Estimation of Car-Sharing Demand Using an Activity-Based Microsimulation Approach: Model Discussion and Preliminary Results

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Abstract

Car-sharing is a system in which individuals have access to a car from a fleet on an hourly basis. The growing popularity of car-sharing is reflected by a continuous increase in the number of users worldwide. However, the estimation of travel demand for this mode has only sporadically been addressed by researchers and not in a completely satisfactory way. The work reported in this paper introduces a new methodology to estimate travel demand for car-sharing: activity-based microsimulation. An existing open source software, MATSim (Multi-Agent Transport Simulation, http://matsim.org), has been enhanced to allow the modeling of the car-sharing mode. This paper reports on the modeling approach and describes the implementation of the car-sharing system. Finally, some preliminary results, based on a simulation scenario with about 160.000 agents and representing the urban area of Zurich, Switzerland, are presented

Keywords

Car-sharing – Activity-based – Agent-based – Travel Demand

1. Introduction

Car-sharing is a system in which individuals participating in a specific program are allowed to use vehicles from a fleet on an hourly basis. The Sefage development project in Zurich, which started in 1948, is known as the first implementation of this concept (*1*). Various other schemes were implemented in the 1970s and 1980s, but most of them operated at a very small scale and none of them survived (*2*). The modern era of car-sharing started in the late 1980s, when new schemes, most of them still in operation today, entered the market. Since then, the basic concept of car-sharing has evolved in slightly different ways throughout the world but "neighborhood car-sharing" (*3*) is still the predominant operational model, especially in Europe.

In recent years, several new developments further modified the world of car-sharing. In many countries, the existing operators, experience substantial growth rates. At the same time, the concept attracts interest in completely new areas of the world (*4, 5*). Moreover, the incredibly fast diffusion of bike-sharing systems can be seen as a positive factor for a further future development of car-sharing, because it has the potential to complement car-sharing systems and because it helps to make the idea of shared-vehicles systems more popular. An example is the AutoLib project (*6*), a huge car-sharing system with 3000 autos in the Paris region that is expected to start operations next year. Its realization was promoted by the great success of the bike-sharing scheme Velib in the same area (*7*). Since 2008, one-way car-sharing, a concept which has been around for a while, but always encountered problems in practical implementations, has been successfully implemented in the cities of Ulm, Germany and Austin, Texas (*8*). Meanwhile, some new approaches to car-sharing are appearing at the horizon. The most interesting one is probably the idea of peer-to-peer car-sharing 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 (*9*). North America has recently witnessed the merger of two of the largest existing operators. In (*10*) it is observed that this development is likely to inaugurate a new era in the commercialization of car-sharing, transforming the idea of shared cars into a mainstream concept. Moreover, this happens because car-sharing answers some current issues like volatile gasoline prices and 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. In this new phase, it is likely that modeling of car-sharing will play an important role. Policy-makers need forecasting models that are policy sensitive and allow the evaluation of different, and possibly complex, scenarios. Venture capital investors need models for the estimation of market potential, whereas a more precise estimation of travel demand would also be valuable to optimize car-sharing operations (e.g. station locations, global and local number of cars, pricing strategies, etc.). These topics have to different extents already been addressed by car-sharing literature. Various examples of estimates of car-sharing market potential, simulations of car-sharing operations, and estimates of the effect of car-sharing on car ownership are available. However, the work of Shaheen and Rodier (*11*) is probably the only example where travel demand and policy effects are forecasted for different scenarios. But they used a modeling framework which allowed only a very simplistic representation of car-sharing. Summarizing, the authors of this paper come to three important conclusions:

- Since travel demand models are estimated on data which represent the current transportation system it is difficult for these models to make predictions for new transport options

- Reliable tools for the evaluation of innovative mobility services/policies might be decisive for their success

- Models with high spatial resolution and many demographic details are needed

As stated in previous work (*12*) these issues can be addressed by a model that couples the activity-based approach with a multi-agent system. Moreover, the paper conceptually outlines the modeling approach in the context of MATSim, an existing traffic microsimulation tool. The present paper introduces a first implementation of this model that at the last stage of its development should be able to reliably predict car-sharing demand. The functioning of the models is illustrated by some preliminary results. The remainder of this paper is organized in four sections. The next section presents the modeling framework. It discusses the modeling requirements for estimating car-sharing demand, and provides a short introduction to activity-based travel demand models and agent-based models in general and to the software MATSim in particular. The following section deals with the implementation of the car-sharing system in MATSim. Subsequently, a test case for the Zurich urban area, including a description of the scenario and a discussion of the results, is presented. The paper closes with some conclusions and an outlook on future work with particular focus on the enhancements that will be added in the near future.

2. Modelling Framework

2.1 Modelling requirements

The estimation of car-sharing demand is a challenging task for various reasons. In classic travel demand (4-step) models, the mode choice module is based on behavioral models that are usually relying on revealed preferences (RP) data. Typically, only two alternatives are accounted for; car and public transport. If we want to add a transport mode like car-sharing, which is a niche product, to the model, only few data points are available for the necessary parameter estimation. The alternative, a issue-specific stated preferences (SP) survey, is costly and not necessarily easily available. The risk is, in either case, to have an unreliable or incomplete model. Moreover, car-sharing is a car mode but also shares attributes of public transport, like an access time and the fact that the service is not always available. Thus, in order to assign travelers to the right alternative, the description of these modes need to be detailed enough to include the characteristics that distinguish them. The more similar are the modes, the more details are necessary. However, to fully exploit this level of detail, travel should be modeled at the individual level with explicit modeling of the modal choice. High spatial resolution allows, for example, a precise computation of the access time to the service. But this does only help if it can be computed for every single traveler. In order to deal with single travelers, individual socio-demographic data is required. In addition to these car-sharing specific requirements, the model should be also policy sensitive and enable the representation of complex scenarios.

2.2 Activity-based travel demand modelling

The idea to put the individual traveler and its activities at the center of travel demand modeling dates back to more than twenty years ago (*13*) and has, since then, found many applications (*14, 15, 16, 17*). 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 not the product of vehicles just roaming around, but 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 derives naturally from the daily plans of all people traveling in the study area. This methodology implies highly detailed description for individuals, as it is required for the modeling of car-sharing.

2.3 Agent-based modelling of travel

Agent-based modeling is an approach to modeling systems comprised of autonomous, interacting agents (*18*). 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. This modeling paradigm has found applications in many domains; in transport one example is (*19*). A transport model of this kind usually runs slower than existing transport models. Also 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 intended 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. Additionally, agent-based applications in transport usually have a high spatial resolution, fulfilling another requirement for the modeling of car-sharing.

2.4 MATSim

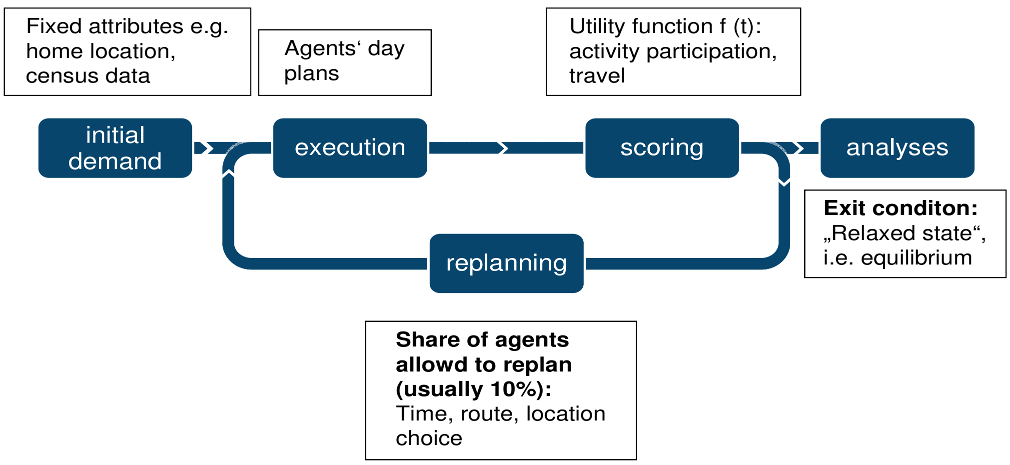
MATSim is a fast, dynamic, agent-based and activity-based microscopic transport modeling toolkit. The basic idea is to let a synthetic population of agents act in a virtual word. The synthetic population reflects census data while the virtual world reflects the infrastructure such as road network, land use, and the available transport services and activity possibilities. Each agent has its daily activity plan, which describes the chain of activities that it 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 get a higher utility. The iterative process continues as long as the overall score of the population increases. The equilibrium reached represents what real individuals do in the real world.

More technically, MATSim is a 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.

Each agent has socio-demographic attributes like age, gender, occupation, home location, car availability, etc. His plan contains information on the daily activities, like where and when those activities will be performed, and which mode of transport will be used to reach the different locations. The underlying activity-chain is assigned to each agent according to its socio-demographic attributes. The plans are executed simultaneously during the traffic flow simulation. Several plans for each agent are retained, given a score, and compared. The plans with the highest scores are kept, and used to create new plans based on the agent's previous experiences. In order to improve their score the agents can vary their departure time, transport modes and routes. For an extension to the optimization of the sequence and number of activities see (*20*). The system iterates between plan generation and traffic flow simulation until a relaxed state is reached (Fig.1).

MATSim's 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 individuals are travelling by car on a network with 882,000 links. Additional information on MATSim can be found in (*21, 22, 23*).

Figure 1 Graphic representation of the MATSim simulation framework



Source: www.matsim.org

2.5 MATSim utility function

The optimization process described above is based on the evaluation of the plans using a specific scoring function. The MATSim scoring function employed in this paper (24) is based on two ideas: a logarithmically decreasing marginal utility for activity duration and a Vickrey (*25*) inspired valuation of the timing of the activities and the travel time. Its general form is

$$(1) \quad Uplan = \sum_{i=1}^{m} Uact_i + \sum_{j=1}^{n} Utravel_j$$

where 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 (1), which is basically the (dis-)utility of traveling, are access/egress time, traveling time and the cost of the trip with a given mode.

$$(2) \quad Utravel = \sum_{j=1}^{n} \alpha_j + \beta^1{}_j * TT + \beta^2{}_j * Cost_j * Dist$$

Access and egress time are not calculated but assigned to each mode in the form of a negative constant α. The cost component represents the kilometric cost for the mode considered. *Dist* is the traveled distance for the leg calculated with different methods for each mode. The travel time (TT) is calculated based on the distance and the speed of the mode (a specific average speed for each mode based on mobility census data). An exception to this is the car mode. It is the only mode that is properly simulated here, i.e. "physically" represented. See Rieser (*26*) for the public transport equivalent. Through this simulation agents interact in the sense that the travel time and, consequently, the generalized cost of a car trip depend on the congestion of the network and, thus, on the mobility behavior of other agents. The constant α and the parameters β^1 and β^2 are different for each mode and have been estimated using stated preferences survey data (for more details on this topic see *27, 28, 29*). 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.

3. The Implemented Model

In the most recent version of the MATSim toolkit, the available modes are car, public transport, bike and walk. Car-sharing is not considered as an option. For all modes except the car mode, the utility of travel is independent of other agents' behavior. Important is that for each mode a generalized cost of travel is defined and the agents are able to compare the utility (or disutility) generated by traveling with a given mode. A new transport mode can be added to the simulation tool in various forms and with different levels details. In this first attempt to introduce car-sharing as a modal option, described here, a relatively simple approach is chosen, because the current focus is to have easily interpretable results that help in the further refinement of the model. The main features of the modeled system are:

- Car-sharing is available to everybody having a driving license (no membership is needed)
- Agents can pick up, park and drop off car-sharing cars only at predetermined locations (stations)
- It is assumed that agents are walking to the pick-up point and from the drop off point
- An unlimited number of cars are available at the stations (no reservation system, every agent trying to use car-sharing will find a car at the station)

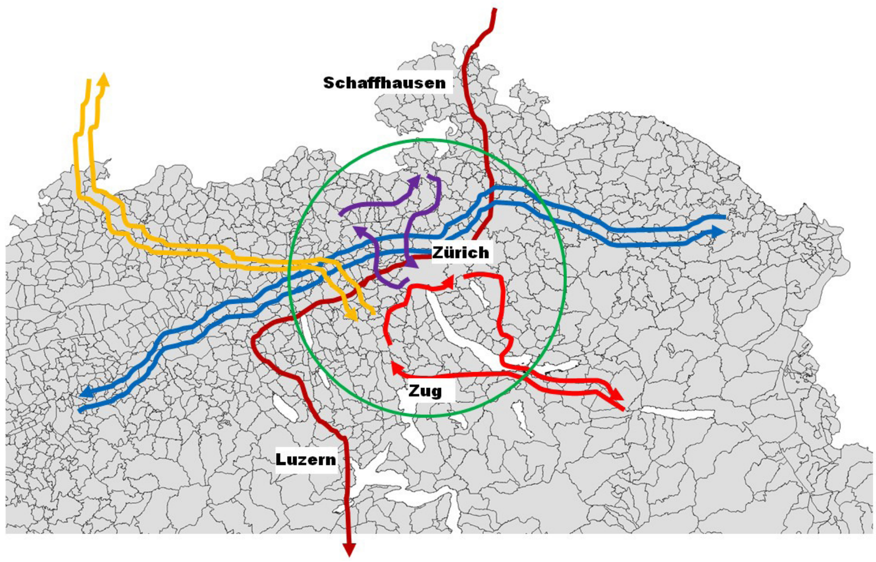
The mode choice module of MATSim is subtour based. A subtour is defined as a sequence of at least two trips starting and ending at the same node. Agents choose the transport mode at this level. This fits well with the way real car-sharing systems are functioning since it forces an agent to bring back the car to the starting station. Additionally, because of the current implementation of the mode choice module, agents need to park the car at a station at the end of each leg of the subtour. A car-sharing leg in the simulation, therefore, consists of three sub-legs: two walk legs (from the start link to the starting station and from the arrival station to the destination link) and a car leg (from the starting station to the arrival station). The utility function for the new mode, similar to (2), needs to be defined. In general, the utility function is intended to reflect the service offered, and this might be more or less detailed. The parameters for already existing transport modes have been estimated with the help of an appropriate SP survey; a specific survey for car-sharing is in preparation. In meantime the parameters for car-sharing are fixed relative to the parameters of existing modes. Since the goal of this study was to test the influence of the walk paths in the choice of using car-sharing, the utility function for car sharing legs treats the walk sub-legs as normal walk legs and car sub-leg as a normal car leg. Note, however, that car-sharing cars are not physically simulated. The current implementation of the physical simulation doesn't support multimodality within one single leg. Nevertheless, the route is assigned with the same router as for the mode car, and the travel time is calculated on the congested network. The physical simulation of car-sharing cars will be addressed in the near future.

4. A test case: the area around Zurich

4.1 The simulation scenario

The set up of a simulation scenario is a time consuming task, involving the integration of different data sets. The description of this process is beyond the scope of this paper. More information can be found in (*21*). The scenario used here is a "Greater Zürich" scenario. It is a subset of the Swiss scenario, and covers an area of about 2800 km^2, obtained by drawing a 30 km circle around the "Bellevue" place in the centre 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 (477 types of activity chains, 9429 types of activity chains classified by duration; eight classes of agents by age and work status are distinguished). The study area has approximately 1 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 is presented in Fig. 2.

Figure 2 Map of the Greater Zurich scenario (green circle) with graphic representation of types of plans included in the scenario



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 car-sharing. In this scenario, 276 car-sharing stations define the locations where an agent is allowed to pick up, park and drop off a car-sharing car. The locations are the actual locations of the Swiss car-sharing operator Mobility in the study area. Mobility CarSharing (*30*) is the only operator in Switzerland and one of the leaders worldwide in terms of number of customers. This obviously adds a lot to the realism of the simulation, even if the number of available cars at the stations and the reservation system are not modeled. For computational reasons the simulation is run on a 10% sample of this scenario, which means that 161.810 agents are actually 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.

With the computer used for the simulation, 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 10 hours of computing time (using 3 cores and 40G RAM) for 50 iterations, which is enough to reach an equilibrium with the settings used.

4.2 Results and discussion

The results presented here are only a preliminary answer to the question of how large the potential demand for car-sharing in the study area is. At this stage of the work the analyses are valuable instruments to understand what still needs to be improved in the model and what is already working well. Moreover, since agent-based modeling is quite a new methodology for the assessment of innovative means of transports, it is important to show which kind of analyses are possible with this tool. For these reasons, the most that can be asked of the current simulation results is to be reasonable and consistent with the assumptions made. To assess what is "reasonable", it is useful to qualitatively discuss "ex ante" which value the market share of car-sharing might reach in the simulation. Since the car-sharing system implemented in the simulation is not the same as the real one of Mobility, it is expected that the market share in the simulation will differ from the real market share of Mobility. However, since the stations in the scenario are exactly the same as those of Mobility, its market share will be probably a good reference. In order to estimate how much it will differ or, at least, if it should be higher or lower, the characteristics of the simulated car-sharing which are expected to be important factors determining the number of users should be evaluated. Factors that are expected to increase the share of car sharing trips are:

1. The number of cars at the stations is unlimited. This implies that adjusting the daily schedule to the availability of a car-sharing car at a certain time of the day is unnecessary.

2. All persons having a driving license can access the system. Membership is not modeled

Factors that are expected to decrease the number of car-sharing trips or that are expected to have undetermined impacts:

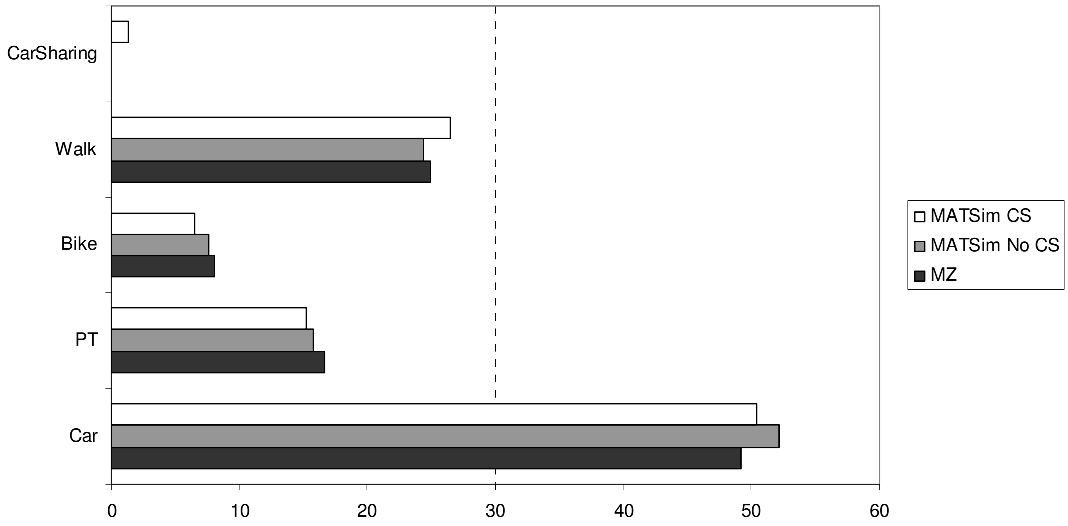
3. The monetary costs of car-sharing are not modeled. The station-to-station sub-leg is handled as a normal car leg. This might push the share slightly up, since car-sharing is probably perceived by most as less comfortable than the own car in real life.

4. The necessity of using car-sharing for some special transport, which would not be possible with the own car, is not modeled. This might restrict the use of car-sharing in the simulation.

5. The constraint to drop off the car at the end of each leg will enable, on the one hand, using car-sharing even in cases where a long activity is involved. On the other hand, trips with a destination far from any car-sharing station will unlikely be car-sharing trips.

The only factor which, intuitively, is expected to have a big impact is the unlimited number of cars at stations. Therefore, it is expected that the factors implying a higher share of the car-sharing mode in the simulated world are predominant. Thus, the simulated number of car-sharing trips should be higher than the real figure. However, it seems plausible that also in the simulation car-sharing will be a niche product, since with the present implementation only agents starting and ending a trip close to car-sharing stations are expected to find car-sharing attractive. Considering that car-sharing now in Switzerland is the chosen mode for less than 0.1% of all trips (*31*), a share between this figure and some few percent points can be expected.

Figure 3 Shares of the transportation modes for the simulation scenario “Greater Zurich” with and without car-sharing.



The modal split results obtained for two alternative scenarios, with and without car-sharing, are presented in Fig.3. As reference the real shares from the Microcensus (MZ, *32*), the Swiss national travel survey, are also reported. The shares are reported as the percentage of trips travelled with a certain mode disregarding the distance. The share of agents using car-sharing in the simulation is 1.3%, which is consistent with expectations. An interesting further insight is the typology of persons using car-sharing with respect to car availability. Table 1, shows the number of trips travelled with car-sharing relative to the total distance walked by the agent in a car-sharing leg (distance from start point to start station plus distance from arrival station to destination point) and its car availability. Distance intervals have been chosen in a way that each interval includes 20% of the total car-sharing trips.

Table 1 Percentage of car-sharing trips with respect to total walk distance and car availability

	Walking distance (m)				
Car Availability	<270m	270m-390m	391m-512m	512m-692m	>692m
Always	10.62%	10.23%	10.19%	9.57%	9.53%
Sometimes	4.71%	4.87%	4.24%	4.25%	3.13%
Never	4.68%	4.90%	5.56%	6.16%	7.36%
Total	20.01%	20.01%	19.99%	19.98%	20.02%

The portion of trips made with car-sharing by agents having a car always available is surprisingly high, but this figure decreases as the distance to be walked increases. The opposite happens for agents never having a car available while agents having the car available only sometimes are more equally distributed among distance classes. This seems a logical result since agents having the car always available will compare the car-sharing option with the car option and the first will only be attractive if walk distances are negligible. Agents without access to a private car will compare the car-sharing option with other, slower, modes (like public transport) and are ready to walk more in order to use car-sharing. But if the leg distance is shorter they will likely prefer cheaper modes (like walk or bicycle). On average, the total distance walked decreases from 590m for agents with car availability "never" to 496m for agents with car availability "always". Finally, this mechanism is confirmed by the relationship between walk distances and travel times. Most of agents having the car always available are using car sharing for short trips, 12 minutes travel time or less, only when the walk distance is short. About 45% of those trips have a walk distance of less than 270m and about 88% of less than 512m (the marks for the first and the third distance bin of Table 1 respectively). The activity-based approach enables many other analyses. Two typical examples are the analyses of trip purposes and demographic groups of car-sharing users. They can be found in Fig. 4 and Fig. 5 respectively.

Figure 4 Car-sharing legs with respect to the purpose of the trip. Both the activity before and after the trip are reported, the order of the sequence is not taken into account (i.e. shop-work and work-shop are considered equal).

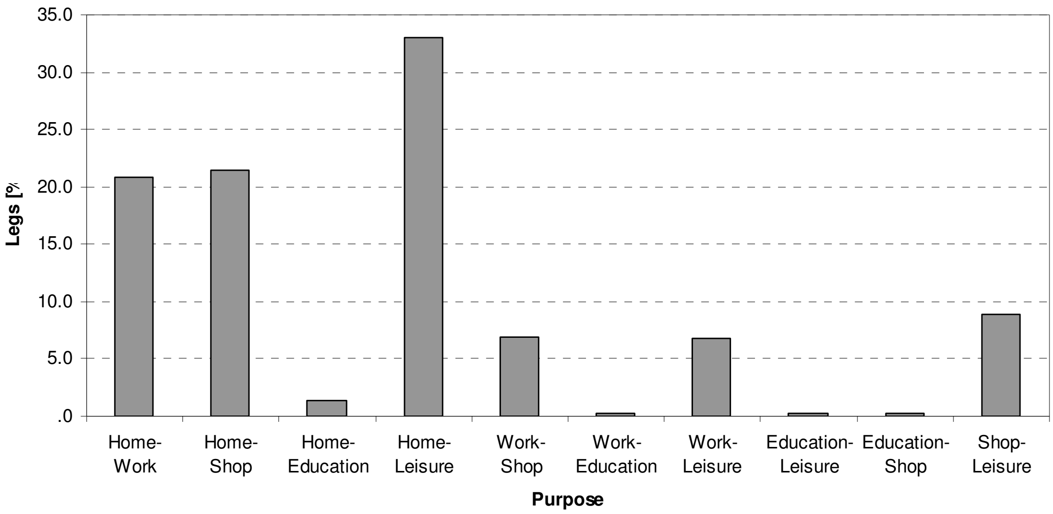
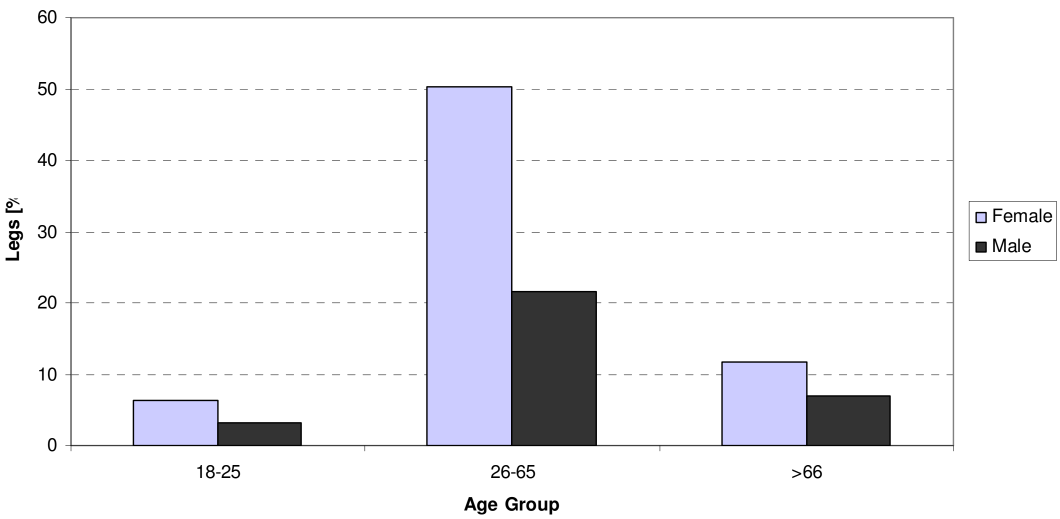


Figure 5 Car-sharing legs with respect to gender and age group.



The distribution of trip purposes is similar to the distribution of the Swiss mobility survey. The interpretation is that the trip purpose is not influential for the choice to use car-sharing, which is consistent with the current specifications of the model. The distribution among age and gender groups shows that female users are largely majority among car-sharing users. Gender preferences are not included in the model yet, and thus, this might appear as an erroneous model outcome. However, in the population used for the simulation male agents have a car always available much more frequently than female agents (56% vs. 42%), which is a possible explanation for the difference in car-sharing use.

5. Conclusions and Outlook

This paper reports on ongoing work aimed to develop a simulation tool which should be able to estimate the travel demand for car-sharing and evaluate different scenarios and policies. The work is motivated by a lack of reliable tools for the estimation of innovative transport modes. The methodology proposed is both activity-based and agent-based and builds on an existing open source project called MATSim. It is a very flexible tool and the number of modeling details which can be added is virtually infinite. Moreover, it has the potential to represent the system at the microscopic level, even when simulating large-scale scenarios with millions of agents, permitting an accurate study of the feasibility of the system, both in technical and economical terms. How precise this tool can estimate the demand for car-sharing is, however, yet to be answered. This can be achieved only by testing different modeling options and scenarios. Hitherto, it was important to show that an activity- and agent-based tool is a realistic option for the modeling of car-sharing. The first operative example described in this paper, which is only a first step towards a more sophisticated approach, provides results in line with the expectations, given the specifications and the level of detail of the model.

The future work will focus on both, performing further analyses and improving the model itself. The simple analyses performed so far only considered the demand, since the goal was to demonstrate that agents in the simulation react reasonably to the characteristics of the car-sharing system. For further verification of the modeled system, it is necessary to check the number of cars effectively picked up and returned at each station. Since the reservation system is not yet modeled, it is assumed that a station is always able to satisfy the demand, whatever the demand is. But it is possible to count “ex post” how many cars have been picked up and returned to each station during the day and, consequently, compute how many cars would have been necessary to fulfill the demand, both globally and locally. This is important because it will be possible to understand how much each car is effectively used and will give a first hint on the profitability of the additional capacity provided to the system.

Moreover, the model could be improved in many different ways. The most straightforward one and, thus, the one which will be attempted next, is the introduction of explicit monetary costs for the transportation modes. This will allow a more realistic modeling of the modal split and, in particular, the choice between car-sharing and private car for private car owners. In fact, this will show which agents might have an interest, in an economic sense, to adopt this transport mode for a given level of price. The simulation of the reservation system, reproducing the effective availability of a car at a given moment and station, will add further realism, but this is probably the most challenging aspect to be modeled and will be considered only in a long term perspective. Additionally, also in the long term perspective, the modeling of the car-sharing operator as an agent will be attempted. This will help finding new solutions for the car-sharing system, allowing a better understanding of the interactions among the different modes in the transportation system. Moreover, it will be an important step towards a more complete and flexible modeling framework, enhancing the palette of scenarios which can be modeled with MATSim. Finally, since MATSim is in itself a large project and many researchers are working on its enhancement, it is worth to cite parallel work which could be relevant for the modeling of car-sharing. The explicit modeling of parking will be added soon to MATsim, making possible the evaluation of the effects that car-sharing have on parking needs (*33*). The possibility to simulate explicitly public transport in the physical model has been recently tested (*26*). This will be extended in the future to the explicit simulation of car-sharing cars adding further realism to the presented tool.

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