How disruptive can shared mobility be? A scenario-based evaluation of shared mobility systems implemented at large scale

Francesco Ciari, Henrik Becker

Francesco Ciari, ETH Zurich, IVT - Institute for Transport Planning and Systems, ciari@ivt.baug.ethz.ch,

Henrik Becker, ETH Zurich, IVT - Institute for Transport Planning and Systems, henrik.becker@ivt.baug.ethz.ch

Abstract

This paper reports on ongoing work on getting a deeper insight into possible integrations of different shared vehicle systems. It introduces an original methodology in three stages, which helps dealing with the complexity of the problem. Using a simulation tool, different scenarios are assessed. The paper presents preliminary results obtained by simulating two extreme-case scenarios with large-scale car-sharing and bike-sharing schemes. The results suggest, that shared mobility, if supplied at large scale and in the right mix, could indeed serve a large share of current travel demand without substantial losses in terms of generalized costs.

1 Introduction

Shared mobility is often mentioned for its potential to disrupt the current transportation system and to help creating a more sustainable one. This idea is supported by the incessant growth of shared mobility systems worldwide within the last decade and a relatively large literature assessing its benefits. However, the current market share of such modes is still generally low and consequently, their actual (positive) impact on the transportation system is not large. Things might change soon, if such systems grew further. Yet, given the complex nature of a transportation system, it is hard to predict how they will interact and what outcome can be expected at the urban scale. For example, in order to accurately predict the impact of shared modes on urban transportation, it will be crucial to understand if and under which circumstances they are complements or competitors. The work presented in this paper is part of an ongoing research project funded by the Swiss National Science Foundation within the “Energy Strategy 2050” scheme aiming at developing new technologies in order to substantially reduce energy consumption in Switzerland by 2050. The project specifically looks at the large-scale implementation and integration of different instances of shared mobility in order to estimate potential energy savings. To achieve this goal, an innovative methodology is used, which comprises three stages. In the first stage, several hypothetical scenarios, representing different combinations and availability levels of shared mobility options, will be generated and evaluated in terms of cost and benefits using the agent-based simulation MATSim [1] (www.matsim.org). To give more substance to the simulation part, the second stage focuses on the acceptability of the different scenarios generated in the previous part. This is done through specifically designed surveys, administered to a sample of the population of the study area. The results of the survey are used to estimate behavioral models, which are then implemented in the simulation. This improves the realism of the simulation and provides more solid insight on the combined use of various shared mobility concepts.

This paper provides two main contributions. First it describes in depth the methodology of the whole project in its three stages and explains its innovative aspects. Second, it provides preliminary results of the first stage dealing in particular with some extreme shared mobility scenarios and their impact on the transportation system.

2 Background

In recent years, shared mobility has been a focus for various disciplines. All present variations of car-sharing, bike-sharing and ride-sharing have been investigated by researchers from around the world. Yet, the paths to today’s success of these modes have been long and bumpy. The systems were ideated, and the first implementations attempted, in between the late 1940s (carsharing and formal carpooling) and the early 1960s (bike sharing). For different reasons these attempts neither lasted long nor inspired immediate followers. Carsharing was ideated to share a resource, the car, which in 1947, when the Sefage program was started in Zurich [2], was useful but expensive and not yet considered as a “must have” object for every household. The fast motorization of the following decades was not the ideal context for the success of this idea. Carpooling has a similar history: the American government promoted it during and immediately after WWII in order to limit oil consumption but the policy went largely forgotten once the political and economic situation had changed. It is not a coincidence that during the oil price shock of the ‘70s, carpooling was actively promoted again and then again forgotten when prices went back to normal levels and until the diffusion of HOV lanes in the US gave momentum to the idea again. The first attempt with bike-sharing – namely the White Bikes Program in Amsterdam in 1960 – failed mainly because of vandalism. This attempt has made clear, that without the possibility to have a tighter control on bikes and users, bike-sharing has only limited chances for success. Other attempts have been deployed over the years, both car-sharing and bike-sharing, but none of those programs was successful enough to spread the “virus” of shared vehicles systems. Only recent advances in information technology have been able to unlock the potential of collaborative mobility solutions and have led to the creation of new ones like free-floating carsharing, peer-to-peer carsharing or dynamic ridesharing.

The amount of research in the field has largely followed the fashion of the various ideas, and in the case of carpooling has followed its ups and downs too. The overwhelming majority of scientific literature on carsharing and bikesharing has been written in the last 20 years [3, 4] whilst carpooling was quite popular among transportation scientist in the ‘70s [5, 6] and in the ‘90s [7, 8]. In contrast, the recent appearance of app-based dynamic ride-sharing services has just started to attract the attention of researchers [9, 10].

The research on carsharing has produced agreement on several issues. For instance, it is widely accepted that the most suitable markets are dense urban areas with good public transport supply [11, 12] or that the prototype user is relatively young, affluent and well educated [13, 14]. In the case of carpooling, in contrast, there is still disagreement for example on the effects of HOV lanes [15, 16] or on motivations to participate to carpooling [17, 18, 19, 20]. Literature on bike-sharing is much less abundant and is mostly concerned with the optimal location of bike-share stations as well as relocation processes, necessary to compensate temporally and spatially imbalances in demand [for example 21 and 22]. The research was complemented by identifying user types [23, 24] and usage patterns [25]. Due to their only recent surge in market share, scientific literature about dynamic ride-sharing schemes is very limited and often deals with legal discussions [e.g. 10]. However, the market potential and current use pattern for such systems have already been investigated [9, 26].

The impact of these collaborative modes on the transport system has also been investigated by several researchers. The works focusing on station-based car-sharing were able to confirm several positive impacts like less vehicle travel and lower emissions [27] reducing the need for parking [28, 29] by reducing private vehicle holdings [30]. Similar studies for free-floating or one-way carsharing have found that the service may at least partly compete public transportation resulting in a still unclear net impact [31, 32]. The impact of bikesharing on the transportation system and travel behavior has also been recently addressed by researchers [33, 34] finding that it can be an effective measure to shift suburban residents’ mode choice towards public transportation, although savings in vehicle kilometers travelled may be more than offset by relocations. When determining the effect of carpooling, it has to be differentiated between inter-household car-pooling, which has been found to reduce vehicle miles travelled [35, 36], and intra-household carpooling, which might incur substitution and trip induction effects [37]. Given the very limited selection of literature on dynamic ride-sharing, its effects on travel behavior are still to be studied.

This short excursus shows that the scientific literature about shared mobility modes has grown in scope and number in recent years. There is already a large corpus of literature that deals with many different aspects of these mobility options. A large part of the research on collaborative mobility is of descriptive nature, but quantitative methods, rather rarely adopted in the early works, are now increasingly popular. Nevertheless, there are still some evident research gaps. Firstly, the explicit modeling of demand for this kind of modes has not yet been thoroughly investigated despite being crucial to forecast how different levels and types of supply would impact the demand. Secondly, they are very often considered as “stand-alone” systems ignoring the whole complexity of the interactions with other (shared) modes. Therefore, it is not yet possible to estimate, how large-scale, integrated systems of collaborative mobility will impact the transportation system. However, this can be particularly relevant in the future, since their growth rates and some societal changes suggest that these modes could gain much larger shares of travel.

3 Methodology

How is it possible to assess the large scale use of shared mobility modes? Experimenting with the implementation of shared mobility solutions at large scales cannot be undertaken in real life, because of the high financial investments necessary. Even if some pilot projects could be organized, it is not possible to deploy such systems at large scale, and try several combinations, just to get an insight on them. Thus, a methodology is needed, which allows to evaluate and compare different future scenarios in a cost-efficient way. The software MATSim has already been used for the simulation of car-sharing [38, 39, 40] and has all the necessary functionalities. However, the nature of the research questions implies other challenges which need to be addressed. The simulated scenarios represent hypothetical future situations, in which shared modes would have a much larger market share than today. The actual constellation of services will depend on the development path of such services and on modifications of people’s preferences in the area. These two items are interdependent. It was therefore necessary to ideate a methodology to circumvent this potential chicken-egg problem. The resulting approach is described in the following subsections. Each of the next three subsections describes one particular stage of this methodology, whilst the fourth briefly describes the simulation framework MATSim.

3.1 Pre-screening of possible shared mobility scenarios

In order to account for future modal preferences, a stated preference survey may be an obvious tool. However, choice situations should reflect the hypothesized future scenarios in order to guarantee consistence. Given the large amount of possible scenarios, this can be challenging. Therefore, in a first step, a pre-screening of possible solutions is performed. To this end, MATSim simulations are used to understand, how the new modes would substitute the existing patterns of modal use and especially of private vehicles and what would be the best way to combine them according to pre-selected criteria. Given the overall goal of the project, the reduction of energy consumption will play a key role in defining the "best" scenarios.

3.2 Surveys and models

To give feedback to the simulation, the second stage aims to get insight on the acceptability of the scenarios generated at the previous stage. This will be done through a specifically designed survey. Assuming different scenarios (that is, different levels of supply and prices for the innovative modes considered) the respondent will be asked if and how their mobility behavior (mode choice, location choice) would change. The scenarios described in the questionnaires will be based on a small set of the previously simulated scenarios. In particular, it will include the scenarios (combinations of modes), which turned out to be more impactful in terms of energy consumption reduction. Using this procedure – that is, to first identify desirable scenarios instead of restricting oneself to scenarios, which can be easily implemented – allows asking the participants more precise questions, describing tangible scenarios instead of generically asking about single mobility options. This also helps to envision possible policies – which would also inspire some of the questions of the survey – therefore providing a better understanding on the feasibility of the best scenarios. The results of the survey will be used to estimate behavioral models, in the form of discrete choice models, which are then implemented in the simulation.

3.3 Final assessment of shared mobility scenarios

At this point, the new simulation runs will entail more sophisticated behavioral models, because mode choice will be based on stated preferences obtained at the previous stage. Other attributes and behaviors (mobility tool ownership, activity chains), will be varied to take into account possible long-term impacts. This second series of simulations will give a final answer on what can be achieved in terms of reduction of energy consumption and other externalities with a large-scale, combined use of various innovative mobility concepts given the appropriate fleets, especially the share of electric vehicles. An additional aspect to be explored is the use of autonomous vehicles. Although they do not yet belong to our daily life, some scientists think that they may soon become an important factor in transportation. The implications are far too broad and complex to be investigated thoroughly in the context of this project. However, if autonomous vehicles will be used for carsharing and ridesharing the scope of these systems could dramatically change, and thus, some scenarios will be based on this assumption.

3.4 The simulation tool

The software MATSim [1] (www.matsim.org) has already been used for the simulation of shared mobility in several studies [e.g. 39, 41]. The simulation is based on a synthetic population of agents representing census data of the study area. The population acts autonomously in a virtual world, which reflects the supply side (road network, land use, available transport services and activity opportunities). Each agent acts according to an individual, predefined plan which contains a chain of activities which are to be performed during the simulation day [42]. As a general rule, performing activities gives a positive utility, whilst travel gives negative utility. One virtual day is simulated iteratively. From iteration to iteration, a predefined set of agents is allowed to change some of their daily decisions in order to search for a plan with a higher utility. The set of choice dimensions can be varied according to the exact purpose of the study, but standard dimensions are: trip starting time, duration of activities, location of secondary activities, mode of transport and route. The simulation follows a co-evolutionary iterative process. At the end of the simulation, the plan that each agent has in use is a plausible approximation of the real world behavior of an individual with similar characteristics. Since the simulation represents individual travelers, it is possible to build scenarios making assumptions at the individual level rather than at the systemic level. Therefore, the model is much more intuitive, as it is based on simple observable behavioral rules.

4 Scenarios and preliminary results

This section deals with scenario generation and their pre-screening (preliminary assessment) with the agent based simulation MATSim.

4.1 Scenario generation

The very first step in this process is the generation and evaluation of some “extreme scenarios” which will provide insight on the possible impact of an extremely wide diffusion of a particular shared mode. This step is necessary because it allows to understand, which kind of trips can realistically be made with which mode, what kind of potential overlap in supply exists, and what kind of cost/benefits can be expected. Ultimately, it will provide fundamental knowledge to create integrated scenarios (scenarios where several instances of shared mobility are all implemented at large scale).

4.1.1 Car-sharing

It is safe to say that, despite impressive growth in the last decade, no carsharing scheme has achieved a substantial market penetration yet. Even in Switzerland, which is the only country with a seamless, nationwide carsharing system, only 2.5% of the license holders are car-sharing members [43]. Nevertheless, membership numbers are expected to grow further, with the proliferation of other mobility-as-a-service schemes and most importantly with the possible entry of self-driving vehicles into car-sharing operations. Therefore, the first extreme scenario assumes that all private car trips are substituted by car-sharing trips. In other words, a large scale free-floating carsharing system is put in place. A further assumption is that travelers will only accept a vehicle, which is at most 5 minutes away.

4.1.2 Bikesharing

Despite Switzerland being the cradle of car-sharing [44], and having some interesting traits in term of “sharing culture” (for example in condominiums, it is quite common to share the washing machine among all apartments), bike-sharing is not very diffused. A possible reason is the hilly topography of most larger cities. The rapid diffusion of E-bikes and their use in bikesharing schemes is expected to overcome the burden of elevation and some schemes are about to launch their services. Therefore, in this scenario, a large e-bike-sharing system is assumed and all trips between 750m and 10km from the base scenario are now made by this mode.

4.2 Simulations: preliminary results

The carsharing scenario was run several times in order to determine the optimal number of vehicles required to offer the desired level of service. As shown in Figure 1, around 60’000 vehicles would be sufficient to meet almost 100% of the demand (of which over 60% would be served within five minutes).

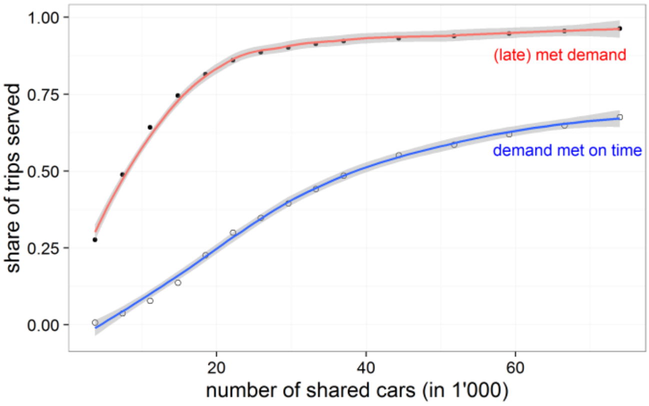

Fig. 1. Fleet size necessary to serve current travel demand

Compared to the base scenario, this constitutes a reduction of about 180’000 cars. Consequently, all private cars could be replaced by such a car-sharing program. At this stage, car-sharing is regarded equivalent to private cars in terms of utiliy, except for the access time at the beginning of the trip. Therefore it is intuitive, that longer car trips are more likely to be substituted by car-sharing, because the access time becomes less important in the evaluation (generalized costs) of the whole trip (Fig. 2).

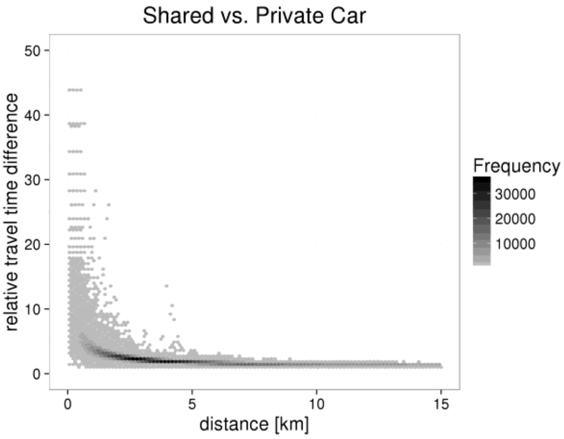

Fig. 2. Travel time difference between shared and private car depending on traveled distance

Therefore, it is necessary to check if e-bikes would be a good complement for this car-sharing system and are be able to capture the rest of the demand. Figure 3 shows, how the utility of using e-bikes compares to the utility of using car, public transit, bycicle or walk for the same trip.

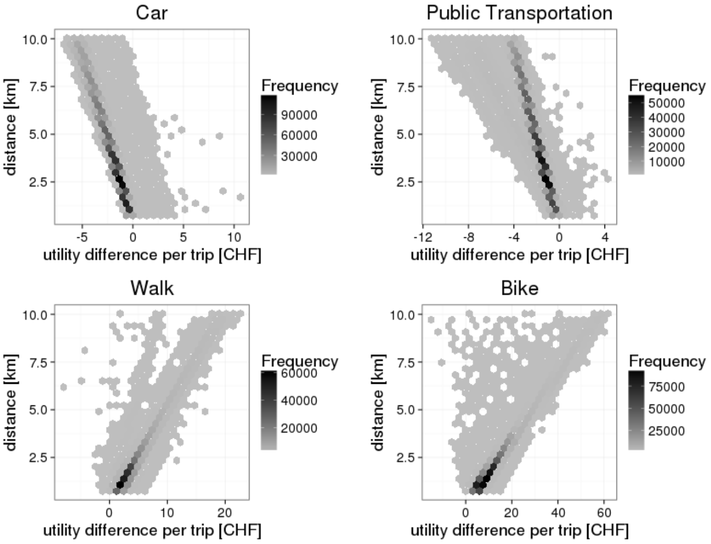

Fig. 3. Utility difference between E-bikes and travel with other modes for a predefined set of trips

It turnes out, that e-bikes are more convenient than walk and regular bikes for short trips and become less attractive as the distance grows. E-bikes are less convenient than car and public transport and the difference grows for longer distances. However, the difference is not very large for short trips especially with respect to public transportation. This basically means, that there is potential for e-bikes to complement the car-sharing system and capture the demand for shorter trips.

4.3 Discussion

The results presented above show that shared e-bikes and car-sharing could be usefully combined in order to capture a large part of current travel demand, in particular car travel. It seems however, that for medium distances (5-10 km), it could be necessary to integrate an additional option for this range as e-bikes are not very competitive against private cars any more, and carsharing in the suggested form is not yet competitive due to the relatively high effect of the access time in this distance range. Ride-sharing could be this additional option, as it would also have a certain, probably similar, access time, but may be cheaper. This requires the exploration of further single-mode extreme scenarios and also of some combined scenarios with two of these modes or even all three. The main point is, that finding an equilibrium between a large scale car-sharing and a large scale ride-sharing scheme will not be trivial. It has been shown that a car-sharing system with the selected specifications can substantially reduce the size of a city's car fleet and that it would be possible to totally avoid private car ownership whilst providing a good level of service. However, if ride-sharing would be based on private cars, a large enough fleet of them should still be available. If this would be rather a shared taxi scheme, one would need to find another equilibrium.

5 Summary and future work

This paper describes a three-stage project with the main goal to find optimal combinations of collaborative mobility solutions, which would provide a substantial reduction of energy consumption without reducing individuals' mobility. This allows to get precious insights on how collaborative mobility solutions could be combined. Additionally, this also helps to understand, which policies could help to achieve a more sustainable, less energy intensive, transportation system. Local governments in many countries have supported the diffusion of collaborative mobility solutions – one of the most prominent examples are bike-sharing systems – although there is only limited evidence on how they impact the transportation system as a whole, especially if they are scaled up and combined. This research will provide such local governments with more awareness on how to invest their limited resources. For shared mobility operators, this research will provide additional insights into the potential of the single solutions and possible combinations. This helps understanding which growth strategies are the most appropriate. If a given threshold, in terms of diffusion/public's patronage, is surpassed, such modes might cannibalize each other's customer base. Although this research, will not specifically study possible competition among different operators of the shared mobility sector, the results will help operators to navigate the market. To get such insight on possible future scenarios, in which shared mobility systems would be implemented at large scale, the agent-based simulation MATSim is used. The preliminary results suggest that e-bikes and car-sharing could serve a large part of the current demand. However, it should not be forgotten, that the simulation as used at this stage does not entail a high level of detail. In fact, some assumptions are rather coarse (for example car-sharing having the same utility of private cars). Nevertheless, it should be stressed, that this series of simulations is intended to explore the solution space and produce a meaningful basis for the generation of stated preference exercises, which are the core of the next stage of the project. The data collected through this survey, will be used to obtain discrete choice models, which will be implemented in the simulation. In the final stage of the project, it will be possible to run new simulations with fully functional representations of car-sharing, bike-sharing and ride-sharing in MATSim. This will provide a plausible insight on how shared mobility modes could be integrated at large scale, capturing a large part of the current travel demand whilst reducing transport-related energy consumption.

Whilst minimizing energy consumption is the main focus of this research, in the future, different dimensions could be included. For example, one could extend the scope to life-cycle energy consumption which would also include embodied energy, or generalize the analyses to include broader environmental and social benefits. Finally, it is worth mentioning that this research covers scenarios, in which shared mobility systems are already available at large scales. The transition from the current system, which is mainly based on vehicle ownership, towards one in which shared mobility is prevalent, is beyond the scope of this research. Although this is without doubt a worthwhile research topic (for example how pricing, availability, comfort, safety and other features will affect the large-scale implementation of shared mobility), the exercise presented here has a fundamentally different approach. Using insights on desirable future scenarios, it will be possible to understand how such scenarios could be realized (i.e. through certain regulatory framework or policy making). In a phase of profound and quick changes, we consider it more important to first determine desirable future scenarios. Subsequently, policies and implementation strategies which could help realizing such scenarios, can be deduced from the insights into those scenarios, and indeed, this strain of research will most likely be an important part of the future work.

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8 Full Authors' information

Francesco Ciari
Swiss Federal Institute of Technology (ETH) Zurich
Institute for Transport Planning and Systems (IVT)
Stefano-Franscini-Platz 5
F 33.2
8093 Zurich
Switzerland
ciari@ivt.baug.ethz.ch

Henrik Becker
Swiss Federal Institute of Technology (ETH) Zurich
Institute for Transport Planning and Systems (IVT)
Stefano-Franscini-Platz 5
F 34.1
8093 Zurich
Switzerland
henrik.becker@ivt.baug.ethz.ch

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