high rate of one-person households, in which car-sharing could positively operate; the same tool has then been tested in Austin (Texas). In [85] Kato et al. find out how the success of car-sharing services is strictly correlated with factors like the size of car-sharing stations, seasonal impact, age of the vehicles and multimodal transport network, i.e., presence of different transportation modes nearby the car-sharing stations. Similar results are obtained in [42], where the role of other transportation modes on car-sharing services penetration is investigated, and in [48], where, through a logistic regression and a duration model, the authors quantify the positive correlation with the number of stations and the role of parking costs on the likelihood of vehicles renting. In [135] the authors model and forecast users membership duration and usage patterns, finding out a positive correlation between vehicle availability and frequency of use and between personal car ownership rate and membership duration. [50] and [89] identify the changes in transport behavior before and after joining car-sharing service. In particular Khan et al. show how in areas with population density up to 10000 persons/square kilometers the introduction of car-sharing leads to a slight decrease in public transport usage, an increase of cycling and walking and an average driving reduction [89]. Furthermore, [88] investigates, through a literature review, how car-sharing services can address health problems. Results show that car-sharing services can reduce car ownership and change travel behavior, with potential positive impacts on health related to the adoption of more active transport modes. This paper also introduces one of the major issues of car-sharing services: the impact of car-sharing in household car ownership. Two opposite trends emerge: some studies state that car-sharing could contribute to a reduction of total number of cars mileage as well as a reduction of car ownership, while other studies affirm that car owners could not forego private car and non-car owners may use car-sharing instead of other public transport modes. [74] and [90] explicitly consider this aspect. In details, the first paper analyzes the de-motorization potential of the service with consequent impacts on environment through surveys to different car-sharing service members in North America, showing the different efficiency between the private car (of which age and model were asked in the surveys) and the car-sharing service. Hildebrandt et al. investigate users travel patterns, vehicle usage and membership duration in correlation to several characteristics of the service, stating that car-sharing users are usually environmental friendly, and that less perceived cost savings usually lead to shorter membership duration and frequency of usage [74]. In [24] both in deep interviews and focus groups are used to investigate the propensity of customers to adopt a bundle of products and services, facing their concerns about the possibility that their needs might be unsatisfied. Results show that it is important for the planners to focus on the interaction with customers for gaining their confidence on the service. Another important issue is to educate customers on the life cycle costs of the products, to increase their awareness on the potential savings related to service adoption. In [33] the authors examine the car-sharing impact on car ownership in dense urban areas, finding that car-sharing members reduce their individual transportation cost and emissions.

In more recent years, several studies concerned the impact of the new emerging ICT and mobile technologies on the car-sharing system [70, 74, 98]. In [74] the authors show the fundamental role of information systems for the success of the car-sharing systems, allowing real time information on the fleets and helping users in the localization of the available vehicles. Applying an optimization model to a one-way car-sharing service, the authors found out a potential increase of car-sharing operators profits due to users' flexibility and real time information. Information systems are analyzed also for electric car-sharing systems in [98], where mobile technology can supply the necessary infrastructure to let the system correctly operate. Firnkorn and Müller consider the strategy of an automaker entering in the car-sharing market (focusing on the specific case of Car2Go) with the scope to start a new business segment and reach positive effects on branding [61]. After the collection of primary data (all Car2Go members in 2010 in the city of Ulm were invited to answer to an on line survey), empirical analysis are conducted to evaluate the impact on private vehicle holding after 18 months of service. Results show that after 18 months of service Car2Go has contributed to a strong reduction of vehicle ownership, with an even stronger potential impact estimated for the future. [138] focuses on how the effects of risk perception of products ownership can influence the adoption of access-based services, bringing to the conclusion that a higher usage of access-based services can increase the likelihood in ownership reduction by the customers. Finally, Kopp et al. analyze the travel behavior of members of a free floating car-sharing service, comparing the results with similar results from a sample of non-members. Results show evidence that car-sharing members are more multimodal than non-members, and even the distance traveled are lower for the car-sharing members [92].

Even if the literature is quite clustered, some trends emerge. First, the perception of the citizens is changing over time with the diffusion of the car-sharing services. Thus, people is moving from a car property vision to a car-as-a-service one. Second, the pervasive presence if ICT and mobile technologies is pushing the penetration of the car-sharing services.

4.2. Demand analysis

Car-sharing systems management has a complexity directly linked to the interplay effect of demand and supply. To optimize operating issues and to estimate the effects of car-sharing services on mobility management it is useful an accurate model of demand and supply [80]. Due to the strong dependence between the availability of vehicles and the number of trips, it is difficult to correctly model the car-sharing demand. Although various car-sharing simulation models were presented across the last years, it emerges a difficulty in representing accurately the supply side, focusing in particular on the cost-benefit analysis necessary to justify investments. Moreover, the recently growth of free floating car-sharing systems introduces further complexity, adding uncertainty as to the location where the vehicles can be picked up and returned. For modeling correctly the service, a key aspect is the data collection (Subsection 4.2.1), in which a properly recording of the variables must be ensured, and the tools developed to carry on the analysis (Subsection 4.2.2). Data collection, i.e., the detection of the variables that are the object of study, is a key activity. Some variables, such as age and gender can be detected easily, others are more difficult (such as variables related to cognitive, emotional, behavioral, learning, etc). In the literature, data are mainly collected by two methods: time series and questionnaires/focus groups/interviews/brainstorming. Time series is a forecasting technique that is based on historical data from which the analyst tries to understand the underlying structure of the phenomenon. The questionnaires contain both open and closed questions. In the first case, the subject chooses between the various alternatives proposed, while in the second may express his views freely. In focus groups a selected group of users are asked about their opinion, perception, beliefs and attitude towards the service, with free interaction between different group members, while in brainstorming a specific problem is addressed by a group of experts and users, with the scope to gather a list of potential solutions. Finally, in direct interviews an operator interview users and non-users of the service to collect the information.

4.2.1. Data collection

The most common method for collecting data to analyze them and such to capture the latent demand is the questionnaire. It is used by Cervero [31] on a macro sample that includes business and neighborhood car-sharing. Later, Zhou and Kockelman administer a questionnaire to the city of Austin, Texas [166]. The purpose of this study is to investigate the latent demand during the launch of the car-sharing service in Austin. Huwer places the emphasis on the combination of public transport with car-sharing service. Members and non-members of car-sharing service are selected randomly and interviewed [75]. Catalano et al. publish a study reporting a stated-preference survey in Palermo [23]. The respondents can choose from different transportation alternatives, which include private car, public transport, car-sharing and car-pooling. Then a random utility model is estimated using the survey data. The authors infer that in a future scenario characterized by active policies to limit private transport use the car-sharing market could increase up to 10%. Sioui et al. use two types of survey to gather data on travel behaviors on a typical day, widespread in Montreal, Canada, to analyze the car-sharing demand [149]. The first one is a regional, large-scale household travel survey and an internet survey, started after the introduction of the service, while the second one includes both former members and current members of the service. The study makes a comparison between respondents of two types of survey with similar characteristics and located in the same municipal sector. Herrmann et al. solve the problem of car relocation in free floating car-sharing [73]. For this purpose, a survey is conducted among users of the Car2Go system in Hamburg, Germany. The survey is intended for users and potential users of free-floating car-sharing service. The same method, extending the analysis also to electric car-sharing, is used by Wappelhorst et al., with 311 persons interviewed for the first project and 280 persons in additional personal short interviews for the second one [159]. Firnkorn and Müller compare the results of two methods measuring the impact of car-sharing on other transportation modes, starting from the same sample [60]. The first method estimates how the mobility behavior of respondents would be with the assumption of unavailability of Car2Go, while the second one determines the respondents past mobility behavior using Car2Go. Rabbitt and Ghosh conduct a survey in Ireland, with 2639 respondents among population of likely users concentrated in areas of higher population densities [131]. They present a new methodology for estimating the potential market and the impact of car-sharing system in Ireland. Accordingly to their results, all the small areas in the Republic of Ireland are sub-divided into groups based on the viability of introduction of car-sharing system in the area. In the same year, Ohta et al. cluster the 1095 respondents of web-based survey into similar sized groups based on the number of cars owned and on the residential area to investigate the effects of community size [123]. In the survey, respondents are provided with car-sharing and eco-cars information and subsequently are asked questions about both car-sharing services and eco-cars. Shaheen et al. [147] interviewed car-sharing actors with mail questionnaires, telephone interviews and other internet information, to compare Canadian car-sharing demand with North American car-sharing demand. In [61] primary data were collected by an online survey on the Car2Go members of the City of Ulm with the aim to analyze the variations in users behavior after the introduction of the service. Focus groups, combined with in deep interviews of car-sharing experts, are used in [24] to investigate the propensity of the customers to adopt bundles of services as a substitute of products. Unlike other studies, in [92] data are collected by a survey based on a GPS tracking smartphone application with the scope to analyze the travel patterns of both members and non-members of a car-sharing service.

Even the mostly part of the survey are covering a quite limited area, the authors try to infer general trends. At the same, no general survey exists, differently from other domains, as guiding behaviors in automotive [20] or the passenger's perceived quality of service in air transportation [129]. There is actually the need of a standard survey that will be used as a basis for the comparison of the different results geographically and would let to infer the behavioral changes over time. This is big lack in the literature that, up to now, is far to be filled.

4.2.2. Tools of analysis

In this section we highlight the main trends in the literature related to the tools used to analyze the data gathered in the research.

Logit and linear regressions. One of the most productive streams of research on car-sharing has been the study of the characteristics of its users. In several works the population characteristics are modeled using a sample of car-sharing users, analyzing these data with a Logit model. Binomial Logit analysis is used in 2003 by Cervero [31] to control variable factors such as price of gasoline and weather, while a matched-pair analytically approach is adopted in [139]. To understand the drivers of adoption of an urban car-sharing program, and to establish which modeling approach was the most effective, De Luca and Di Pace [47] investigate multinomial Logit, hierarchical Logit, cross nested Logit and mixed multinomial Logit models. Frost and Sullivan outline the role the car-sharing sector can play in reducing the private car usage in London to 2020. Statistical analysis (multiple linear regression and a compound annual growth rate) shows which existing socio-demographic and neighborhood factors have most affected car-sharing membership. Ohta [123] in his study on Japan, uses a multiple linear regression analysis, to examine the effects of individual attributes, including gender, age, number of cars per household and area of residence, with the purpose of finding information on behavioral intentions regarding joining a car-sharing organization in different situations. In 2014, Schmöller and Bogenberger [139] analyze the differences of the booking behavior between free floating car-sharing and hybrid car-sharing. Hybrid car-sharing differs for the size of parking area where cars can park (e.g. 1 km^2 areas predefined by the city). Free floating car-sharing includes information about time, data and coordinates of beginning and ending of the corresponding booking, while hybrid car-sharing contain only name of the area but not the actual coordinates. In [157] the authors apply the conceptual framework called Perceived Activity Set (developed by the same authors) to car-sharing market in the city of London, investigating both round trip (two way) and point to point (one way) service modes. The aim of the study is to investigate the impact of car-sharing services on the other forms of transport. A qualitative survey is used to investigate the opinion of respondents relating subscribing and using car-sharing services, and a following a quantitative model is used to forecast the number of potential subscribers, the level of usage and the impact on other forms of transport. The results suggest that the number of potential members of a one way service mode car-sharing is between three and four times as large as the comparable number of a two way service mode. Furthermore, the greatest reduction in overall vehicle traveled miles was found from the introducing of two way service mode. The reason lies in the fact that two way service mode is seen as a complement of public transport, while one way service mode is more likely seen as a substitute of public transport. Historical data and zone categorization are used in [161] to introduce a relocation model considering both electric and conventional vehicles, combining relocation with charging (for the electric vehicles), and refueling (for the conventional ones). Booking data are also analyzed in [117, 140] to introduce the relocation problem and the short time booking predictions in free-floating car-sharing services. In [17] car-sharing map data from a large station-based car-sharing operator in France are analyzed to determine whether a station is profitable or not for the operator. In [158] customer data are used to explain, through a regression model, spatial variations in car-sharing activities in the proximity of particular points of interest. Another important issue for car-sharing systems is to determine the operating area. In [142] population density, housing rent, city center distance, and hotel and restaurant density are used as independent variables to predict booking hot spots in a free-floating car-sharing system. The influence of the stations' location on potential membership is analyzed in [37] for a two-way car-sharing system. The importance of the collaboration between public and private sector is addressed in [155] to provide recommendations for both sectors, starting from the results of expert interviews conducted with governments and private operators.

Simulation. Ciari et al. in [36] and again, the following year, the same authors in [35] propose an Activity-Based Microsimulation Approach called MATSim, based on two features of car-sharing system: the access to rental car and the time dependent fee. Starting from micro level, model can determinate macro behavior of the system. A test was carried on in Greater Zurich where the car-sharing stations are 276. Instead, the second paper use the multi-agent simulation MATSim to evaluate different car-sharing scenarios for the city of Berlin. The likelihood of the whole representation is guaranteed by the fact that the artificial population is based on census data and on travel diaries surveys. The first scenario considers only station-based car-sharing available, while the second scenario suggests that there is a peak around 8 AM, and in the third scenario seems that the addition of free floating to traditional car-sharing does not affect the latter. In 2013 Weikl and Bogenberger presented a new integrate two-step model for optimal vehicle positioning and relocation and apply an optimization algorithm for finding the best relocation strategy in case of deviation [160]. The empirical basis of this work are real historical vehicle data of a real-life free-floating car-sharing system in Munich, Germany. The historical data consists of the geo-referenced start and end locations of the conducted trips, booking times and booking duration, satisfied and unsatisfied booking requests (online requests/searches by mobile phone or Internet which did not lead to a booking), trip distances and parking duration. The relocation problem is also addressed in [38, 82, 122] to present models to simulate different relocation strategies, with the aim to maximize the profitability of the service. A comparison between different relocation strategies, also involving autonomous vehicles, is presented in [30].

To predict the potential market demand for the car-sharing operator impact, [106] developed a simulation model based on Stated Preference experiments in order to obtain the necessary insights for this newly proposed transport mode. In 2012, an agent-based scheduling and energy management system was used to optimize the utilization of the energy produced locally and of the batteries in an electric car-sharing fleet [64]. In 2014 Lopes et al. apply an agent based model to represent the daily operation of a hypothetical car-sharing program operating in the city of Lisbon [101]. Some indicators were chosen to evaluate the performance of the system, both from an economic perspective and from an operational point of view. [67] combines technology road-map and system dynamics simulation to evaluate the environmental, social and economic perspectives of car-sharing in Korea for a long-term period of 50 months. This work represents the first attempt to simulate the demand and behavior changes of users, which are expected to be a major barrier for the car-sharing business. In [67] three scenarios of car-sharing services are developed and analyzed by the authors as an illustrative example of a scenario-planning approach to develop technology road-maps. Using system dynamics each strategic model for technology road-map is then transferred to the operational viewpoint.

Neural network. In 2007, Xu et al. [163] propose an evolutionary neural network to address the problem of forecasting net flow of car-sharing systems. The forecast is made according to the data obtained by real case of Singapore car-sharing. For the forecast, it's important to choose an appropriate neural network structure, including the number of hidden layers, and the number of nodes in each hidden layer. The common approach is to fix the structure and then use genetic algorithm to search the global minimum and back propagation method to speed up the convergence around the local minimum.

The literature shows a large usage of Logit model, with all its variations (binomial Logit, multinomial Logit, hierarchical Logit, cross nested Logit and mixed multinomial Logit), used in estimating the parameters of a qualitative response model. Logistic regression is used to refer specifically to problems in which the dependent variable is binary, while problems with more than two categories are referred to multinomial logistic regression, or, if the multiple categories are ordered, to ordinal logistic regression. Another methodology heavily used is the simulation-based approach, while only one paper adopts neural networks [163]. It is not clear if this trend is due to the specific expertise of the authors or by a clear predominance of Logit models over the remaining methods. Thus, a possible and suggested research line might be to better explore new tools, as neural networks, or hybridized simulation-optimization methods, that proved their efficacy in several applications [67, 129, 163].

4.3. Optimization in car-sharing services

As stated in Section 3, the use of optimization tools (i.e., combinatorial and stochastic optimization, and simulation) is limited in car-sharing services. Design of the service, infrastructures and fleet management are the main objectives to be optimized in a car-sharing system.

To support planners of car-sharing services in business and service design, Geum et al. proposed a scenario building approach that integrates technology roadmapping and system dynamics. This framework aims to evaluate scenarios, reflecting the results on technology roadmap, and the long term behavior of the system [67]. Other papers address business and service objectives using simulation approaches. Ciari et al. developed an activity-based microsimulator [36] and, more recently, an agent-based simulation [35] to estimate the travel demand and to evaluate how different policies can affect it in station-based and free floating modes. New car-sharing modes has been studied recently mixing standard modes [35, 79]. A hybrid system that integrate one-way and an existing two-way mode is studied by Jorge et al.. They present an optimization method to design and evaluate the hybrid system. When trips connect high demand generator nodes (e.g. airports), the hybrid system increases profitability and, enabling relocation operations, improves the demand served.

Infrastructure objectives mainly refers to find the optimal location of car-sharing stations and their capacity. Kumar and Bierlaire optimize the locations of future stations around the city of Nice, France, by a linear regression and an optimization model [94]. In [45], three Mixed Integer Programs (MIPs) are used for determining the optimal locations for stations and selection trips of a one-way car-sharing operator in Lisbon, Portugal. A MIP model is also used in [136] to manage in real time the relocation and maintenance operations in a one-way car-sharing system. De Almeida Correia and Antunes minimize the cost of relocation explicitly considering car imbalance issues in MIPs. MIP is also the base of the equilibrium network design model formulated by Nair and Miller-Hooks. With the aim to determine the optimal configuration, in terms of location and capacity of stations, the model maximizes the revenue of the operator [118]. The same problem is studied by Rickenberg et al.. The authors propose an optimization model that finds the best location and size of stations given a users' demand and preferences. The model is than integrated in a Decision Support System (DSS) [134]. Simulation-optimization approach is used for the same problem in [81]. The simulation considers uncertainty on trips and tests a vehicle relocation policy at time. Most of the studies analyze location problems in general and do not consider political issues that limit the possible location of new stations [14, 99]. Focusing on user's perceptions, [77] proposed an approach to help local authorities at selecting new sites for existing electric car-sharing services. The approach is based on the modeling of the preferences of the potential subscriber of the service.

Fleet management optimization includes the planning of the fleet size, the relocation strategies of the vehicles, pricing and parking policies. At a tactical level, optimization tools are used to investigate the optimal fleet size (number of cars) of a car-sharing system. In [56], the authors addressed the problem of determining the optimal fleet size of an electric car-sharing service. The system is modeled as a discrete event system in a closed queuing network, considering the specific requirements of the electric vehicles utilization. In [101] the authors solve the same problem by an agent based simulation to asses the potential of one-way car-sharing system. The model determines the fleet size, the location of stations and position of vehicles, as well as the relocating operation, scheduling and pricing policies. It also incorporates the uncertainty on the demand and the road network of Lisbon. Nourinejad and Roorda consider the cooperation of tactical and operational decisions in fleet sizing. They combined two integer programming models to plan the fleet size for a given demand and to schedule relocating operations that maximize the profit of one-way, two-way and hybrid car-sharing systems [120]. Relocation strategies answer to imbalance issues in one-way mode aiming to reduce management costs and to provide flexibility of the service. Operator-based relocations are evaluated in [86], while a comparison between operators based and users based relocation strategies is presented in [27]. The same authors evaluate a scenario in which fully automated vehicles can move among different stations when relocation is required in [29]. The development of these technologies could mainly impact positively on the efficiency of the transport system, optimizing landscape usage and increasing the transportation safety [1]. Simulation based optimal vehicle assignment and relocation at the stations have been proposed. [156] presented grouping of users to balance the system, while [73] address the same problem using a discrete-event simulation model. Kaspi et al. use an agent-based simulator to evaluate the improvement in terms of quality and flexibility of one-way mode with parking reservation policies [84]. Optimization methods have been used for relocation problems [19, 55, 54, 18]. Bruglieri et al. use a MIP for the relocation of 30 electric vehicles in Milan reducing the average working time for the operations. A multi-stage stochastic linear programming model has been proposed by Fan to handle with uncertain demand, while Boyacı et al. present a multi objective model with electric vehicles charging requirements. From a resources view-point, Kek et al. propose a DSS based on an simulation-optimization environment to evaluate the effects of different relocation strategies and to determine manpower and operating parameters. Marouf et al. solve the vehicle distribution problem focusing on automatic parking and platooning of the vehicles for reducing the manpower [107]. As cited above, relocation strategies have been broadly studied in literature, showing the high costs related to imbalance issues. Dynamic pricing policies can improve the profit of operators more than perfect balance scenario [83]. Jorge et al. propose a strategy based on using the clients' behavior to improve the balance of vehicles within the network by means of dynamic pricing policies for trips, decreasing the price when a trip increases the balance of the system. The optimal prices are defined with a non-linear optimization model. In [22] an optimization problem is addressed in order to maximize the total number of satisfied demands with a limited number of relocation operations. From this analysis emerges how the fleet management is the objective most studied in literature from an optimization view-point. Moreover, [72] presents a relocation strategy in which the relocation staff is moved with a shuttle, and the objective is to maximize the number of relocation operations minimizing the travel duration of the shuttle.

Although the uncertainty is a key factor in optimizing and planning car-sharing operations, it is usually surrogated by simulation-based methods and decisions are driven by deterministic and combinatorial programs. Several papers presented scenario approaches and forecasting techniques to handle with dynamic and stochastic demand in the car-sharing environment. Other sources of uncertainty, mainly related to the network, are only partially considered (e.g. road congestion). They should be explicitly considered in optimization tools, in particular for business, design and strategic decisions. Just a few papers make use of more sophisticated methods, as stochastic programming or non-linear approximations of the uncertainty should be considered [153, 154]. Moreover, the optimization models in the literature privilege operational aspects, disregarding the business development and management ones. In particular, no study considering the tariffs and their link to the operation issues emerges from our analysis. This is a big lack typical of a research community closed in its domain and with almost no cross-contamination with other domains. This is a big thread for the car-sharing industry. In fact, the typical outcome is or a clear separation between academics and industry, or a failure of the business model due to an erroneous business development schema.

4.4. Business models, business development and economics

To our knowledge, [13] is the only paper that partially analyze the business of sharing mobility services, in particular of car-pooling, using a framework linking business factors and service strategies. The framework mainly focuses on service aspects and does not consider explicitly more complex aspects, as the business model, its link to the business development model, as well as the value proposition of the different car-sharing companies. This, in fact, impacts on the tariff schemes, as well as on the service penetration in the market. As this lack can be partially tolerated in a pioneering phase, it must be compulsorily considered in a more mature phase of the market [124]. As highlighted also in [127], the current tariff schemes are rigid. On the contrary, too flexible tariff schemes risk to compromise the profitability and the operations efficiency of the car-sharing service, as happened in the telecommunication sector. In this context, the tariffs represent a way to fit on the one hand public policies, operating models and business strategies defined by companies and on the other hand the users'behaviors. These customizable tariffs and the balance between the above mentioned components push the service penetration in the market. A first in-depth study of the link between the Business Models and the tariff schemes is recently presented in [127]. The authors propose a comparative analysis of the Business Models of different companies according to the GUEST Lean Business methodology [125, 128] and derive a simulation-optimization tool able to perform a quantitative comparison of different tariff schemes. Although those first studies, more research should be devoted in this direction, by integrating other methodologies that was already proven to be effective in other domains as bilevel optimization and stochastic programming [71, 130, 44].

5. Conclusions

More recently, car-sharing services have become increasingly popular all over the world: old operators have increased their fleets and approached new market places, and new operators have started their business. Furthermore, the growing attention in environmental issues involved an increased attention in the usage of electric and hybrid vehicles. In addition, the development of information and communication technology (ICT) allowed the market penetration of new car-sharing models, such as free floating car-sharing services. In fact, as stated by Hayashi et al., car-sharing companies are realizing and offering new services through the use of ICT tools. Moreover, the introduction of ICT-enabled functionalities compatible with mobile devices, enhances the adoption and thus, spreads the car-sharing service between users. For example, some ICT-enabled services are the unlocking/locking of the vehicle using smart card or mobile app, dynamic location information on maps, etc. In this paper, we introduced a taxonomy able to categorize the existing literature and, by applying it, to derive some trends and directions for the future research. In more detail, it emerges a gap between the literature and the business development of the market. This gap becomes more and more evident when we look at the revenues generated by the companies, still marginal compared to the capital in use. As stated in the introduction, a taxonomy is only the first step. In fact, the business model and the link between the business and the operations models, the tariff scheme, need to be integrated.

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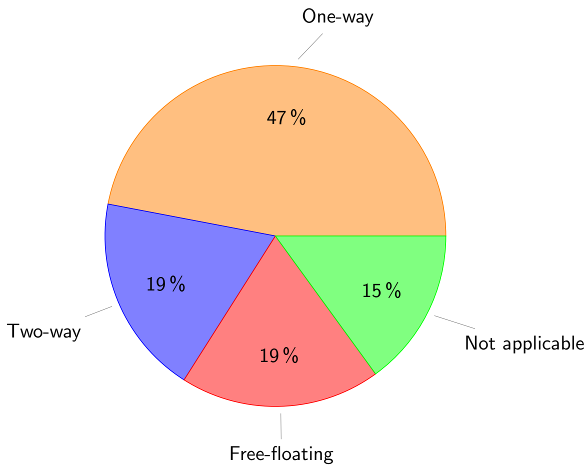


Figure 2: Modes

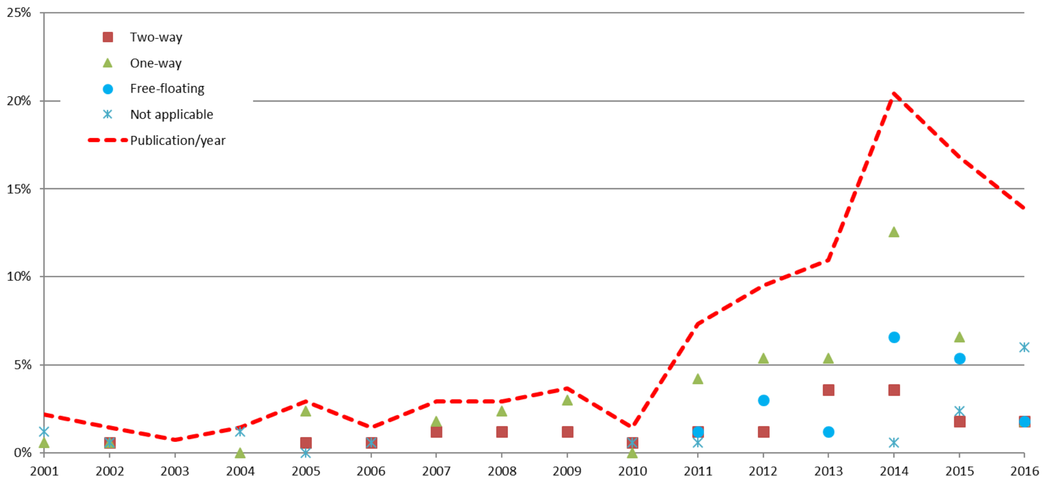


Figure 3: Number of papers referring to modes of car-sharing services

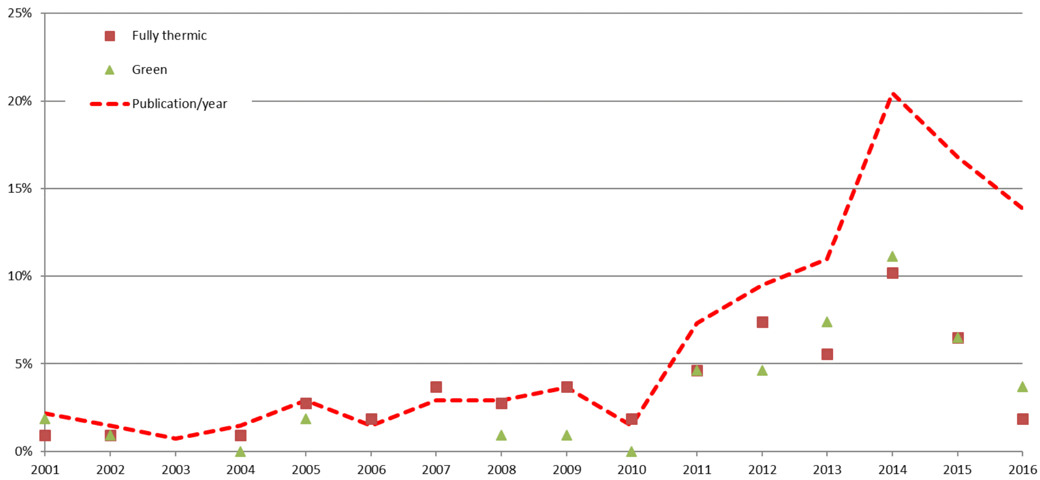
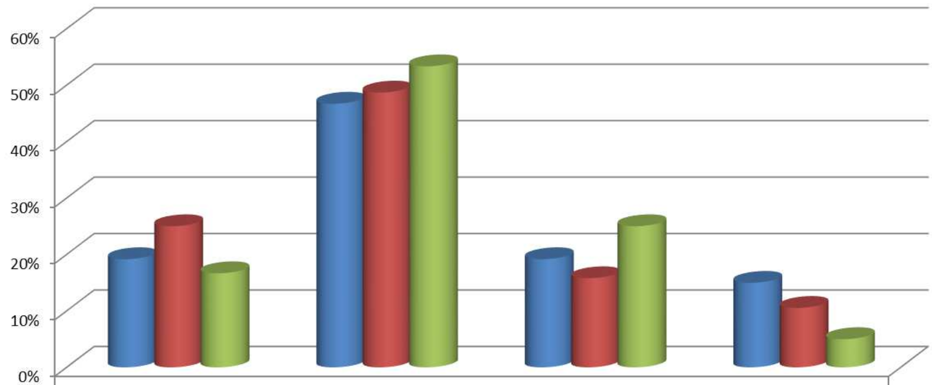


Figure 4: Number of papers referring to types of engine in car-sharing services



	Two-way	One-way	Free-floating	Not applicable
Overall	19%	47%	19%	15%
Fully thermic	25%	49%	16%	11%
Green	17%	53%	25%	5%

Figure 5: Cross analysis of engine and modes

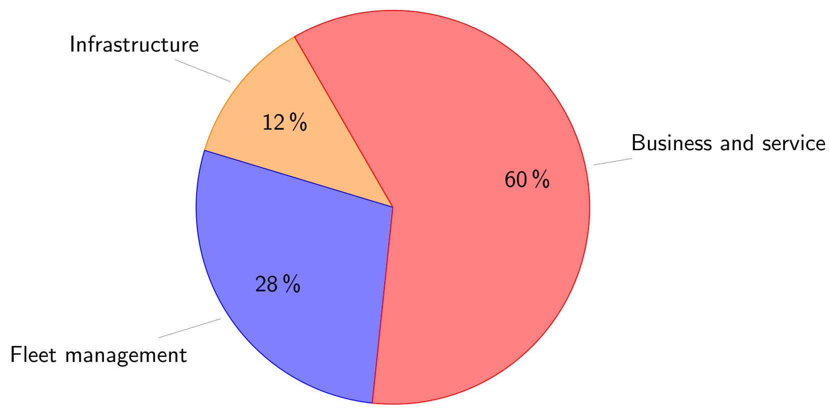


Figure 6: Optimization objectives

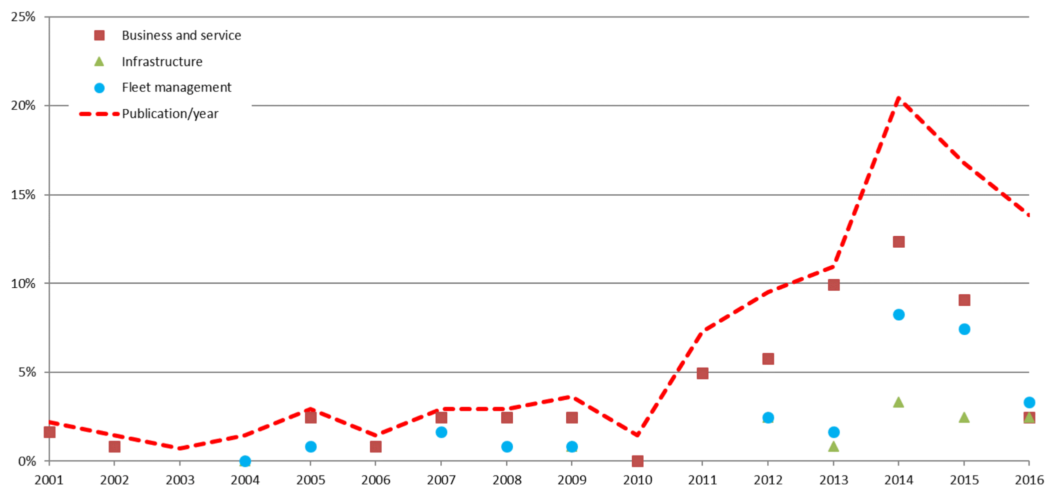
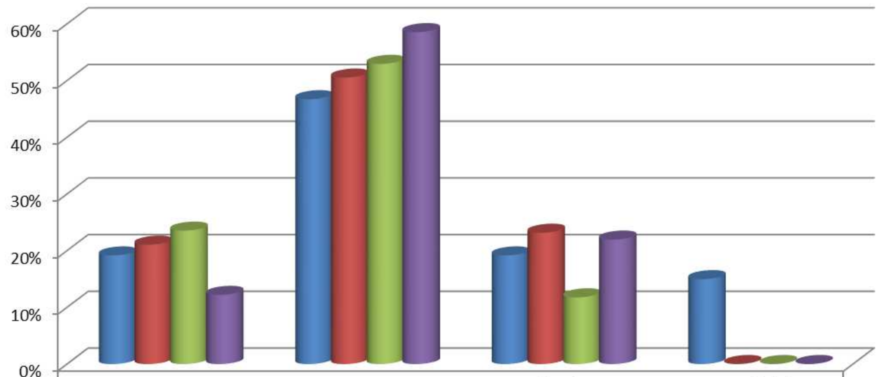


Figure 7: Number of papers referring to the objectives of optimization



	Two-way	One-way	Free-floating	Not applicable
Overall	19%	47%	19%	15%
Business and service	21%	51%	23%	0%
Infrastructure	24%	53%	12%	0%
Fleet management	12%	59%	22%	0%

Figure 8: Cross analysis of optimization objectives and modes

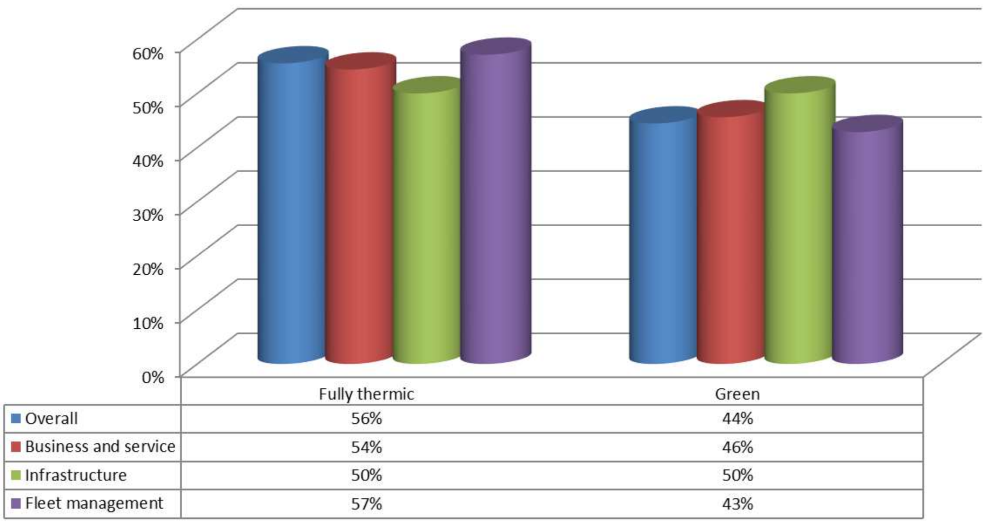


Figure 9: Cross analysis of optimization objectives and types of engine

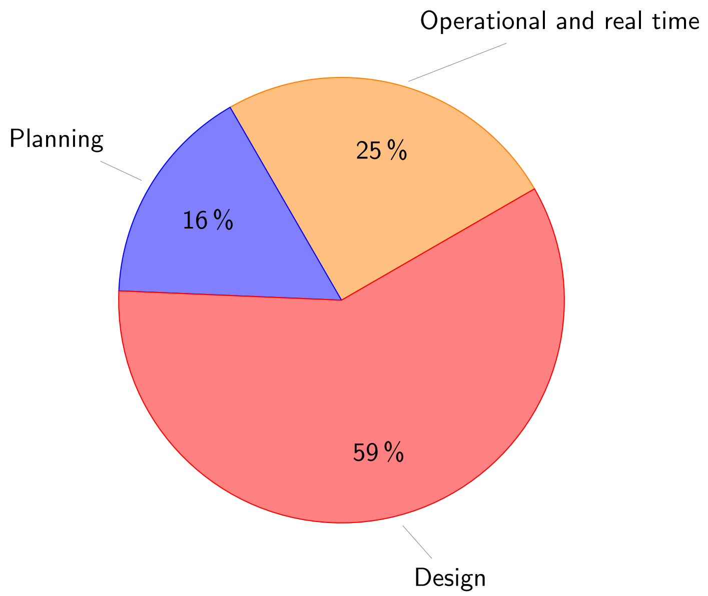


Figure 10: Time horizon analysis

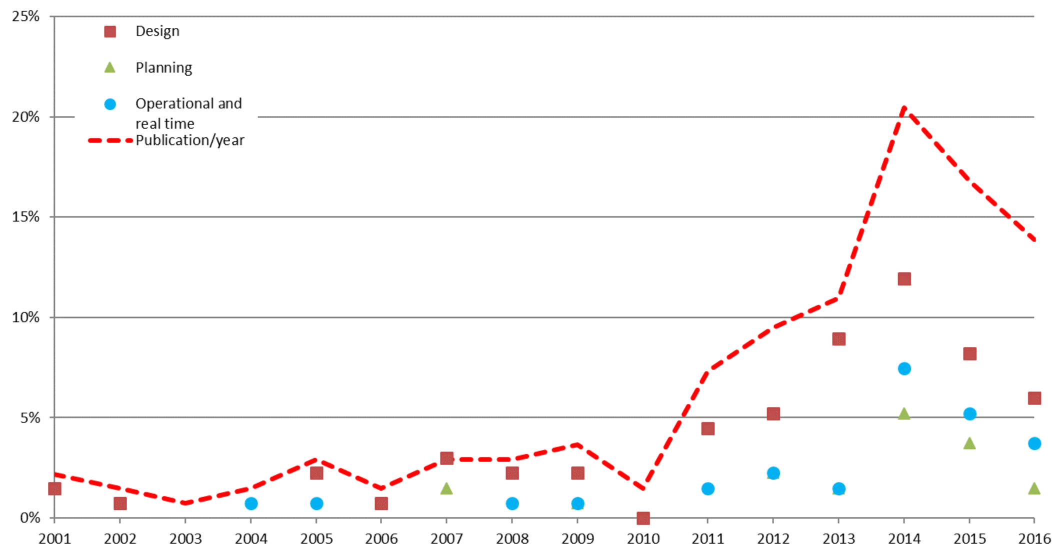
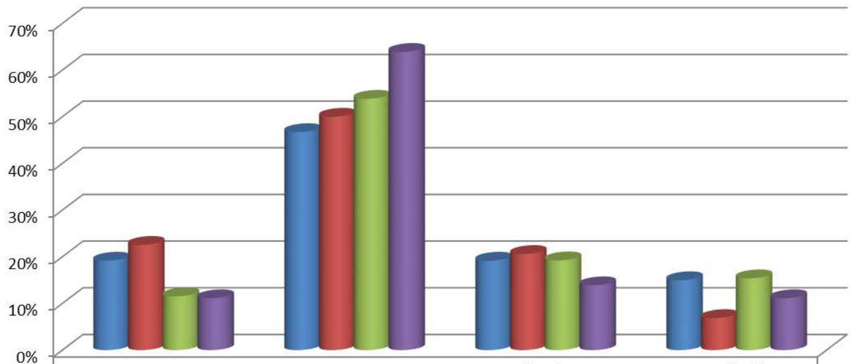
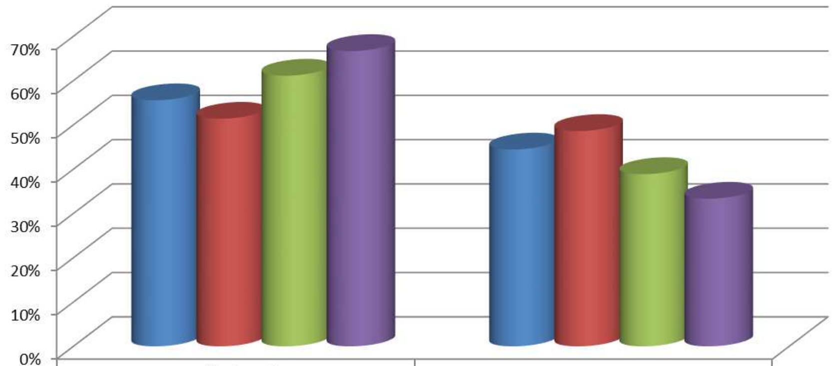


Figure 11: Number of papers referring to the time horizon analysis



	Two-way	One-way	Free-floating	Not applicable
Overall	19%	47%	19%	15%
Design	23%	50%	21%	7%
Planning	12%	54%	19%	15%
Operational and real time	11%	64%	14%	11%

Figure 12: Cross analysis of time horizon and modes



	Fully thermic	Green
Overall	56%	44%
Design	51%	49%
Planning	61%	39%
Operational and real time	67%	33%

Figure 13: Cross analysis of time horizon and engine type

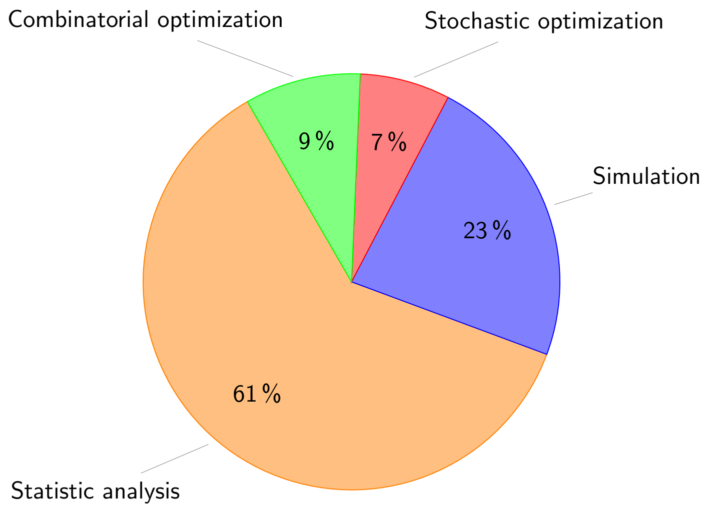


Figure 14: Methodology analysis

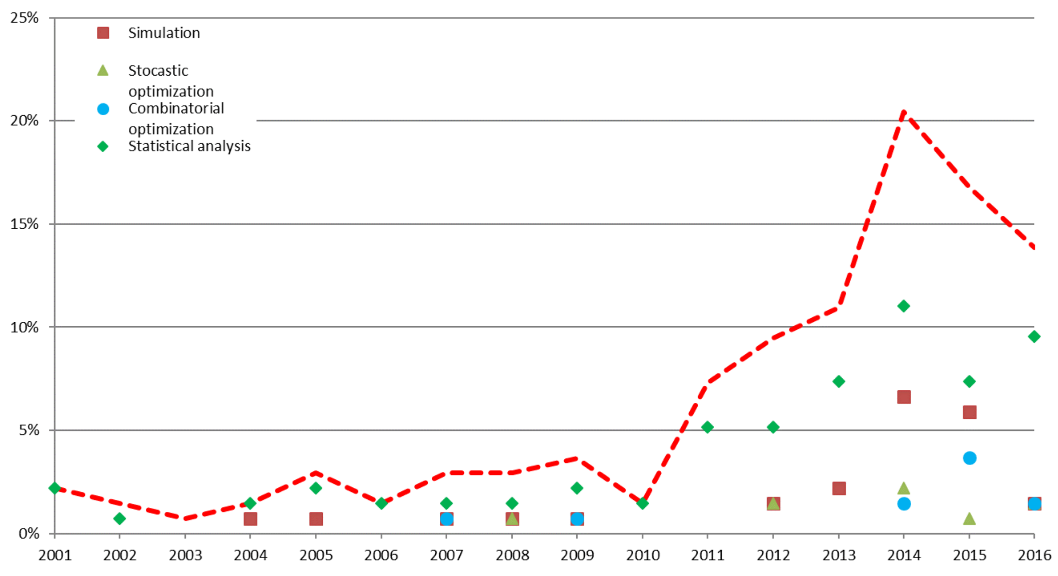
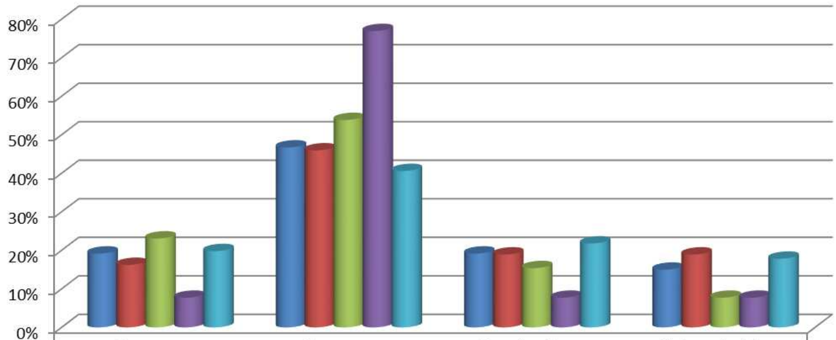
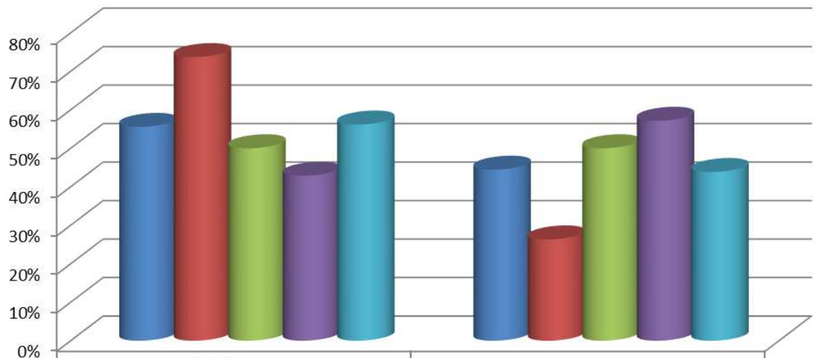


Figure 15: Number of papers referring to the methodology analysis



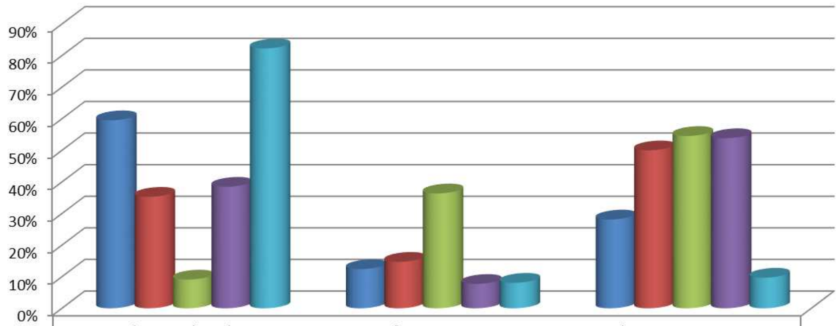
	Two-way	One-way	Free-floating	Not applicable
Overall	19%	47%	19%	15%
Simulation	16%	46%	19%	19%
Stocastic optimization	23%	54%	15%	8%
Combinatorial optimization	8%	77%	8%	8%
Statistical analysis	20%	41%	22%	18%

Figure 16: Cross analysis of methodologies and modes



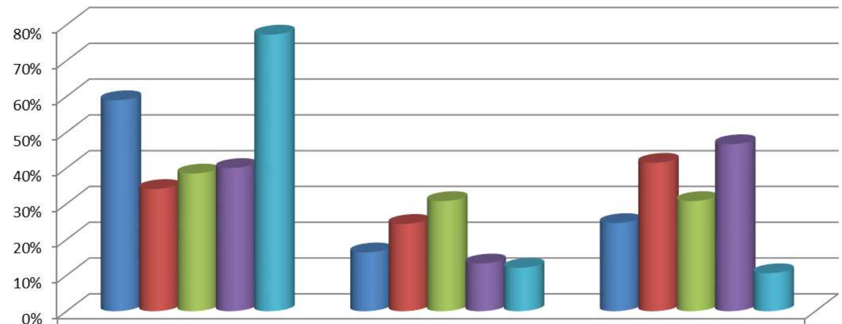
	Fully thermic	Green
Overall	56%	44%
Simulation	74%	26%
Stocastic optimization	50%	50%
Combinatorial optimization	43%	57%
Statistical analysis	56%	44%

Figure 17: Cross analysis of methodologies and types of engine



	Business and service	Infrastructure	Fleet management
Overall	60%	12%	28%
Simulation	35%	15%	50%
Stocastic optimization	9%	36%	55%
Combinatorial optimization	38%	8%	54%
Statistical analysis	82%	8%	10%

Figure 18: Cross analysis of methodologies and objectives of the optimization



	Design	Planning	Operational and real time
Overall	59%	16%	25%
Simulation	34%	24%	41%
Stocastic optimization	38%	31%	31%
Combinatorial optimization	40%	13%	47%
Statistical analysis	77%	12%	11%

Figure 19: Cross analysis of methodologies and time horizons of the decisions