Doctoral Thesis

Sharing as a key to rethink urban mobility
Investigating and modeling innovative transport systems

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SHARING AS A KEY TO RETHINK URBAN MOBILITY:
INVESTIGATING AND MODELING INNOVATIVE TRANSPORT SYSTEMS

A dissertation submitted to

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for the degree of

DOCTOR OF SCIENCES

presented by

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Abstract

The search for solutions of the growing transportation problems of metropolitan areas is a challenge for researchers of many different disciplines. The current high traffic volumes and increasingly diverse travel demand require a more efficient use of environmental and financial resources. It is well known that the current system imposes a heavy burden on society in terms of energy consumption and external costs such as accidents, noise emissions, pollution, space consumption etc. But it is often neglected that this system also entails social exclusion, and that it is for different reasons inaccessible to various categories of people.

This dissertation focuses on two modes, carsharing and carpooling, which have already a relatively long history but have not yet emerged as prevalent modal options. Nevertheless, they are obvious candidates as modes which could reshape urban mobility. Cars are idle most of the time, making them an underused resource in many cases; or a bad investment. Carsharing, separating car use from car ownership is a possible answer to the issue. Similarly, very low average occupancy of vehicles, coupled with the ease of communication that persons of our time enjoy, would suggest a good potential for carpooling. More in general, the place of automobiles in our society is slowly but steadily changing. Since Henry Ford and the T-model, car ownership represented an achievement in people’s life. This time now seem to be fading. In the US young people spend more money in electronic gadgets (computers, gaming consoles, smart phones, etc.) than on cars. In Europe and Japan similar trends have been observed. Importantly, the car is losing its appeal as a status symbol (Goodwin, 2011). Moreover, other trends are modifying our daily life – the way we are sharing things, both material and immaterial, new consumption patterns, etc. – suggesting that modes of transport involving sharing might be on the verge of making a breakthrough and become much more prevalent than they are right now. However, we are not yet so far and the path to such a scenario could be still long, and research will probably have a crucial role.

However, the current high interest among the transportation community for these modes contrasts with the substantial lack of planning tools in general and predictive models of the demand in particular. This dissertation, therefore, is aimed to go a step in this direction. This is made in two ways. The first is working to extend the existing multi-agent transport simulation MATSim to include carsharing. The second is producing additional knowledge on carsharing and carpooling, especially in the Swiss context. The two parts of the work, however, are not disjointed. A modeling approach like that of MATSim – agent-based simulations – goes beyond the mere representation of transport. It is
more about simulating daily life of people—in a very simplified manner though—and obviously has many underlying models. This is where the two streams of work meet. The developing part is centered on the creation of a suitable framework to simulate carsharing with the goal of embedding it in the larger MATSim framework. The other investigations, although intended to directly produce new knowledge, are also aimed to provide the necessary background for the developing part. This dissertation therefore covers various themes related with sharing in transportation—carsharing membership, carsharing with electric cars, attitude toward carpooling, carpooling and carsharing choice models—and for each of them is reported how the findings has been, or could be, used in the simulation framework. A version of MATSim extended to the simulation of carsharing is also described and it is applied on a large scale scenario representing the urban area around Zurich.
La ricerca di soluzioni ai crescenti problemi di trasporti nelle aree metropolitane di tutto il mondo è una sfida aperta per i ricercatori di varie discipline. Gli elevati volumi di traffico attuali e la crescente varietà ed imprevedibilità della domanda, richiedono un uso più efficiente delle risorse ambientali e finanziarie. È ben noto che il sistema di trasporti attuale impone un pesante contributo per la società in termini di consumo di energia ed esternalità come incidenti, emissioni acustiche, inquinamento dell’aria, consumo del territorio, etc. Tuttavia è spesso trascurato il fatto che esso provoca anche esclusione sociale perché per ragioni diverse è inaccessibile a varie categorie di persone.

Questa tesi si concentra sullo studio di due modi di trasporto, il carsharing ed il carpooling, che hanno già una storia relativamente lunga, ma che non sono ancora emersi come opzioni di mobilità largamente diffuse. Ciononostante, sono ovvi candidati nel ruolo di modi di trasporto che potrebbero rimodellare la mobilità urbana. Le auto restano parcheggiate la maggior parte del tempo e sono quindi risorse sottoutilizzate, o un cattivo investimento. Il carsharing, separando l’utilizzo dell’auto dalla proprietà è una possibile risposta al problema. Analogamente, il basso grado di occupazione dei veicoli che circolano per strada, abbinato al facile accesso ad ogni genere di telecomunicazioni vissuto dalle persone del nostro tempo, suggeriscono un ottimo potenziale per il carpooling. Più in generale, il posto dell’automobile nella nostra società sta cambiando lentamente ma in modo evidente. Fin dai tempi di Henry Ford e il modello T, possedere un auto ha rappresentato un punto di arrivo nella vita delle persone. Questa epoca sembra adesso svanire. In Nordamerica le giovani generazioni spendono più soldi in apparecchi elettronici (computers, cellular, play-stations, etc.) che in autovetture. Tendenze simili sono state osservate anche in Europa ed in Giappone e mostrano come le auto stiano perdendo il loro ruolo di status-symbol (Goodwin, 2011). Inoltre, altre tendenze stanno modificando le nostre abitudini – i nuovi modi di condividere le cose, sia materiali che immateriali, nuovi stili di consumo, etc. – suggerendo che i modi di trasporto che implicano una forma di condivisione potrebbero essere sul punto di acquisire un’importanza molto maggiore di quella che hanno adesso. Tuttavia, non siamo ancora a questo punto e la strada per realizzare questo scenario può essere ancora lunga, e la ricerca rivestirà probabilmente un ruolo cruciale.

Ciò nonostante, il diffuso interesse che i ricercatori nel campo dei trasporti stanno dimostrando recentemente per il carsharing ed il carpooling, contrasta con una sostanziale mancanza di strumenti per la loro pianificazione in generale e in particolare, per modelli predittivi della domanda. La
presente tesi quindi, mira a fare un passo avanti in questa direzione. Questo avviene in due modi. Il primo è estendendo un programma di simulazione ad agenti già esistente, chiamato MATSim, per rendere possibile la simulazione del carsharing. Il secondo è di produrre nuove conoscenze sul carsharing e sul carpooling, in particolare nel contesto svizzero. Tuttavia, le due parti non sono disgiunte. Un tipo di modello come MATSim – una simulazione multiagente – va oltre la semplice rappresentazione dei trasporti. Si tratta molto più di simulare la vita delle persone – sebbene in un modo semplificato – e quindi, chiaramente, è costituito in realtà dall’integrazione di vari modelli. Questo è il punto dove le due parti del lavoro di questa tesi s’incontrano. La parte di programmazione è incentrata sulla creazione di una struttura per la simulazione del carsharing con lo scopo ultimo di integrarla nel modello complessivo. Il resto della ricerca, nonostante i risultati delle singole parti abbiamo un valore indipendentemente dalle altre, ha anche lo scopo di provvedere la base necessaria per la parte di programmazione. In questa tesi quindi sono trattati diversi temi tutti attinenti ai trasporti condivisi – partecipazione al carsharing, carsharing con auto elettriche, attitudine verso il carpooling, modelli di scelta per carpooling e carsharing – e per ciascuno di essi è riportato come sono stati, o come potrebbero, essere usati nella struttura di MATSim. Una versione di MATSim modificata che permette la simulazione del carsharing è descritta ed è applicata a uno scenario di grandi dimensioni che rappresenta l’area urbana di Zurigo.
Acknowledgments

A few times during my (long) time at the IVT I wondered what I would have written in a hypothetical acknowledgement chapter and who should have been mentioned there. Obviously, I did it supposing that at some point I would have had the occasion to write one. Typically, there is one in PhD thesis, but quite a few times I was really convinced that I would have never managed to complete mine. Apparently, I was wrong and I have one to write now. My previous thoughts should make my task a bit easier now, but I realize that I was largely underestimating the number of persons that I have to express my gratitude to.

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1. Introduction

1.1 Context

Sharing is a trendy word. This has probably been one of the key words in the beginning of the new century and things do not seem set to change any soon. On the contrary, life at the time of the digital revolution, we might call it life 2.0, is much about sharing. Sharing experiences, thoughts, opinions, information, pictures, music, movies, through the internet has become an increasingly important part of our daily life. This is also reflected in the economic world, where firms dealing with this immaterial world are attracting huge attention and huge investments. The buzz raised by the entry of Facebook on the stock market with a valuation of about 100 billion US$ is a prime example of this trend. This is the most visible part of how important sharing has recently become but not the only one. The trend is not limited to the immaterial world, and technology and the web, which allow us to exchange all of the above in the form of digital artifacts, also have a prominent role in the sharing of physical objects. But first, what does sharing an object mean? If for sharing is meant the fact of using something which is not personally owned against a payment and for a specific amount of time, it simply means renting. Rental companies have been around already for a long time, offering a variety of objects. From holiday houses to tuxedos, there are many examples of objects which traditionally have a large market for rentals. However, things changed in the last few years. The dramatic increase in the ability of people sharing information, and the speed at which information can be shared, elaborated and updated, has opened up a lot of new opportunities to extend the concept to a much larger variety of objects and to a much larger scale, generating something different than traditional renting. The ubiquitous internet access that people of our time enjoy, though, is the motor of the current boom but not the only reason. The trend preceded internet’s large diffusion and some authors have seen this as one aspect of a society where owning things would be substituted by having access to them. This type of society was described by Jeremy Rifkin (2000) in his book “The Age of Access” based on various trends which appeared already in the last decades of the last century. He observed that some markets changed from goods markets to service markets and that information technology could only push this further. His prediction was correct and the various facets of this phenomenon were analyzed by several authors since. The book “The Mesh” (Gansky, 2011) focuses on peer-to-peer power and businesses exploiting the new opportunities offered by a highly connected world. It explains why now is the right time to set up a sharing business citing as key factors information technology, which allows timely and personalized services, and urbanization,
which provides a critical mass of geographically close potential peers. At a more general level, the economic crisis which hit western countries in the last years caused distrust in old companies, viewed as part of the problem, and pushed people to reconsider what is strictly necessary and what is superfluous. The discourse on climate change is also a factor, raising traditional businesses costs and reducing the market for “throwaway goods”. Environmental consciousness is consistent with sharing not only because it is a more sustainable way of consumption, but also because of its possible implications on objects design. An object which is thought to be shared in the first place should be durable, because it is used more intensely, and flexible, because different persons with different attitudes and preferences will use it. Reversing the perspective and watching it from the consumer point of view, the idea of collaborative consumption – introduced by Botsman and Rogers (2010) in “What Is Mine Is Yours” – is effective because it fosters good ideas, in this case intended as good services, and help them diffuse faster than it used to. Sharing a “like” or a “dislike” in a social network is often as much a social as an economic activity. The number, and the dimension, of business based on this form of mass collaboration – the travel website Trip Advisor is one of the most prominent examples – has grown fast in the last years. The observation that this is a mere exploitation of altruistic behaving individuals by a company making money out of it might deserve some credit, but might be misleading too. It diverts the attention from the crucial point that mass collaboration reverses the idea of self-interest as economy’s driving force, as suggested by Adam Smith and, later, by Milton Friedman who attributed everybody’s welfare as the product of the economic actors aiming to fulfill their particular interests. If in this “Me economy” the single person with its egoistic behavior is at the center of the stage, the technologies allowing sharing self-created contents help to shift the center to the community and on transactions which are not always strictly of economic nature but have in most of the cases an economic relevance. The internet, being democratic and decentralized, helped disrupting existing structures and created an ideal environment for a renewed culture of sharing. Obviously, it does not mean yet that traditional markets are history. People keep buying things. Nevertheless, mere ownership is not anymore at center stage, and the context might have never been as favorable as it is now for the success of ideas which involve sharing.

1.2 Motivations

The search for solutions of the growing transportation problems of metropolitan areas is a challenge for researchers of many different disciplines. The current high traffic volumes and increasingly diverse travel demand require a more efficient use of environmental and financial resources. It is
well known that the current system imposes a heavy burden on society in terms of energy consumption and external costs such as accidents, noise emissions, pollution, space consumption etc. But it is often neglected that this system also entails social exclusion, and that it is for different reasons inaccessible to various categories of people. At its start this dissertation was supposed to be about new ways to solve those problems. In particular the evaluation on how to combine different innovative modes of transport in order to have a more efficient and more equitable transportation system, especially in urban areas. The first step was choosing suitable modes. The context described in the previous paragraph made carsharing and carpooling (or any form of ridesharing other than traditional public transport) obvious candidates for the goal. Shared vehicles systems, like carsharing, including its peer-to-peer form, and bike sharing, are clear examples of the trend described. Cars are idle most of the time, making them an underused resource in many cases; or a bad investment. Similarly, very low average occupancy of vehicles traveling, coupled with the ease of communication that our generation is enjoining, would suggest a good potential for carpooling too. More in general the place of automobiles in our society is slowly but steadily changing. Since Henry Ford and the T-model, car ownership represented an achievement in people’s life. This time now seem to be fading. In the US young people spend more money on buying electronic gadgets (computers, gaming consoles, smart phones, etc.) than on cars. In Europe and Japan similar trends have been observed. Importantly, the car is losing its appeal as a status symbol (Goodwin, 2011). This opens up new opportunities to rethink auto use which is exactly what carsharing and carpooling are. The second step was choosing an evaluation framework. In this case, however, it was soon evident that instruments for the evaluation of a system of this type were still lacking. It was clear, in particular, that no modeling tools were available to forecast the demand for carsharing and carpooling. Therefore, the focus partly shifted to the methodological side and the creation of a predictive model for those modes has been since one of the priority of this dissertation. As result, this dissertation includes both the investigation of some peculiar aspects of carsharing and carpooling with rather classic methodologies, as well as the development of a suitable, new simulation-based modeling tool.

1.3 Organization

The chapters are in part based on previous papers presented at conferences or published in journals and, therefore, although modified, most of them are largely self-contained. Nevertheless, this dissertation is not structured as the sum of independent papers. It is rather conceived as an exploration of various aspects of carsharing and carpooling, which eventually results in the simulation experiments of chapter 8. This is true in particular for carsharing, while for carpooling the
possibility of implementing the presented findings in a simulation framework is only suggested but not realized.

Chapter 2 introduces carsharing and carpooling and offers a short review of the most significant research on these topics. Agent-based modeling and discrete choice models, which are mentioned and used several times in this dissertation, are also presented in this chapter.

Chapter 3 proposes a new modeling approach to estimate carsharing membership based on socio-demographic attributes and on accessibility measures. A logistic regression, based on Swiss national travel diaries, is used to obtain a model that is implemented and run on the whole Swiss population. The results are compared to actual membership data. Based on the model, an optimization framework for carsharing station location is also proposed. A genetic algorithm is used to find the constellation of stations which maximizes carsharing membership in a given area.

In chapter 4 data of carsharing use is explored in order to find out if electric vehicles might be used in carsharing systems. The analyses provided allow drawing some conclusions on which would be the most critical aspects for the electrification of carsharing.

Chapter 5 reports on a large survey that was aimed to find out the attitude of the Swiss public toward carpooling. The survey comprised qualitative multi-response questions and two stated preferences exercises, one focused on carpooling and the other, intended to provide an insight on the general inclination of the public toward innovative transport systems, focused on carsharing. The responses of the qualitative part are discussed and used for a combined factor and cluster analysis. The results of the stated preference exercises were used for the estimation of multinomial logit models. Altogether this chapter provides rich insight on the perception of carpooling and carsharing in Switzerland and gives the basis for a quantitative evaluation of their potential use.

In chapter 6 a simulation model for the estimation of carsharing demand is presented. The model mimics the actual carsharing supply in Switzerland and focuses on two aspects of carsharing: the access to the stations and the time-dependent fee. The path between the home location and the pick-up station is explicitly calculated while the cost of using carsharing in the simulation reflects the actual fee structure of the Swiss carsharing operator Mobility (Mobility, 2012).

Chapter 7 explains how the model presented in chapter 6 could be enhanced to model one-way carsharing, points out all the challenges involved and proposes a conceptual framework to overcome them.
The metropolitan area of Zurich is taken as a test case. In chapter 8 the results obtained with the simulation model of chapter 6 are presented. The chapter also includes the results of the simulation where the membership model of chapter 3 is included.

Chapter 9 summarizes the results of the previous chapters and explains the most significant directions in which this work should be continued.
2. Background

This chapter is intended to give the reader an overview on some concepts which are important throughout this dissertation.

On the thematic level, this dissertation focuses on carsharing and carpooling. Although sometimes confused — it does not help that in the UK carpooling is sometimes known under the name carsharing and carsharing as car clubs — the two modes are very different and based on two distinct ideas. Nevertheless, they have a common background, as both modes’ ultimate goal is increasing the efficiency of vehicles’ use through some form of sharing. This is highlighted in this chapter, which provides the definitions and a short history of carsharing and carpooling. Additionally, a literature review is presented, which shows how both modes have attracted increasing interest in the research community in the last years. It aims to point out which have been the main contributions to the field, which were the methodologies used and the main directions in which further research should go. It is not intended to go in depth into any single topic or to be exhaustive. In some cases, more extended reflections on particular aspects are added in the specific chapter for which they are relevant. The methodological level is approached exactly the same way. Agent-based modeling of transportation is the methodology used for the simulation experiments of chapter 8 where several ideas and results of previous chapters are used. In the present chapter, agent-based modeling is explained referring to some of the most prominent examples of it, including MATSim, which is the multi-agent simulation used in this dissertation. Discrete choice modeling also has a central role in this work. Many of the underlying models in MATSim are discrete choice models and two chapters of this dissertation deal, for a large part, with the estimation of discrete choice models. Random utility theory, on which discrete choice modeling is based, is briefly introduced in here, followed by an overview on multinomial logit, the most common model specification. The sections on carsharing and carpooling are the result of the integration of some previous papers’ background sections (Ciari et al., 2009; Ciari and Axhausen, 2011; Ciari and Axhausen, 2012) with new material. The section about agent-based modeling draws heavily on a previous paper which most of Zurich’s MATSim developers co-authored (Meister et al., 2010). The part on discrete choice modeling is new and the book by Ortuzar and Willumsen (2006) is its main source.
2.1 Carsharing

2.1.1 Definition, brief history and state of the art of carsharing

The basic idea of carsharing is that a fleet of cars can be shared by many users; they can drive a car when they need it, but they don’t need to own one. The system has been implemented in different forms, but basically can be distinguished from traditional auto rental services because car sharing is oriented to short-term rentals and because fuel costs are included in the rental rate. There are plenty of formal definitions of car sharing. One of the most concise and precise is the one given by the code of the state of Washington, USA (Millard-Ball et al., 2005): “A membership program intended to offer an alternative to car ownership under which persons or entities that become members are permitted to use vehicles from a fleet on an hourly basis”.

Carsharing in its modern form is a relatively new system but the idea in itself is already some decades old. The first known implementation of carsharing dates back to 1948, with the Sefage development project in Zurich (Harms and Truffer, 1998). Various other schemes were implemented during the 1970s and 1980s, but most of them were at a very small scale and they invariably failed after a few years of activity. Sometimes, they were part of an experimental program, and a long term survival of the program was not envisaged from the start. Only at the end of the 1980s did the concept eventually find its way to a larger public with new programs that are still in operation today. Switzerland is also the place where the modern car sharing was created. In 1987 two different cooperatives were independently founded in Zurich and in Stans, merging later under the name of Mobility (Muheim, 1998). Shortly afterwards, in 1988, StattAuto Berlin (Stattauto, 2012) was founded and soon other car sharing operators established themselves in different parts of Europe, North America and Asia. Although the basic concept of carsharing has evolved in many different ways throughout the world, there are characteristics that are recurrent in most carsharing programs. Over time, profit-making organizations have emerged as the most important actors in the carsharing market, catching the largest market share, even if non-profit organizations are still predominant in terms of number of organizations. “Neighborhood carsharing” (Barth and Shaheen, 2002) is the predominant operational model. Vehicles are located at parking facilities that are distributed throughout a region. The core idea is to conveniently serve a set of members living in the neighborhood of the station (the location of the car). There is usually the obligation for the customer to return the car to the same spot. Services such as instant access, one-way trips, open-ended
reservations, etc., go beyond this basic scheme, but until recently they have only found sporadic applications (Schwieger, 2003; ICVS, 2008). Private users still constitute the bulk of carsharing customers, but business users are considered by some (Mobility, 2012) the most promising market for further expansion of carsharing. Business carsharing, where a firm offers its employees access to carsharing for business trips instead of owning a car fleet, is growing faster than private use, but still accounts for a small portion of global carsharing use. Most carsharing operators require that customers pay a membership fee. Sometimes this is a deposit that is refunded when membership ends. The rates are usually a combination of per hour and per km rates; maximum rates for daily rental sometimes apply. In Europe, most operators offer a relatively wide range of vehicles, from small city cars to relatively large cargo vehicles. However, in most cases the type of fuel is not an important attribute of the car. In North America and Asia, the combination of carsharing with LEV (low emission vehicles) is more common (Shaheen and Cohen, 2007). For the time being, most established carsharing schemes offer access to cars via smart card or PIN (personal identification number), and reservations are almost exclusively made by Internet. This form of carsharing uses both on-street and off-street parking spaces as stations and therefore, finding and financing parking spaces are often important barriers to further expansion. Sometimes local governments provide park spaces for free or for moderate prices to carsharing organization as a form of subsidy motivated by the benefits that carsharing is supposed to bring to a community.

In recent years, several new developments have modified the world of carsharing. Carsharing systems and more in general shared-vehicle systems are increasingly popular all over the world. The number of available shared vehicles overall increases both, because new vehicles are added by existing operators and because new operators start their activities, including in areas of the world where carsharing was not yet present (Shaheen and Martin, 2006; Shaheen and Cohen, 2007). Moreover, the incredibly fast diffusion of bike-sharing systems can be seen as a positive factor for a further future development of carsharing, because it has the potential to complement carsharing systems and because it helps to make the idea of shared-vehicles systems more popular. One example is the AutoLib project (Autolib, 2012), a huge carsharing system with 3’000 vehicles in the Paris region which started operations in 2011. Its realization was promoted by the great success of the bike-sharing scheme Velib in the same area (Velib, 2012). The system uses electric cars and the concept of one-way carsharing, which has been around for a while, but always encountered problems in practical implementations. Its revival recently started with the successful implementation in the cities of Ulm, Germany and Austin, Texas (Car2go, 2012). Meanwhile, some new approaches to carsharing are appearing at the horizon. The most interesting one is probably the
idea of peer-to-peer carsharing systems, where private auto owners make their car available to other members of the association who want to rent the car for a short period (Brook, 2010). The market, especially in Europe, has witnessed an interesting new phenomenon. For the first time, car-makers – i.e. Daimler, Peugeot, BMW, etc. – are directly involved in carsharing operations in the search of new ways to market the product car. At a time when numbers sold vary widely from year to year in most of the western countries and the chance of a surge thanks to developing countries’ markets is hindered by the emergence of new car-makers in those same countries (India, China), this is understandable. What impact this will have on the carsharing world will be seen in the future. However, it is reasonable to expect that it will accelerate an already existing trend towards larger carsharing companies and larger carsharing systems (Brook, 2010). North America, in fact, has recently witnessed the merger of two of the largest existing operators. In Shaheen et al. (2009) it is observed that this development is likely to inaugurate a new era in the commercialization of carsharing, transforming the idea of shared cars into a mainstream concept. Moreover, its increasing success happens because carsharing is a possible answer to a current issue like volatile gasoline prices and in the long term, reducing car oriented behavior, might help mitigating climate change. All these developments justify an optimistic outlook regarding a future increase in car sharing popularity that will probably draw increased attention from policy makers and venture capital investors.

2.1.2 Literature on carsharing

Academic literature on carsharing has been relatively abundant for the last 15, 20 years and remarkably sparse before, reflecting the diffusion of the system, especially in North America.

Researchers reported on a large variety of topics related to carsharing, using both qualitative and quantitative methodologies. We suggest that the large majority of carsharing literature falls into one of the following categories:

- Market analysis
- Impacts of carsharing
- Carsharing operations and management

The categorization is inspired by the work of Millard-Ball et al. for the Transportation Research Board (2005), which probably contains the most complete literature review on carsharing, although in the meantime somewhat outdated.
Market Analysis

Market analysis is probably the largest of the three categories proposed. Under this category falls all work aiming to identify and analyze actual and potential markets for carsharing. The main questions that this stream of work is trying to answer are: Who are carsharing users? Who is attracted by carsharing? What are the motivations to join carsharing? Which types of trips are made with carsharing? Which areas are more suitable for carsharing? Researchers analyzing data from different countries have reached similar conclusions and the prototype of the carsharing user can be delineated as follows:

- Relatively young (late 20’s to early 40’s)
- Well educated
- Income higher than average

Motivations to join carsharing are somewhat less consistent throughout the available literature but an overall trend is that early adopters are often ideologically motivated, while, as the system grows bigger, economic aspects and convenience become more important. Nowadays, that carsharing is far better-known than it was twenty years ago at the beginning of modern carsharing era, users have rather a pragmatic approach. Private trips are mostly leisure trips or cargo trips (i.e., shopping trips resulting in heavy or large purchases); trips to and from work are almost absent. There is consensus in the literature about some fundamental aspects of carsharing markets’ geography. The most suitable areas are dense urban areas with a good public transport supply (Grasset and Morency, 2010; Stillwater et al., 2008). However, it should not be forgotten, that many European countries have a more developed public transport network than North America, which in some cases allow operators to offer carsharing also in small centers. Switzerland is probably the most notable of such cases.

Some researchers have used the results of market analyses to make prognoses about the extension of carsharing. This has been made at different geographic levels and studies range from the estimation of potential growth of a specific system in a specific region (Schuster et al., 2005; Haefeli, 2006) to those for a whole country and a generic system (Prettenthaler and Steininger, 1999; Nobis, 2006). The type of potential estimated varied, but the most common measure used was in terms of percentage of households joining the system. The majority of the estimates of carsharing growth potential was very optimistic and used very simple methods. A very common approach has been for example to find the profile of prototype carsharing users in terms of socio-demographic attributes and then project this on the whole population studied.
**Impacts of carsharing**

Under impacts of carsharing are addressed the impact of carsharing on users, the transportation system and the environment. In fact, many positive impacts are commonly associated to carsharing, but not all these impacts are documented by empirical data. The issue is discussed in detail by Millard-Ball et al. (2005), and is synthesized in Figure 1. These results are derived from the work of many researchers around the world (Lane, 2005; Cervero and Tsai, 2004; Katzev et al., 2000; Shaheen et al., 1998; Harms and Truffer, 1998, just to mention a few of them) and there is a substantial agreement that lower parking demand and more fuel efficient vehicles are the most important benefits at a general level. The individuals using the system report fairly consistently about cost savings and increased mobility. Other benefits often attributed to carsharing, like congestion reduction, lower emissions or less vehicle travel have not been confirmed by solid data. Indeed, the authorities of some countries, decline incentivizing carsharing because such benefits are not supported by solid enough data (Kato et al., 2011).

![Figure 1: Benefits of car sharing (source: Millard-Ball et al., 2005)](image)

**Carsharing operations and management**

Under the last of the proposed categories, carsharing operations and management, falls all research which either describes actual systems, or proposes approaches to improve some aspects of carsharing. In the work of Barth and Todd (1999), a simulation tool is proposed to find the optimal number of cars at the stations in order to offer the desired level of service and minimize relocations. Enoch and Taylor (2006) make a review of the support mechanisms that were put in place by
different levels of government in various countries to help carsharing to develop. Some researchers (Uesugi et al., 2007; Awasthi et al., 2008; Wang et al., 2010; Correia and Antunes, 2012) have attempted to solve the problem of the optimal redistribution of vehicles in one-way carsharing systems. These approaches are typically drawing on operation research techniques. The work of Brook (2004) analyzes the issues of starting a carsharing system and review different operational models. Various works by Shaheen, one of the most prolific researchers on carsharing, have dealt with this category of topics. Among the latest, one deals with parking policy issues for carsharing organizations (Shaheen et al., 2009), and another one provides a ten years retrospective of carsharing operations in North America. Another effort was dedicated to the classification of different types of carsharing systems (Barth and Shaheen, 2002).

Finally, it is worth to have a look at some research which is outside the field of transportation science but can be of interest for carsharing researchers. Of particular interest is the idea that the diffusion of carsharing could follow the general diffusion paths of new products. The likelihood of adoption of an innovation would then depend on the potential adopters’ perception. The individual evaluates the advantages, the soundness of the product against the individual’s needs and self-perception, its complexity and the opportunity to try it without cost. Finally, the speed of the diffusion of the innovation is in itself an important consideration because it demonstrates its long-term viability. This is in accordance with the classic work of Rogers (1962), where the S-shaped curve for the diffusion of innovations is introduced. In this literature, the existence of a critical mass in the diffusion of innovations is discussed. The presence of this critical mass is related to the idea of network externalities. That is an additional utility for the persons using a new product, directly or indirectly, if the diffusion of the product continues. The utility of carsharing adoption by a single individual does not depend directly on the global number of adopters. However, it can be argued that externalities do exist since a higher number of adopters correspond to a possible increase in the number of services and in their quality. One additional useful concept can be drawn from the literature about product service systems. In Mont (2004) it is observed that the socio-cultural situation in which a sharing system is taking place is a crucial aspect for its success and thus the scale it can reach. In many societies, renting and sharing is associated with low socio-economic status, personal sacrifice in freedom and excessive complications in scheduling daily life, while in another society it is very common. Thus, the socio-cultural situation is important for understanding if and why individuals are ready to modify their behavior, and suggests the predisposition of a society to adopt new products or services. Those aspects have been cited only very sparsely in carsharing literature, but they might be crucial for a better understanding of carsharing diffusion and future potential growth. In the social
science field Harms (2003) provided a very detailed study on the attitude of the public toward carsharing and under which condition, and for which categories of persons, this mode could be extended beyond its actual size in Germany. She also observed the relevance of innovation diffusion theories and stressed that marketing strategies and political support are crucial for carsharing success.

Overall, carsharing literature is wider than it is deep (LeVine, 2011). One of the most important theme missing is the modeling of carsharing demand. The literature is almost completely lacking of predictive models although their importance might grow in the next years because of increased dimensions of the systems and because of growing competition.

2.2 Carpooling

Formal carpooling - sometimes also the term ride-sharing is used, although generally referring to non-formal implementations - in the following simply carpooling, is defined as two or more persons, not belonging to the same household, sharing a trip, or a part of it, with the passengers usually contributing to the driver’s expenses. The trip should be one that the driver needs to carry out in any case.

2.2.1 History of carpooling

Carpooling in its broader sense, including within-household-carpooling and informal extra-household carpooling, is and has always been a common mode of travel. It seems safe to assume that it exists since automobiles exist. First attempts to formalize carpooling and extend it beyond joint travel with family and acquaintances, however, happened much later; probably in the United States during the Second World War. In order to save resources, a large poster campaign was set-up to encourage this mode beyond the household (Chan and Shaheen, 2012). The fast post-war economic recovery, coupled with new development patterns and high motorization put carpooling aside for about twenty years, even if some associations in Europe attempted to promote it as a sort of organized hitchhiking (Gomm and Hansen, 2010). The idea came up again during the “oil shocks” of the 1970’s but, again, once the oil crises ended, at the beginning of the 80s’, carpooling was largely forgotten both in Europe and America. This was the end of the first carpooling era. The diffusion of HOV (high occupancy vehicles) lanes on highways starting from the 70s’, helped carpooling to come back a second time in the US. Additionally, same states, California is probably the most prominent example, had local air pollution regulations which included compulsory employer-based ride-sharing programs.
Numerous studies dealt with these topics (Giuliano et al., 1990; Brownstone and Golob, 1992; Parkany, 1998; Golob and Golob, 2002). After a period of decline (Ferguson, 1997), internet diffusion probably was the main factor of a renewed interest in carpooling. A proliferation of web sites offering matching services happened since then, although most of them work at a very small local scale and are not really effective. In Europe there are some successful examples among those providing matching for long distance trips (Mitfahrgelegenheit, 2012; Allostop, 2012). Internet-based matching services focusing on commuter trips were successful only in very few cases, despite a renewed attention at all levels of government both in North America and in Europe (Chan and Shaheen, 2012). The last frontier of carpooling is also due to a technological innovation; the rapid diffusion of smart-phones means real-time information on potential participant’s location making the real-time dynamic matching of ride mates possible. As of today, this is the most advanced form of carpooling and many companies are trying to set up a business based on this idea. So far, there are only very few success stories (Avego, 2012) and those are at a very local scale. Also in Switzerland, several web-based carpooling platforms are active – that is, platforms, where potential drivers and passengers can find potential trip mates – but none of them is large enough to guarantee a long term success of the system. However, attempts of applications at larger a scale are coming and the next few years might be crucial, bringing either the definitive affirmation of carpooling or its fall in yet another period of lethargy.

2.2.2 Literature on carpooling

The research on carpooling has been relatively abundant, including in recent years. It is probably a consequence of the general interest growth for mobility forms which are part of what is sometimes called “sustainable mobility”. Various aspects of carpooling where investigated ranging from, users’ behavior and users’ preferences to motivations to participate in carpooling. Nevertheless, it is difficult to summarize the carpooling literature. First of all, despite the early diffusion of the system researchers started only in the mid-70s’ to show interest toward carpooling (Ferguson, 1997). Additionally, papers referring to carpooling are often reporting on carpooling in general, without any distinction between formal and informal carpooling. Here the topic is formal carpooling – that is, two or more persons, not belonging to the same household, sharing a trip, or a part of it, with the passengers usually contributing to the driver’s expenses – and, therefore, the following short review does not contain work where the topic is explicitly limited to intra-household carpooling, which deals with different forms of carpooling, like casual carpooling (also known as slugging) or real-time dynamic carpooling or which focus on the optimization of carpool matching.
An early study on carpooling in the North-American contest is the work of Kendall (1975). It focuses on work-trips and presents actual and potential carpooling levels together with characteristics of carpool trips, incentives, impacts of increased carpooling and issues related to matching services. He also develops a model to predict the maximum potential level of carpooling in an urban area and applies the model to the Boston region. Based on those results, a potential between 47 and 71% of peak period auto commuters at national level is estimated. It is also calculated, that it would bring a reduction in fuel consumption of more than 10%. Kurth and Hood (1977) emphasize employers’ importance, because they provide a setting in which information about potential participants can be easily obtained and also because, they assume, work colleagues have a similar destination and similar schedules. They also point out that pool sizes might be an issue because for some participants large pools would be “a too strong limitation of the kind of intimacy that they expect driving their car”. Ben-Akiva and Aterthon (1977), using discrete choice modeling, found, that disincentives to use the car alone are more effective than incentives to carpool, but possibly less acceptable to the public and a successful strategy should try to combine both. Parking related (dis)incentives appear to be the most effective. Finally, they also point out that a part of vehicle traveled miles (VTM) reduction will be off-set by the newly generated VMT of other members of the household that previously did not have access to a car.

Various carpooling schemes active in UK in the 70s’ are evaluated by Bonsall (1981). According to his classification, carpooling implies pooling cars (a group of persons pool their cars using one of them alternatively for joint travel), while carsharing also includes lift giving. He considers also vanpooling as a particular form of carpooling, where a minibus is used. The study delivers many interesting findings. One is that the presence of incentives is crucial in explaining participation rates, while advertising is a key for the success of a scheme but too much advertising is not only unnecessary but potentially detrimental to the scheme since it might attract less serious carpoolers. Moreover, he observes that many of the participants are former public transport riders. If they would not be allowed to participate most of the schemes would have trouble finding valid matches between participants and lack critical mass. The reduced public transport patronage may be a problem and an indiscriminate incentivizing of carpooling might have undesired effects on the whole transportation system. Most of the pools were composed of a routine driver and a routine passenger, real pools are the minority. The conclusions are that carpooling is a good substitute for public transport in sparsely populated areas and also has a value as a travel demand management but only limited effect on reducing congestion, energy consumption, and pollution. These positive impacts, overall, were overestimated by previous studies. The work of Teal (1987) is based on the US NPTS data.
(Nationwide Personal Transportation Survey) and uses discriminant analysis to describe carpooling behavior. It distinguishes three types of carpooling: intra-household, strangers pooling their cars, passengers (they do not provide a car in the pool). He finds out that socio-demography makes for a large amount of the behavior but does not explain it all. Factors influencing carpooling positively are: long commuting distances, high commuting cost, and fewer workers than vehicles in the household (vehicle shortage). He argues also that employer based ride matching services are good but they can hardly help going beyond the “natural” carpooling level.

The relation between HOV lanes and carpooling has interested various researchers. Giuliano et al. (1990) studied the effects of HOV lanes in peak-hour carpooling behavior. They find that HOV lanes have an effect but it is small and a critical question is if it is worth the investment for the facility. They also confirm the finding of previous research that that less affluent individuals and individuals with longer commuting distances are the most promising target groups. Giuliano et al. (1993), studying the impact of a regulation in southern California which incentivizes ridesharing, observed a positive effect, suggesting the existence of an easily exploitable group of willing carpoolers. However, the effect was stronger where previously low carpooling levels were registered. If carpooling is successfully implemented, latent demand may also be a problem, bringing the volumes relatively fast to pre-regulation level of congestion. The paper by Brownstone and Golob (1992) studies the effects of certain incentives designed to promote ridesharing on work trips. They used ordered probit models of commuters’ mode choices with three alternatives: always rideshare, sometimes rideshare, and always drive alone. They are based on a study of full-time workers’ commuting behavior in the greater Los Angeles area. Their main conclusions are that women, individual belonging to households with multiple workers, longer commutes, and larger worksites are more likely to rideshare. Partial equilibrium policy simulations with their model indicate that providing all workers with reserved parking, ridesharing subsidies, guaranteed rides home, and high-occupancy vehicle lanes would reduce drive-alone commuting between 11 and 18 percent. A stated-preference experiment performed in Calgary to investigate the decision to carpool to work was the topic in Hunt and McMillan (1997). The respondents choose among five successive pairs of possible automobile use alternatives. Their most important finding is probably that the extra time spent serving the ride-mate is evaluated almost 50% more than the travel time of a direct trip. Parkany (1998) finds that HOT (High occupancy / toll lane) have a neutral effect, observing the same carpooling behavior as in other similar stretches where no such facility is implemented. It confirms also that incentives (parking, matching, and ride home guarantee) have a relatively strong impact on carpooling. Yang and Huang (1999) evaluated carpooling and congestion pricing in the presence or absence of carpool lanes in a
multi-lane highway using a deterministic equilibrium model. They found that toll differentiation is necessary only when special lanes are provided for high-occupancy-vehicles.

Studying carpooling behavior in the Montreal area Morency (2007) found that carpooling was declining and the societal framework (increased car access, more women working) make the claim that carpooling is a possibly effective measure to reduce congestion questionable, but Blumenberg and Smart (2010) found a favorable societal framework for carpooling where below-of-average income and strong family and community ties incentivize resource sharing. Based on a logistic regression Builung et al. (2010) suggest that spatial accessibility to matches, household auto ownership, and socio-demographics influence carpooling more than proximity to carpool infrastructure and personal attitudes (e.g. concern for the environment, cost), while DeLoach and Tiemann (2012) found that increase in gasoline price is the main cause for recent US carpooling increase and that park-n-pool is emerging as the most diffused way to carpool. Habib et al. (2011) proposed an econometric modelling framework which considers both the choice set formation (if carpooling is a viable choice) and the actual choice. They conclude that it is crucial to use such a structure because some factors can have opposite effects at the different level of decision making. Vanoutrive et al. (2012) analyze what is more important to determine carpooling behavior in the Belgian context: organization type, location or promotion. They use a multilevel regression model which predicts the share of carpooling at large workplaces: location (accessibility), organization (activity sector), and promotion (carpool-oriented mobility management measures) are the factors considered. They found that higher levels of carpooling are found at less accessible locations, and in the activity sectors construction, manufacturing and transport.

From this review it is apparent that carpooling has been by far more popular among North American researchers than among their European counterparts. However, the European Union considered carpooling a possible inexpensive but effective approach to mitigate congestion problems and encouraged the creation of consortiums of universities to investigate this topic several times. Those projects have not the production of academic literature as a primary goal, but are rather related to real-life test implementations used to draw best-practice knowledge and therefore are worth mentioning. The main projects funded by the European Union dealing with the topic have been:

- The project CARPLUS (Integration of carpooling among the union cities) was conducted between 1996 and 1998. Within this framework an internet-based matching tool was developed and tested Madrid, Rome, Paris, Stuttgart and Zurich.

- With the project ICARO (Increase of car occupancy through innovative measures and technical instruments, 1997-1999) it was attempted to help the establishment of carpooling
introducing various forms of incentives. This was practically tested in the cities of Brussels, Leeds, Salzburg, Graz, Pilsen, and Zurich, altogether with a very limited degree of success.

- In the TECAPSY project (Trans-European carpooling and parking systems) in the years 2001 and 2002, it was attempted to integrate a carpooling system with a real-time parking information system.

- The project TAPESTRY (Travel Awareness Publicity and Education Supporting a Sustainable Transport Strategy in Europe), ran from 2000 to 2003. Various form of environmental friendly transport where tested in European cities and carpooling was one of them.

The overall impression that one can get from carpooling literature is that strong evidence on attitudes and behavior related to this mobility option are still lacking. The topic has drawn interest in the academic field starting from the late 70s’ and throughout the years until the present, but the persistence of formal carpooling as an acceptable option for only a small niche of users, with few cases of larger diffusion at local level, is evident and does not help the research. The progressive diffusion of carsharing, for example, has allowed understanding which findings of early studies were rather depending on small samples and local conditions and which had indeed a more general validity. This has not (yet?) happened for carpooling and, despite a large number of good research studies, the feeling is still strong that the research is going through the same topics over and over again without achieving solid and transferable knowledge. Things might change if the great interest that both the academic world and the business world are showing for real-time dynamic ridesharing will be translated into a public success any time soon.

2.3 Agent Based Modeling

From a transport modeling perspective, multi-agent simulation is a method to integrate activity-based demand generation with dynamic traffic assignment. Activity-based demand generation (ABDG) models generate a sequential list of activities and trips connecting these activities for every person in the study area. The idea to put the individual traveler and its activities at the center of travel demand modeling dates back to almost forty years ago (Jones et al., 1983; Kitamura, 1988) and has, since then, found many applications (e.g. Bowman et al., 1999; Arentze et al., 2000; Vovsha et al., 2002; Bhat et al., 2004). This is a way to overcome many of the limitations that traditional trip-based models encounter. In particular much more information is available on the predicted traffic. Moreover, activity-based modeling reflects the fact that traffic is the consequence of decisions made at the individual level. Persons are travelling because they have needs which can only be fulfilled by performing activities at different places. They need to work to earn money, they use this money to buy objects they need, to be involved in leisure activities, and so on. In fact, the travel demand in a given area derives naturally from the daily plans of all people living and carrying out activities in that
area. Several operational packages with a wide variety of methods have been developed, each of them applied to a different region. In some of these packages random utility theory is used to generate daily activity plans. Examples are SACSIM for the Sacramento Area, California, and the comprehensive econometric microsimulator for daily activity-travel patterns (CEMDAP) applied to the Dallas-Fort Worth Area (Bradley et al., 2010; Bhat et al., 2004). Other packages use a rule-based approach demand generation which is derived from psychological decision rules observed in stated-adaptation or other types of surveys. Examples include the travel activity scheduler for household agents (TASHA) for the Greater Toronto Area, and the learning-based simulation system ALBATROSS recently applied to the Netherlands in the context of an air-quality study (Roorda et al., 2008; Beck et al., 2009). Most of the above approaches to generate a regional transport model have in common that only the first three steps of the traditional four-step model are performed on the basis of individual travelers. For the traffic assignment step, the trips listed in the activity plans are independently aggregated to time-dependent (typically hourly) OD matrices which are fed into a dynamic traffic assignment (DTA). It assigns routes to time-dependent O-D flows so that the routes, in conjunction with their resulting traffic pattern, fulfill some predefined criterion (Peeta and Ziliaskopulos, 2001). For example, the routes may fulfill Nash equilibrium, meaning that at any time of day none of the O-D flows can find a faster path than those that are already used. An often used alternative criterion is time-dependent stochastic user equilibrium, meaning that each O-D flow is distributed across possible routes following a pre-specified distribution function at each point in time. The typical way to solve the DTA problem is to use iterations between a router and a traffic simulation (also called network loading algorithm). Flows on routes that do not fulfill the pre-specified criterion are slowly adjusted into the right direction. The iterations stop when no more adjustments are necessary — that is, when the iterations have reached a fixed point (Watling, 1996). Examples of DTA implementations are a dynamic version of VISUM (Vrtic and Axhausen, 2003), DynaMIT (Ben-Akiva et al., 2002) and Dynasmart (Mahmassani et al., 1992). Conceptually, the iterative procedure of DTA can be extended to other dimensions of travel decisions beyond route choice. Examples are “best-reply” models for departure time choice (de Palma and Marchal, 2002; Ettema et al., 2005) or optimal mode choice. Elements of demand generation are thus elevated from a simple pre-process to an integrated part of demand supply equilibration, as mode choice, departure time choice or even the activity sequence may be susceptible to changes in traffic patterns. In the context of ABDG, the entire activity plan becomes the unit of decision. At this point, multi-agent microsimulation is introduced. An agent-based approach to iterative route assignment has been developed early in TRANSIMS (Simon et al., 1999) which has recently been moved to open source. Temporally consistent daily activity plans can be directly implemented as the strategy of the
agent. The idea behind agent-based models is that the agents follow predetermined behavioral rules and that a system-wide behavior emerges from a simulation in which agents interact in a predefined scenario. A transport model of this kind usually runs slower than existing transport models. Still, the result of the model in terms of traffic flows may be quite similar. But with the agent-based approach it is possible to explore why a certain outcome occurs, and there are more possibilities for experimenting. For example, preferences of agents can be set to reproduce actual people’s preferences or not, enabling the test of “what-if” scenarios based on simple behavioral rules. However, the most valuable aspect of the methodology is the opportunity to test hypotheses and to gain an insight in the systemic behavior resulting from individual responses to policies. The travel behavior emerges from the simulation and allows for a discussion of likely behavior changes. The use of agent-based simulations enables the modeler to fully exploit the potential of travelers’ data at the individual level implied by the activity-based approach.

2.3.1 MATSim

The simulation package used in this dissertation is MATSim (Matsim, 2012), which is jointly developed in Berlin by the Institute for Land and Sea Transport Systems at the TU, and in Zurich by the Institute for Transport planning and Systems at the ETH and by the spin-off company senozon (Senozon, 2012).

The basic idea of MATSim is to let a synthetic population of agents act in a virtual world. The synthetic population reflects census data while the virtual world reflects the infrastructure such as road network, land use, and the available transport services and activity opportunities. Each agent has its daily activity plan describing the chain of activities that he needs to perform in the virtual world. Each agent tries to perform optimally according to a utility function that defines what is useful for an agent. One virtual day is iteratively simulated. From iteration to iteration a predefined amount of agents are allowed to change some of their daily decisions to search for a plan with a higher utility. The iterative process continues as long as the overall score of the population increases. This point is assumed to be the equilibrium point of the simulated system. The plan that each agent has in use at equilibrium is supposed to be a plausible approximation of the real world behavior of the individual.

More technically, MATSim is an open source toolkit composed of different modules. Each module is responsible for one part of the whole process. A module can have an underlying model (e.g. the traffic simulation, the mode choice, etc.) and can work together with, but also independently from, other modules. In this sense, MATSim can be seen as a comprehensive, flexible framework, which simulates the daily life of persons and produces travel demand as a side product.
This approach implies the repeated realization of ABDG in an iterative process. This becomes computationally more expensive as additional dimensions of travel behavior are included. Think e.g. of shortest-path search in high-resolution networks or the calculation of complex random utility models for ABDG such as the model by Bowman and Ben-Akiva (2001). To resolve this issue, learning is introduced in the feedback cycle: An agent can hold a set of activity plans in its “memory”, and chooses one of them for the traffic simulation (Raney and Nagel, 2006). The agent will thus not immediately “forget” the activity plan it executed the iteration before, but may use it again in later iterations. The evaluation of the plan may change from iteration to iteration, depending on the respective traffic conditions. The simulation structure of the resulting co-evolutionary system is depicted in Figure 2, and can be summarized as follows.

**Initial demand:** For every agent, one initial activity plan is generated. Input data such as population and land use data, as well as network data are processed to generate this initial demand. The agent database, which holds the agents and all their attributes in the RAM, reads the initial plans file, creates the agent objects and loads their plans into their memory as specified by the file. Since at this initial stage each agent usually has only one plan, it marks that one as “selected”, indicating it has chosen that plan for execution (see next step).

**Plan execution:** In the plan execution step, the selected activity plans are simulated along the timeline in the model representation of the physical world. Implementations of the plan execution have to take into account boundary conditions of the infrastructure in which activities and movements are performed. These are e.g. the maximum storage and flow capacities of the road network, or opening times of activity facilities. Moreover, activity plans force an agent not to leave
an activity before it has arrived there. The result of the plan execution is a list of events which are localized in time and space. They contain information about when an agent was performing an activity, travelling, entering or leaving a network link etc. These events are handled by the subsequent elements of MATSim (scoring, replanning, analysis etc.).

Scoring: The agent database reads the events information from the plan execution step and sends each event to the agent which generated it. Each agent uses its events to calculate the new score of its selected plan — the one which was most recently executed. The scores of the other, not selected plans are not modified.

Agent memory update: The initial demand typically consists of one activity plan per agent. Every time an agent is selected for replanning (see next step), another plan is added to its memory. An agent can maximally hold a predefined number of plans $n$ in its memory, plus another one if the agent was selected for replanning in the current iteration. In this case, one plan will be removed at the beginning of the next iteration. This is a variation of elitist selection in genetic algorithms, which guarantees that the individual with the highest fitness will survive the selection process to the next generation (De Jong, 1975). Generally, values of 3 or above are desired.

Plan selection: Each agent decides which plan to select from its memory for execution in the next iteration. It chooses from the following options:

Replanning: With a probability of $p_{replan,m}$, the agent is chosen for replanning by replanning module $m$. It selects a random plan from its memory, and sends a copy of it to the replanning module. After this copy will have been modified by the replanning module, it is added to the agent memory. The modified copy is then marked as selected for execution in the next iteration.

While the probabilities $p_{replan,m}$ may have different values, and may differ from iteration to iteration, in this study the same value is used for all replanning modules across all iterations.

Probabilistic selection: For agents not chosen by a replanning module, one existing plan is selected for execution according to the following equation:

$$P(i) = \frac{e^{score \cdot S_i}}{\sum_j e^{score \cdot S_j}}$$

(1)
where \( P(i) \) is the selection probability of plan \( i \) out of all \( j \) plans in the agent’s memory, given their scores \( S_j \). The term \( \theta_{\text{score}} \) is the score parameter for plan selection. The higher the value of \( \theta_{\text{score}} \), the more the agent tends to choose the plan with the best score. If a plan has no score for any reason, it is selected automatically. The purpose of this selection strategy is to reevaluate existing strategies in order to make them comparable to new activity plans generated by replanning modules. The logit-type formula achieves an agent-based stochastic user-equilibrium, with the activity plan being the unit of choice (Nagel and Flötteröd, 2009).

**Termination:** The iteration cycle is stopped after the properties of the system fulfill some stopping criterion. Conceptually, the system has to run until the agents cannot significantly improve the score of the executed plans that is when agent-based stochastic user equilibrium is reached. As no formal stopping criterion was available for this study, the iteration cycle is stopped.

One of the most important characteristics of MATSim, and also one of its strength compared with similar toolkits, is the ability to simulate scenarios with several millions agents and/or networks with hundreds of thousands of streets. Its most prominent application is a simulation of the travel behavior of the entire Swiss population, where 7.5 millions of agents are simulated, and about 2.3 million agents are travelling by car on a network with 882,000 links. It is distributed under the Gnu Public License (GPL), which means that it can be downloaded and used free of charge, it is written in Java, and runs on all major operating systems, including Linux, Windows and Mac OS X.

### 2.4 Discrete choice models

In transportation studies, as in many other disciplines related to economics and social sciences, it is generally assumed that individuals are acting according to the “Homo Economicus” paradigm. According to Persky (1995), the first use of the form “Homo Economicus” was probably due to Pareto in 1906, but the concept to which the term refers is certainly older. Mill in one essay of 1836 considers that a useful abstraction in economic analysis would be that of: “…a being who desires to possess wealth, and who is capable of judging the comparative efficacy of means for obtaining that end”. These few words are a good way to understand the essence of the “Homo Economicus” paradigm, a rational individual knowing what he wants and having all the information needed in order to obtain it in the best possible way. The key word of the description is probably “rational”;
human beings of this “species” are able to rationally order preferences, to maximize personal satisfaction, to analyse and forecast in order to conceive the right strategy for the scope.

The assumption that human beings can be modelled this way in economics has been long debated. Sociologists in particular strongly criticized the assumption that individuals are acting only for their own interest and satisfaction and an altruistic component in the behaviour is completely neglected. The perfect rationality was also considered an inappropriate way to describe human behaviour. But also some economists argued that in real life nobody has perfect information and incertitude is an important factor of the economic decision process. Despite all these criticisms, the model is at the basis of theories still largely used in various disciplines. In transportation studies the use of this concept is related with the use of discrete choice models. The theoretical basis of this family of models is the random utility theory, developed by Domencich and McFadden (1975). The theory postulates the following (Ortuzar and Willumsen, 2006):

- Individuals belong to a homogeneous population, possess perfect information and they always select the option which maximizes their personal utility.

- There is a set of available alternatives and a set of measures which describes the alternatives and the individuals.

- Alternatives are associated to an utility measure which may be different of each of the individuals and depend of both his and the alternative’s attributes.

The modeller does not have complete information on what are all the factors considered by individuals in the choice process and, therefore, the utility is described by two components:

- A measurable part which is composed of the measured attributes

- A random part which reflects particular tastes of individuals, but also measurement errors

The utility of alternative I for the person j can be thus expressed by:

\[ U_{ij} = V_{ij} + \varepsilon_{ij} \]

The error term gives two important properties to this formulation:

- Two individuals with the same measurable attributes might not choose the same alternative.

- An individual might not choose the one alternative which is seen as the best option from the modeller perspective.

This formulation also implies that the modeller needs to assume a certain distribution for the error term. The most popular discrete choice model is the multinomial logit (MNL), which can be generated assuming that the error terms of the utility function are independently and identically
distributed following a type I extreme value (Gumbel) distribution (Domencich and McFadden, 1975) and (Louviere et al., 2000). With this formulation the probability of an alternative being chosen is:

\[
P_{iq} = \frac{e^{\beta V_{iq}}}{\sum_j e^{\beta V_{jq}}} \tag{3}
\]

The most important properties, and probably also the most criticized, of MNL models is that they comply with the axiom of Independence of irrelevant alternatives (IIA). It postulates that if two alternatives have a non-zero probability of being chosen, the ratio of on probability over the other is unchanged by the presence of any additional alternative. The property is problematic if alternatives are correlated because the model is not able to recognize this correlation. Despite its limits, the MNL is widely used in various fields because of the relative ease of estimation of the parameters and its flexibility. The coefficients are normally estimated with the maximum likelihood method. It means that the parameters are calculated “a posteriori” once that a particular model form is specified and based on a set of observations. The solution is typically found using an iterative procedure, where the goal is to estimate the values of the parameters which maximize the likelihood of the model to reproduce the observed choices.

Various models have been proposed to overcome MNL limits whereas mixed logit models are the most prominent example. These models have the important characteristic of allowing the inclusion of person specific taste parameters which follows a specific density function. In other words, this allows relaxing the assumption of constant marginal utility coefficients across individuals. The main drawback of this functional specification is that the estimation of the parameters implies the solution of an integral which cannot be solved analytically. Instead, a simulated maximum-likelihood is used in order to find the parameters. In practice this mean much longer estimation times. Probably, this is a possible explanation why, despite being considered by some scholars the “model of the future”, and being indeed increasingly used in the research, many practitioners still prefer traditional MNLs.

The observations of set of individuals in a given choice situation can be revealed preferences (RP), when the dataset contains information on the actual choices, or stated preferences (SP), when the dataset contain information about hypothetical choices. These latter are obtained from specific questionnaires where respondents are confronted to hypothetical choice situations designed by the researcher. This approach, which can be used alone or combined with RP data, allows more freedom testing the reaction of the respondents to different alternatives’ attribute levels and permit to model choices involving not yet existing services.
3. Carsharing membership

3.1 Introduction

In the Introduction of this dissertation I provided a definition of carsharing. Now we focus on one single aspect of that definition: the fact that it is a membership program. It means that, in general, the access to carsharing vehicles is restricted to members. They usually gain access to the system paying a fee which grants membership for a limited period of time, typically one year. In some cases, usually if the system is operated by a co-op, it is eventually possible to become co-op member paying a membership share which will generally be higher than the annual fee. Membership is lifelong and can be voluntarily interrupted taking the share, or part of it, back. Another possibility offered by some carsharing operators is business membership. Business members are employers who reserve one or more cars of the carsharing fleet during business hours for their employees work related use. Within this time only the employees are allowed to use those cars, while the rest of the time they can be used by any other member of the specific carsharing system.

Whatever the form, it is important to stress that carsharing users are necessarily members in the first place. Therefore, if the goal is to understand who and how uses carsharing, it is necessary to focus first on who these carsharing members are. In the context of this dissertation, being the main overall goal to implement predictive models of sharing systems, it is necessary to develop first a predictive model of carsharing membership. This is the main topic of this chapter.

3.2 Related work

The subject of this chapter is tightly related with the part of the carsharing literature which deals with potential growth of carsharing (see 2.1.1). In fact, most of these studies try to assess the potential future dimension of carsharing in terms of participants to the program. The concept of being a participant can be actually intended in various different ways, in particular a distinction between active and passive membership might be done, but an estimation of future membership is, at least implicitly, necessarily involved in the process. Nevertheless, being the goal of this chapter to propose and validate a predictive membership model, and not to provide an estimation of future membership for Switzerland or any country, the short review of these works is mostly of methodological interest. Early attempts to predict carsharing potential mostly concentrated on two
aspects, the socio-demographic profile and the yearly car mileage of users. Petersen (1995) for example found that in the German market the break-even point in terms of annual traveled kilometers – that is, compare kilometric cost of carsharing with that of private car and find out at which use level cost are equal – was at 18’000 km per year, or 15’000 per year if considering also insurance. Based on this, Pretenthaler and Steininger (1999) found that according to Austrian average yearly mileage, 69% of Austrian households living in an urban area would have a financial benefit joining carsharing. However, they recognize that this number does not take into account the time spent at the destination end of the trip, which is free for a private car but need to be paid with carsharing. Considering this the number of potential users falls to 22%, and if also lifestyle/prestige aspects are taken into account the potential is further reduced to 9% of households living in urban areas. In Schuster et al. (2005) is estimated that about 4% of private vehicles in the Baltimore area could be substituted by carsharing. The conclusion is based on revealed travel data, and compares ownership cost with sharing cost for all vehicles in the sample. The approach used is similar to that of the previous works but it improves it in the sense that the various cost component for the two options are explicitly accounted for. The work of Haefeli (2006) to predict carsharing potential for the Swiss market is based on a less common approach. A maximum potential is calculated with a rather simple approach based on socio-demography of the population. Then the actually exploitable potential is discussed according to different hypothetical scenarios. This approach, therefore, beside the maximum theoretical potential, which is estimated at about 10% of licensed drivers, does not provide other precise numbers. Nevertheless, it delineates a broad palette of different possible futures scenarios taking into account many factors, including soft ones, which play a role in carsharing success. In a paper by Nobis (2006), both subjective (attitudes) and objective criteria (current mobility behavior) are taken into account, to estimate car sharing potential in Germany. The conclusion is a potential of about 6% of licensed drivers living in municipalities with more than 20’000 inhabitants (equivalent to 2M individuals). Other works have dealt with the same problem with similar approaches. A common limit of the studies reviewed, and of studies on carsharing potential overall, is the fact that actual carsharing availability at the micro level is never considered. This might one of the reasons why most of the papers on this subject have given very optimistic predictions of carsharing potential and without any information, from an operator point of view, on how much of this potential might be really worth to be exploited. In fact, other studies (Muheim, 1998; Katzev et al., 2000) stated that the distance from home (or from work location) is an important factor for the use of carsharing and, indeed, Martens et al. (2011) found out that part of the demand is driven by the supply, that is, new stations generates new demand or exploit a latent demand for carsharing. Finally, the dissertation of Le Vine (2011) deserves a special mention in this list. It is one
of the very few works which specifically investigates carsharing membership. On the methodological level, in particular, it shows how it is possible to structure a choice situation to have both “strategic” (long term decisions) and “tactical” decisions. Moreover, it introduces a new concept of person’s level of accessibility to opportunities and describe how the desired accessibility influences strategic decisions.

3.3 Methodology and data

Even if the goal of the literature reviewed above is slightly different from the one here, some lessons can be learned. The characteristics of the supply should enter in the model otherwise the estimates are closer to a quantification of latent demand for carsharing than to membership prediction. Moreover, the instrument used should be flexible and take into account the trade-offs between attributes. The effects of different attributes might offset each other and a model which explicitly takes this into account is crucial to accurately predict membership. For those reasons a discrete choice model approach was chosen. It is easy to implement and has the characteristics required. Seen the nature of the problem, the model chosen was a binary logistic regression where the two choices “Yes” (being a member) or “No” (not being a member) are considered. The models were estimated based on revealed preferences data and validated with actual membership data from the Swiss operator Mobility. The two datasets are shortly introduced below.

3.3.1 Micro-Census

In Switzerland a statistical survey of the population’s travel behavior (Micro-Census on Travel Behavior) was conducted about every five years since 1974 by the Federal Office for Statistics (Bundesamt für Statistik) together with the Federal Office for Spatial Development (Bundesamt für Raumentwicklung). In 2010, 62'868 individuals belonging to 59’971 households were contacted by telephone to answer questions about the following topics: vehicle ownership, possession of driver’s licenses and/or public transport travel cards; daily travel patterns (number of trips, duration of trips, distances travelled); purpose of trips and means of transport used; one-day excursions and excursions with overnight stays; views regarding Swiss transport policies. This is the most complete data set available describing traveling habits of the Swiss population and the sample is representative at both, the household and the individual level, and different weights for cases apply (ARE and BFS, 2012). The survey is usually published about two years after it takes place and for that reason the 2010 survey’s results were available only short before the end of this dissertation. In fact, the work of this section was done first with data from the 2005 survey and actualized later. In addition to the
obvious interest in using the newest dataset available, in 2010’s survey some additional data on carsharing use were collected. The short time made impossible the use of this additional data; some detail on what could be done in the future is given below. The Micro-Census contains various datasets, and in one of them can be found information about the set of mobility tools that a particular person owns, including carsharing membership. Important to note here is that Mobility, the only Swiss carsharing operator, offers various types of membership. In particular, Mobility is one of those operators offering membership for both private customers and business customers. The formulation of the question about carsharing in the survey seems clear enough to suppose that a positive answer actually corresponds to that person being private member. Nevertheless, since the distinction is not made in the question, as it would be correct, we should keep in mind that some persons having access to carsharing through their employer might have reported themselves as carsharing members. Another point is that, we do not know if a particular member is active or not. Active members are those actually using carsharing. The kernel of the Micro-Census dataset is the information about the trips made by the respondents. In that part, traditionally, nothing was said about the use of carsharing and a trip with carsharing is simply reported as a car trip. Although in the 2010 survey things changed and carsharing trips are reported as such, it is only a partial advance to this respect since it is not expected that all carsharing members actually used carsharing during the sampled day. In fact, this is not even really an issue for membership estimation, but it is an important shortcoming trying to validate travel predictions with this data set which is worth to keep in mind.

3.3.2 Mobility Data

For the validation of the model that we want to estimate, we obtained from Mobility the complete set of members’ data for the 2010, which contains 76’218 members. The data set includes the actual home location of the person and some basic socio-demographics like age and gender. The main limit of the data is the fact that the coordinates refer to the last known domicile of the member which might be not the one of 2010 but, in general Swiss people do not change their home location very often (Killer, 2011) and the data is nevertheless the best possible that can be obtained to validate this kind of model.

3.3.3 Data issues

As mentioned, micro-census participants were asked about being or not members of a carsharing organization. The number of positive answers among driving license owners was 1391, or 3.3% of the sample. The actual number of private members of Mobility Switzerland amounted to 76’218 individuals, which is about 1.5% of the population with driving license. Estimating the model on the
sample without taking this issue into account could cause the model to overestimate the number of members. A possible way to solve this problem is giving a weight to all carsharing members of the sample, which takes into account their oversampling. After some attempts though, this solution was abandoned because the applications of the corresponding models to whole Swiss population did not give the expected number of members. It could be related to another aspect of the data set which is worth pointing out: the number of persons who are carsharing members in the sample. The choice of not being carsharing member dominates the other. The effect is that a large part of the choice of not being carsharing member is explained by a constant in the equation describing the utility of this alternative. Moreover, the few observations, in which carsharing membership has been chosen, make the estimation of the model statistically less reliable. The effect of using a weight as the one discussed above is that each observation is counted only partly. In practice, some of the parameters computed were statistically less significant. For that reason, instead, we decided to keep the estimation without weight and use the constant as a calibration parameter. Finally, other relevant data issues are given by the combination of the datasets used. The application of the model is based on the population census of 2000. The model is calculated based on micro-census 2010 and the stations reproduce 2011 status. It is hard to make a prognosis of the effects on models parameters, but it is clearly not an optimal combination and the models will be applied to the new population based on 2010 census as soon as it will be available.

3.4 Models

Based on the aforementioned data, binary logit regressions were estimated. The goal was to have two different specifications of the membership model, one using the whole set of variables available, and one where only the variables attached to agents in the simulation MATSim were used. The first specification is intended for general interpretation purpose, while the second allows for a successive implementation of the model in the simulation framework. Since no information about the actual choice set is available, the models does not contain the attributes of the alternatives, but only socio-demographic attributes of the individuals. This is a significant limit of the model proposed. However, the supply side is explicitly considered in the model since a measure of carsharing accessibility for each person, including both accessibilities from home and from work, was calculated with the following formula:

\[ A(p) = \ln\left(\sum_{i=1}^{n} X_i \cdot e^{-\beta \cdot dist_{ih}}\right) + \ln\left(\sum_{i=1}^{n} X_i \cdot e^{-\beta \cdot dist_{iw}}\right) \]
This type of formulation has already been used in a previous study on accessibility of Swiss municipalities (Fröhlich et al., 2005). The weight parameter $\beta$ is set to 0.2 as in the cited study and in Weis (2012), $\text{dist}_{ih}$ and $\text{dist}_{iw}$, are calculated as the distance between the station $i$ and home and work location of person $p$ respectively and $X_i$ is the number of cars at station $i$. This is an important improvement over other models which have been used in the past to estimate carsharing potential because it takes into account the availability of the system at the micro level. Relating membership to the effective presence of carsharing supply, it provides a more flexible framework to evaluate potential membership since it takes into account the trade-offs between socio-demography and the effect of accessibility. In a way, it measures how the presence of carsharing in a given area influences the choice to become member. Additionally, it puts in relationship the expected membership with the investment of the operator determined by the number of stations. This is a first step in order to have instruments which can help to understand how much of the potential eventually available is really worth to be exploited or to optimize the investment which can be undergone at a given time in a given area. The weight parameter $\beta$ also deserves a short additional discussion. The value corresponds to an assumption on how stations influence membership. The parameter needs to be positive, meaning that accessibility actually decreases with increasing distance. Numbers close to zero mean a relatively flat decay of accessibility while larger numbers means an abrupt decay. In other words, it gives a measure at which distance persons feel that a given station is accessible. Additional investigations will be made in the future to explicitly estimate the parameter or at least to produce an “educated guess”. Another option, also not attempted here, might be to use it as a calibration parameter.
To help understanding the results of the models, which are presented in the remainder of this section, it is useful to show the distribution of carsharing membership along some key variables of the sample, including accessibility. This is in Table 1.

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<td></td>
<td>Never</td>
<td>0.057</td>
<td>0.943</td>
</tr>
<tr>
<td>Language area</td>
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<td>0.040</td>
<td>0.960</td>
</tr>
<tr>
<td></td>
<td>French speaking</td>
<td>0.020</td>
<td>0.980</td>
</tr>
<tr>
<td></td>
<td>Italian speaking</td>
<td>0.004</td>
<td>0.996</td>
</tr>
<tr>
<td></td>
<td>Rhaeto-romanic speaking</td>
<td>0.021</td>
<td>0.979</td>
</tr>
</tbody>
</table>

| Accessibility Home | 1.663 | 0.977 | 0.000 | 25.502 |
| Accessibility Work | 2.281 | 0.854 | 0.000 | 28.647 |
| Density            | 68.867 | 43.000 | 1.000 | 2155.000 |

Table 1: Summary of some key statistics of carsharing members (Micro-census 2010)
3.4.1 General model

The variables, the estimates of the parameters and their significance for the first specification of the model, are reported in Table 2.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Membership</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Access Home</td>
<td>0.07</td>
</tr>
<tr>
<td>Access Work</td>
<td>0.02</td>
</tr>
<tr>
<td>Age 31-45</td>
<td>0.02</td>
</tr>
<tr>
<td>Car Never Available</td>
<td>0.54</td>
</tr>
<tr>
<td>Car Sometimes Available</td>
<td>1.42</td>
</tr>
<tr>
<td>GA Ticket</td>
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</tr>
<tr>
<td>Half Fare Ticket</td>
<td>0.72</td>
</tr>
<tr>
<td>Other Season Ticket</td>
<td>0.50</td>
</tr>
<tr>
<td>Compulsory Education</td>
<td>0.33</td>
</tr>
<tr>
<td>Secondary Education</td>
<td>0.28</td>
</tr>
<tr>
<td>Tertiary Education</td>
<td>0.87</td>
</tr>
<tr>
<td>German speaking</td>
<td>0.44</td>
</tr>
<tr>
<td>Male</td>
<td>0.30</td>
</tr>
<tr>
<td>Suburban area</td>
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<td>Minor centers</td>
<td>-</td>
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<td>Industrial centers</td>
<td>-</td>
</tr>
<tr>
<td>Extra-urban area</td>
<td>-</td>
</tr>
<tr>
<td>Age 18-30</td>
<td>-</td>
</tr>
<tr>
<td>Age &gt; 60</td>
<td>-</td>
</tr>
<tr>
<td>Constant</td>
<td>-</td>
</tr>
</tbody>
</table>

# Observations: 42'196
Adj. Rho-square: 0.839

Table 2: Parameters estimates for the first membership model

All parameters but one are highly significant, and have the expected sign. The one less significant, the parameter of age group between 31 and 45, has the expected sign too and for that reason was kept. Going through the estimates, from the top to the bottom of the table, we can observe: The access measures to carsharing from home and from work are both significant with a 90% confidence interval, but access from home has an influence which is more than three time stronger. Taking the age class between 46 and 59 as a reference, very young people (under 30) and older people (above 60) are less likely to be carsharing members. The effect is stronger and statistically more significant for young people.
Education level has been coded with four categories and primary school was the reference category. Therefore, all the three dummies in the model correspond to an education level higher than the primary school. All of them show a positive correlation with the likelihood to be carsharing member whereas the magnitude of the parameters is larger for higher levels of education (i.e. university absolvent are comparatively most likely to be members).

Car availability was expected to be a crucial predictor of carsharing membership. The estimates confirm this, even if in a somewhat surprising manner. Having the car available sometimes is a stronger predictor than having the car never available. A possible explanation is that among individuals without car access within their household, some might conduct a completely car-free life and, therefore, not being interested in carsharing. This would be possibly consistent with the lower significance and the smaller estimate because the lack of car access would be a predictor of two opposite behaviors.

Season ticket ownership is, as expected, an important predictor for carsharing membership. Three possibilities are considered and have been coded as dummy variable: GA season ticket (a ticket valid one year which gives access to all public transport throughout Switzerland), an Half-Fare ticket (the owner pays only half the price of a regular ticket) and any other season-ticket among those available. All are significant and positively correlated to carsharing membership.

The zone type of residence is another variable which is typically reported to be of prominent importance for the choice of carsharing. Four dummy variables have been used which describe the spatial environment in which the individual resides, choosing central zones of an agglomeration as the reference category. As expected, individuals living in any other zone types are less likely to be carsharing members.

Other socio-demographic characteristics were observed to influence carsharing membership. One is gender, male individual are apparently more likely to be members. The other is the language spoken. Switzerland is a tri-lingual country (or tetra-lingual including Romansh) and it was already observed that German speaking Swiss as compared to French and Italian speaking are more inclined to use public transport (Ciari et al., 2008). In fact, it appears that German speaking individuals are more likely to be carsharing members too. Moreover, some exploratory experiments where separate models were computed for German speaking and non-German speaking showed that some parameters estimates may differ even substantially. However, since splitting the models means to compute their parameters on fewer observations and that reduced the significance of several variables, we decided to stick to a single model for the whole country. The approach, though, was
used for the MATSim version of the models. Since they contain fewer variables the splitting did not cause any major trouble in terms of parameters’ significance.

**Demand elasticity**

An additional aspect to watch at is demand elasticity. Elasticity reflects the relative change of a dependent variable which results from a relative change of an independent variable. In multinominal Logit-Modell (MNL) elasticity is the percent change of the choice probability (as dependent variable in the model) of an alternative, which is caused by the change of an attribute by 1%. These elasticities can be applied directly on the whole sample, hence represent the change of the total demand of an alternative as a reaction on the change of their attributes. The general formula for the calculation of elasticity is:

\[ \varepsilon_x = \frac{\delta P}{P} \cdot \frac{\delta P}{\delta x} \cdot \frac{x}{P}, \]

\( \varepsilon_x \) = demand elasticity respective attribute x

P = choice probability for the alternative

Inserting in this equation the formula for the calculation of choice probabilities in the multinominal Logit-modell, for the elasticity of the respective attribute x results the following equation:

\[ \varepsilon_x = \beta_x \cdot (1 - P) \cdot x, \]

where \( \beta_x \) is the estimated parameter for variable x.

The elasticity of the choice (being a member) with respect to access to carsharing from home and from work is reported in Figure 3.
It can be observed that the elasticity curve is much steeper for home access than for work access. This is no surprise and it means that an increase in access to carsharing from home potentially has a much stronger influence on the decision to become member.

### 3.4.2 MATSim Model

For the MATSim model, a slightly different approach was taken and two models, one for the German speaking part of Switzerland and one for the rest of the country, were estimated. The necessary adjustments in order to implement the model in MATSim's framework are:

- Only a dummy variable for season tickets is modeled
- No information about the zones is available
- No information about the education level is available

Education level and information about the zones are actually available in some MATSim scenarios, but they were not used here to have a model usable with any MATSim scenario. The estimates for the MATSim models are reported in Table 3.
Table 3: Parameters estimate for the MATSim models

Note that this is a minimal specification, in the sense that some other information can be attached but is not included as standard in MATSim. Zone information, in particular, can be added easily if the relevant geocoded information is available. The type of area in which the person lives, which usually is an important predictor of carsharing participation, is approximated by the density in terms of inhabitants of the hectare where the individual lives.

As anticipated the estimates are departing even significantly between the two models. The most interesting differences to observe are:

a) German speaking individuals are more influenced in their choice by density and accessibility than the rest of the population

b) For German speaking the influence of not having access to a car at all or only sometimes is similar, while for the others the car available sometimes is a stronger predictor of membership, as for the overall model.

c) The constant for not being a member is smaller for German speaking.

Overall it gives the impression of a higher carsharing inclination, but also awareness, in the German speaking population.
3.5 Results for Switzerland

The MATSim version of the model has been implemented and run on the population currently used for the simulation. This is an artificial population based on both the Swiss Census of the year 2000 and the travel diaries survey of the year 2005, the older version of the data set used to estimate the membership model and previously described. The fact that we are using data sets from different years obviously introduces an inconsistency, but for the moment it was not possible to get around this. More details on the generation of the population can be found in Ciari et al. (2007). The model predicts a number of 76'536 members, which is almost exactly the right amount, since the number of members in 2010 amounted to 76'218. A crucial aspect to be tested is if the model is able to reproduce the spatial distribution of real members. The spatial distribution for the real members and that predicted by the model are reported in Figure 4 and Figure 5. The graph is obtained binning the members on 5km by 5km areas (bins). The colors represent the density of members in the bin, where cold colors stand for low densities and warm colors for high densities. It can be observed that at national level, the distribution pattern is reproduced fairly well. The differences that can be noticed suggest that the model is slightly overestimating carsharing membership in the French and the Italian speaking parts of Switzerland despite using two distinct models. Worth to point out too, the colors distribution is very similar, but the scale (we used a binning with 4 equal percentiles based on the natural logarithm of the number of members) is slightly different. This means: the general spatial pattern is fairly well reproduced but at the local level large differences may exist. Figure 6, which represents the spatial distribution of estimation errors, confirms this and a clear pattern can be observed: in areas with few members (the size of the dots reflects the number of members in the area) and more in general in sparsely populated areas there is a strong overestimation tendency. In urban areas errors are smaller; many zones are estimated about right or even underestimated, especially in German speaking zones.
Figure 4: Distributions of actual Mobility members

Figure 5: Distributions of Mobility members according to model’s prediction
An additional analysis can be made at the micro scale. This is to verify if the effect of accessibility in the model is consistent with real distribution patterns. To make this, a region of 5 km by 5 km was chosen. The choice fell on a region which includes the city of Bern, a densely inhabited area, in the northern part of the region, but also a sparsely inhabited area on the south-west of the region. The reasons for this choice were: a) the high number of members in the area and b) the particularly close result of the model compared to reality. The two features were expected to guarantee an easy interpretation of the distribution patterns. The region is represented in two figures, one where actual membership is reported (Figure 7) and one with the simulated membership (Figure 8). Both figures also report the location of mobility stations in the area. It can be observed that, as expected, members concentrate close to a mobility station in the reality. The same pattern is also visible in the figure which reports the simulated membership.
Figure 7: Distributions of actual Mobility members for a 5km-by-5km region

Figure 8: Distributions of members according to model’s prediction for a 5km-by-5km region
3.6 Using the membership model to optimize station location

Carsharing operators so far have not really tackled the problem of planning their station network. In fact, it appears that most of the operators take what they can in terms of locations for their stations, rather than planning the station network. The typical reason, as also reported in the literature (Millard-Ball et al., 2005), is, that carsharing organizations are not financially strong enough to pick the best locations or not politically strong enough to get them from public authorities. Therefore, they traditionally try to make their best with what they can get without really having a comprehensive plan. Nevertheless, a methodology to find out optimal locations for carsharing stations would be beneficial for the carsharing industry. Even if other carsharing models are coming - like free-flow carsharing, peer-to-peer carsharing, which do not involve the existence of stations - it seems unlikely that the traditional station based approach, maybe with some innovations like one-way trips, will be definitely obsolete any time soon. Some new big carsharing projects, the most prominent is Autolib in Paris, confirm this. A thoroughly inspection of all links and all combinations can give the operator the ability to have a more proactive behavior in picking up locations for stations. The first question to be posed dealing with the planning of a network of carsharing stations is: what does optimization of the network mean? Or in other words: what is the measure that one wants to use to define the network performance? Nowadays many carsharing operators are profit oriented, maximization of the ratio between investment and revenue, which broadly speaking means maximization of traveled km and rental times, is probably the first answer coming to mind. However, especially in Europe, where cities are granting spaces for carsharing to operators, or renting them for good conditions because carsharing is supposed to help reducing congestion, maximization of traveled km might be a controversial goal. Membership maximization is more neutral in this sense and, although a broad membership is intuitively a premise to a broad use of the system, it does not say anything about the intensity of the use. Additionally, the prediction of actual travel with the simulation approach that is proposed in this dissertation (see chapter 6) is computationally intensive. The optimization of the network in terms of use level would take a prohibitively long computation time.

In fact, even the method proposed here cannot deal with very large stations networks because of computation time issues. For example, a network like the one of Mobility, with 1'340 stations in 480 cities and villages, is too large to be optimized at once. However, the carsharing network at national
level is the sum of various local networks in urban areas and some single stations in smaller centers. Between those zones there are other zones, more or less wide, where the service is not present. In other words, this is not a seamless network, and it reasonable to optimize those local networks separately as long as the distance between them is large enough.

3.6.1 The membership maximization module

This paragraph describes a module which is aimed to find a set of carsharing station locations which maximizes carsharing membership. This is inspired by an algorithm developed to find out optimal location for retail stores (Ciari and Axhausen, 2011). In short, the process starts with a set of an initial station, which can be random, and a set of links which are possible locations for the stations. The goal of the module is to find a constellation of stations which maximizes the estimated membership. The location of stations is controlled by a specific genetic algorithm. At each step of the algorithm different constellations are evaluated. The membership model described in this chapter is used for the evaluation. This means that at each step, for each agent of the scenarios used, the logit probability of being carsharing member is calculated. Genetic algorithms are in general able to find the overall optimum, however their convergence is slow compared to some of the most commonly used heuristics. The procedure can be stopped at a certain point, when the solution stabilizes. This approach allows finding a good solution in a reasonable time, but does not give the guarantee to reach the overall optimum.

A more formal description of the problem is:

Let $N = \{l_1, \ldots, l_n\}$ be the set of connected links which represents the road network of a given geographic region. Note that the links represent more in general the set of the possible locations in the region.

Let $AL = \{l_i, \ldots, l_j\}$ be the set of available links for locating a carsharing station and let $S = \{s_1, \ldots, s_m\}$ be the set of carsharing stations which may be or may not be the existing stations in the region.

A station is defined as $s_i = \{l_i, c_i\}$ with $i \in \{1, \ldots, m\}$; where $l_i \in N$ and $c_i \in \mathbb{N}$ is the number of cars available at station $i$.

Finally, let $P = \{p_1, \ldots, p_k\}$ be the set of persons living in the region and $C$ a subset of $P$ containing all persons being carsharing members.

The objective function of the algorithm can be simply formulated as:
where the number of customers will depend on the position of the stations. The algorithm will operate like this:

1. Find new locations for the stations using current station locations and $AL$ as possible locations.
2. Evaluate the current locations.
3. Exit if the exit criterion is met, go to 1 otherwise.

The evaluation step means that at every iteration the logit probability of each person belonging to $P$ is computed and membership is assigned (or not) using a random number generator. Note that this is different than maximize the total logit probability of the population $P$.

### 3.7 Summary

This chapter reported on a logistic regression model for the estimation of carsharing membership in Switzerland. The model is based on revealed data on carsharing membership for a large, representative sample of the Swiss population. The model has been implemented in Java and run on a population of agents which reproduces the whole Swiss population. The estimated membership has been validated against actual membership data of the Swiss carsharing operator Mobility, showing that the model is able to reproduce the overall number of members with a small margin of error, and most importantly, reproduces actual spatial distribution patterns at both macro and micro level. Finally, it has been proposed a possible framework to use the membership model in the calculation of the objective function optimizing carsharing stations location. The results of this optimization process are presented in chapter 8.
4. Can carsharing go electric? Investigating private car and carsharing use patterns in Switzerland

The idea of using electric cars in shared fleets came early in the history of carsharing. In fact, since carsharing was primarily thought to be a possible last mile solution or, at most, a solution for small errands in the city, autonomy was not the main concern. Additionally, carsharing in its early stages was seen, even more than now, as an ecologically appealing system and the coupling with electric cars was seen as natural, despite the technology being at a very initial phase. In spite of some attempts (Massot et al., 1999), modern carsharing systems around the world did not offer electric cars in their fleet until very recently, with only few exceptions (Shaheen et al., 2002). The cost of electric cars and the problem of autonomy were the most important reasons. Now that both carsharing and electric cars have reached a much larger popularity, carsharing as a concrete alternative to car ownership, especially for city dwellers, electric cars as an increasingly credible alternative to internal combustion engine cars, the idea of using electric cars in carsharing fleets is again relevant. The prime example in this sense is the new Autolib system in Paris, directly managed by the car producer, where the whole fleet is made of electric cars. This revival poses again the question of electric car range. Nowadays, thanks to a much improved battery technology, electric cars can reach autonomies of about 200 km and further improvements are expected in the future. However, it is known that in most of western countries, and in particular in Europe, the average daily travel distance is much lower than this value, in Switzerland for example is 36.7 km (ARE and BFS, 2012). Average travel distance, however, is not the actual concern in the case of electric cars. The distribution of the daily travelled distance by a person is crucial for his/her readiness to buy an electric car. If many days with car travel longer than electric car range are expected, the acquisition of an electric car by this person is expected to be unlikely. In the case of carsharing the relevant measure is the distance traveled by one car per day. The very essence of carsharing is the fact that multiple members use the same car, reducing the overall number of cars. It is also the interest of the operator to have a high use ratio for its vehicles because it means a higher profitability for its investment. However, a high use ratio will generally mean shorter intervals between two rental events. This might be critical in order to use electric vehicles for carsharing.

In this chapter data about private car and carsharing use are analyzed to gain an insight on the possibility to use electric cars for carsharing systems. More in general, it also gives some hints on differences between private car use and carsharing use. A very simple exploratory approach is used; various graphs are derived from the available quantitative data and discussed. This chapter,
therefore, should be considered a preliminary study to gain an initial understanding of the issue. In the future, electric vehicles will be formally modeled within the MATSim framework and different scenarios including carsharing with electric vehicles will be tested.

4.1 Data

A data set with all trips made by customers of the Swiss operator Mobility is the basis of the analyses which follows. It contains around 300'000 rental events registered between January 1st 2010 and December 31st 2010. These are all the rentals in the canton of Zurich in that period. The available information for each entry of the dataset is: ID of the person, ID of the vehicle, coordinates of the pick-up station, starting time (of the reservation), end time (of the rental, might be earlier, or in some rare case later than the end time of the reservation), and distance covered.

4.2 Electric cars range and charging time

The theme of this paragraph is in itself a large strand of research, but the scope here is limited to the exposition of a few assumptions, which will guide the analyses of the following pages. As a reference for the range of an electric car the Nissan Leaf (Wikipedia, 2012; Nissan, 2012) was taken. The reason is that it is considered the first mass-marketed electric car worldwide (World Car Awards, 2012), but also because in the meantime - it has been marketed starting from 2010 - some independent information is available regarding its range. Nissan Leaf’s range is 175 km according to the New European Driving Cycle and 117 km range for the EPA (Environmental Protection Agency, USA). In an independent study (Green Autoblog, 2011) conducted in 2010, where the Leaf was tested under various conditions the following figures are reported:

1. Driving constantly at 60 km/h with an ambient temperature of 20°C, the range was 222 km.
2. Averaging 38 km/h in city traffic the range is 168 km, assuming air conditioning (A/C) is not in use with a temperature of 25°C.
3. In heavy stop-and-go traffic, averaging 10 km/h with temperatures of 30°C and A/C on, the range drops to 75 km.
4. At 88 km/h on the highway with temperature of 35°C and A/C on, the range was 112 km.
5. With winter temperatures of -10°C with the heater on, the range drops to 100 km in stop-and-go traffic, assuming an average speed of 25 km/h.
These examples give an idea of how much the range can vary according to weather conditions and speed. As for the charging time we refer to that of the manufacturer, since we were not able to find any different data. There are two options, the normal charging, using a normal electric plug, will recharge the battery in 8 hours; a fast charging, which needs a special facility, will recharge 80% of the battery in 30 minutes and completely in 1 hour. In the following analysis, three range values will be considered:

- Maximum = 200 km (From case 1)
- Average = 140 km (Averaging cases 2 and 4, which are both closer to everyday conditions)
- Minimum = 70 km (From case 3)

4.3 Analysis of the data

The first analysis proposed show the differences in terms of time length and distance of out-of-home tours made by carsharing and by private car (Figure 9 and Figure 10 respectively). The cases are assigned to predefined bins of 5 minutes per 5 kilometer ranges. The colors correspond to the number of cases, higher numbers on the logarithmic scale correspond to more frequent cases. Observing the two graphs, it is apparent that a car, be it privately owned or shared, is often used for very short daily tours. Nevertheless, the density regions of the Micro-Census graph are much flatter than those of the carsharing graph with respect to the distance dimension which means that in a given amount of time carsharing users are traveling longer distances. This makes sense considering that a part of the carsharing use fee is time dependent. Somehow surprising is the high number of reservations with a very long duration. This suggests an unsuspected large use of carsharing in a rental-car-like manner. In fact, a part of those tours are made with carsharing even if theoretically a rental car would have cost less for the occasion. A possible explanation is that in some cases convenience plays an important role and offsets, at least partly, the additional cost.
Figure 9: Time-Distance distribution of Carsharing tours, included „rentals”

Figure 10: Time-Distance distribution of Micro-Census tours
As these long-duration tours are mostly long distance tours (distance > 100km), it might pose a problem if electric cars were to be used in the carsharing system, as the battery would very likely need a recharge (or multiple recharges) within the rental period. The question there is, if the users would accept this additional burden or not. Another reason which can explain the high number of long term rentals is, that business use of carsharing can imply multiday reservations. Since in the available data no distinction has been made between private and business use, we cannot consider this in our analysis.

Nevertheless, we can analyze short term rentals, traditionally considered the bulk of carsharing use, separately. Aiming to do that, there is the issue of finding a criterion to determine which trips belong to this category. Instead of deciding a time and/or a distance limit, which would be completely arbitrary, we decided to take for a separate analysis all trips which would be cheaper if a traditional rental car was used. This allows to literally “draw a line” between the two types of use. This can be justified by the fact that on the web page of the Swiss operator Mobility a tool to compare the price of carsharing with a rental car is available to users.

Even if, for reasons that we do not know, some members prefer to use carsharing also for those trips, we argue, that it is an acceptable border to distinguish the trips. The trips filtered with this criterion are presented in Figure 11 for carsharing and in Figure 12 for private cars respectively. Note that while for carsharing there is a diagonal frontier in the graph, determined by the cost function, for car travel the X and Y axis intercepts of the first graph were used as limits for distance and time respectively. The prices for renting two cars of the same category by Mobility and by Avis, one of the major rental companies in Switzerland and partner of Mobility, were used. The cars used for comparison are a Renault Megane III SW offered by Mobility and an Astra SW offered by Avis. Prices have been calculated taking into account estimated gasoline consumption for the rental car (in the carsharing car this is included). The price for the Mobility car was:

- **Time cost:** 3.2 SFr/h (7-23) and 0.8 SFr/h (23-7)
- **Distance cost:** 0.76 SFr/km (1-100 km) and 0.38 SFr/km (>100km)

The price for a rental car is not fixed and depends, among other factors, on the day of the week and on the season. Additionally, sometimes there are offers which can substantially cut the regular price. Assuming that longer trips are generally less spontaneous trips, we used a price of 80 SFr per day, which is an average between one of such offers and the regular prices obtained inquiring the reservation web page on different days and rental durations (Avis, 2012). The price for the fuel has been taken as 1.8 SFr/Liter (Benzin-Preis-Vergleich Schweiz, 2012) and the car’s consumption as 8 Liters/100km (Opel, 2012).
Figure 11: Time-Distance distribution of Carsharing tours, excluded tours where rental was cheaper. 1 = lowest density, 5 = highest density

Figure 12: Time-Distance distribution of Micro-Census tours, cut at 1200 minutes and 100 km
The distribution of the tours for carsharing and private cars in terms of distance and duration can be seen in Figure 11 and Figure 12. In these graphs the different patterns are even clearer than in those of the previous figures. Private cars are often used for very short distances but in many cases the tours are relatively long in duration. It suggests a use to perform activities which last long and the fact, that the private car is a “waiting servant” and time does not need to be paid, plays an important role. In this sense it is important to notice a two peaks pattern where the first corresponds to relatively short activities (around three hours out of home) and the second corresponds to longer activities (around ten hours out of home). The second peak very likely corresponds to people using the car to go to work. Carsharing cars are used for tours with comparatively long distances and short times. This makes sense, since again, time is part of the fee for carsharing and shows that carsharing vehicles are used more efficiently than private ones. As for the possible electrification, it is important to note that most of these tours are well within the range of electric cars, even the minimum range that we considered. Therefore for the single rental event electrification should not pose any problem for this category of reservations. Yet, this does not guarantee that electrification is feasible. The next issue to be checked is the time interval between two consecutive carsharing operations. If intervals are too short, there is no time for recharge and this might make some of the rentals impossible to be completed. We verified that the average time interval between two rental events is about 13 hours. However, the standard deviation is more than 17 hours and very short intervals are frequent. For that reason, the number of time intervals below the two recharging thresholds was checked.

In Figure 13 the cumulative percentage of intervals up to a certain temporal threshold is reported. It can be seen that: only in 5.1% of the cases there is less than 30 minutes time between two successive rental events, while in 42.1% of the cases there is less than 8 hours. These numbers tell us that using a dedicated fast recharging system at the stations only a very small portion of the customers in the sample would have need to start their tour without the battery recharged (at least at 80%), but the proportion increases dramatically, if charging through a normal plug is considered.
Finally, we looked at the frequency of cases in which the range would have been effectively not enough to complete the tour, and also at those cases, in which a recharge would have been needed before the next rental. To do this we looked at distances traveled and we summed the distance of the next rental event in case the interval between the two events was shorter than 30 minutes (and so on if also the next events was within a 30 minutes time interval). The resulting distances were then compared to minimum, average and maximum ranges. In Table 4 the results of these computations are presented.

<table>
<thead>
<tr>
<th>Range</th>
<th>Single event [%]</th>
<th>Multiple events [%]</th>
<th>All [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max (200 km)</td>
<td>3.6</td>
<td>0.4</td>
<td>4.0</td>
</tr>
<tr>
<td>Avg. (140 km)</td>
<td>7.1</td>
<td>0.8</td>
<td>7.9</td>
</tr>
<tr>
<td>Min (70 km)</td>
<td>17.8</td>
<td>2.2</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Table 4: Carsharing rental distances and electric car range
This shows that the maximum range is exceeded in a small amount of cases (4%) but this almost doubles if average conditions are considered, and it climbs up to 20% if minimum range is considered. The table shows also that the recharging operation between two rental events is necessary only in very few cases. Even considering minimum range, only 2.2% of the rental events would have not been possible.

4.4 Conclusions

The simple exploration of the data we proposed in this chapter allows us to make some observations regarding carsharing use in general and to the opportunity of using electric vehicles. The data confirm that private owned cars and carsharing cars are used differently. Short distance tours are prevalent in private car use but those tours are often long in terms of duration. Carsharing cars are used more efficiently in the sense that they are taken only if “it is worth it”. In particular, short tours implying long activities are uncommon, meaning a more intensive use of the car within the time of the rental. The large amount of short trips made by car could be targeted as a potential expansion area for carsharing. For the use of electric cars, however, this finding is neutral. The main issue for the use of electric car is the range and the frequency to which car batteries need to be recharged. A way to attract this type of use might be the introduction of a one-way system. This raises many other issues which are beyond the present discussion.

On average the interval between two rental events for a single carsharing vehicle is long, but there are huge differences from vehicle to vehicle. A recharging time of 8 hours - which are necessary if normal plugs are used - would be a big issue and would prevent recharging the car in more than 40% of the cases. For that reason, electrifying carsharing would be probably sensible only if dedicated fast recharging station would be used. This changes if also the kilometers effectively traveled are considered. Hypothesizing that users would accept to have a non-full battery at the start of their tour – as it is now with regular cars but obviously with other implications being that the range of electric cars is much shorter – and considering cumulative travel for consecutive rental events, it appears that the actual range is crucial for the feasibility of the system. If the maximum range is assumed, only in 4% of the tours the range is insufficient. But, assuming the average range, or the minimum range, it changes this figure to 7.9% and 20% respectively. This is too much to be neglected, but the good news are that only a very small portion of those tours are chains with an interval of less than 30 minutes. This means that the main question is if users would accept recharging the battery during the rental, and the interval between two reservations is, with current use intensity for carsharing
vehicles, less of a problem. Therefore, as a bottom line, it seems that electric cars could be potentially used for carsharing operations, according to Swiss data, but a widespread network of fast-recharge facilities might be crucial for their acceptance.
5. Choosing carpooling as a mode: stated choice experiments and a qualitative study for Switzerland

This chapter is based on two papers: “Choosing carpooling or car sharing as a mode: Swiss stated choice experiments” presented 91st Annual Meeting of the Transportation Research Board, Washington, in January 2012 and “Why do people carpool: Results from a Swiss survey” presented at the 12th Swiss Transport Research Conference, Ascona in May 2012.

5.1 Introduction

It is commonly believed that extending carpooling might have a large impact reducing traffic congestion in urban and suburban areas, especially for commuting travel. In spite of this common opinion there have been few successful implementations of carpooling where such effects were clearly documented. In fact, large, organized carpooling implementations are almost unheard of (See Section 2.2). A relatively large research effort has been undertaken, at both Swiss and international level, investigating some particular aspects of carpooling, users behavior and the general attitude of the public toward this form of mobility. Nevertheless, the question of why so far carpooling did not establish itself as a widely used mode of transport is yet unanswered.

This chapter reports on a project that aimed finding out the potential of carpooling in Switzerland. The project was financed by the Swiss authority for roads (ASTRA) and conducted together with the firms PTV Swiss and Rundum Mobil. The project lasted three years (2008-2011) and was composed of two main work packages. On the one hand an extensive survey on mobility behavior and the attitude toward carpooling was conducted. On the other hand a simulation tool was used to estimate how many pools would be possible to build under given boundaries. Thanks to this it has been possible to consider both objective and subjective aspects of carpooling.

The survey was composed of multi-response qualitative questions and stated preference exercises. The results of the latter were used to generate a behavioral model that was embedded in the simulation. The present chapter reports on both parts of the survey. The stated preferences part also included an exercise on carsharing. In the context of the survey it was intended as a term of comparison for carpooling. Carsharing is also an alternative to private car use but is fairly popular in Switzerland, at least compared to most of other countries.
5.2 Carpooling in Switzerland

In the Swiss context carpooling was the subject of many studies over the years. This span from studies on matching tools (Anner, 1993) through studies investigating the applicability of HOV lanes in Switzerland (Rapp, 2000) to a work on the feasibility and efficacy of carpooling for big events (Anner, 2003). A number of studies, however, are focused on one single project, called CARLOS, which goal was to promote carpooling in non-urban contexts through the introduction of specific meeting-points (Wachter, 2001; Artho, 2003; Wälti, 2005; Artho and Matti, 2006). Additionally, in the region, where the pilot test was set up, various surveys among the participants were conducted.

In the years 2006/2007 and 2009/2010 the Center for Innovative and Sustainable Mobility (Dienstleistungszentrum für innovative und nachhaltige Mobilität) funded a web site and experimented with a SMS based ride matching system. In Switzerland research on factors influencing carpooling use is rare, with the exception of the already mentioned surveys for CARLOS. The main limit of the studies based on the CARLOS experience is that, given the low usage of the system and the small area where it was deployed, the general validity of the results is questionable even at Swiss level, as acknowledged by the authors.

A specific nationwide statistic of carpooling use is not available, but for the Zurich region, the largest Swiss metro area, a previous study (Frick et al., 2008) assessed that about 2% of persons above 15 years of age uses carpooling every day, and another 16% uses carpooling 2 to 5 times a week. It is not specified if they carpool with a member of the household or not. The lack of solid data providing a reliable insight on carpooling attitude and behavior that we stated in Section 2.2 is apparent also at the Swiss level.

5.3 Data Collection

The participants were recruited among respondents of a year-round continuous survey commissioned by Swiss Federal Railway Company, known as KEP (Continuous Survey of Passengers, Swiss Federal Railway). This is a computer-assisted telephone interview (CATI) survey, in which approximately 400 persons per week are interviewed. All trips exceeding 3 km length made by the respondent in the week previous to the interview are recorded with their attributes such as origin, destination, travel and waiting times, etc. Eligible for our study were all interviewees owning a driving license and with at least one reported trip above 10 km length. The minimum length criterion was introduced assuming that persons with a longer trip are more likely to consider carpooling as an option. Those accepting to participate in the study were asked the following additional questions:
• Exact origin and destination addresses of one of the trips longer than 10 km
• If the person carpooled on a regular basis in the last year
• Membership in a carsharing program
• Use of carsharing in the last year
• Original cost of the car (cost as new, if owns a car)
• Fuel consumption of the respondent’s car (if any)

This additional information was used together with the information collected in the survey as a basis for the construction of personalized, realistic, mode choice experiments. The recruitment took place in two tranches, between August 23 and October 25 2010 and between January 1 and April 18 2011. More than 2’000 potential participants were recruited, but some of them, for various reasons, were excluded from the sample. The final sample’s size of the SP experiment was 1’683 persons.

5.3.1 Response Rate

Despite being the questionnaire long and complex – the total length was 27 pages, the SP experiments accounted for 15 pages, the multi-response questions accounted for the rest – the overall response rate was 51% (876 respondents). This is not only a satisfactory rate, but also higher than the expected rate given the a-priori assessed response burden as described in Axhausen and Weis (2009). The expected response rate, as it can be seen in Figure 14 was 40%, which is eleven points less than the response actually obtained.

Figure 14: A-priori estimate of response rate
5.3.2 Sample Summary Statistics

Some key socio-demographic attributes allow for a qualitative evaluation of how much the respondents are a representative sample of the Swiss population. In Table 5, a comparison is made among the respondents, the recruited participants and the population in the 2005 Swiss National Travel Diary Survey (ARE and BfS, 2007). The figures for respondents and recruited individuals are compared with all respondents in the Swiss mobility census owning a driving license. The comparison between respondents (those who sent the questionnaire back at least partly filled) and recruited (those to who the questionnaires were sent) allows to evaluate if the response rate depended on some particular socio-demographic attribute. Apparently, this was not the case, since the figures are fairly similar for almost all the variables considered. The comparison with the Swiss mobility census shows if the sample is representative for the part of the Swiss population (adults with a driving license) which the study targeted.

Moreover, it gives an idea which categories of individuals were more motivated to participate in (and respond to) the study. From the simple observation of the table some noticeable facts are:

- Males were more likely to participate
- Younger individuals (18-35) were less likely to participate
- Wealthier people were more likely to participate
- Higher educated persons are more likely to participate
- Participants belong to comparatively large families
- Participants live in households with comparatively many cars
- Participants are above-average public transport discount cards owners

The higher share of male participants is typical of Swiss SP survey work. Wealthier and better educated individuals and public transport users are usually keener to participate in such studies. Apparently, such categories of people are more interested in, but also have a higher awareness of, transport related subjects.
### Table 5: Summary of some survey’s sample key statistics. Persons with driving license only

<table>
<thead>
<tr>
<th>Category</th>
<th>Respondents [%]</th>
<th>Recruited [%]</th>
<th>MZ 2005 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>55.0</td>
<td>56.4</td>
<td>50.0</td>
</tr>
<tr>
<td>Female</td>
<td>45.0</td>
<td>43.6</td>
<td>50.0</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-35</td>
<td>15.9</td>
<td>19.6</td>
<td>25.3</td>
</tr>
<tr>
<td>35-50</td>
<td>39.9</td>
<td>38.4</td>
<td>32.4</td>
</tr>
<tr>
<td>51-65</td>
<td>30.2</td>
<td>29.8</td>
<td>26.7</td>
</tr>
<tr>
<td>&gt; 65</td>
<td>14.0</td>
<td>12.2</td>
<td>15.9</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compulsory Education or less</td>
<td>5.6</td>
<td>6.1</td>
<td>11.2</td>
</tr>
<tr>
<td>Professional School</td>
<td>48.6</td>
<td>47.7</td>
<td>61.7</td>
</tr>
<tr>
<td>College/University</td>
<td>44.5</td>
<td>46.2</td>
<td>27.1</td>
</tr>
<tr>
<td><strong>Cars in the Household</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4.0</td>
<td>4.5</td>
<td>9.1</td>
</tr>
<tr>
<td>1</td>
<td>47.4</td>
<td>47.3</td>
<td>55.3</td>
</tr>
<tr>
<td>2</td>
<td>39.7</td>
<td>38.5</td>
<td>28.9</td>
</tr>
<tr>
<td>&gt; 2</td>
<td>8.9</td>
<td>9.7</td>
<td>6.7</td>
</tr>
<tr>
<td><strong>Persons in the Household</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>10.6</td>
<td>10.8</td>
<td>27.7</td>
</tr>
<tr>
<td>2</td>
<td>41.0</td>
<td>37.6</td>
<td>36.0</td>
</tr>
<tr>
<td>3</td>
<td>15.4</td>
<td>17.0</td>
<td>11.7</td>
</tr>
<tr>
<td>4</td>
<td>23.4</td>
<td>24.9</td>
<td>17.6</td>
</tr>
<tr>
<td>&gt; 4</td>
<td>9.6</td>
<td>9.7</td>
<td>7.0</td>
</tr>
<tr>
<td><strong>PT Season Ticket</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>44.6</td>
<td>46.5</td>
<td>56.4</td>
</tr>
<tr>
<td>Half Fare</td>
<td>40.9</td>
<td>39.8</td>
<td>30.3</td>
</tr>
<tr>
<td>GA</td>
<td>10.8</td>
<td>9.9</td>
<td>5.8</td>
</tr>
<tr>
<td>Other Discount Card</td>
<td>3.7</td>
<td>3.7</td>
<td>7.4</td>
</tr>
<tr>
<td><strong>Income</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2,000</td>
<td>3.6</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>2,001 – 4,000</td>
<td>7.5</td>
<td></td>
<td>15.7</td>
</tr>
<tr>
<td>4,001-6,000</td>
<td>22.1</td>
<td>27.6</td>
<td></td>
</tr>
<tr>
<td>6,001 – 8,000</td>
<td>21.3</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>8,001 – 10,000</td>
<td>16.1</td>
<td>14.3</td>
<td></td>
</tr>
<tr>
<td>10,001 – 12,000</td>
<td>12.7</td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>12,001 – 14,000</td>
<td>5.3</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>14,001 – 16,000</td>
<td>3.7</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>&gt; 16,000</td>
<td>7.6</td>
<td>3.3</td>
<td></td>
</tr>
</tbody>
</table>

5.4  **Stated Preferences Exercise**

#### 5.4.1  Experiments’ design

The idea of reproducing realistic situations in SP experiments, based on revealed data, is not new – see for example Algers et al. (1995) and Louvière et al. (2000) – and, indeed, was the standard approach for other Swiss studies (e.g. Vrtic et al., 2007; Weis et al., 2010). For this study, for each
participant, information about more than one trip was available, but one reference trip was chosen through the aforementioned additional questions. The attributes of the alternatives presented to this person in the SP experiments were derived from this particular trip. For the mode car the attributes were calculated using the agent-based travel demand and traffic flow simulation MATSim (www.MATSIM.org), which calculates distances on a high definition network and travel time is time-of-day dependent, reflecting congestion. The cost was calculated according to reported consumption of the car or taken as 10 km/liter if no other information was available. The cost for parking, which is also accounted for, was taken as the price for two hours in non-central area of the city of Zurich. For the public transport alternative, attributes were calculated using a specifically programmed script which accesses the Swiss Federal Railway Internet timetable. For the other modes more details are described later in this section. In an SP experiment each respondent receives multiple situations and chooses from a given set of alternatives. The values of alternatives’ attributes in the situations are a variation of the values calculated based on the reference trip. The magnitude of these variations has a given range, which may depend or not on specific assumptions of how some of the alternative attributes could vary in the future. The use of different levels for the attributes in the different situations is necessary capturing respondents trade-offs among alternatives. The design for the experiments – how the attribute values are combined for the alternatives in each choice situation – was determined with the software Ngene (Rose et al., 2008).

5.4.2 Experiment 1: Carpooling

In the first SP experiment four alternatives were considered: car, public transport, carpooling as driver and carpooling as passenger. Each respondent received eight situations and was invited to choose the preferred alternative. The respondent’s burden of having to choose among four alternatives in each situation was a concern. For this reason respondents were randomly assigned to one of three groups, each of them corresponding to a combination of three of the four modes listed above. By limiting the burden on the respondents, this strategy keeps the response rate high. The large sample guarantees the statistical significance of the results despite each alternative mode being evaluated in a smaller number of cases. The three combinations proposed were:

- Car – Public Transport – Carpooling as driver
- Car – Public Transport – Carpooling as passenger
- Car – Carpooling as driver – Carpooling as passenger

Some of the assumptions underlying the SP experiment reflect the answers of 30 employees of firms interested in carpooling, interviewed in a sort of pre-survey. For example it was assumed that
gasoline cost would be simply split between driver and passenger (50% each), since about 70% of the respondents of that pre-survey indicated the cost of gasoline as the right basis for splitting car costs among carpooling participants. Travel distance was considered the same as for the mode car while travel time was increased by five minutes – perceived by most of the respondents as the maximum acceptable deviation – to take into account waiting times at the meeting point. Parking for the driver was as for the mode car. It was also considered that a few times per year driver and passenger would miss each other and thus need to reorganize the trip. The ranges of attributes for this experiment are shown in Table 6. Ranges need to be large enough to induce behavioral changes. No assumptions on future developments of prices or travel times were made.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Attribute</th>
<th>Reference</th>
<th>Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Car</td>
<td>Cost (Gasoline)</td>
<td>*</td>
<td>-10% 10% 50%</td>
</tr>
<tr>
<td></td>
<td>Parking</td>
<td>4</td>
<td>-20% 20% 50%</td>
</tr>
<tr>
<td></td>
<td>Travel Time (In Vehicle)</td>
<td>*</td>
<td>-20% 0 20%</td>
</tr>
<tr>
<td></td>
<td>Walking Time</td>
<td>5</td>
<td>-100% 0 100%</td>
</tr>
<tr>
<td>Public Transport</td>
<td>Cost (Ticket)</td>
<td>*</td>
<td>-20% 0 50%</td>
</tr>
<tr>
<td></td>
<td>Travel Time (In Vehicle)</td>
<td>*</td>
<td>-20% 0 20%</td>
</tr>
<tr>
<td></td>
<td>Transfers</td>
<td>1</td>
<td>-1 0 +1</td>
</tr>
<tr>
<td></td>
<td>Walking Time</td>
<td>5</td>
<td>-20% 0 20%</td>
</tr>
<tr>
<td></td>
<td>Waiting Time</td>
<td>7</td>
<td>-30% -10% 20%</td>
</tr>
<tr>
<td>Car Pooling as Passenger</td>
<td>Cost (Participation)</td>
<td>½ car cost</td>
<td>-10% 10% 50%</td>
</tr>
<tr>
<td></td>
<td>Travel Time (In Vehicle)</td>
<td>Car + 5 min.</td>
<td>-20% 0 20%</td>
</tr>
<tr>
<td></td>
<td>Walking Time</td>
<td>5</td>
<td>-100% 0 100%</td>
</tr>
<tr>
<td></td>
<td>Type of Passenger</td>
<td>Acquaintance</td>
<td>Unknown Acquaintance Colleague</td>
</tr>
<tr>
<td></td>
<td>Risk of missing the lift</td>
<td>1 in 4 Months</td>
<td>-50% 0 50%</td>
</tr>
<tr>
<td>Car Pooling as Driver</td>
<td>Cost (Gasoline)</td>
<td>½ car cost</td>
<td>-10% 10% 50%</td>
</tr>
<tr>
<td></td>
<td>Parking</td>
<td>4</td>
<td>-20% 20% 50%</td>
</tr>
<tr>
<td></td>
<td>Travel Time (In Vehicle)</td>
<td>Car + 5 min.</td>
<td>-20% 0 20%</td>
</tr>
<tr>
<td></td>
<td>Walking Time</td>
<td>5</td>
<td>-100% 0 100%</td>
</tr>
<tr>
<td></td>
<td>Type of Passenger</td>
<td>Acquaintance</td>
<td>Unknown Acquaintance Colleague</td>
</tr>
<tr>
<td></td>
<td>Risk of missing the passenger</td>
<td>1 in 4 Months</td>
<td>-50% 0 50%</td>
</tr>
</tbody>
</table>

Table 6: Variables used for the construction of the first SP experiments and respective variations. Variables with the sign * in the “reference” column are specifically calculated for each respondent as reported in the text.
Since some of the values were based on the characteristics of one of the reported trips some
statistics of these variables among the sample are also reported, this is in Table 7.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Attribute</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Car</td>
<td>Cost (CHF)</td>
<td>7.75</td>
<td>4.00</td>
<td>0.10</td>
<td>171.00</td>
</tr>
<tr>
<td></td>
<td>Travel Time (Minutes)</td>
<td>43.21</td>
<td>29.00</td>
<td>5.00</td>
<td>298.00</td>
</tr>
<tr>
<td>Public Transport</td>
<td>Cost (CHF)</td>
<td>10.24</td>
<td>4.56</td>
<td>0.00</td>
<td>244.80</td>
</tr>
<tr>
<td></td>
<td>Travel Time (Minutes)</td>
<td>45.83</td>
<td>33.60</td>
<td>6.00</td>
<td>372.00</td>
</tr>
<tr>
<td>CPP</td>
<td>Cost (CHF)</td>
<td>3.93</td>
<td>2.40</td>
<td>0.20</td>
<td>245.00</td>
</tr>
<tr>
<td></td>
<td>Travel Time (Minutes)</td>
<td>40.75</td>
<td>28.80</td>
<td>5.00</td>
<td>245.00</td>
</tr>
<tr>
<td>CPD</td>
<td>Cost (CHF)</td>
<td>3.86</td>
<td>2.36</td>
<td>0.20</td>
<td>37.50</td>
</tr>
<tr>
<td></td>
<td>Travel Time (Minutes)</td>
<td>45.76</td>
<td>34.20</td>
<td>9.00</td>
<td>251.00</td>
</tr>
</tbody>
</table>

Table 7: Statistics of variables used in Experiment 1

Finally, before to present the models, the result of the choice exercise are reported in Table 8. It shows that stated choices are sensibly departing from actual choices. It is a sign that the ranges of values proposed in the exercise were large enough to generate the necessary variability.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Revealed [%]</th>
<th>Stated [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>68.4</td>
<td>39.8</td>
</tr>
<tr>
<td>CPD</td>
<td>-</td>
<td>16.3</td>
</tr>
<tr>
<td>CPP</td>
<td>19.9</td>
<td>35.0</td>
</tr>
<tr>
<td>Public Transport</td>
<td>11.1</td>
<td>8.9</td>
</tr>
<tr>
<td>Other</td>
<td>0.6</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 8: Stated and revealed preferences for Experiment 1

5.4.3 Experiment 2: Carsharing

In the second SP experiment the alternatives were car, public transport and carsharing. All respondents received six choice situations. The cost of carsharing travel was an issue. The norm in SP experiments if car and public transport are among the modal options to be considered are, respectively, the cost of the ticket and the cost of the gasoline. The parking cost can be eventually added. In the case of carsharing the user fee covers other costs which are not usually taken into
account in such experiments, nor generally by the driver of a private car as cost of a particular trip; car insurance and amortization costs are the most important. For that reason, in the second SP experiment total kilometer costs were used; calculated using appropriate tables available on the web page of a Swiss automobile club (TCS, 2011). In order to have personalized costs, twelve different categories were considered according to the type of car (using price as proxy, with four levels) and to the yearly mileage (with three levels). Consumption, as in the previous exercise, was the one declared by the respondent. The cost for carsharing was calculated using the current prices of the Swiss operator Mobility (Mobility, 2012). The carsharing car was, as far as possible, of a similar category as the respondent’s own car. Another issue was how to take into account the time related part of the carsharing fee. Carsharing users, in general, pay a fee, which is the sum of a distance dependent fee and a time dependent fee. The latter broadly depend on the duration of the round-trip tour; at least in the case of carsharing systems, like Mobility, not allowing one-way rentals. Ideally, one would compare tours and not trips; however, since it was not possible to have the precise information needed for the whole tour, the experiment is made at the trip level. Resulting tradeoffs will be more favorable to carsharing than they would be otherwise, and the resulting models might tend to overestimate carsharing use. The ranges for the second experiment are reported in Table 9.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Attribute</th>
<th>Reference</th>
<th>Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Car</td>
<td>Cost (Gasoline)</td>
<td>*</td>
<td>-10%</td>
</tr>
<tr>
<td></td>
<td>Parking</td>
<td></td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>Travel Time (In Vehicle)</td>
<td>*</td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>Walking Time</td>
<td></td>
<td>-100%</td>
</tr>
<tr>
<td>Public Transport</td>
<td>Cost (Ticket)</td>
<td>*</td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>Travel Time (In Vehicle)</td>
<td>*</td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>Transfers</td>
<td></td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>Walking Time</td>
<td></td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>Waiting Time</td>
<td></td>
<td>-30%</td>
</tr>
<tr>
<td>Car Sharing</td>
<td>Cost</td>
<td>*</td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>Parking</td>
<td></td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>Travel Time (In Vehicle)</td>
<td>*</td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>Walking Time</td>
<td></td>
<td>-100%</td>
</tr>
<tr>
<td></td>
<td>PT time</td>
<td></td>
<td>-100%</td>
</tr>
</tbody>
</table>

Table 9: Variables used for the construction of the second SP experiments and respective variations. Variables with the sign * in the “reference” column are specifically calculated for each respondent as reported in the text.
Average trip characteristics of the sample are in Table 10.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Attribute</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Car</td>
<td>Cost (CHF)</td>
<td>44.83</td>
<td>23.19</td>
<td>0.55</td>
<td>747.40</td>
</tr>
<tr>
<td></td>
<td>Travel Time (Minutes)</td>
<td>40.79</td>
<td>28.00</td>
<td>3.20</td>
<td>318.00</td>
</tr>
<tr>
<td>Public Transport</td>
<td>Cost (CHF)</td>
<td>15.04</td>
<td>8.25</td>
<td>0.64</td>
<td>244.80</td>
</tr>
<tr>
<td></td>
<td>Travel Time (Minutes)</td>
<td>62.00</td>
<td>47.20</td>
<td>3.00</td>
<td>419.00</td>
</tr>
<tr>
<td>Car Sharing</td>
<td>Cost (CHF)</td>
<td>41.45</td>
<td>23.40</td>
<td>0.83</td>
<td>439.67</td>
</tr>
<tr>
<td></td>
<td>Travel Time (Minutes)</td>
<td>36.85</td>
<td>26.56</td>
<td>3.20</td>
<td>308.40</td>
</tr>
</tbody>
</table>

Table 10: Statistics of variables used in Experiment 2

Mode shares in the second experiment can be seen in Table 11 together with actual choices. Also in this case the necessary variability seems to be there.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Revealed [%]</th>
<th>Stated [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>66.9</td>
<td>51.2</td>
</tr>
<tr>
<td>Car Sharing</td>
<td>0.5*</td>
<td>14.9</td>
</tr>
<tr>
<td>Public Transport</td>
<td>19.9</td>
<td>33.9</td>
</tr>
<tr>
<td>Car Passenger</td>
<td>11.1</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>0.6</td>
<td>-</td>
</tr>
</tbody>
</table>

*Estimated

Table 11: Stated and revealed preferences for Experiment 2

5.4.4 Non-traders

Non-traders are a problem of SP surveys. Non-traders are those respondents, who always pick the same alternative ignoring the different attributes’ levels among the sketched situations. A possible interpretation is that some respondents, not particularly motivated but committed to complete the questionnaire, pick one alternative in the first situation and choose the same in all the others. According to this, non-traders’ answers should be removed from the sample. In some cases, however, a non-trading behavior might simply reflect real-life situations. For example, one might want to use the car, disregarding an apparently more convenient option, because one must bring the children to school; the other might prefer public transport because has already bought an annual
season ticket, and so on. In such cases non-traders behavior reflects a decision on the strategic level and must be taken into account. Therefore, all cases have been used for the analysis and the mode chosen in the reference case has been used as an inertia indicator. The number of non-traders for the two experiments and the mode chosen is in Table 12.

The number may appear high but this is in line with previous studies (Weis and Axhausen, 2009). Moreover it should be considered that it was asked about a service that it does not really exist making it more difficult for some persons to imagine the situation. Finally, the much higher number of non-traders for the carsharing experiment is not a surprise because the dataset mainly contains commuting trips or trips made on a regular basis. Moreover, the recruiting was made for an experiment on carpooling. The self-selection which often happens in such cases might have determined a lower motivation for the carsharing experiment.

<table>
<thead>
<tr>
<th>Mode</th>
<th>CP Experiment [%]</th>
<th>CS Experiment [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>18.4</td>
<td>28.1</td>
</tr>
<tr>
<td>Car Sharing</td>
<td>-</td>
<td>2.4</td>
</tr>
<tr>
<td>Public Transport</td>
<td>4.9</td>
<td>20.4</td>
</tr>
<tr>
<td>CPD</td>
<td>8.0</td>
<td>-</td>
</tr>
<tr>
<td>CPP</td>
<td>6.8</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>38.2</strong></td>
<td><strong>50.9</strong></td>
</tr>
</tbody>
</table>

Table 12: Non-traders in the two experiments and their modal choice.

5.4.5 Estimation of the models

The models were estimated using the software Biogeme (Bierlaire, 2003; Bierlaire, 2008), which estimates the parameters of various discrete choice models, including logit models, that were the modeling form chosen in this study. Logit models have the advantage of being relatively simple and easy to implement; a possible risk is to have biased parameters if not all relevant variables are included in the model. Starting the estimation process with very simple models and adding new variables one by one allows to better understand their impact on the overall model fit. As a guideline, variables were retained in the model if the correspondent parameter estimate had the expected sign, even if not highly significant; and were discarded, if the sign was not as expected and the parameter estimate was not significant. The critical case, in which the sign is different from expectation and the parameter estimate is significant, did not occur. The fact that, from a given point on, parameters were stable, suggests the all most relevant variables are in the model. An attempt was also made to estimate separate models for different purposes; a strategy used in some previous
studies (Weis et al., 2010; Axhausen et al., 2008) that sometimes increases the fit of the model and the reliability of the estimates. However the purpose specific sub-models did not give, in any respect, better results than the global models. Similarly, an attempt to use nested logit instead of multinomial logit did not provide any significant improvement, which was to some extent surprising. In fact, the structure of the exercise appears suitable for a nested specification. Indeed, various different nested specifications were attempted: a) driving and non-driving mode (with private car and carpooling as driver in the first nest and carpooling as passenger and public transport in the second), b) private car and shared mobility forms (with solo driving in the first nest), c) innovative and traditional transport modes (both carpooling in the first, public transport and car in the second). None of the tested structures was significant. In other words, no evidence is there that the choice process is happening following any of these nested forms.

Continuous Interactions
The present work employs continuous interactions between tastes and socio-demographic attributes, namely trip distance and income. This formulation, originally introduced by Mackie et al. (2003) and already previously used in Swiss studies (Bierlaire, 2008; Hess et al., 2008), is alternative to the use of arbitrary segmentations into different income and distance classes. The interactions are formulated as follows:

\[ f(y,x) = \beta_x y/y^* \lambda_y x, \]

where \( y \) is the observed value for a given socio-demographic variable, and \( y^* \) is a reference value, usually the mean value across a sample population. The sensitivity to an attribute \( x \) is composed by the parameter \( \beta_x \) and a multiplier, which varies with \( y \). The estimate of \( \lambda_{y,x} \) represents the elasticity of the sensitivity to \( x \) with respect to changes in \( y \). If \( \lambda_{y,x} \) has a negative value, the (absolute) sensitivity decreases with increases in \( y \), with the opposite applying in the case of positive values for \( \lambda_{y,x} \). Finally, the rate of the interaction is determined by the absolute value of \( \lambda_{y,x} \) where a value of 0 indicates a lack of interaction.

Estimation Results
For each SP experiment three different specifications of the models are presented, the linear, the nonlinear, and the mixed-logit nonlinear. The estimates of the parameters are shown and discussed, and some willingness to pay (WTP) indicators are presented and commented. The impact of nonlinear terms on WTP indicators is discussed with the help of the relevant plots and finally elasticity of some variables is also discussed.
Carpooling Experiment

In the first experiment the alternatives are: car, public transport, carpooling (driver) and carpooling (passenger). Table 13 summarizes the final models.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Utility parameters name</th>
<th>Value</th>
<th>Robust t-test</th>
<th>Value</th>
<th>Robust t-test</th>
<th>Value</th>
<th>Robust t-test</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>Elasticity Distance</td>
<td>-0.26</td>
<td>-4.15</td>
<td>-0.37</td>
<td>-4.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elasticity Income</td>
<td>-0.35</td>
<td>-2.44</td>
<td>-0.30</td>
<td>-1.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Walking time</td>
<td>-0.05</td>
<td>-6.44</td>
<td>-0.05</td>
<td>-6.54</td>
<td>-0.07</td>
<td>-4.98</td>
<td></td>
</tr>
<tr>
<td>PT</td>
<td>Travel time</td>
<td>-0.02</td>
<td>-4.66</td>
<td>-0.04</td>
<td>-5.00</td>
<td>-0.06</td>
<td>-4.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Travel cost</td>
<td>-0.05</td>
<td>-5.67</td>
<td>-0.04</td>
<td>-4.94</td>
<td>-0.07</td>
<td>-2.73</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transfers waiting time</td>
<td>-0.10</td>
<td>-4.54</td>
<td>-0.09</td>
<td>-4.52</td>
<td>-0.06</td>
<td>-2.30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transfers (n)</td>
<td>-0.12</td>
<td>-1.75</td>
<td>-0.11</td>
<td>-1.66</td>
<td>-0.10</td>
<td>-1.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Season Ticket</td>
<td>1.21</td>
<td>4.40</td>
<td>1.14</td>
<td>4.36</td>
<td>0.86</td>
<td>2.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Log(Age)</td>
<td>1.87</td>
<td>4.85</td>
<td>1.89</td>
<td>4.99</td>
<td>1.29</td>
<td>1.84</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inertia</td>
<td>2.76</td>
<td>7.63</td>
<td>2.68</td>
<td>7.83</td>
<td>1.92</td>
<td>4.11</td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>Constant</td>
<td>8.36</td>
<td>5.28</td>
<td>8.44</td>
<td>5.42</td>
<td>5.21</td>
<td>1.89</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Travel time</td>
<td>-0.03</td>
<td>-7.33</td>
<td>-0.06</td>
<td>-5.61</td>
<td>-0.09</td>
<td>-4.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Travel cost</td>
<td>-0.13</td>
<td>-9.00</td>
<td>-0.12</td>
<td>-8.80</td>
<td>-0.11</td>
<td>-6.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Parking cost</td>
<td>-0.06</td>
<td>-1.60</td>
<td>-0.06</td>
<td>-1.53</td>
<td>-0.10</td>
<td>-2.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>0.82</td>
<td>3.92</td>
<td>0.78</td>
<td>3.93</td>
<td>0.43</td>
<td>1.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Car always available</td>
<td>0.52</td>
<td>3.97</td>
<td>0.54</td>
<td>4.23</td>
<td>0.97</td>
<td>3.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inertia</td>
<td>0.98</td>
<td>9.68</td>
<td>0.91</td>
<td>9.14</td>
<td>1.11</td>
<td>4.36</td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>Sigma 1</td>
<td>2.05</td>
<td>12.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.19</td>
</tr>
<tr>
<td>Carpooling</td>
<td>Constant</td>
<td>8.82</td>
<td>5.38</td>
<td>8.99</td>
<td>5.57</td>
<td>5.02</td>
<td>1.75</td>
<td></td>
</tr>
<tr>
<td>Driver</td>
<td>Travel time</td>
<td>-0.04</td>
<td>-9.16</td>
<td>-0.07</td>
<td>-6.69</td>
<td>-0.11</td>
<td>-6.42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Travel cost</td>
<td>-0.13</td>
<td>-9.00</td>
<td>-0.12</td>
<td>-8.80</td>
<td>-0.11</td>
<td>-6.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Parking cost</td>
<td>-0.16</td>
<td>-3.39</td>
<td>-0.17</td>
<td>-3.59</td>
<td>-0.17</td>
<td>-3.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Availability to participate</td>
<td>0.43</td>
<td>2.84</td>
<td>0.43</td>
<td>2.87</td>
<td>0.46</td>
<td>1.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sigma 2</td>
<td>1.35</td>
<td>6.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.83</td>
</tr>
<tr>
<td>Carpooling</td>
<td>Constant</td>
<td>10.00</td>
<td>5.60</td>
<td>8.89</td>
<td>5.61</td>
<td>5.47</td>
<td>2.01</td>
<td></td>
</tr>
<tr>
<td>Passenger</td>
<td>Travel time</td>
<td>-0.04</td>
<td>-9.58</td>
<td>-0.09</td>
<td>-6.07</td>
<td>-0.14</td>
<td>-5.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Travel cost</td>
<td>-0.12</td>
<td>-9.00</td>
<td>-0.12</td>
<td>-8.80</td>
<td>-0.11</td>
<td>-6.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Availability to participate</td>
<td>0.50</td>
<td>4.24</td>
<td>0.52</td>
<td>4.40</td>
<td>0.31</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Log (income)</td>
<td>-0.16</td>
<td>-2.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sigma 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.58</td>
</tr>
<tr>
<td>Carpooling</td>
<td>Previous Experience CP</td>
<td>-0.10</td>
<td>-0.77</td>
<td>-0.10</td>
<td>-0.85</td>
<td>0.15</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>-0.77</td>
<td>-3.71</td>
<td>-0.71</td>
<td>-3.59</td>
<td>-0.43</td>
<td>-1.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>German Speaking</td>
<td>0.19</td>
<td>2.04</td>
<td>0.19</td>
<td>2.14</td>
<td>0.31</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Household Dimension</td>
<td>0.07</td>
<td>1.97</td>
<td>0.06</td>
<td>1.81</td>
<td>0.08</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Work trip</td>
<td>0.11</td>
<td>1.39</td>
<td>0.15</td>
<td>1.84</td>
<td>0.30</td>
<td>1.32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive opinion on CP</td>
<td>1.15</td>
<td>10.36</td>
<td>1.12</td>
<td>10.33</td>
<td>1.15</td>
<td>4.32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Higher education</td>
<td>0.20</td>
<td>2.39</td>
<td>0.18</td>
<td>2.24</td>
<td>0.40</td>
<td>1.89</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trip mate Acquaintance</td>
<td>0.34</td>
<td>4.21</td>
<td>0.34</td>
<td>4.27</td>
<td>0.45</td>
<td>4.63</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trip mate Colleague</td>
<td>0.31</td>
<td>3.78</td>
<td>0.30</td>
<td>3.67</td>
<td>0.60</td>
<td>5.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No show risk</td>
<td>-0.05</td>
<td>-2.62</td>
<td>-0.05</td>
<td>-2.63</td>
<td>-0.08</td>
<td>-3.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carsharing user (SP)</td>
<td>0.98</td>
<td>9.70</td>
<td>0.97</td>
<td>9.88</td>
<td>1.20</td>
<td>4.46</td>
<td></td>
</tr>
</tbody>
</table>

Table 13: Parameters’ estimates for Experiment 1
The three models are respectively a linear, a non-linear and a mixed-logit specification. The majority of the estimated parameters are mode-specific, with the exceptions for some attributes, common to both carpooling modes that have a single estimate. Three parameters have a unique estimation for all modes. All parameters are of the expected sign and, aside from a few parameters, highly significant. The fit of the model is increased introducing the interaction terms, although not substantially while the mixed-logit specification, where three additional parameters to take into account personal tastes have been estimated, has a much higher fit. The estimates of the sigmas give a measure of personal tastes variability among the sample for a specific mode. Their variance in particular shows that there is a relatively large variability especially for the mode car. Most of the parameters used are fairly stable across the first two specifications of the models. The parameters of travel time and travel cost are, as expected, an exception, because the second model has the interaction terms. Almost all those estimates are highly significant. A few are statistically less reliable, but none of them is strongly insignificant. The estimates of the mixed-logit model are sometimes departing more from those of the previous models. In the first two models a part of the variability in the choices that depend on tastes, which are not represented, is assumed to depend on other attributes of the alternatives, causing a bias in the estimates. In the specific case travel time parameters’ estimates are among those that changed most. Some of the most important points raised by these results are discussed here. A dummy variable for female users in the carpooling modes is negative. This confirms that female individuals are less attracted to carpooling, maybe for security concerns. As largely expected a stated positive orientation toward carpooling and a stated availability to carpool have a strong positive impact on the choice to carpool. Inertia – a dummy variable taking the value one if the stated choice was equal to the reported choice – was significant for both car and public transport. It is a measure of how difficult is to make people change their modal patterns. Even more interesting, it was attempted to use the stated choice of the carsharing experiment as a variable in the present one (the variable carsharing user). The hypothesis was that those modes attract similar type of individuals. The results confirmed the hypothesis, the estimate is highly significant or in other words choosing carsharing in one stated choice experiment is a predictor of choosing carpooling in the other. This is important because although these two modes are often simply put together in the bunch of “alternative modes” or also “sustainable modes” no evidence was there to tell that they could attract the same socio-demographic groups. It is commonly acknowledged that the German speaking population of Switzerland has more open attitude towards innovative transport solutions. This is confirmed by the positive and significant parameter for the dummy variable “German speaking” in carpooling alternatives. In general, persons with a higher education level (college and higher) and members of larger households are more likely to choose
carpooling. The degree to which a potential trip mate is already known before to carpool is also an important choice factor (variables “Acquaintance” and “Colleague”). The purpose of the trip also plays a role, i.e. carpooling is more likely to happen for work trips. The most important WTP indicators are shown in Table 14.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Linear</th>
<th>Nonlinear</th>
<th>Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTTS CPD</td>
<td>CHF/h</td>
<td>19.2</td>
<td>36.3</td>
</tr>
<tr>
<td>VTTS CPP</td>
<td>CHF/h</td>
<td>21.6</td>
<td>44.2</td>
</tr>
<tr>
<td>VTTS Car</td>
<td>CHF/h</td>
<td>15.1</td>
<td>28.4</td>
</tr>
<tr>
<td>VTTS PT</td>
<td>CHF/h</td>
<td>21.8</td>
<td>57.1</td>
</tr>
<tr>
<td>WTP PT Transfers (#)</td>
<td>CHF/Transfer</td>
<td>2.4</td>
<td>2.9</td>
</tr>
<tr>
<td>WTP PT Transfer Time</td>
<td>CHF/h</td>
<td>113.3</td>
<td>137.5</td>
</tr>
<tr>
<td>WTP Walk PT</td>
<td>CHF/h</td>
<td>60.0</td>
<td>77.7</td>
</tr>
<tr>
<td>WTP Walk CP</td>
<td>CHF/h</td>
<td>24.2</td>
<td>25.2</td>
</tr>
</tbody>
</table>

Average Income = 8’300 CHF/Month
Average Trip Distance = 38.1 km

Table 14: Willingness-to-pay (WTP) indicators and Trade-offs for Experiment 1. In the nonlinear case the value is calculated using income and travel time sample’s averages for income and travel time, as reported in the table. Abbreviations are as follow: VTTS = Value of Travel Time Saving, CPD = carpooling driver, CPP = carpooling passenger, PT = public transport

In all models, linear and nonlinear, the public transport alternative has the highest value of travel time saving (VTTS), which is consistent with the high number of commuting trips in the sample. CPD is lower than CPP but higher than Car. The relatively large difference between the two carpooling alternatives in the panel specification is somewhat surprising. Given the characteristics of those modes – not as fast as car travel but faster than public transport, not as cheap as public transport but cheaper than car travel – one would expect similar VTTS for the two modes. An individual is ready to pay more to reduce the travel time of an unpleasant mode, than for more pleasant modes. This, keeping in mind that “pleasant” and “unpleasant” are subjective and merely depend on tastes. However, it is commonly accepted that the less pleasant modes usually turn out in surveys to have lower values of travel time savings (Mackie et al., 2003). This would be because more affluent people, who generally have higher values of time, prevalently use such pleasant modes. From this perspective, one can try to understand the reason of that difference. The hypothesis is that passenger and driver are splitting gasoline costs and CPP does not involve substantial longer travel time than the CPD or the car alternative. The driver needs to pay the parking, as a normal car driver,
which makes CPD slightly more expensive than CPP. Under these circumstances, CPP may be seen like a cheap taxi ride while CPD only offers a small reduction in travel expenses conditional to drive somebody. This may explain why CPP is seen as a better option. In general it seems that carpooling has a good unexploited potential, as hypothesized earlier, in Switzerland. Apparently, existing platforms are not yet effective enough exploiting potential. Other significant points arising from an inspection of Table 14 are:

PT: The WTP for waiting time reduction may appear very high, but is reasonable considering that it includes actual transfer time. The WTP for walking time is also high, but reasonable in comparison with the WTP for in-vehicle time.

CPP: The WTP for walking time is much lower than the one of public transport which is surprising. Even more surprisingly, this is lower than the WTP for in-vehicle-time. This availability to walk to reach the pick-up point suggests a high motivation to carpool, especially in this role as passenger. Perhaps some respondent see this short walk as a pleasant activity knowing that at the end they will find a car waiting for them instead of inconvenient as in the case of public transport. The changes in the value of travel time savings (VTTS) according to variation in income and travel distance are shown in Figure 15.

- VTTS is generally higher for persons with higher income.
- VTTS is lower for persons traveling longer distances.

The two plots are a way to see what the elasticity parameters actually mean. Persons with a higher income tend to have higher VTTS for any mode since their value of time is generally higher. In fact, the value that anybody gives to his own time is supposed to be proportional to the person’s wage. The income effect is also documented in the official Swiss values of travel time savings for Cost-Benefit analysis (VSS, 2007). Regarding distance, it appears reasonable that the marginal (negative) value of an additional minute of travel is higher for a short trip than for a long trip. However, in the mentioned Swiss norm and in some previous studies (Axhausen et al., 2008, Hess et al., 2008)) a reversed relationship between them was found. Our finding is not unprecedented in the Swiss context. Indeed Weis and Axhausen (2009) found similar results using a similar sample (also a sub-sample of the KEP).
Figure 15: Value of Travel Time Savings (VTTS) according to Travel Distance
Therefore, the specificities of the sample in terms of socio-demography of the individuals, but also in terms of their preferences and in terms of the type of trips, seem to be the reason for this result not in accord with the current Swiss norm.

Elasticities of the choice with respect to travel time were also evaluated for the different modes (Fig. 16). Their value in absolute terms increases with increasing travel time. A relative change in travel time has larger effect on both carpooling modes. This might seem in contrast with the previous findings on VTTS. It probably means that individuals are open to carpool but they have precise expectations in terms of time and if they are not fulfilled they are ready to go back to their usual modal choices.

![Figure 16: Elasticities of the choice to travel time variation](image)

**Carsharing Experiment**

In the second experiment the alternatives are: car, public transport and carsharing. In this case, all the estimated parameters are mode-specific. The estimation results for the final models, linear and nonlinear, are presented in Table 15.

As in the previous SP exercise all the estimates are of the expected sign and, aside from a few parameters, highly significant. The fit of the model is only marginally increased by the introduction of the interactions terms while the mixed-logit formulation has a much higher fit.
Inertia and the stated choice to use carpooling in the other experiment are important predictors and highly significant in this second experiment too. The variance of Sigma parameters is high and significant, in particular for carsharing. This means a very large variability of tastes for this mode.

Leisure trips, the bulk of carsharing use in reality, are only marginally more likely to be carsharing trips in the responses. Experience or membership does not count in the choice; an attempt to

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Utility parameters name</th>
<th>Value</th>
<th>Robust t-test</th>
<th>Value</th>
<th>Robust t-test</th>
<th>Value</th>
<th>Robust t-test</th>
<th>Variance</th>
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<td>-10.04</td>
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<td>Season Ticket</td>
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<td>9.34</td>
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<td>Log(Age)</td>
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<td>0.91</td>
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<td>8.55</td>
<td>2.76</td>
<td>3.83</td>
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<td>German Switzerland</td>
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<td>-6.53</td>
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<td>Elasticity Income</td>
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<td>0.08</td>
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<td>Constant</td>
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<td>Male</td>
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<td>1.49</td>
<td>0.37</td>
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<td>Car always available</td>
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<td>2.83</td>
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<td>2.68</td>
<td>0.25</td>
<td>0.59</td>
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<td>Inertia (RP)</td>
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<td>6.68</td>
<td>0.51</td>
<td>6.63</td>
<td>1.17</td>
<td>4.34</td>
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<td>-4.73</td>
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<td>Elasticity Income</td>
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<td>-2.65</td>
<td>-0.77</td>
<td>-2.67</td>
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</tr>
<tr>
<td></td>
<td>Sigma 1</td>
<td>2.31</td>
<td>14.00</td>
<td>5.35</td>
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<td></td>
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<tr>
<td><strong>CS</strong></td>
<td>Choice carpooling (SP)</td>
<td>1.49</td>
<td>9.52</td>
<td>1.47</td>
<td>9.48</td>
<td>2.69</td>
<td>7.44</td>
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<td>Walking Time</td>
<td>-0.11</td>
<td>-7.80</td>
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<td>-7.75</td>
<td>-0.16</td>
<td>-8.16</td>
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<tr>
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<td>Household Dimension</td>
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<td>-0.40</td>
<td>-0.01</td>
<td>-0.32</td>
<td>0.04</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Log (Income)</td>
<td>0.01</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
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<td>Leisure trip</td>
<td>0.18</td>
<td>1.97</td>
<td>0.19</td>
<td>2.02</td>
<td>0.13</td>
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<tr>
<td></td>
<td>PT trip to CS (Time)</td>
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<td>-6.04</td>
<td>-0.13</td>
<td>-5.99</td>
<td>-0.24</td>
<td>-7.67</td>
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<td>Parking cost</td>
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<td>Travel cost</td>
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<td>-6.24</td>
<td>-0.02</td>
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<td>-0.05</td>
<td>-6.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Travel time</td>
<td>-0.02</td>
<td>-5.83</td>
<td>-0.02</td>
<td>-6.13</td>
<td>-0.06</td>
<td>-7.23</td>
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</tr>
<tr>
<td></td>
<td>Higher education</td>
<td>0.04</td>
<td>0.43</td>
<td>0.06</td>
<td>0.60</td>
<td>0.16</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elasticity Distance</td>
<td>-0.24</td>
<td>-2.13</td>
<td>-0.41</td>
<td>-4.55</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Elasticity Income</td>
<td>-0.29</td>
<td>-2.02</td>
<td>-0.52</td>
<td>-2.26</td>
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</tr>
<tr>
<td></td>
<td>Sigma 2</td>
<td>4.60</td>
<td>13.84</td>
<td>21.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 15: Parameters’ estimates for Experiment 2
introduce them in the model failed because they were insignificant. In the linear version of the model there is a somewhat surprising correlation between higher income levels and carsharing use but this is not statistically significant. A more accurate evaluation on the behavior of individuals toward carsharing can be gained with the most important WTP indicators. They are shown in Table 16.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Unit</th>
<th>Linear</th>
<th>Nonlinear</th>
<th>Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTTS Car</td>
<td>CHF/h</td>
<td>158.4</td>
<td>171.4</td>
<td>173.4</td>
</tr>
<tr>
<td>VTTS CS</td>
<td>CHF/h</td>
<td>70.2</td>
<td>78.9</td>
<td>84.9</td>
</tr>
<tr>
<td>VTTS PT</td>
<td>CHF/h</td>
<td>38.7</td>
<td>51.5</td>
<td>73.5</td>
</tr>
<tr>
<td>WTP PT Transfer Time</td>
<td>CHF/h</td>
<td>65.0</td>
<td>59.1</td>
<td>67.7</td>
</tr>
<tr>
<td>WTP PT Transfers (#)</td>
<td>CHF /Transfer</td>
<td>4.2</td>
<td>4.4</td>
<td>5.6</td>
</tr>
<tr>
<td>WTP Walk PT</td>
<td>CHF /h</td>
<td>66.9</td>
<td>79.1</td>
<td>148.8</td>
</tr>
<tr>
<td>WTP Walk CS</td>
<td>CHF /min</td>
<td>326.7</td>
<td>361.3</td>
<td>203.9</td>
</tr>
<tr>
<td>WTP PT Time to Station CS</td>
<td>CHF /min</td>
<td>389.6</td>
<td>427.6</td>
<td>319.7</td>
</tr>
</tbody>
</table>

Average Income = 8'300 CHF/Month
Average Trip Distance = 38.1 km

Table 16: Willingness-to-pay (WTP) indicators and Trade-offs for Experiment 2

In this case values are generally higher, which is related with the use of full-costs for car. Some observations derived from Table 16 are:

- VTTS is more consistent with the traditional interpretation as the pleasantness of a mode; the car alternative has the highest and public transport the lowest VTTS, carsharing lies in between.

- The walking time to reach a carsharing station has a really high value compared to corresponding PT walking time values. It confirms that convenient access to car sharing is a key for its success.

- The time spent on public transport to reach the carsharing station is valued even higher (worse); apparently potential users are not willing to use public transport to reach the stations. Again, an access to carsharing within short walking distance is a fundamental factor of success.
The changes in the value of travel time savings for the carsharing mode, according to variation in income and travel time can be observed in Figure 17.

Figure 17: Value of Travel Time Savings (VTTS) according to travel distance variation

Observing the plot the following characteristics can be seen:

- VTTS is higher for higher level of income and for shorter distances.
- Income and distance have a similar impact on sensitivities (elasticity values are close).
- Sensitivities are smaller for longer distances.
The plot confirms that the use of carsharing follows a “traditional” pattern and more affluent people have a higher VTTS for it. Longer distances reduce it which is, as in the case of carpooling, in contrast with the Swiss norm, but similar to the finding of a previous study made with similar data.

The plot of the elasticity of the choice with respect to travel time (Figure 18) is also similar to that of carpooling. A less familiar mode probably has the chance of being evaluated more strictly.

![Figure 18: Elasticities of the choice to travel time variations](image)

**Use of WTP indicators**

The WTP indicators allow policy-makers and planners to provide a monetary evaluation of a given policy or investment using a cost-benefit approach. Transport policies and projects are usually justified with the amount of time that travellers will save. WTP indicators are used to quantify the economic benefit and compare it to the cost. For example a subsidy policy in favour of carpooling might increase the share of this mode. As a consequence, the number of cars on the road would be reduced, reducing travel times. Using the model estimated for this study, coupled with a transportation model, it is possible to evaluate the reduction of travel time corresponding to a given level of subsidies. WTP indicators are used to evaluate the gain in monetary terms and compare it to the cost of the policy. Similar evaluations are possible for policies regarding carsharing.
5.5 Attitude toward Carpooling

The present section evaluates the attitude of the public toward carpooling. First, responses are discussed to give a general impression of sample’s attitude. Second, a combination of factor and cluster analysis is used to classify respondents in groups having different attitudes toward carpooling.

5.5.1 Discussion of the responses

The qualitative part of the questionnaire is divided in three parts. The first was composed of general questions on carpooling, the second included questions on existing platforms and on the characteristics an ideal platform should have, the third dealt with carpooling for commuters, which is typically considered the best target for this mode. Most of the respondents (78%) have a positive opinion on carpooling while only a few (1.1%) have a very negative opinion. The low share of respondents without opinion (8.8%) suggests that carpooling is a familiar concept, although not widely used. Individuals willing to carpool actively are a slight majority of the sample (Figure 19).

The fact that more than the half of respondents is willing to carpool, or consider this at least likely to happen, suggests a large unexploited potential in the Swiss context. However, there is a relatively large difference between the number of those having a positive opinion on carpooling and that of those ready to put it in practice. Apparently, some respondents have an approach of the kind “this is good but not for me”.

Figure 19: Willingness to carpool as driver or passenger
One question asked for important characteristics of an eventual ride-mate assigned through a platform. The driving style of the ride-mate is the most important characteristic, with good manners and not smoking following, being cited by more than half of respondents. A group of three questions addressed the motivations to join or not join carpooling (See Figure 20). The first questions looked at carpooling benefits. Environmental issues are dominant and, more in general, altruistic aspects are, on average, more important than utilitarian ones. The possible barriers for using formal carpooling were also investigated. The most disliked aspect of carpooling is adapting to a particular departure time. Safety is also an issue but comes after a few other aspects of practical nature which are considered more important. This is in contrast with previous literature (Chan and Shaheen, 2012; Raney, 2009) and might reflect the low local crime rate: security is definitely important but not the very first thing that comes up as a possible barrier. The last question of this group asked for the most important characteristics of a matching platform. Effective personal data protection is the characteristic most highly rated. Responses give the overall impression, that practical aspects are much more important than social aspects. Looking at the same figure, it is clear that respondents are not particularly interested in very advanced features, like looking for a ride on the road, or in a platform with “social-network like” features, as a reputation rating system or restrictions on specific participants.

From other questions we found that most of potential participants (70%) would be willing to use gasoline costs as a basis for sharing the cost of the trip and that, for a large majority (83%), potential drivers would consider a deviation of 10 minutes to pick up a passenger as acceptable.
Figure 20: Carpooling benefits, possible barriers and platform characteristics
A final question was about which incentive potential carpoolers would appreciate the most (see Figure 21). It is interesting to observe that an insurance to have a lift on the way back home, which is obviously relevant in case of one-way matching, is the most appreciated incentive. Financial incentives and reserved parking are also very important incentives for more than 40% of the respondents. These results are consistent with previous findings (Parkany, 1998; Bonsall, 1981; Teal, 1987).

![Importance of carpooling incentives](image)

**Figure 21: Importance of carpooling incentives**

Overall, the sample has a very positive attitude toward carpooling. Slightly more than the half would be ready to carpool, either as a driver or passenger. It is important to note that the large majority of the respondents were consistent in asserting their availability to carpool. Out of the 89 respondents who gave different answers – affirming that they would participate in one role and not in the other – 74 answered “rather yes” for one role and “rather no” for the other (see Figure 19). Those with very contrasting opinions for the two roles are strictly an exception and, in general, people are available to take either role or none. The good disposition toward carpooling, however, should not hide the fact that respondents are well aware of some issues pertinent to carpooling. To make the use of carpooling possible well beyond the current small scale use such issues should be addressed.
5.5.2 Factor analysis and cluster analysis

The results reported in the previous paragraph are useful for a general idea on respondents’ attitude towards carpooling. It is to expect, however, that the attitude of individuals, or of a particular group of individuals, can diverge from this general attitude substantially. In fact the charts presented do not give any hint on how the different responses correlate among them. If it would be possible to find a sort of a pattern in the answers, this might be used to describe different groups of people with similar opinions on carpooling. The concept of homogeneous groups having similar tastes or behaviors is widely used in various disciplines (Härdle and Simar, 2012). The group of methodologies used to this purpose is known as cluster analysis. The application of cluster analysis to a large number of variables can produce results which are hard to interpret. For this reason, we use first another technique known as factor analysis. The idea behind factor analysis is that the variability among observed, correlated variables can be described in terms of fewer unobserved variables called factors. Factor analysis looks to the interdependencies between observed variables in order to reduce the set of variables in a dataset. A thorough coverage of both methodologies can be found in Härdle and Simar (2012).

The factor analysis has been carried out using the software SPSS. In total, 6 factors were extracted out of 25 variables. These factors explain 42% of the variance. In order to ease the interpretation of the factors a Varimax rotation with Kaiser criteria was used. The rotated factors matrix is reported in Table 17. The variables are answers to questions about carpooling characteristics, barriers to carpooling and platform characteristics previously discussed. These questions were chosen because of their common set of possible answers: “Very important”, “Rather important”, “Rather unimportant” and “Totally unimportant”. The use of other questions, with different sets of possible answers, would imply a normalization of the answers. This is a somewhat arbitrary procedure that can bias the results in a way hard to interpret, which is the reason why this was not attempted. The numbers in bold characters in the table are either numbers above the 0.5 threshold or are the highest on a given row.
| Environmental benefits | .860 | .142 | .000 | .065 | .000 | -.034 |
| CO2 - reduction | .849 | .175 | -.012 | .034 | .005 | -.005 |
| Traffic reduction | .822 | .021 | .055 | -.021 | .023 | .105 |
| Parking pressure reduction | .705 | .052 | .121 | -.049 | .049 | .177 |
| Rules for sharing costs | .027 | .737 | .252 | .030 | .100 | .165 |
| Data protection | .042 | .656 | .151 | .073 | .218 | -.017 |
| Short sign-up time | .118 | .550 | .004 | .228 | .054 | .126 |
| Cellphone number | .118 | .523 | .096 | .137 | .086 | .185 |
| Smoker/Non Smoker | .151 | .374 | -.012 | .145 | .136 | .166 |
| Reliability of the passenger | .104 | .053 | .704 | .159 | .029 | .148 |
| Reliability of the driver | .045 | .176 | .664 | .172 | .102 | .128 |
| Doubts about costs | .030 | .287 | .514 | .204 | .031 | .257 |
| Possibility intermediate stop | .002 | .052 | .357 | .288 | .122 | .181 |
| Fixed departure time | .004 | .132 | .157 | .556 | .149 | -.049 |
| Registration effort | -.060 | .123 | .237 | .470 | .072 | .277 |
| Gender preferences | .051 | .254 | .073 | -.012 | .562 | .201 |
| Traveling with strangers | -.056 | -.044 | .343 | .199 | .547 | -.082 |
| Reputation rating system | .060 | .362 | .015 | .055 | .531 | .203 |
| Restriction to a certain group | .017 | .163 | .115 | .183 | .480 | .119 |
| Low matching probability | .054 | .060 | .287 | .300 | .042 | .434 |
| Too many platforms | -.009 | .082 | .188 | .314 | .053 | .406 |
| On-the-fly search for ride-mates | .086 | .307 | .018 | .011 | .138 | .378 |
| Cost reduction | .221 | .199 | .190 | -.034 | .054 | .331 |
| New contacts | .203 | .069 | .151 | -.081 | -.007 | .291 |
| Time saving | -.001 | .062 | .014 | .009 | .072 | .191 |

Table 17: Rotated factors matrix
Factors are interpreted as:

- **F1 = Altruism / Environmentalism**
- **F2 = Convenience / Usability of the platform**
- **F3 = Reliability / Safety**
- **F4 = Temporal restrictions / Waste of time**
- **F5 = Community / Social Network**
- **F6 = Egoism / Scepticism**

The cluster analysis was based on the six factors found and using the K-means algorithm (Härdle and Simar, 2012). This algorithm is considered more reliable than hierarchical clustering algorithms, but the necessity to fix the number of clusters a-priori is an obvious drawback. To overcome this, diagnostic checks were run, with both K-means and hierarchical clustering. This led to the definition of four clusters. Table 18 reports the cluster centres. They give a measure of the affinity of a group with a given factor. A positive value means high affinity, a negative value means low affinity. Based on this and average socio-demographic characteristics (see Table 19) it is possible to describe the clusters.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability / Safety</td>
<td>-.138</td>
<td>.066</td>
<td>.564</td>
<td>-.816</td>
</tr>
<tr>
<td>Altruism / Environmentalism</td>
<td>-.449</td>
<td>-1.358</td>
<td>.407</td>
<td>.353</td>
</tr>
<tr>
<td>Egoism / Scepticism</td>
<td>-.467</td>
<td>.036</td>
<td>.223</td>
<td>-.260</td>
</tr>
<tr>
<td>Community / Social Network</td>
<td>-.544</td>
<td>.059</td>
<td>.172</td>
<td>-.190</td>
</tr>
<tr>
<td>Temporal restrictions / Waste of time</td>
<td>-.708</td>
<td>.189</td>
<td>.059</td>
<td>-.084</td>
</tr>
<tr>
<td>Convenience / Usability of the platform</td>
<td>-2.739</td>
<td>.272</td>
<td>.123</td>
<td>.114</td>
</tr>
</tbody>
</table>

Table 18: Cluster centres: values which are the highest in a cluster or of a row are in bold, with the exception of negative values.
<table>
<thead>
<tr>
<th></th>
<th>Clusters</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>All</th>
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<tr>
<td>Gender (Male)</td>
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<td>64.03</td>
<td>50.90</td>
<td>62.39</td>
<td>57.59</td>
</tr>
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<td>9.35</td>
<td>6.33</td>
<td>8.97</td>
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<tr>
<td></td>
<td>30-39</td>
<td>3.03</td>
<td>22.30</td>
<td>12.65</td>
<td>20.09</td>
<td>16.40</td>
</tr>
<tr>
<td></td>
<td>40-49</td>
<td>15.15</td>
<td>30.22</td>
<td>31.63</td>
<td>30.34</td>
<td>30.22</td>
</tr>
<tr>
<td></td>
<td>50-59</td>
<td>21.21</td>
<td>23.74</td>
<td>21.39</td>
<td>24.79</td>
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<tr>
<td></td>
<td>60+</td>
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<td>14.39</td>
<td>28.01</td>
<td>15.81</td>
<td>22.90</td>
</tr>
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<td>HH Income</td>
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<td>0.00</td>
<td>5.04</td>
<td>3.92</td>
<td>2.99</td>
<td>3.66</td>
</tr>
<tr>
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<td>2001-4000</td>
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<td>6.47</td>
<td>8.43</td>
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</tr>
<tr>
<td></td>
<td>4001-6000</td>
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<td>15.83</td>
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<tr>
<td></td>
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<td></td>
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<tr>
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<td>3.31</td>
<td>8.55</td>
<td>5.42</td>
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<td>7.53</td>
<td>8.55</td>
<td>7.72</td>
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<td>5.42</td>
<td>4.27</td>
<td>5.42</td>
</tr>
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<td>56.02</td>
<td>35.90</td>
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<td>55.72</td>
<td>47.44</td>
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<tr>
<td></td>
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<td>41.45</td>
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<td>&gt;4</td>
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<td>11.11</td>
<td>9.08</td>
</tr>
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<td>79.86</td>
<td>61.45</td>
<td>73.93</td>
<td>69.78</td>
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<tr>
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<td>16.55</td>
<td>17.77</td>
<td>15.81</td>
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<tr>
<td></td>
<td>Italian</td>
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<td>3.60</td>
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<td>10.26</td>
<td>13.55</td>
</tr>
<tr>
<td>Cars</td>
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<td>1.44</td>
<td>1.81</td>
<td>3.42</td>
<td>2.17</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>54.55</td>
<td>37.41</td>
<td>53.61</td>
<td>46.58</td>
<td>48.37</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>39.39</td>
<td>48.20</td>
<td>37.95</td>
<td>41.45</td>
<td>41.06</td>
</tr>
<tr>
<td></td>
<td>&gt;2</td>
<td>6.06</td>
<td>12.95</td>
<td>6.63</td>
<td>8.55</td>
<td>8.40</td>
</tr>
<tr>
<td>Season Tickets Owners</td>
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<td>48.92</td>
<td>51.51</td>
<td>64.10</td>
<td>55.28</td>
</tr>
<tr>
<td>Among owners:</td>
<td>GA</td>
<td>5.26</td>
<td>12.31</td>
<td>17.16</td>
<td>20.27</td>
<td>16.96</td>
</tr>
<tr>
<td></td>
<td>HF</td>
<td>84.21</td>
<td>67.69</td>
<td>72.78</td>
<td>63.51</td>
<td>69.08</td>
</tr>
<tr>
<td>Carsharing Member</td>
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<td>0.00</td>
<td>4.32</td>
<td>3.92</td>
<td>3.42</td>
<td>3.66</td>
</tr>
<tr>
<td>Work</td>
<td>Full time</td>
<td>21.21</td>
<td>66.19</td>
<td>41.57</td>
<td>61.97</td>
<td>51.76</td>
</tr>
<tr>
<td></td>
<td>Part time</td>
<td>24.24</td>
<td>19.42</td>
<td>28.92</td>
<td>23.93</td>
<td>25.34</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>54.55</td>
<td>14.39</td>
<td>29.52</td>
<td>14.10</td>
<td>22.90</td>
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<tr>
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<td>Fairly Likely</td>
<td>15.15</td>
<td>31.65</td>
<td>35.54</td>
<td>46.15</td>
<td>37.26</td>
</tr>
<tr>
<td></td>
<td>Fairly</td>
<td>18.18</td>
<td>36.69</td>
<td>34.34</td>
<td>26.92</td>
<td>31.71</td>
</tr>
<tr>
<td></td>
<td>Very</td>
<td>57.58</td>
<td>22.30</td>
<td>12.65</td>
<td>7.69</td>
<td>14.91</td>
</tr>
<tr>
<td>CP Passenger</td>
<td>Very Likely</td>
<td>6.67</td>
<td>11.11</td>
<td>18.54</td>
<td>18.35</td>
<td>16.57</td>
</tr>
<tr>
<td></td>
<td>Fairly Likely</td>
<td>20.00</td>
<td>26.19</td>
<td>35.43</td>
<td>44.95</td>
<td>36.09</td>
</tr>
<tr>
<td></td>
<td>Fairly</td>
<td>16.67</td>
<td>45.24</td>
<td>32.78</td>
<td>27.98</td>
<td>32.84</td>
</tr>
<tr>
<td></td>
<td>Very</td>
<td>56.67</td>
<td>17.46</td>
<td>12.91</td>
<td>7.80</td>
<td>14.05</td>
</tr>
</tbody>
</table>

Table 19: Average socio-demographic attributes for the clusters and the whole sample
**Negative / non-interested (Cluster 1)**
This type is characterized by negative values for all the factors, meaning that none of the factors is important to members of this group. The cluster is the smallest with only 33 members (4.5% of the sample). More than half of the members are above the age of 60 and most of the members live in small households and tend to have low levels of income. It is also the group with the lowest level of education and the only group in which all members have at least one car in the household. The type is predominantly diffused in the German speaking part of Switzerland and among male individuals. As expected, the large majority of members think that their participation in a formal carpooling would be unlikely both as a driver (78%) and as a passenger (75%). Overall, this type is not open to carpooling and, likely, to new mobility forms in general either. Moreover, the high motorization and the low percentage of people employed suggest that carpooling might simply not really fit the needs of this group. Arguably, they don’t make trips on a regular basis and they consider a matching for sporadic errands too complicated to be an option.

**Pragmatic (Cluster 2)**
The members of this group find the convenience and the features of the platform of great importance. They are also concerned about reliability issues which might arise, but not particularly about safety. In principle they seem ready to participate but only if “it works”. They are not ideologically motivated, environment is not a concern for them, but if carpooling can give them some kind of benefit, of economic nature or other, they would likely join. This cluster (18.8% of the respondents) is the one with the largest percentage of male members and of young people (31% are between 18 and 39). Members are predominantly in the central part of the income scale while education levels’ distribution is fairly close to sample average. Additionally, this type is overrepresented in German speaking Switzerland, has the highest rate of persons living in a 3 or 4 person household and is the group whose households have most cars. The group has also the highest share of full time employees but also the lowest share of season ticket owners. The number of respondents who state they are likely to participate in carpooling is higher than for the previous cluster, but still below the sample average. This group seems to be mainly composed of young professionals with a busy daily life who could be convinced to use carpooling only if this would not hinder their daily life and clear benefits would be ensured.

**Sceptical environmentalist (Cluster 3)**
This type gives a high importance to altruistic and environmental aspects of carpooling but also shows a good dose of scepticism and is particularly concerned about safety. About 45% of the respondents belong to this group. Not surprisingly, this group is the one with the highest female component. They are a bit older than average, but mostly still working. Low income households are
overrepresented as well as individuals with secondary school education only, while tertiary degree is rarer than among other types. The group is overrepresented in the French and, more pronounced, in the Italian speaking part of Switzerland. Both the household size and the number of cars are under the sample average, the first substantially and the second only slightly, with a predominance of households with only one car. About half of the respondents of this group report they would likely participate in carpooling. This is almost exactly as the sample average. All in all, it seems that this group of individuals is convinced that carpooling is a good thing and its implementation is meaningful and could help solving some transportation and environmental problems, but thinks it is not something that could work for them or they are scared about it.

**The enthusiastic environmentalist type (Cluster 4)**

For the members of this type (32% of the respondents) the supposed benefits of carpooling for the transportation system and the environment are the only really important aspects. The convenience of the platform is considered of some importance, all other factors are not. Younger people are slightly more likely to belong to this type while, on the contrary, persons over 60 years of age have a slightly lower chance being in this group. Low income levels are underrepresented and all levels over the average income (the average income is 8’900 SFr. which falls, therefore, in the 8’000-10’000 category) are slightly overrepresented. This is the group with the highest education level, more than 59% have a tertiary education, and the type is distributed close to overall sample average in terms of language groups, with a little overrepresentation in German speaking Switzerland. The household is on average large; the individuals of this cluster have the highest chance of living with 4 or more persons (11%). Motorization is fairly consistent with the sample overall, except for having the highest share of carless people (3.4%) and, accordingly, by far the highest rate of season tickets for public transport. The group has also the highest share of people employed; only 14% of the members are not employed. Respondents of this cluster who would be ready to participate exceed 60% for both possible roles, while only a very small minority (about 7%) would consider his or her participation in formal carpooling very unlikely. This group is the one with the most positive attitude toward carpooling. They take a strongly ideological approach; the benefits that carpooling should provide for the transportation system and the environment are the driving factors to join, and members seem persuaded that the system would function properly and are not particularly concerned about practical issues.

5.5.3 **How to use the clusters**

The use of cluster analysis is widespread in sciences where qualitative data is prevalent, like certain domains of medicine or marketing. In marketing, in particular, it is typically used to formulate the
right selling strategy for each customer segment. A particular group might be sensitive to a particular advertisement campaign because it is interested in specific features. Cluster analysis is also useful to find out if there are any groups which are not targets at all, allowing focusing on those who really are potential customers.

The cluster analysis above gives hints on the attitude of Swiss people toward carpooling. If carpooling is to be used at large scale, it is important to understand who would be interested in using it and under which conditions this would actually happen. The assignment of respondents to different groups of homogeneous characters offers the opportunity to formulate specific strategies. The first group considered here is the Enthusiastic environmentalist (Cluster 4). Those belonging to this group are likely early adopters of the system and their enthusiastic approach to carpooling, and probably to everything they consider to be good for the environment and society, might make a substantial advertisement effort superfluous. The carpooling platform should be set up and advertised enough to capture those enthusiasts, but, from that point on, the best strategy would be to avoid, or fix quickly, all the possible dysfunctions in the system. Keeping the early adopters happy with the functioning of the platform would have the double function of avoiding their concern about the practical aspects of the system to emerge and cause disaffection, which might prevent other types to join carpooling. The Sceptical environmentalist type (Cluster 3), in fact, seems ready to participate in large numbers if the functioning and security of the system are demonstrated. This is the largest group and to transform their positive opinion into active participation is the key to long term success. Finally, the Pragmatic type (Cluster 2) could be also interested in joining once the hypothesized personal benefits of participating are supported by solid evidence. It is important to note that the pragmatic type is likely to be far more frequent in the population than in the sample. Socio-demographic characteristics of this type are closer to those of the whole Swiss population than those of other groups (See Table 19). This is consistent with the effects of a self-selection process which could have biased the recruitment toward particularly carpooling friendly participants. Therefore, the participation of the members of this group might be crucial for the long term success of formal carpooling and, in a later phase, they might be the most important target of any advertising campaign. The smallest group is that of the Non-interested individuals but might have also been under-sampled in the recruitment process. They seem to be such unwilling carpoolers that it is hard to imagine a strategy to convince them to accept the system. The picture might change once that the numbers of carpooling will substantially rise and the perception of carpooling of this group improved likewise. The setup of a meaningful strategy for this group would necessarily pass, therefore, through another survey to be made when these conditions have actually been met.
5.6 Summary and outlook

Formal carpooling programs do exist in Switzerland but, as in many other countries, they are very small. It is evident that any attempt to extend the use of carpooling substantially beyond the current scale requires understanding the preferences and the inclinations of the public toward this mode. The work presented provides this understanding for the Swiss context and proposes a strategy to increase carpooling use. A large survey has been performed with more than 2’000 participants and a response rate of about 51%. The survey included both a multi-response questionnaire and a stated preferences exercise. The fact that formal carpooling is not a familiar concept seems to be reflected in the way people confront the simulated choice situation, making choices a bit less consistent. The lower fit of the carpooling model, compared to that of carsharing, a more established concept in Switzerland, despite the higher number of observations, seems to confirm that. Nonetheless, the fit of the model is satisfactory and a useful insight was obtained. The Value of Travel Time Savings (VTTS) is influenced by income and travel distance for both carpooling options. Persons with higher income and shorter trips tend to have a higher VTTS. This is different than in the Swiss norm but as in a previous study made on similar data. More interestingly, the two carpooling alternatives have a higher VTTS than car, suggesting that they are preferred to this alternative, which was not necessarily expected. This might mean that the choice to carpool is not only of economic nature, but other motivations – environmental, social, etc. – that are not captured by the model, play also an important role. Finally, potential carpoolers seem to prefer to be passenger rather than drivers, which suggests that carpooling as passenger is a more attractive option, being comfortable and comparatively cheap. In the case of carsharing VTTS follows a similar pattern as for carpooling. The different WTP indicators appear reliable and might be used for the quantitative evaluation of policies or for planning purposes. Their values also confirm the eminent importance of access convenience in the choice of carsharing. Unlike the case of carpooling, the choice of carsharing seems more economically driven and not necessarily related to some particular ideological inclination. This is a logical output if one considers that carsharing in Switzerland is not a new product but rather well known and, in relative terms, a widely used alternative to private car use. It is possible to implement and run the models on the whole Swiss population to estimate the potential modal share for carpooling in Switzerland. Key for this estimate is the availability of the relevant data – the variables of the models – for the whole population. The result would be a sort of upper bound, since the problem of pooling people together wouldn’t be taken into account. If data on the time distribution of trips is also available – i.e. commuting trips – it is possible to solve the problem of creating compatible cliques, obtaining a more realistic estimation of carpooling potential. MATSim allows this
type of implementation of the models being all the necessary data for a Swiss scenario available in
the modeling tool. The implementation of the model presented here in MATSim is beyond the scope
of this dissertation but is already on its way (Dubernet and Axhausen, 2012).

From the other part of the survey it was found that the general attitude toward carpooling is
overwhelmingly positive with 78% of respondents having a positive opinion on this mode and with
51% of them being “very likely” or “fairly likely” to use formal carpooling as a mode if the
opportunity was available. Some findings, like the importance and the type of preferred incentives
and the fact that elderly people are less likely to participate in carpooling, confirmed what was found
in the previous literature. The main concerns about carpooling participation are of practical nature.
Safety, which previous studies indicated as a prevalent issue for potential carpoolers, is important for
elderly people and women but not for other groups. The finding departing most from previous
studies is the availability to carpool of relatively affluent people. It is usually acknowledged that low
income persons are more likely to carpool, but here it appears to be the other way round. This might
reflect a change of paradigm caused by a new environmental and social sensibility. This is confirmed
by the fact that among carpooling benefits, those for the environment and the transportation system
are considered the most important.

Cluster analysis suggested the existence of four groups with different carpooling attitudes:
Enthusiastic environmentalists, Skeptical environmentalists, Pragmatics and Non-interested. A
strategy to expand carpooling use in Switzerland could use the groups directing “ad hoc” messages to
each of them. While Enthusiastic environmentalists are expected to join a hypothetical platform
without much advertising effort, a successful campaign should put a substantial effort convincing
Skeptical environmentalists and Pragmatics to participate. Non-interested are likely not worth the
effort and should be not targeted by such a campaign.

Future work is planned to bring together the two parts of the survey which have been analyzed
separately so far, the qualitative part and the stated choice experiments, with their discrete choice
models, in a previous one. In a future effort it will be attempted to make use of the largest possible
part of the qualitative information in order to improve the discrete choice models estimated. The
cluster analysis was already a first step in this direction. The types can be used as variables in the
models providing a straightforward way to include latent structures in the respondent’s preferences.
Additionally, it is possible to estimate separate models for the different clusters, obtaining much
more refined behavioral models. Parallel, latent class models could be also estimated in order to
verify if similar structures are found.
The level at which respondents manifested a positive attitude toward carpooling, and the share of the groups, might be surprising for readers aware that carpooling is a rarely used mode in Switzerland. They could wonder how such positive attitude can possibly translate in an actually poor performance. There are various possible explanations. The first thing worth to remember is that the sample might not be representative of the whole Swiss population, as explained in section 5.3. It is well known that self-selection typically biases the sample in a way that persons with positive attitude toward the theme of the survey are more likely to participate. Moreover such surveys sometimes produce results which are closer to people’s self-representation than to reality. These are probably the most important limitations of this study. Finally, we might also witness a learning process in carpooling use. The typical “S” shape, meaning a flat growth of carpooling use for a relatively long time would be followed by a steady growth phase. This latter should necessarily be anticipated by a phase where the use has not yet increased but the awareness of the public has. If this is true, carpooling could become soon a prevalent mode of transport. The emergence of a platform addressing all the issues raised by the respondents, be that in the form of an aggregation of existing Swiss platforms or a brand new platform will be crucial. In other words, even in this hypothetical favorable scenario, the results are not saying that a future success of carpooling is guaranteed. They rather suggest that right now could be the right time to deploy an aggressive strategy to promote carpooling in Switzerland.
6.   **Modeling Carsharing demand using an agent-based micro-simulation approach: a model for the agent based simulation MATSim**

This chapter is based on the paper “Estimation of Carsharing Demand Using an Activity-Based Microsimulation Approach: Model Discussion and Some Results” published in the International Journal of Sustainable Transportation.

6.1  **Modeling framework**

6.1.1  **Modeling requirements**

In classic travel demand (4-step) models, the mode choice module was typically taking only two modes into account, car and public transport. Recent efforts have enhanced this to account for other modes (i.e. bicycle and walk travel) but, to the best of our knowledge, the integration of the carsharing mode in that module has not yet been attempted. In fact, the estimation of carsharing demand is a challenging task for various reasons and one could argue that classic modeling tools are not well suited for this. In general, they are estimated on data, which represent the current transportation system and are not based on general behavioral rules that persons are supposed to follow. Therefore, it is difficult for these models to make predictions for new transport options. Carsharing is a car mode but also shares attributes with public transport, like access time and the fact that service is not always available. Thus, in order to assign travelers to the right alternative, the description of the modes needs to be detailed enough to include the characteristics that distinguish them. The more similar the modes are the more details are necessary. However, to fully exploit the level of detail, travel should be modeled at the individual level with explicit modeling of modal choice. A precise computation of access time to the service implies both, high spatial resolution of the model and representation of single travelers. In order to deal with single travelers, individual socio-demographic data is required. In the literature, various reports on themes like estimating carsharing market potential, simulating carsharing operations and estimating the effect of carsharing on car ownership are available. The work of Shaheen and Rodier (2004) is probably the only example where travel demand and policy effects are forecast for different scenarios. However, they used a modeling framework that allowed only a very simplistic representation of carsharing. They correctly observed that reliable tools for the estimation of innovative mobility services/policies are missing and overcoming this lack might be crucial for their success. Summarizing, there are three important conclusions:
• Since travel demand models are estimated on data that represents the current transportation system, it is difficult for these models to make predictions for new transport options
• Models with high spatial resolution and many demographic details are needed
• Reliable tools for the evaluation of innovative mobility services/policies might be decisive for their success

As stated in previous work (Ciari et al., 2009), a possible way to address these issues is to use a modeling approach that couples the activity-based approach with a multi-agent system. MATSim, the multi-agent simulation that will be used here, is an example of this coupling.

They constitute a considerable step forward compared with previous approaches. Nevertheless, Shaheen and Rodier observe that a tool allowing the evaluation of more complex scenarios would be a priority in order to obtain more reliable results. They also suggest that a more precise representation of the services would be desirable, and that the lack of tools to evaluate innovative mobility service/policy effects could be a barrier to their implementation on a regional level.

6.1.2 MATSim utility function

MATSim has already been described in section 2.3. The optimization process described there is based on the evaluation of the plans using a specific scoring function. The MATSim scoring function employed in this paper is based on two ideas: a logarithmically decreasing marginal utility for activity duration and a Vickrey (Vickrey, 1969; Charypar and Nagel, 2005) inspired valuation of the timing of the activities and the travel time. Its general form is

\[ U_{\text{plan}} = \sum_{i=1}^{m} (U_{\text{act},i} + U_{\text{travel},i}), \]

where the global utility of a plan is maximized. The number \( m \) is the number of activities and \( n \) the number of legs included in the plan. The elements included in the second term of equation (9), which is basically the disutility of traveling, are access/egress time, traveling time and the cost of the trip with a given mode. Thus, the cost of traveling from activity \( i-1 \) to activity \( i \) with transport mode \( \text{mode} \) can be expressed as follows:

\[ U_{\text{travel},i,\text{mode}} = \alpha_{\text{mode}} + \beta_{\text{tr,mode}} * TT + \beta_{\text{cost,mode}} * \text{Cost}_{\text{mode}} * \text{Dist} \]
In the basic model, access and egress time are not calculated but assigned to each mode in the form of a non-positive constant $\alpha_{\text{mode}}$. The cost component represents the kilometric cost for the mode considered and is an average based on Swiss values (TCS, 2011). It is assumed to be zero for cycling and walking, while their values for the other modes are:

$$\text{Cost}_{\text{car}} = 0.12 \text{ Sfr/km}; \text{Cost}_{\text{pt}} = 0.28 \text{ Sfr/km}; \text{Cost}_{\text{pt,season tickects}} = 0.14 \text{ Sfr/km}.$$  

The two different values for public transport take into account the fact that a passenger might own a season ticket of some kind. $\text{Dist}$ is the distance traveled for the leg calculated with specific methods for each mode. The travel time (TT) is either derived from the simulation or calculated based on the distance and the speed of the mode. The constant average speed of the public transport mode is based on measurements in the city of Zurich while speeds for cycling and walking are based on the National travel diary. They are respectively:

$$v_{\text{pt}} = 15.7 \text{ km/h}; v_{\text{bike}} = 14 \text{ km/h}; v_{\text{walk}} = 2.8 \text{ km/h}$$

The speed for the car mode is the “real” travel time obtained through the simulation. Through this physical representation, based on a queue model, agents interact in the sense that they are competing for the infrastructure. Therefore, travel time and, consequently, the generalized cost of a car trip depend on congestion on the network and, thus, on the mobility behavior of other agents. The constant $\alpha_{\text{mode}}$ and the parameters $\beta_{\text{tt,mode}}$ and $\beta_{\text{cost,mode}}$ are different for each mode and have been estimated using stated preference survey data (Vrtic et al., 2008). The parameters represent the marginal utility of another unit of time and the marginal utility of another unit of money spent on traveling by mode.

Other kinds of out-of-pocket expenses (like parking costs) can be added in the same way, as well as other aspects of travel with a specific mode. The utility function allows the user to vary the characteristics of different modes and observe the reaction of agents to such variations.

### 6.2 The base model

In the standard version of MATSim, the available modes are car, public transport, bike and walk. Carsharing is not considered as an option. A new transport mode can be added to the simulation tool in various forms and with different levels of detail. In any case, it is necessary to introduce a function that represents the generalized cost of travel with the given mode in a form similar to (9). In the work presented here, two of the fundamental features that characterize the carsharing mode, access
to carsharing cars and the fare structure are explicitly modeled. Our assumption is that a model with a correct representation of these two features is able to give plausible estimates of carsharing use in terms of modal share, and to induce in the agents some of the typical carsharing use patterns. A convenient access to carsharing cars has been found of particular importance in most of the surveys conducted among carsharing users and, indeed, is often referred as the most important factor for joining a carsharing program. The fare of carsharing is generally the sum of a time dependent part and a distance dependent part. The users are charged for both the distance they travel and the time they keep the car (or more precisely the time they reserved the car). This feature is specific to carsharing and it is known to have a strong influence on use patterns (Millard-Ball et al., 2005). In order to explicitly represent the mentioned features, the model has been enhanced as follows:

- Carsharing stations have been introduced; stations are located at the actual carsharing locations in the modelled area.
- One agent can pick up the car only at one of the predefined stations, and must bring it back to the same one.
- Agents always choose the closest station to the starting facility.
- Agents walk to the pick-up point.
- The agent’s utility function is enhanced to account for carsharing. A time dependent penalty is introduced to mimic carsharing fare structure.

Other features, which are also specific to carsharing programs, like membership and reservations, have not been taken into account yet, which means that in the simulation the following applies:

- Carsharing is available to everybody having a driving license (no membership is needed)
- An unlimited number of cars is available at the stations

These are unrealistic assumptions and a better modeling of such features will be addressed in future work. The function representing generalized cost of travel for car sharing is:

\[
U_{\text{travel}, cs} = \alpha_{cs} + \beta_{\text{cost,cs}} \text{Cost}_t \times RT + \beta_{\text{t,walk}} \times (AT + ET) + \beta_{\text{t,cs}} \times TT + \beta_{\text{cost,cs}} \times \text{Cost}_d \times \text{Dist}
\]

Compared to (9), equation (10) has five terms instead of three. The first, the constant $\alpha_{cs}$ has a different meaning than the constant in the previous equation since access/egress are explicitly represented in the equation. This is intended to mimic the minimum cost of carsharing, since the minimum reservation length offered by the Swiss operator Mobility is 30 minutes. This term is important to keep agents from using carsharing in the simulation for only few minutes. The second term refers to the time dependent part of the fee. RT is the total reservation time minus 30 minutes (already taken into account) and Cost$_t$ represents the cost for one hour reservation time. The
parameter $\beta_{cost,car}$ represents the marginal utility of an additional unit spent on traveling with carsharing. The third term is the walk path to and from the station and is evaluated as a normal walk leg. The other two terms represent the car route and have the same meaning as in equation (10). The time cost is set to 2 SFr/h while the distance cost is set to 0.64 SFr/km, which is the standard carsharing fee in Switzerland.

The mode choice module of MATSim is subtour based. A subtour is defined as a sequence of at least two trips starting and ending at the same node. Agents choose the transport mode at this level. This fits well with the way real carsharing systems are functioning since it forces an agent to bring back the car to the starting station.

A last aspect of the model that is worth mentioning is the physical simulation. In the version of MATSim used here only private cars are physically simulated. The physical simulation allows taking into account the interactions among agents; basically their competition for the infrastructure. Too many agents on a certain road at a certain time will cause congestion and agents will try in successive iterations to switch time or route in order to obtain a better score. This generates a dynamic assignment of the demand to the network. If an agent uses a mode other than the car mode, the attributes of this travel (distance, time) are calculated independently from the situation on the network. This is equivalent to assuming that such modes neither are influenced by nor influence congestion on the network. In fact, in a real world situation, this is largely true for the walk mode and more or less true for the bike mode. This is, however, a major simplification for public transport travel. A detailed discussion of that feature of the model is beyond the scope of this paper, but, it is important to explain how carsharing is modeled to this respect. It is obvious that it cannot be assumed that the congestion on the network is not influential for carsharing travel. Nevertheless, since car sharing cars make up only for less than 1% of global car travel (the sum of private cars plus carsharing cars) it seems reasonable to assume that carsharing users contribute only very marginally to congestion on the network. They are, however, affected by the congestion that the other car travelers cause. For that reason, carsharing cars are not physically simulated, but travel time for carsharing is calculated on the congested network. Therefore, travel time for carsharing in the simulation does depend on the level of congestion of the network at the time when and on the route where carsharing travel happens.
6.3 Enhancements to the base model: adding membership

The membership model presented in chapter 3 was used to enhance the base model. In practice it simply means to add a preprocess step in which the model (actually two, as described in 3.4.2) are run over the artificial population of agents. By this, membership is assigned (or not) to the agents. The output of the pre-process is an enhanced MATSim plans file which can be therefore used as input for a normal run. Besides that, only a very small modification to the code of the replanning module was necessary to allow the simulator to deal with the new membership card, which simply means precluding carsharing use to non-members in the simulation. The resulting model was run on a large scale scenario; the output of those runs is presented and discussed in chapter 8 together with that of the base model.

6.4 Conclusions and outlook

This chapter reports on the development of a simulation tool that should be able to estimate the travel demand for carsharing and evaluate different scenarios and policies. The main motivation for the work is the expected increase in importance of tools for the evaluation of innovative transport modes in the near future. Such tools are not yet available and the one presented in this paper is an important step in this direction. The methodology proposed is both activity-based and agent-based and builds on an existing open source project called MATSim. This type of model is known to allow for a very rich description of both persons and infrastructure, and MATSim is no exception. This comes at the cost of being computationally intensive. Additionally, the richness of detail does not imply the accuracy of the model, in particular at the micro-scale. However, it is important that such a level of detail is possible because it allows introducing simple behavioral rules at the micro level that determine the macro behavior of the system. The key is to use behavioral rules that are easy enough to observe from real world experience but also “fundamental” enough to induce a plausible behavior in the agents not only for a particular activity or for a particular mode of transport, but in general. This results in the really important feature of showing an emerging behavior at the macro-scale that is caused, but not directly implied, by the rules at the lower level. This emerging behavior is the main reason why agent-based simulation is a suitable tool for modeling innovative transport systems. Moreover, this kind of modeling tool does not rely too much on past information to make predictions. The implementation described in this chapter focused on two of the most important aspects of carsharing, the access to the cars and the time dependent fee structure. These two aspects are known to be of great importance for carsharing users and a model aiming to predict
carsharing demand should take them into account. About an application of the model to a real-life large-scale scenario is reported in chapter 8.
7. Modeling one-way shared vehicle systems with an agent-based approach

This chapter is based on the paper “Modeling one-way shared vehicle systems: an agent based approach” presented at the 13th International Conference on Travel Behavior, Toronto, July 2012.

7.1 Introduction

One-way shared vehicle systems are a particular form of shared vehicle systems where vehicles can be picked up from one point (generally a station of a specific network) and returned to a different point. The approach is widely used for bike-sharing systems, while its application in carsharing systems knows right now sees a revival after some experiments and a few unsuccessful experiences (Brook, 2010). One-way shared-vehicle systems, even more than traditional systems with station bounded vehicles, can improve the quality of an urban transportation system, integrating public transport with a service that provides a low-cost but highly flexible alternative to private mobility. However, a number of critical issues related to the implementation and the operation of such systems are still unsolved. The main problem of one-way systems is the occurrence of imbalances in the availability of vehicles at stations as a natural consequence of individual user behaviour. Practically, there are stations where vehicle availability does not meet user demand and others where a lack of free docking spaces prevents users from returning vehicles. Currently, system operators confront the problem redistributing vehicles across stations, but this operation represents one of the main cost factors in shared vehicle systems, and is a barrier to their further development. The system should be planned so that imbalances are prevented, or minimized. This implies, however, an accurate forecast of the demand with both high temporal and spatial resolution. The present chapter addresses the creation of a model predicting one-way shared vehicle systems demand. This is based on the existing carsharing module presented in the previous chapter (see Chapter 6). Extending MATSim to simulate one-way shared vehicle systems presents various challenges. Modal choices in MATSim are made at the subtour level – any sequence of trips which starts and ends at the same point – which is a perfect framework for traditional carsharing but is not suitable to represent a one-way system. A possible way to overcome this limitation is allowing multimodality within a subtour; this has been already attempted in a simple way in the mentioned work on carsharing and in a more sophisticated way in the work on public transport (Rieser, 2010). The modelling of stations need to include the spatial and temporal availability of vehicles and station operations (pick-up, drop-off, relocation, etc.). Similar operations have been already modelled in
MATSim in Galus et al. (2012). Additionally, the representation of vehicle availability makes it necessary that agents modify the daily-plans during execution (physical simulation). If an agent planned using a shared vehicle but it turns out that no vehicle is available at the pick-up point, the agent must modify the plan, for example using another mode of transport. This feature is not yet implemented in MATSim, but it will be possible to build on some previous work where the possibility to modify the route during execution has been introduced (Dobler et al., 2012). The main contribution of this chapter is to provide all the concepts which allow overcoming the mentioned issues and bringing them together in a coherent framework. This will be the basis for a predictive one-way shared vehicle systems demand model with high temporal and spatial resolution and in which the use of the vehicles will be explicitly simulated, making agents capable of choosing according to the availability of a vehicle at a given station.

The next section provides a short historic overview of one-way shared vehicle systems and some observations on the existing literature. Section 3 explains the challenges of developing a simulation model predicting one-way shared vehicles systems demand and proposes and discusses some concepts which might be used to enhance the existing carsharing model and to fulfil this goal.

The last section summarizes the chapter and proposes directions for future work.

7.2 Background

The one-way station-based approach, as mentioned in the previous chapter, is used for both bike-sharing and carsharing systems. However, the path that car-sharing and bike-sharing operators followed to come to this form of shared vehicle system is very different, as it is their diffusion. In the case of bicycles, it all started with fairly informal systems which did not included any station. A set of public bikes where available to the public for free use within a given area. Those systems, therefore, were free-flow systems. They are considered the first-generation of bike-sharing and all suffered of vandalism and theft. The second generation tried to solve such problems introducing coin-deposit systems but only the appearance of the third generation, which is characterized by the introduction of smart technologies, strongly improved the situation on such issues (Shaheen et al., 2011). The solution includes the use of smart cards which limit the use of the system to registered persons and is associated with automated stations where bikes can be picked up and dropped off. In this sense, bike-sharing systems started with a completely flexible approach (free flow) but were forced to revert to a less flexible one because confronted with otherwise hard to solve (at least at that time)
issues. Carsharing saw a different path. It started with the still prevalent two-way station-based approach and the one-way option has been explored by operators as an additional feature at various stages of its history. In fact, the first one-way carsharing systems were an experimental and small scale (Massot et al., 2001; Barth and Todd, 2003). The first attempt to introduce the one-way feature at a larger scale was probably in Singapore, known as the Diracc project (Barth et al., 2006). In a first phase, the scheme was directly operated by the Japanese car-manufacturer Honda in close collaboration with the Singapore government and had an experimental nature too. This was followed by a second phase where the system was run as a for-profit scheme, but the high relocation costs recently brought the operator to revert to a traditional station-based system (Brook, 2010). Despite that, recent developments in carsharing are bringing the one-way option under the spotlight. The Autolib system, which started its operations in 2011 in Paris, is supposed to become the largest carsharing system in a single city with an announced number of 4’000 cars (Autolib, 2012). Other operators go even beyond the one-way feature (car2go, 2012; DriveNow, 2012), proposing free-flow systems. Those systems are innovative also because they are directly operated by car manufacturers (Daimler and BMW respectively).

Despite decades of history, not many research efforts reporting on existing systems were focusing on the one-way feature in the past from a user (travel behavior) perspective. In the case of bike-sharing this is likely because the one-way feature is taken for granted and its effects on customer behavior are in general neglected. In the case of carsharing, as reported above, this is simply related with the low number of such systems and the fact that some of them started operations only very recently. Some papers, however, dealt with the issues associated to one-way operations from an operator perspective, and in particular with the vehicle relocation problem. For example, a group of researchers, most of them based in Singapore, developed a simulation approach to model one-way carsharing operations using real data of the Diracc system (Kek et al., 2009). They used the simulation as basis for a substantial amount of work testing different solutions for the relocation problem. Some work was also undertaken regarding the management of free-flow carsharing in Ulm, Germany (Göppel and Blumenstock, 2012). The work of Schwieger (2003) is one of the few dealing with one-way carsharing considering the customer perspective too. It reports about a trial by the German operator Stattauto (Stattauto, 2012) allowing the one-way option for a limited number of stations and a limited period of time. His main findings are that customers consider one-way a “nice to have” feature and not a fundamental one, while availability concerns are the most important shortcoming of one-way systems since advance reservations were not possible. Additionally, the socio-demographic profile of customers using the service was in line with the overall profile,
suggesting that the option would not attract new users. However, this was only a trial for a limited
time and the results are not suitable to capture that effect. Finally, from an operator perspective, the
earnings per car per day sank of only 0.6%, which means that the additional costs to manage the
fleet were almost entirely compensated by the additional income for the service.

7.3 Modeling approach

The existing carsharing model, presented in the chapter 6, is not suitable to simulate one-way
carsharing and in general one-way shared vehicle systems. The main goal of this paper is to discuss
the main issues implied by an extension of the existing model to overcome this limitation. Ideas to
overcome other shortcomings, though, are also discussed and possible solutions are proposed. In
this sense, the ideas proposed here are the bases to enhance the existing model obtaining a
comprehensive modelling tool able to simulate any kind of shared vehicle system, including free flow
systems, which could be modelled with minor modifications. Possible solutions to such issues are the
subject of the present section. Please note that, for the sake of simplicity, since the previous model
was about modelling two-way carsharing, from here on one-way carsharing will be used as far as the
new modelling approach is concerned but, again, keeping in mind that the same applies for any one-
way shared vehicle system, unless explicitly stated otherwise in the text.

7.3.1 Mode choice

As mentioned in the previous chapter, subtours are taken in MATSim as the “natural” resolution to
observe and model modal choices. Therefore, one single mode for a whole subtour is assigned. In
other words, all the trips (legs) composing the subtour are simulated with the same mode. The sub-
tour based approach allows accounting consistently for the differential availability of modes. Subtour
mode choices are in general treated as independent events but it is assumed that a transportation
mean is available if it was available also at the end of the previous subtour. Some modes are
assumed to be available for everybody at any point and at any moment (walk for example), but other
modes (car and bike), are available only if they have been used in the previous subtour. Going
backwards, the first of a chain of subtours of an agent is always starting at home, where it is assumed
that all possible modes for the specific agent are available. Note that the concept of “previous” is
both temporal and spatial. The previous of a given subtour is the first, in temporal terms, of the
previous subtours containing the starting point of the considered subtour. The main limit of this approach is that it cannot handle multimodality. MATSim currently takes into account multimodality only for those modes that are “implicitly” multimodal. Public transport for example generally implies a walk stage to reach the station and an in-vehicle stage, which is the proper public transport travel. In such cases the walk stage is explicitly accounted for in terms of travel time using a specific router with specific speed settings. This type of multimodality happens within one leg. However, it is not possible to simulate subtours where different legs are travelled with different modes. The flexibility to do so is clearly one of the most important features of one-way carsharing systems and needs to be simulated. The most obvious solution, using a trip based approach, is not a feasible option. It would require major changes in the whole software package and, most importantly, would affect all other modes too. In fact, the replanning step of the simulation works at the subtour level and its modification is beyond the scope of the work presented here. The solution proposed, therefore, necessarily needs to address the problem keeping the current structure. A possible approach is to create an additional layer of choice within the subtour. The idea is that a subtour traveled with carsharing needs to be further processed and specific modes, eventually different from carsharing, need to be assigned to the leg. The implementation of this solution however is a possible source of inconsistency in the simulation and should be used with caution. If a module changes the mode of some of the legs, the scoring module of the simulation is able to handle it correctly, since it works with single legs, but the replanning module might be not because it works at the subtour level. The decisive point is that to a particular carsharing subtour only a specific sequence of modes can be assigned. From the replanning module’s perspective, a subtour can have only one mode. If this mode is carsharing the module will assume that all the legs are carsharing legs. The genetic algorithm embedded in the replanning module uses the score information of previously used plans and tries, by design, to find the best possible attributes for the plan. If in this process some attributes are changed by an external module, the process might converge, but it would be unclear what the result obtained truly represents. But if this particular carsharing subtour is associated to a precise sequence of modes (which might also include non-carsharing legs) the process would converge without the need for additional adjustments. In practical terms, if carsharing is assigned to a particular subtour, it will be first verified if its use is meaningful for all the legs of the subtour or only for some of them. Meaningful is clearly subjective and might be different for different agents in different situations, but at first a distance based cut-off point might be used. For example, only legs where starting and arrival point are within a given distance from a station will be considered meaningful for carsharing use. Since only walk and public transport are available at any point and at any time in the simulation only these two modes will be considered as possible “subsidiary” modes in a carsharing subtour. At first
we can assume here that there is a distance related cut-off point for walk and public transport use. This would produce a carsharing subtour which eventually has some legs different from carsharing and which contains a fixed sequence of modes. Obviously, it does not take yet availability into account, which will be treated in the next paragraph. The approach can be extended taking into account personal tastes or the characteristics of the activities in the subtour. In principle, if revealed data of an existing one-way system are available, a specific model (for example a discrete choice model) could control this. Even if the estimation of such models should not be possible, it might be corrected to account for special situations which are supposed to be particularly suitable for one-way systems. If an agent goes to a shopping center traveling with public transport, it might be assigned a higher probability that carsharing is used on the way-back, if available, because the agent might have bought a bulky item. Conversely, an agent traveling to a restaurant in the evening might travel back with public transport because the alcohol consumed might prevent him from driving.

The approach proposed, from a programming effort standpoint has the advantage of being relatively straightforward. Some reflections on its suitability to actually model one-way carsharing is provided at the end of this chapter.

### 7.3.2 Vehicle availability

Considering unlimited vehicle supply at the stations is a simplistic approach, yet the results obtained with the existing model (Ciari et al., 2012) shows that it does not affect the ability to predict the overall use of the system and revealed data is reproduced fairly well. The explanation that we proposed is that during week-days the capacity of the carsharing system is less an issue than on weekends. In other words the use of carsharing is rather limited by the structure of typical week-day activity-chains than by the capacity of the system. The prevalent activity chains during the week are of the home-work-home type and because of their nature, a typical work time being 8 hours, they are not suitable for carsharing. More in general, all subtours implying long activities are not particularly suitable for traditional carsharing. Such limitation does not apply for one-way carsharing and from this point of view any trip could be traveled with carsharing. This makes the explicit modeling of stations capacity even more important than in the case of two-ways carsharing. In this paragraph two approaches to solve this problem are proposed. This is similar to what Waraich already proposed for parking choice (Waraich et al., 2012).
7.3.3 Post process

The first approach proposed is the simpler of the two. The idea is to let the simulation handle carsharing legs as if a car would be available. After the scoring a specific module checks all carsharing subtours leg per leg and verifies if a car was effectively available. In case that it was not, the plan is passed forward to a specific module where alternative modes are assigned for the legs which were not possible. This also modifies the scoring accordingly. This approach is very simple to implement; the additional module should only retrieve the relevant information from last iteration’s execution step and assign a new mode, but has several limitations. The most important one is probably that it only guarantees that capacity constraints at the single stations are respected but does not guarantee that the behavior of the agents is consistent. In fact this is exactly the same problem as for the mode choice. For all other modules of the simulation, all such subtours would simply an a priori fixed sequence of carsharing and non-carsharing legs (as described in the previous section of this chapter). This creates an inconsistency because two plans that are equal might have different score even with otherwise equal conditions. Consequently, even if the process might converge, it would be unclear what the result obtained truly represents.

7.3.4 Real time

A second solution is to keep track in real-time of vehicle availability. To keep stations’ vehicle inventory up-to-date is straightforward but has implications which make this approach much more challenging in terms of programming. If it is possible that an agent is supposed to use carsharing does not find a car available, an alternative mode needs to be found “on-the-fly”. This implies that the agent is able to change his planned mode. As seen, MATSim does not support this feature in its base version since the iterative approach implies that an a priori fixed plan is executed multiple times for every agent. At the system level this eventually result in user equilibrium. Some work, however, has already been done in order to model unexpected events in MATSim (Dobler et al., 2012), and it can be used to solve the current issue. The approach is called within-day replanning and allows agents to change some characteristics of the plan executed during simulation. In general each within-day replanning action is categorized by two parameters: the replanned element of the plan (an activity or a trip) and the point in time when the replanned plan element is executed (right now or at a future point in time). If an activity is replanned, several changes are possible. Its start and end time can be adapted, its location can be changed, it can be dropped or created new from scratch. For a trip the origin and the destination, the route, the mode of transport and the departure time can be replanned. The second parameter that categorizes a replanning action depends on the point in time
when the replanned plan element is executed. This can be either the currently performed plan element or one that is planned to be performed in the future. Due to the limited available information, a within-day replanning approach will, in contrast to an iterative approach, not necessarily converge to user equilibrium. Decisions made during the simulated time period may seem to be optimal when they are made. However, if they are evaluated retrospectively, an agent might realize that they were not. Nevertheless this approach allows keeping the consistency of the plans executed in contrast to the post-processing approach. The plans are actually modified and the new resulting modal chains, which might contain multiple modes, are processed as such by the next steps of the simulation. It might be argued, though, that using this approach does not keep the necessary consistency as described for the mode choice overall, since changes are made to the intra-subtour modal chain, which is supposed to be fixed. However, this is not the case because those are simply adaptations to an unexpected situation and not part of a strategy to optimize the intra-subtour part of the modal chain. In this sense, and this is what it counts for the underlying optimization, the score still refers to the previously fixed intra-subtour modal chain, despite the modes for the single legs being possibly different.

7.3.5 Physical simulation

As explained in chapter 3 the fact of not physically simulating carsharing as a mode is not a real concern as far as carsharing use has a small share in the modal split. Additionally, unlike the explicit representation of intra-subtour multimodality, the feature is not strictly necessary to simulate one-way carsharing. For these reasons no specific solutions for this unsolved issue of the previous model is proposed. Nevertheless, it would be a further step in the direction of a fully consistent model. Some work to a more general simulation with different types of vehicles has already been done by other MATSim (Rieser, 2010) developers and this might be used in the future to further enhance the model.

7.3.6 Discussion

Now the question is: how far does the proposed model provide a realistic picture of one-way carsharing use? A definitive answer will come from a validation process, possibly with data coming from various one-way carsharing systems. Nevertheless, already now it is possible to tell what the proposed approach does and what does not. It solves the issue of treating a multimodal subtour with different modes in different legs, although in an imperfect way. Assuming a particular modal chain, it implicitly assumes a planned use of one-way carsharing. Real use will certainly contain such behavior
but it is expected that this type of carsharing also induces an opportunistic use – i.e. if I’m planning to go somewhere with public transport and I incidentally get to know that a vacant car is at a convenient station location I might change my planned modal choice. This type of behavior is not represented by a model as the one described, though it might be added using within-day-replanning. The modeling approach proposed improves the previous model also in other aspects. Two different approaches have been proposed which tackle the capacity constraint issue. The first is simpler and does not modify the main steps of the normal iterative process of MATSim. Plans containing carsharing are post-processed in order to restore capacity limits at the stations and take into account actual vehicles availability. The appeal of this approach is its extreme simplicity of implementation, but the consistence of the whole simulation is not guaranteed anymore. The second uses an already developed module aimed to deal with unexpected events called “within-day replanning”. This allows keeping the plans consistent in the simulation at the cost of a more substantial programming effort and longer computation time. The modeling of membership, which was also an unsolved issue in the previous model formulation discussed in a previous chapter.

7.3.7 Summary and Outlook

This Chapter deals with the modelling of shared vehicle systems, with a particular focus on one-way shared vehicle systems. This effort builds on a previously developed model intended to predict classic two-way shared vehicle system demand. Although the model was able to reproduce with a good level of accuracy, in terms of number of users, the demand for carsharing in a test area (the metropolitan area of Zurich, Switzerland), it has some evident limits which needed to be addressed. Additionally, the model was not able to deal with one-way systems. The work presented here is of conceptual nature and is aimed to lay the foundation for an implementation of a model in the immediate future which will be: a) able to predict demand of one-way systems b) address the most prominent limits of the previous model.

In the paper it was explained what makes the modelling of one-way shared vehicles systems substantially different than the modelling of their two-ways counterparts. The main issue to be confronted for the implementation of a model fulfilling the previous agenda is how to keep the simulation consistent while introducing features which are not strictly compatible with its current structure. An approach was proposed to deal with multimodality and in particular with multimodality within a subtour. The problem of taking into account system capacity – that is, explicitly account for car availability at carsharing stations – was also considered and two possible solutions were proposed and discussed. The ultimate goal which will be pursued in the near future is to test both
approaches on a large scale scenario and compare the results obtained. Although the second approach clearly is the best in terms of conceptual soundness, it should not be excluded that the first can bring reasonable results. If it does, it might serve as useful backup of the best model in all those cases where computation time is an issue. In particular in case of hypothetical large scale scenarios with very large one-way systems, and arguably a large modal share for this mode, the within-day replanning approach might be inappropriate because it might be too slow.
8. Test case: estimating carsharing demand for the Zurich area

The carsharing model presented in chapter 7 was tested on a real-life large-scale scenario representing the area around the city of Zurich, Switzerland. A second test was made using the membership model of chapter 3, together with the existing carsharing model. The main goal of this series of simulations is to obtain results which can be compared to revealed data in order to validate the model. In addition, the station location optimization approach presented in section 3.6 was also tested.

8.1 The simulation scenario

The test case scenario used here is a “Greater Zurich” scenario. It is a subset of the Swiss scenario, and covers an area of about 2'800 km², obtained by drawing a 30 km circle around the “Bellevue” square in the center of Zurich. This scenario is built with geo-coded data from the year 2000 population census (individuals, households, commuting matrices), the year 2000 census of workplaces (facilities by type and capacity) and the national travel survey for the year 2005 (9'429 types of activity chains classified by duration of the activities, their number, types and sequence; eight classes of agents by age and work status are distinguished). The study area has approximately one million inhabitants. Moreover, the scenario contains all agents that have plans with at least one activity within the area and all agents crossing the area during their travel. Transit traffic through the country is included based on relevant border survey data. A map of the scenario’s area is presented in Figure 22.

The road network model has more than 236’000 directed links and more than 73’000 nodes. It is obtained from the Teleatlas navigation network. The number of facilities for out-of-home activities is 373’155. A MATSim specific subdivision of activities into 4 different types is used: work, education, shop, and leisure. These activity types represent the possible entries in an agent’s plan. The transport modes allowed are: car, public transport, bicycle, walk, and carsharing. In this scenario, 276 carsharing stations define the locations where an agent is allowed to pick up and drop off a carsharing car. The locations are the locations of the Swiss carsharing operator Mobility CarSharing (Mobility webpage) in the study area. Mobility CarSharing is the only operator in Switzerland; it operates 2’350 Cars at 1’200 stations and is one of the leaders worldwide in terms of number of customers.
For computational reasons, the simulation is run on a 10% sample of this scenario, which means that 161’810 agents are simulated. The network capacity is also scaled (each link’s capacity is set to 10% of the original capacity) in order to have realistic traffic flows on the network links. In the 10% sample, the number of agents crossing the study area while transiting Switzerland is 5’791, linked to 880 home facilities outside Switzerland.

All the simulations described in this chapter were run on a shared-memory machine of the type Sun Fire X4600 M2 with 8 dual-core CPUs and 128 GB RAM. The 10% sample scenario takes about 14 hours of computing time (using 3 cores and 40G RAM) for 40 iterations, which is enough to reach equilibrium with the settings used for a standard scenario.

8.2 Carsharing model

The goal of this work is to show that the simple model described in the chapter 6 is able to reproduce a reasonable modal split, and capture some of the use patterns typical for carsharing. The results of the simulation, whenever possible, are compared to the relevant real world data. In general, they are compared with data obtained from the Swiss National Travel Survey, also known as Micro-census (ARE and Bfs, 2007), or from customer data of the Swiss operator Mobility CarSharing. The latter is use data of 107 of the 274 stations located in the study area collected between August and November 2010. Each station is known with its exact location (coordinates) and the number of cars available. There were 6’700 customers who used a car from those stations in that time period and for
all of them slightly randomized coordinates of their home locations are available. The cars were used by these customers for a total of 25’000 trips. For each trip start and end time of the rental and the distance driven are available.

8.2.1 Results

The first analysis compares the modal split obtained from the simulation, with the modal split reported in the Micro-census by respondents living in the study area (Figure 23).

![Figure 23: Shares of the transportation modes, at the trip level, for the simulation scenario “Greater Zurich” and for the corresponding area in the Swiss Micro-census](image)

The modal split values are the percentage of trips travelled with a certain mode disregarding the distance. The share of agents using carsharing in the simulation is 0.6%. Since carsharing is not a reported mode in the Swiss Micro-census, its share was derived from a national study on carsharing use (Haefeli, 2006). According to this study the current nationwide modal share of carsharing is 0.1% of all trips. An estimate for the simulated area can be obtained considering the number of carsharing cars available at national level and the number of carsharing cars available in the area and assuming that all carsharing cars are used, on average, for the same number of daily trips. This results in an estimate of 0.5% of the trips in the simulated area. This means that the simulation delivers good results. To some extent, they are even better results than expected considering that the current specifications of the model – the unlimited number of cars at the stations and the fact that membership is not taken into account in the model – would have suggested a substantial overestimate. A possible interpretation is the fact that we are simulating a week-day where the
capacity of the carsharing system is less an issue than on weekends. In other words the use of carsharing is rather limited by the structure of typical week-day activity-chains than by the capacity of the system.

The next analyses check that the two features of carsharing that were explicitly introduced in the model are inducing the correct behavior in the agents. First, the influence of the time dependent fee is verified. For this, the rental time in the simulation (subtour length) is compared with that of real carsharing customers in Switzerland. Additionally, in order to show that tours made with carsharing are, on average, shorter than tours made with the other modes, the distribution of tour durations in the Micro-census is also reported (Figure 24).

![Figure 24: Comparison of the rental time in the simulation with the actual rental time of Mobility customers and with tours time length in the Micro-census](image)

It can be observed that the general shape of the distribution derived from the simulation is very different to that derived from Micro-census. Shorter rentals are prevalent, and very long rentals are much less common, though the simulation underestimates the rentals between two and three hours. The second comparison with the distribution of all tours makes clear that the similarity is not a pure coincidence but a consequence of the fee structure. In fact, on average, tours reported in the Swiss
Mobility Survey are longer and also their distribution is different. There is a peak for very short tours and another one, more pronounced, for tours of about ten hours, which reflects the schedule of people commuting to work. This confirms that the agents in the simulation are reacting as expected to the time dependent fee introduced. The next analysis aims to verify that the agents are reacting correctly to the explicit modelling of access/egress distances. To show we checked if distances between the starting points of carsharing tours and the stations are similar in the simulation and in reality (Figure 25).

![Figure 25: Comparison of the distance between start location and station used in the simulation and for Mobility customers.](image)

In this case, the two distributions are matching well, the shapes are the same and most of the values are quite close. It means that the agents in the simulation choose the “right” stations to pick up carsharing cars. Specific data about the transport mode used by Mobility CarSharing customers to pick up carsharing cars is not available.

So far it was shown that the model works reasonably well among the dimensions that are explicitly modeled. The next step is to verify that the explicit representation of access to the stations and the time dependent part of the fee are sufficient to induce other typical carsharing use patterns in the simulation. First, we look at the purpose of the tours for which carsharing is used. It is well known that carsharing is used mostly for travel that is not made on a regular basis and in many cases involves leisure and shopping activities. Since no specific information regarding the trip purpose of
carsharing users in Switzerland is available, Figure 26 compares the distribution of trip purposes for carsharing users in the simulation to the distribution for all modes in the Swiss census.

![Figure 26: Distribution of carsharing tours with respect to their purpose in the simulation compared to those of all Micro-census tours](image)

As expected, carsharing is preeminently used for shopping and leisure activities in the simulation, and this to a much larger extent than other modes are used. This indicates that the use pattern in the simulation is reasonable. Nonetheless, the share of legs with work as purpose, appears to be high and casts some doubt; but an analysis of the tours in the simulation showed that about 70% of those work legs are part of a work-work chain. This means that those trips have been made by agents that were already at work somewhere and needed a car to go somewhere else as part of their working activity. This is consistent with how business carsharing is functioning, which is indeed offered by Mobility, and this number might reflect this type of carsharing use. However, the specific use data by Mobility is unavailable and, therefore, a direct comparison is not possible. Moreover, even without counting those trips, the residual share of trips with work purpose, about 7% of the total, might be an overestimate. An improvement of the model in this respect depends on the future availability of relevant data. The aim would be to find out how many work trips are actually made using carsharing and how an eventual overestimate in the simulation could be prevented. In any case, the important fact here is to show that the fee structure with its time dependent part pushes the agents to use carsharing cars prevalently for the “right” activities and not for commuting.
Finally, the distribution of departure times in the simulation is compared to departure times of Mobility customers. Again, in order to show that these distributions are peculiar to carsharing, the distribution of tour departure times with any mode is also reported (Figure 27).

![Carsharing departure times compared to those of Mobility customers and to tours departure times of Micro-census](image-url)

**Figure 27:** Carsharing departure times compared to those of Mobility customers and to tours departure times of Micro-census

Figure shows that in the simulation too many departures occur in the evening or very early in the morning. Nevertheless, the general shape of the distribution generated by the simulation is similar to that of Mobility customers and, more importantly, is considerably different from the global one, where the characteristic morning peak can be seen. Thus, the simulation is able, although without high accuracy, to reproduce a pattern that is observable in reality.

### 8.2.2 Summary

The model presented has been tested for this purpose and shown to be able giving plausible results in terms of overall carsharing use and also with respect to the two mentioned features. In addition, some typical carsharing use patterns not directly implied by the model have emerged from the simulation, as hypothesized. The model can be improved in many ways – apart of restricting access to carsharing to members, which is the dealt with in the next paragraph – two of the most obvious are the introduction of the physical simulation of carsharing cars and of a reservation system with a
limited number of cars available at each station. The long term goal is to build a predictive and policy sensitive model that can be used by practitioners and policy makers in order to test different carsharing scenarios. The model is still not quite ready for that use, but it is, in our opinion, a very promising advance in the search for reliable predictive models of carsharing demand.

8.3 Carsharing model with membership model

The model was run also using a population to which a carsharing membership attribute was attached. This was made running the model presented in 3.4.2 on the agent population of MATSim, as explained in 6.3.1.

8.3.1 Results

Overall the results are not departing substantially from those presented in the previous paragraph. Nevertheless, some interesting facts emerged. The number of users of carsharing in this simulation dropped to 0.35% and the number of iterations necessary for the system to relax (in this case interpreted as a stabilization of the number of carsharing users) was double than for the previous experiment (80 iterations instead of 40).

The distance that users are walking to pick-up a carsharing car was one of the measures which were expected to change. Although with the previous version of the model the results fitted already fairly well, the characteristics of the membership model suggests the change. The model takes into account the accessibility of the system for the agents and we showed in 3.5 (Figure 4 and Figure 5) that the spatial distribution of members around stations obtained with the model is reasonably close to the actual one. Therefore, an improvement of the simulation to this respect was expected. The results, shown in Figure 28, confirm the expectations. The general shape was quite similar to the real one already with the previous model, and this did not change. Now, however, the peak on the left side of the graph, which represents persons picking up the car within 100m-200m from their start location, is more pronounced, as it actually is.
With respect to the other results presented for the previous model, departure time, subtour purpose and rental time, we did not have specific expectations. Nevertheless, since now only the “right” agents – in the sense that the model tend to assign membership to the same socio-demographic groups which are carsharing member in the reality – they also have different activity-chains than the population on average and this is likely to produce some difference with the previous results.
In the case of departure time, shown in Figure 29, it is actually the case. The distribution is not perfect but much closer to the actual one than with the previous model. The real distribution has three peaks – around 10:00, around 15:00 and around 20:00 – the simulated one has a similar shape although the size of the peak is different and only the central one approach the real one. An even more important improvement is the fact that the relatively high number of carsharing tours early in the morning, which are predicted by the previous model, almost completely disappear. The next comparison takes into account tour purpose, this can be seen in Figure 30.
In this case no major changes can be observed. The values are quite similar to the previous ones and, indeed, the number of users driving carsharing for work purpose is even higher than before, although only slightly. This can be explained thinking at the age structure of carsharing members. The age groups between 31 and 45 years and those between 46 and 59 are those who are more likely to be members, but those who are more likely to work too. Compared to the previous situation where everybody could use carsharing, this slight increase is not really a surprise. Importantly, the figure is still much lower than over the population in general, which is an emerging effect of the time dependent part of carsharing fee. Similar observations can be made regarding rental time, which is presented in Figure 31. The peak for short rental time is now more accentuated, which is correct, but is a bit too much to the left (too many very short rental events). All in all, the change is probably nor an improvement neither a worsening. A worsening is the fact that now a peak for rental times of around 600 minutes appears. It fits with more carsharing tours having work purpose, as seen in the previous figure, but it probably means that the type of work trip where carsharing is used now changed and it does not involve only short work activities.
8.3.2 Summary

The addition of the membership model in the carsharing simulation produces various effects. The number of carsharing users drops, limiting but not completely eliminating the previous overestimation. More importantly, it helps to improve the simulation among other dimensions: the distance that carsharing users are walking to pick-up a carsharing car in the simulation fits now better the control data. The same can be said for the departure time. The main problem of the simulation remains: too many work tours. In both carsharing simulations, the one without and the one with membership model, it appears that the time dependent fee of carsharing help limiting the number of those tours. However, a new utility function taking into account, among other things, the purpose of the trip, would very likely help to completely solve the problem and fit better actual carsharing users behavior.

8.4 Station-location optimization

The membership model was used as objective function of a station location optimization process as described in chapter 3. We have seen in the previous paragraph that in the simulation area there are 26’814 actual carsharing members and that the model run on the 10% scenario estimates a membership of 2’653 agents which is fairly accurate. The optimization process is supposed to find new locations for the stations which increase the number of members estimated by the model. It is
based on a genetic algorithm and takes a substantial amount of time; the exact run time depends on internal parameters of the algorithm. The runs operated so far were of explorative nature and the main goal was to verify that there is actually room to increase the membership. For the moment, no exit criteria have been defined for the optimization and the process kept going until a predefined number of generations were evaluated. The optimization has been run for several complete runs according to a predefined experimental design, however, some small changes on the code were performed during the process and, therefore, only three of them are comparable. For all of them the number of available links was set equal to the number of stations. This means that the algorithm pick-up the new locations from a set composed by the existing locations, 274 stations, plus 274 links chosen randomly from the network (see section 8.2), for a total of 548 links. The other parameters which were changed are:

**Generations**: The number of steps of the algorithm at which individuals’ fitness is evaluated.

**Population size**: the number of individuals (constellations) that are generated at each generation.

For the three runs considered the values 1’000 and 2’000 were used for the generations, while the values 10 and 20 were used for the population size, giving the following combinations:

Run 1: Generations = 1’000; Population size = 10

Run 2: Generations = 1’000; Population size = 20

Run 3: Generations = 2’000; Population size = 20

8.4.1 Results

The results obtained for the three runs are reported in Table 20. The number of members is increased with respect to the one estimated by the model with the current station locations. It confirms the hypothesis made that there is potential for improvement of station locations.
Table 20: Results for Run 1, Run 2 and Run 3

<table>
<thead>
<tr>
<th></th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Members</td>
<td>2'717</td>
<td>2'816</td>
<td>2'979</td>
</tr>
<tr>
<td>Increase</td>
<td>64</td>
<td>163</td>
<td>326</td>
</tr>
<tr>
<td>Increase (%)</td>
<td>2.41</td>
<td>6.14</td>
<td>12.28</td>
</tr>
<tr>
<td>Stations Moved</td>
<td>13</td>
<td>94</td>
<td>123</td>
</tr>
<tr>
<td>Stations Moved (%)</td>
<td>4.76</td>
<td>35.17</td>
<td>41.97</td>
</tr>
<tr>
<td>Run Time (h)</td>
<td>33.61</td>
<td>59.66</td>
<td>120.29</td>
</tr>
</tbody>
</table>

The results improved as the number of generations and the population size increased, as expected. However, the computation time increased along and Run 3 lasted for slightly more than 5 days. The increase of the number of estimated members for Run 3 is 12.28%, which would be probably considered an interesting figure by any carsharing operator. Moreover, only a small number of runs were performed and it is likely that increasing further the number of generations and the population size even better solutions could be found. The fact that in Run 3 even not the half of the stations was moved by the algorithm seems to confirm this. It should be kept in mind, though, that for practical purposes it might be more interesting to find how to produce a major improvement with a limited number of movements since those movement are arguably associated with costs.

8.4.2 Conclusions

Those showed in this section are only preliminary results. Nevertheless, the few exploratory runs performed so far confirm the potentialities of the method proposed. As far as the membership model behind the optimization process is estimating membership levels fairly well, as the results showed in section 3.5 seem to confirm, the algorithm presented is able to find station constellations which increase the number of members. Keeping in mind this premise, the results confirm that current carsharing locations are not optimal locations and such an instrument was consistently able to find better locations. The method, though, still has many limitations. Additional runs are still needed in order to understand how good the best of the results obtained really is and, more in general, to set a rule to exit the algorithm. The algorithm, for the moment, is limited to shuffle existing stations and assign them new locations, but the number of cars is fixed for a specific station. The introduction of the number of cars in the optimization process might further increase the possible gains in terms of members, but would also increase the dimension of the problem. The computation time is already an issue. Although an instrument of this type, once fine-tuned and
market ready, is not supposed to be put at work on a day-by-day basis, a less computational expensive process would be desirable. Moreover, the method proposed is not able to deal with large networks. These two issues might be mitigated using the same base idea, use the membership model as the objective function, but with a different algorithm. For example some faster heuristic, like simulated annealing or taboo search, could be attempted.
9. Summary and outlook

9.1 Summary

This dissertation dealt with various themes all revolving around a concept: sharing in transportation. New trends in our daily life – the way we are sharing things, both material and immaterial, but also new consumption patterns – suggest that modes of transport involving sharing might be on the verge of making a breakthrough and become much more prevalent than they are right now. However, we are not so far yet and the path to such a scenario – which I would personally consider a very important intermediary step to go beyond the current private-car-oriented mobility – could be still long. The work is focused on two modes, carsharing and carpooling, which have already a relatively long history but have not yet emerged as prevalent modal options. A literature review on carsharing and carpooling showed that a large part of it is of descriptive nature and there are still many directions which need to be investigated. In particular, the current high interest in the transportation community for these modes contrasts with the substantial lack of planning tools in general and predictive models of the demand in particular. This dissertation, therefore, was intended to go a step in this direction. This was made mainly in two ways. The first was working to extend the existing multi-agent transport simulation MATSim to include carsharing. The second was producing some additional knowledge on carsharing and carpooling, especially, in the Swiss context. The two parts of the work, however, are not disjoint. A modeling approach like that of MATSim – agent-based simulations – goes beyond the mere representation of transport. It is more about simulating daily life of people –in a very simplified manner though – and obviously has many underlying models. This is where the two streams of work meet. The developing part was centered on the creation of a suitable framework to simulate carsharing with the goal of embedding it in the larger MATSim framework. The other investigations although intended to directly produce new knowledge were also aimed to provide the necessary background for the developing part.

The membership model of chapter 3 is estimated based on travel diaries data and uses a simple regression technique to predict carsharing participation. It is hypothesized that not only socio-demographics characteristics influences the choice but also the built environment. For that, the model includes zone type and accessibility to carsharing as variables. This latter is important because puts in relationship the supply side with the choice of being carsharing members. It was found – this is the main contribution of this part – that access is an important factor predicting carsharing membership. Applying the model on national level the predicted spatial distribution matches reasonably well actual carsharing members’ distribution and, importantly, spatial patterns around
the stations, in particular those in dense urban areas. The model was also used as a basis to optimize carsharing stations’ location. A genetic algorithm was used to maximize the simulated number of customer calculated with the model. The approach is not yet fully ready for use but the tests are encouraging and this is an important step toward a tool for the optimization of carsharing station locations.

Chapter 4 is a simple exploratory analysis of carsharing rental data which allowed us to confirm that private owned cars and carsharing cars are used differently. A substantial part of private car use involves very short distances but long durations. Carsharing cars are used more efficiently; short distances with long activities are uncommon, meaning a more intensive use of the car within the time of the rental. The main topic of the chapter, however, was the question if the use of electric cars might make sense for carsharing. On average the interval between two rental events for a single carsharing vehicle is long, but there are huge differences from vehicle to vehicle. The time between rental events is crucial since there are minimum recharging times which depend on the type of recharging facility. The most important finding there was that a general electrification of carsharing in Switzerland would be probably meaningful only if dedicated network of fast recharging stations would be used.

The chapter on attitude toward carpooling and carsharing is the longest of the whole dissertation and various contributions are described in this part. Based on a large survey which contained both stated preference exercises and multiple-response questionnaires several analyses were performed. The stated preference data was used to estimate discrete choice models. Three different formulations were used; a linear one, one with non-linear interactions and one which takes into account the panel nature of the data (several observations per individual). The parameter estimates did not revealed any big surprises, the sign of the parameters was as expected and the large majority of them were significant. Worth to mention is that inertia – a dummy variable taking the value one if the stated choice was equal to the reported choice – was significant for both car and public transport. It shows how difficult can be to make people change their modal patterns, especially for commuting trips. Even more interesting, it was attempted to use one of the stated choices of one experiment as a variable of the other, with the hypothesis that those modes attract similar type of individuals. The results confirmed the hypothesis, both parameters are highly significant and large, which means that choosing carpooling in one experiment is a predictor of choosing carsharing in the other and the other way round. This is important because although these two modes are often simply put together in the bunch of “alternative modes” or also “sustainable modes” no evidence was there to tell that they could attract the same socio-demographic groups. Another important
finding is that carpooling is strongly associated with its supposed environmental benefits. This emerged, more or less strongly at various points of the analyses. For example, the two carpooling alternatives have a higher VTTS than car, meaning that they are preferred alternatives, which suggest that in the choice to carpool other motivations than economic ones—environmental, social, etc.—that are not captured by the model, play an important role. Moreover, relatively affluent people show a high availability to carpool, which is in contrast with findings in previous research. Again, this might reflect a change of paradigm caused by a new environmental and social sensibility. This seems to be confirmed by the fact that among carpooling benefits, those for the environment and the transportation system are considered the most important by respondents. This did not happen with carsharing where choice seems to be more economically driven and not ideologically motivated; understandably considering that carsharing in Switzerland is comparatively widely known and used and is not anymore confined among environmental activists. Cluster analysis suggested the existence of four groups with different carpooling attitudes: Enthusiastic environmentalists, Skeptical environmentalists, Pragmatics and Non-interested. A strategy to expand carpooling use in Switzerland could use the groups directing “ad hoc” messages to each of them. Overall the results seem very encouraging for the future of carpooling in Switzerland; however they not tell that its future diffusion at a larger scale in Switzerland is guaranteed, but now might be the right time to deploy an aggressive strategy to promote carpooling.

Chapter 6 presents the carsharing model implemented in MATSim. It is rather technical and explains the modifications which were necessary in order to model carsharing in the framework. In particular, the scoring function was modified in order to simulate a realistic fee structure for carsharing including both time dependent and distance dependent fees. Accessibility to carsharing was also sketched introducing actual stations locations in the simulation scenario. These two aspects are known to be of great importance for carsharing users and, although other important aspects are still missing, it was supposed that they would have been sufficient to induce a reasonable carsharing behavior in the agents. The experiments made running the model on a large scale scenario representing the urban area around the Swiss city of Zurich, reported in chapter 8, confirmed this. The distances that the agents traveled to pick up a car of the system were similar to those actually traveled by Mobility customers. The rental time was also reproduced fairly well and agents using carsharing were preeminently using it for short duration subtours. Embedding the membership model in the base model the results, overall, were improved. Distances walked were fitting even better and most importantly, the time of the day in which carsharing is used was much closer to actual data. However, there are probably still too many work subtours traveled with carsharing in the
simulation and this problem should be addressed. The embedding of the membership model is also an example of the process described above; that is some standalone research that was then integrated in the simulation framework. All in all, the simulation is not yet quite ready as a planning instrument but the results shown are promising and more improvements are on the way. This brings us to the second paragraph of this chapter which is about future work.

### 9.2 Future Work

As it is probably the case for many doctoral students, wrapping up this work, the impression was strong that this research was more about raising questions than about answering them. Even if it is the case, some say that research is at least as much about finding the right questions as about answering them and therefore, this would be not necessarily a bad thing. For sure, this makes things a lot easier when it comes to write about the future work.

The long term goal of the modeling effort was to build a predictive and policy sensitive model that can be used by practitioners and policy makers in order to test different carsharing scenarios. This has been not fully achieved within this dissertation but the models presented are performing already fairly well and some additional improvements are coming in the next future. Some of them are those described in chapter 7, which was not mentioned in the previous summary because it is basically all on future work. It addresses specifically one of the most important limitations of the simulation: the lack of a reservation system or, more in general, a representation of actual capacity of the system in the simulation. Moreover, it focuses on one-way systems too, which are literally booming in the form of bike-sharing systems and are starting to gain popularity also for carsharing. Even if the work is not complete and the chapter is strictly of conceptual nature, it is important to understand the type of challenges related with embedding new models, or new functionalities, in a large software project like MATSim. The physical simulation of carsharing cars is also in the agenda and even if it is not expected that the behavior of the simulations will be substantially changed in the validation runs, where carsharing only has a very little share, it will be a very important step to test hypothetical scenarios where carsharing is deployed at large scale. Finally, a specific behavioral model capturing the way people are actually choosing carsharing as a mode would cap the whole model. Actually, this was already attempted using the results of the carsharing model of chapter 5. The attempt failed in the sense that we did not managed to fit those results into an apparently meaningful model which could be embedded in the MATSim utility function. It could be obviously only a limit of the effort made and perhaps it will work in the future. However, one should be also aware that the stated preferences exercise on carsharing was a great opportunity to shed some light on how Swiss people
 perceive this mode, but this approach was not necessarily well suited to provide such behavioral model. In the context of the research on carpooling we made what it was possible to make, but it is questionable if the decision process really involves comparing modes in that way. Additional work, therefore, will be put also in this fundamental aspect of modeling carsharing use.

As for the carpooling models the future work should bring together the two parts of the survey which have been analyzed separately so far, the qualitative part and the stated choice experiments with their discrete choice models. In a future effort it will be attempted to make use of the largest possible part of the qualitative information in order to further improve the discrete choice models estimates. The cluster analysis was already a first step in this direction. The types can be used as variables in the models, providing a straightforward way to include latent structures in the respondent’s preferences. Additionally, it is possible to estimate separate models for the different clusters, obtaining much more refined behavioral models. Parallel, latent class models could be also estimated in order to verify if similar structures are found. In general, there is still a lot of data collected in that survey which has not been yet fully exploited and the potential is there for several additional analyses. Moreover, it could be also used as basis for some additional survey which would complement the knowledge acquired. The limited time of the dissertation, even of one lasting more than the canonical three years as this one, made not possible to use the models estimated to simulate carpooling. In this case, however, there is no apparent impediment to do so and work on this is already on its way at our institute (Dubernet et al., 2012).

The analyses on carsharing data proposed in chapter 4 are not yet embedded in any way in the rest of the work. Nonetheless, the idea to explore how carsharing with electric cars could work was not incidental. The coupling of carsharing with electric cars is increasingly a theme and even the Swiss operator Mobility is starting to offer this kind of vehicle. The analyses proposed, therefore, have their value as standalone research, but were intended too to try understanding which aspects were critical in a future simulation which will include electric carsharing vehicles.

Some final thoughts go to all the data which is needed to develop and run agent-based simulations. This is maybe not directly about future work but the availability of the relevant data will be crucial for the future developing of the simulation presented. These modeling tools are data intensive and working with modes which are used by only small niches of the population obviously increases the difficulty in getting the desired dataset since it might be that this dataset does not even exist. This can make things frustrating and sometimes did; a relevant part of the data used in this dissertation was available only in the last year. Nevertheless, this modeling technique, because of its very nature,
is probably the only one really suitable to simulate innovative modes of transport. With this perspective, and as far as the work - that already done and that planned for the future - can be a small contribution going beyond our current mobility pattern toward more sustainable ones, it is definitely worth the effort.
10. References


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11. Curriculum Vitae

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Work experience

Since 2006
Researcher at IVT, ETH Zurich (Switzerland).

2006
Arsenal Research, Vienna (Austria): Three months stage, focus on pedestrian mobility.

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Adastra language school, Vienna (Austria): Teacher of Italian language courses.

2004-2005
Università di Studi di Firenze, Firenze (Italy): Collaboration with the Department of applied mathematics, main focus on Car-Pooling.
2001 –2003

CiRIEC, International Center of Research and Information on the Public, Social and Cooperative Economy, Florence (Italy)

Education

2003  Master Degree in Environmental Engineering at the Università degli studi di Firenze (Italy).

Languages

Italian: Native

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Publications

Refereed Journal Papers


Refereed Conference Papers


Other Conference Papers


Working Papers and other publications


Presentations (Without paper)

• Ciari, F. (2011) Matsim, an agent based traffic simulator, CTS Seminar, University of Illinois at Chicago, August 2011.

Lectures and Tutorials

• Ciari, F. (2012) Introduction to MATSim, Avignon, February 2012.

Supervised Student theses

• Dubernet, T. (2010) Activity-based simulation and joint decision modeling, Master Thesis, IVT, ETH Zurich, Institute for Transport Planning and Université de Technologie de Compiègne (France)

Scholarships

• 2006: Scholarship of the Foundation BLANCEFLOR Boncompagni-Ludovisi, née Bildt (Sweden).

Other activities

• Trainer of a Basketball team
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