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An agent-based approach

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Modeling one-way shared vehicle systems: an agent-based approach
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Abstract

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, and less frequently but increasingly for carsharing systems. This paper addresses the creation of a predictive model of one-way shared vehicle systems demand in the context of a multi-agent activity-based simulation. The model presented is based on an existing simulation software called MATSim and on previous work which was aimed to the simulation of classic two-ways carsharing. The main shortcoming of that model was that station capacity was ignored assuming an infinite availability of carsharing vehicles. Moreover the model was not able to cope with one-way carsharing. The main contribution of this paper is to provide 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.

Keywords

One-way, shared vehicle systems, carsharing, predictive models, agent-based, demand estimation
Preferred Citation
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 a revival after some experiments and a few unsuccessful experiences. 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, it means that there are stations where vehicles 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 solution of this issue is necessarily tied with a planning of the system which prevent, or minimize, imbalances. This implies, however, an accurate forecast of the demand with both high temporal and spatial resolution. This paper addresses the creation of a predictive model of one-way shared vehicle systems demand in the context of a multi-agent activity-based simulation. The model presented is based on an existing simulation software called MATSim. Extending MATSim to simulate one-way shared vehicle systems presents various challenges. Previous work was already dedicated to the addition of carsharing as a mode but it was based on traditional, station based carsharing. The model proposed takes two fundamental aspects of carsharing into account, the time related fee and the access to the station. However, the model currently assumes an unlimited carsharing fleet. Additionally, 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 Waraich et al. (2012). Additionally, the representation of vehicles availability make necessary that agents modify the daily-plans during execution (physical simulation). In fact, 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 paper 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
makes some reflections on the existing literature on this topic. Section 3 describes the agent-based traffic simulation MATSim and the existing predictive model of carsharing demand. Section 4 explains what are the challenges 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 fulfill this goal. Section 5 is a brief summary of the paper and proposes some directions for the future work.

2. Background

The one-way station-based approach, as mentioned in the previous section, is used for both bike and car shared vehicles 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 knew a different path. Traditionally it is tied with the still prevalent two-ways 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 had an experimental nature and were used only at 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 the one in Singapore, known as 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 two-ways system (Brook, 2010). Despite that, recent developments in carsharing are bringing the one-way option to the big stage. 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 4000 cars (www.paris.fr/autolib). Some other operators go even beyond the one-way feature (www.car2go.com, www.drive-now.com). Those systems are innovative also because they are directly operated by the car manufacturer (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. In the case of bike-sharing this is likely because the one-way feature is taken as 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 little 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. 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. They used the simulation as basis for a substantial amount of work testing different solutions for the relocation problem. Some work was undertaken also regarding the management of free-flow carsharing in Ulm, Germany (Göppel and Blumenstock, 2012). The work of Schwieger (2004) 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 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 reliability concerns are the most important perceived shortcoming of one-way systems since reservations well ahead were not possible. Additionally, the socio-demographic profile of customers using the service was in line with the overall profile, although, being only a trial for a limited time, the results are not suitable to capture the effects on new profiles usually not interested in carsharing. Finally, from an operator perspective, the earnings per car per day sank of 0.6%, which means that the costs to manage the fleet were compensated by the additional income for the service.

3. MATSim and the Existing Carsharing Module

The model will be based on an existing tool, called MATSim (www.matsim.org) which is developed jointly at IVT in Zurich and at the TU Berlin and published under GNU license. MATSim is a fast, dynamic, agent-based and activity-based transport simulation. The basic idea is to let a synthetic population of agents act in a virtual copy of the real 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 a plan which represents the chain of activities which it is supposed to perform during the simulation day. Agents try to perform optimally according to a utility function that defines what is useful for them. As a general rule, the performing of activities gives a positive utility while travel gives negative utility. 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 choice dimensions are:

- Starting time and duration of activities
- Location of activities
- Mode of transport
- Route
- Parking

A graphic representation of the simulation network is in Figure 1.
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 a plausible approximation of the real world behaviour of the individual.

### 3.1. The existing carsharing module

In the most recent standard version of MATSim, the available modes are car, public transport, bike and walk; carsharing is not modeled. However, a preliminary effort to model carsharing demand has been already made (Ciari et al., 2011). In that work, two of the fundamental features that characterize the carsharing mode, access to carsharing cars and the fare structure are explicitly modeled. The underlying assumption is that a model with a correct representation of these two features is able to give plausible estimates of carsharing usage in terms of modal share, and to induce in the agents some of the typical carsharing usage 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 usage patterns (Millard-Ball et al., 2005).

In order to explicitly represent the mentioned features, the model was implemented as follows:

- Carsharing stations are located at the actual carsharing locations in the modeled 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 was 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 in the model 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

The addition of a new transport mode implies the introduction of a function that represents the generalized cost of travel that mode. The function representing generalized cost of travel for car sharing is:

$$ U_{\text{travel},d,cs} = \alpha_{cs} + \beta_{\text{cost},cs} \cdot \text{Cost}_t \cdot RT + \beta_{\text{p,walk}} \cdot (AT + ET) + \beta_{\text{g,cs}} \cdot TT + \beta_{\text{cost},cs} \cdot \text{Cost}_d \cdot \text{Dist} \quad (1) $$

The equation is linear and has five terms. The first, the constant $\alpha_{cs}$, 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 $\text{Cost}_t$ represents the cost for one hour reservation time. The parameter $\beta_{\text{cost},cs}$ 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. 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 how traditional 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 for this work 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.

4. Modelling approach

The existing carsharing model, presented in the previous section, is not suitable to simulate one-way carsharing and more 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-ways 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.

4.1 Mode choice

As mentioned in the previous section, 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. Remounting back, 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 stage. 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 in this paper. 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 leg different than 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 alcohol consume might prevent him to drive.

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 section.

### 4.2 Vehicle availability

Considering unlimited vehicle supply at the stations is a simplistic approach, yet the results obtained with the existing model (Ciari et al., Forthcoming) 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 sub-tours 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).

4.2.1 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 sub-tours 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 be implemented; 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 sub-tours would simply an a priori fixed sequence of carsharing and non-carsharing legs (as described in the previous paragraph of this section). 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.

4.2.2 Real time

A second solution is to keep track in real-time of vehicles availability. To keep stations’ vehicles 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 need to be found “on-the-fly”. This implies agent being able to change their 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 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 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.

4.3 Physical simulation

As explained in Section 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 has been 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 (Marcel diss) developers and this might be used in the future to further enhance the model.

4.4 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 model does and what does not. The model 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 is implicitly assumed a planned use of one-way carsharing. Real use will certainly contain such behavior but it is expected that this type of carsharing also incite to 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 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 was not treated in this paper but was already tackled and discussed in a separate paper (Ciari and Axhausen, 2011).

5. Summary and Outlook

This paper 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-ways shared vehicles systems demand. Although the model was able to reproduce with a good level of accuracy the demand for carsharing in a test area (the metropolitan area of Zurich, Switzerland), it had 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 should 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 previously developed model has been described and its limits explained. 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 pursuit in the near future is to test both approaches on a large scale scenario and compared 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 can be an issue. In particular, hypothetical large scale scenarios with very large one-way systems, and consequently a large modal share for this mode, the within-day replanning approach might result inappropriate because too slow.

6. References


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