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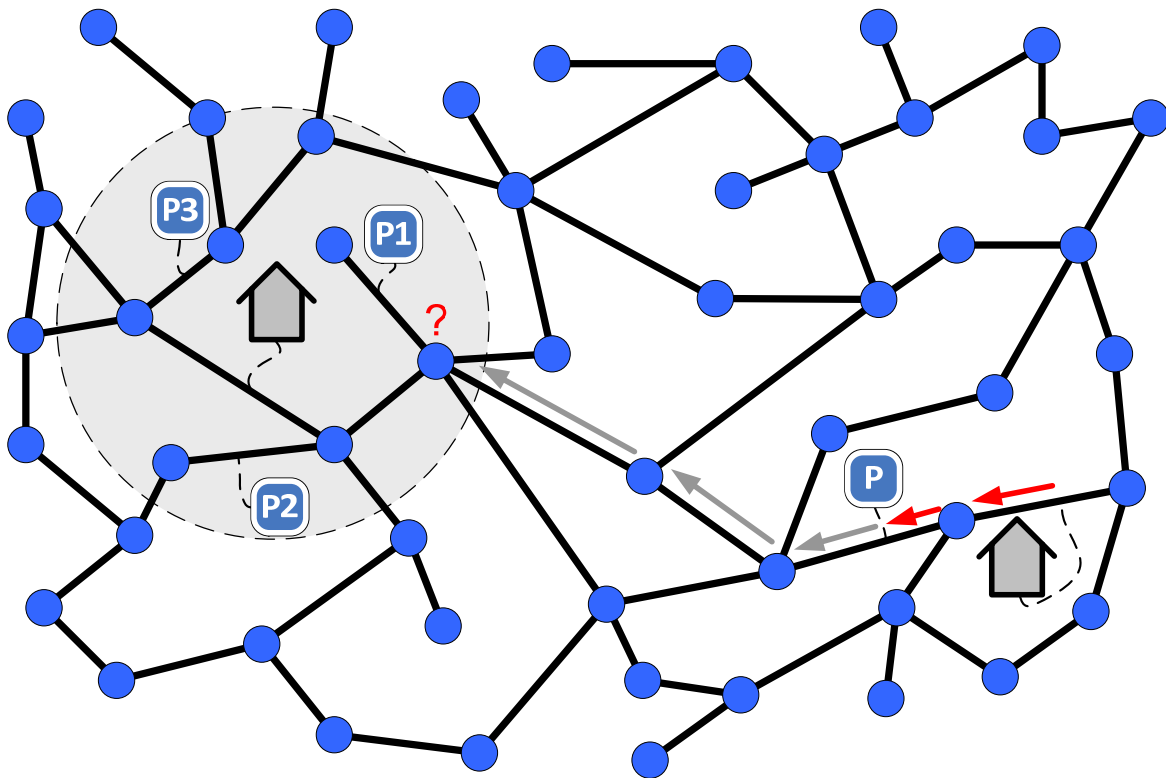
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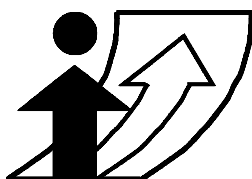
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Modelling Parking Search Behaviour with an Agent-Based Approach

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Modelling Parking Search Behaviour with an Agent-Based Approach

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Abstract

In the recent years several agent-based parking models have emerged, which provide policy makers with temporally and spatially rich data, what would be impossible to acquire using aggregated models. As we found out, all recent agent-based parking search models, lack the ability to account for the influence of parking shortages on mode or location choice. We close this modelling gap by proposing a new parking search model, which should be built on top of an existing agent-based traffic simulation called MATSim. We point out, that the parking strategy evaluation procedure of the previous parking search models delivers systematically too high search times which can be avoided using the proposed approach. Furthermore we also describe how individual valuation of parking search components (e.g. search time, cost and walk time) could be incorporated in the model. Currently an implementation of the proposed parking search model and an application for the city of Zurich is in progress.

Keywords

Agent-based, parking search, micro-simulation, evolutionary, MATSim

Preferred Citation

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1. Introduction

Cities facing parking shortage, often have several options at their disposal, which can range from increasing parking price/capacity to promoting usage of public transit. In this regard parking models can help policy makers to narrow down possible choices and help their decisions through the simulation of possible scenarios.

In the recent decades, there has been a shift from aggregated models to models with high temporal and spatial resolution where individual drivers (*agents*) are at the core of the simulation (e.g. Benenson *et al.*, 2008; Spitaels *et al.*, 2009). These so-called *agent-based* parking models can potentially simulate in detail the change by a policy measure both from the agent's perspective (e.g. change in search time, walk distance, cost) or from the overall systems perspective (e.g. change in travel mode, parking revenue or traffic counts).

Parking search models have been around for decades, e.g. see Young (1986) for parking search inside parking lots and Axhausen (1989a, 1990) for an agent-based parking model including parking type choice and search. As the computational power has risen, more detailed agent-based parking models have emerged in the last decade, which is the focus of the current paper.

In the following section, we briefly describe the most evolved agent-based parking models and highlight both their advantages and also which features are still missing. In the third section we describe a new agent-based parking model, which makes trade-offs between the existing solutions and also introduces new ideas. A discussion including comparison of the new parking model to the existing ones is given in the fourth section, which is followed by a conclusion.

2. Related Work

In the following we describe agent-based parking models, which have emerged in the last decade. PARKAGENT is such an agent-based parking model (Benenson *et al.*, 2008), which was applied to residential parking and distinguishes between several groups of agents (e.g. residential and visitors). The destination of the agents are fixed at the beginning of the simulation. The agent enters the simulation 250 m away from the destination, from where it follows a set of rules to search for parking. This includes estimating the parking capacity situation as driving towards the destination and deciding in each time step, if to park or continue driving. If the agent does not find any parking after reaching the destination, it continues driving and just takes any parking it can get. If the search time is more than 10 min, the agent just drives to the closest paid off-street parking to the destination. The whole simulation is very detailed (e.g. also includes different speeds for different phases of the parking search) and is applied to a neighbourhood in Tel Aviv with severe parking shortage and where the impact the addition of one/several parking facilities is investigated (scenario includes ca. 12'000 agents).

The second agent-based parking model, called SUSTAPARK (Spitaels *et al.*, 2009), was applied together with several policy runs to the city centre of Leuven, Belgium containing ca. 14'000 agent. SUSTAPARK has a wider scope than the first model, as it also contains a traffic simulation. Based on surveys on parking behaviour, they have defined a couple of rules, which the agents follow to find parking. At the beginning of the simulation, the activities of the agents are defined with activity duration. The agents are then routed between the activities and try to find a parking close to the destination. The search for street parking is based on a disutility function, which increases with the search time. If the disutility surpasses a certain threshold, the agent parks the car off-street. Furthermore several rules are defined to switch between strategies, which includes a multinomial logit (MNL) model for switching between parking types. Also there is a differentiation between visitors and local commuters about the available knowledge of the local parking situation.

A major drawback of the two models described above, is that shortage in parking supply has no influence on travel time, travel mode or destination choice. A more recent agent-based parking model (Waraich and Axhausen, 2012) includes these features, as it builds on top of an existing agent-based traffic simulation called MATSim (MATSim-T, 2012). In the following MATSim is described, as the proposed model in this paper also builds on top of MATSim.

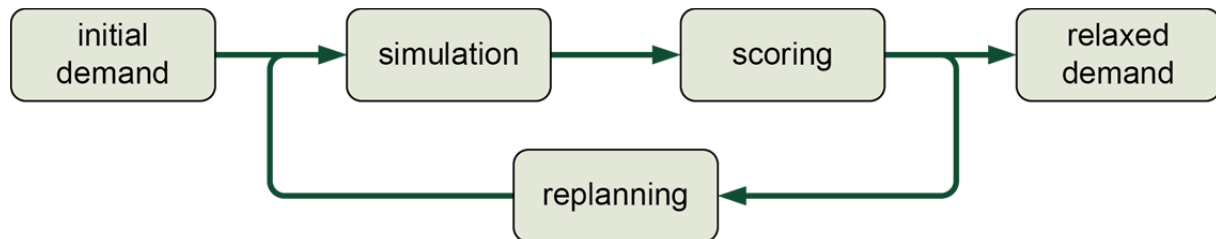


Figure 1: Co-evolutionary simulation process of MATSim

Figure 1 shows MATSim’s simulation process: Each agent in MATSim has a daily plan of trips and activities, such as going to work, school or shopping. The initial daily plans of agents are provided as input in the initial demand step together with supply models, e.g. street network and building facilities. The goal of the MATSim simulation process is to optimize the plan for each agent. The plans of all agents are executed by a micro-simulation, resulting in traffic flow along network links, which can cause traffic congestion. The execution of these plans is then scored and assigned a utility. For example a person with lower travel time has a higher utility than one, which has a longer travel time, e.g. due to a traffic congestion. Furthermore working and other activities increase the utility. The goal of each agent is to maximize the utility of its daily plan by *replanning* its plan after each iteration, e.g. changing routes, working time, travel mode or location choice. After each iteration, either a new plan is created by changing a previously executed plan, or a previous plan is reselected. Plans with a higher score have a higher chance of reselection, while plans with lower score are deleted over time, as only a limited number of plans per agent is kept. This idea corresponds to the mutation, selection and survival of the fittest concept in a co-evolutionary algorithm (Holland, 1992).

The execution of all plans, its scoring and replanning is called an iteration. The simulation is an iterative process, which approaches a point of rest corresponding to a user equilibrium, called *relaxed demand*. More details about the conceptual framework and the optimization process of the MATSim toolkit can be found in (MATSim-T, 2012).

The parking model described by Waraich and Axhausen (2012) builds on top of MATSim and includes a simulation of the parking choice and parking occupancy. For a given destination, the algorithm chooses between available parking based on the agent’s utility function and selects the parking with the highest utility score (taking walking distance and price into account). Thereby it considers several types of parking, e.g. private parking or reserved parking for disabled people. After selecting a parking, the utility score for the parking choice is also added to the overall utility score of the agent in MATSim, so that a feedback to the traffic simulation is possible. This means, if there is a shortage in parking supply at a certain location, this can increase the walk time or parking cost, so that over time the agent is offered several options, e.g. to change travel mode (e.g. to public transit) or try coming earlier to get an unoccupied parking. The model described in Waraich and Axhausen (2012) was applied to a scenario for Zurich, containing ca. 180’000 agents. The main drawback of the model is, that it only contains parking choice and not parking search, meaning that although the actual filling up of car parking is simulated by the model, perfect knowledge by the agents of the environment of the destination is assumed and no parking search is performed.

Although, there are various features differences in these models, the main missing parts of these models are as follows: Both PARKAGENT and SUSTAPARK lack the capability of feedback to the traffic simulation and are therefore incapable of simulating parking policies, which might affect mode choice or location

choice. Although the parking choice model (Waraich and Axhausen, 2012) does not lack this feature, it is missing the essential capability to simulate parking search. The model described in the next section tries to fill this gap, together with proposing a new approach for evaluating parking search strategies.

3. The Parking Search Model

The proposed parking search model in this section is envisioned to be built on top of the agent-based traffic micro-simulation (MATSim), so that many aspects of travel, such as routing, mode choice, travel time change, location choice, etc. are already in place. These are all aspects of travel behaviour on which parking policy changes might have an impact.

Before introducing the new parking search model, we first define a couple of requirements for it.

3.1 Requirements

3.1.1 Individual Valuation of Time

Although all three agent-based parking models mentioned in the related work section argue that they can model individual behaviour, till now important attributes, which have influence on the parking choice are still missing. For example the income of the agent is not present in any of these models, although it is well reported that the income can have an influence on the parking search components, such as search time, walk time and parking cost (Axhausen and Polak 1991; Weis, 2011). Furthermore income is not the only such attribute which has influence on parking choice and other agent attributes (e.g. gender or age) should also be considered for inclusion, if they are deemed relevant. For example the age might have an effect on parking decisions, e.g. aged person wanting to walk less.

Another aspect, which is also mentioned in some of these model descriptions, but missing in the model are the interactions of the parking components with other properties of parking. E.g. in Hess and Polak (2004) it is reported, that the valuation of the parking components changes with the trip purpose and Weis *et al.* (2011) found that people are willing to pay more to reduce parking search time for shorter activity durations than longer ones.

This means, the proposed parking search algorithm has to provide interfaces which allow inclusion of the relevant attributes and parameters into the utility function.

3.1.2 More than one Strategy

The algorithm should be able to deal with several parking search strategies. This includes having the possibility to have both fixed assignment of strategies or probabilistic assignment. But the major feature, which is only partly available in the existing parking models, is the possibility to find the optimal strategy for an agent based on his individual valuation of time (see Section 4.1 for a further discussion on the comparison of the new approach to the existing ones).

3.1.3 Trade-off with Long-term Decisions

As stated earlier, it is essential that a parking search algorithm can have an impact on long-term decisions of people, due to a policy change, e.g. mode choice and location choice.

3.1.4 Flexibility

The framework should be flexible, to be applied on various cities, with different sets of parking infrastructure (e.g. residential parking card, time dependent prices per street, etc.). Furthermore a whole range of parking policies should be possible to investigate with the framework, e.g. price change, capacity change, law enforcement increase, etc. The reason for providing such flexibility is to promote the usage of the model by other researchers, because like MATSim the new model is intended to be open source and available to others via the MATSim webpage (see MATSim-T, 2012).

3.2 Proposed Parking Search Model

In MATSim the activity plans of agents are fixed at the starting of the iteration. But in order to perform parking search one needs the capability to adapt the agent’s plan, as the agent approaches the destination area. Just recently, a module was added to MATSim, which allows *within-day replanning* of agents during the micro-simulation (Dobler *et al.*, forthcoming). By applying this framework, the route of an agent can be changed to simulate parking search. Figure 2 shows, how the original plan of an agent in MATSim looks like, where the car trip starts and ends directly at the activity link. We propose, this plan should be adapted so that it contains walk legs between parking and the actual activities and also the routes should be adapted.

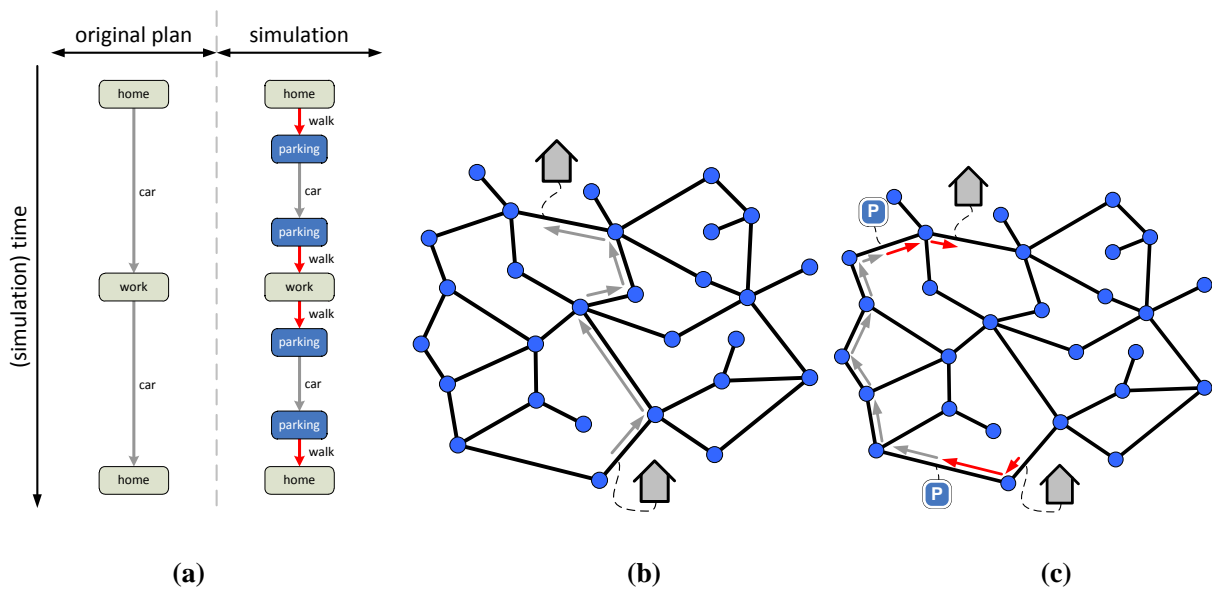


Figure 2: (a) The original plan contains only car trips, which is adapted by adding parking activities and walk legs. (b) The agent’s original route starts at the link of the original activity and ends at the link of the destination activity. (c) With the proposed parking search, the agent would first walk to the parked car, which may be located on a different link than the activity and then start driving from there. This may change the original route.

3.2.1 Parking Strategy and Evaluation

We define a parking strategy as any set of rules, which brings an agent approaching an activity location to any type of parking. This means, a parking strategy can be anything such as driving directly to a private parking, reserved parking, off-street parking, searching for parking on-street parking or first searching on-street and then going to a garage parking. The parking strategy can further take individual preferences into account, e.g. if a person is disabled the parking strategy can include this preference both in the search algorithm as well take this into account over the utility function (long walking distances giving worse scores).

As there is a requirement for the new model, that for different trip purpose different valuation of time should be included, we even go a step further and say, that for each trip purpose the parking strategy set available to an agent can be different. For example, an agent might have a residence card street parking at home. At work the agent might have free parking provided by the company and when he goes shopping, he might have several search options (parking strategies), as he can use a garage parking, or a free street parking or first try a street parking and use a garage parking as a last resort and some people might even consider illegal parking as an option.

As at each activity an agent has several parking strategies available, it needs to be defined how the agent can evaluate these strategies. One option which should be available is to fix the parking strategies at the beginning of the simulation, e.g. based on some statistics (one strategy per activity). A second option which is envisioned, is that parking strategies are selected according to a given probability distribution, which can be different for each agent (e.g. using an MNL model). The third option is to optimize the parking strategy starting with all parking strategies/options available for destination. In order to find the best strategy (from the agent's perspective), one needs to evaluate each of the strategy one by one. But in order to do this correctly, we have defined a couple of conditions, which we think should be met by the strategy evaluation algorithm:

1. In order to ensure stability of the simulation, the number of strategy changes per iteration should not be too high. This is important, as some strategies work based on past experience (e.g. agents might have a set of roads in mind, where they can find a parking with a high probability, see (Axhausen, 1989b)). If all agents change their strategies in each iteration, this could not work. This is similar to the general replanning condition in MATSim, which recommends only a small number of plan changes per iteration.
2. Each strategy must be re-evaluated from time to time, so that the strategy can be executed and scored for the updated environment of the agent found in a specific iteration.
3. If at any iteration the user stops the simulation, with a high probability a parking strategy should have been executed in the last iteration, which is optimal (based on experience from strategies evaluated till that point).

An algorithm, which fulfils these three conditions is depicted in Figure 3. The algorithm works as follows: For each destination an agent has n parking search strategies available s_1, \dots, s_n . We initialize the score of each of these strategies at the beginning of the simulation to $-\infty$. For the first iteration, a search strategy is selected at random. After the execution of an iteration, the score of the parking strategy is updated and forwarded to the MATSim simulation to give feedback (see more details in section 3.2.2). Thereafter, the parking strategy is selected, which should be executed in the next iteration in the following way: Most of the time the strategy with the best score is selected and only each k -th iteration (e.g. 10^{th}) a new strategy is evaluated, which has not been evaluated for the longest time (corresponding to round robin scheduling, which ensures fairness).

A good value for k can be found by experimentation (similar to the share of replanning per iteration in MATSim). Both “too high” and “too low” values of k can lead to undesirable behaviour. Too high k values mean, that the system needs a lot of time, until all strategies have been evaluated and it could take longer for the system to relax. A low value increases the volatility in the system, where in the extreme case ($k=1$ and $n>1$) the algorithm evaluates in each iteration a different parking strategy and as such does not optimize the parking strategies at all.

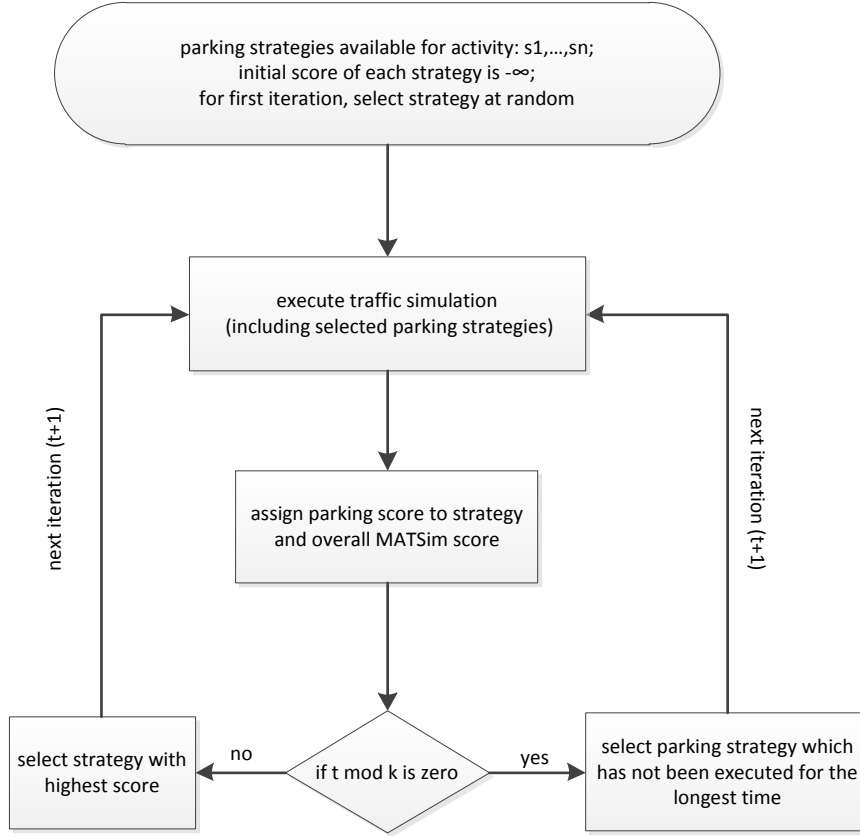


Figure 3: Selection of parking strategy for execution in next iteration

3.2.2 Utility Function and Scoring

When a strategy has been executed, all information for assigning a score to it is available (e.g. parking search time, walk time and cost). In general the utility of a parking operation of an agent i has the form as in equation 1. For example the parking cost component can contain the agent's beta which can further depend on other personal attributes (e.g. income) and also other properties (e.g. activity duration). The parking cost can also include a parking fine in case of illegal parking. The ϵ_i represents the random error term, which could be implemented efficiently as proposed by Horni *et al.* (2011).

$$U_{parking,i} = U_{P_{cost},i} + U_{P_{searchTime},i} + U_{P_{walk},i} + \epsilon_i \quad (1)$$

The parking utility is added to the overall utility function in MATSim which looks like equation (2).

$$U_{plan,i} = \sum U_{travelTime,i} + U_{travelCost,i} + U_{performActivity,i} \dots + \sum U_{parking,i} \quad (2)$$

By doing so, similar to the approach taken in Waraich and Axhausen (2012), a feedback about the parking situation is given to the overall evolutionary algorithm in MATSim. E.g. if an agent gets a bad score for parking at a certain destination, the plan in MATSim gets a bad score and may be replaced over time with a plan, which either changes the travel mode or if possible the location of the agent (if secondary location such as shopping).

3.2.3 Parking Policy Change Example

In the following we give an example, how a policy change might be evaluated with the proposed parking search model (see Figure 4). Let us assume, that an agent has a free company provided parking initially and therefore has just one parking strategy assigned, as there is no need for him to look for other options (using the company parking is the best parking option). Now the company may decide to change its parking policy and to not provide free parking any more to employees. Due to the change in parking policy, one can now model the agent differently as it has now several parking strategies available, from which the parking model needs to find the best strategy. One option for the agent might be to continue using the company parking and paying a fee. The second option might be to look for cheaper on-street parking and the third one to consider off-street parking. The proposed algorithm would evaluate all three options and find the solution, which maximizes utility. If all options are bad for the agent, the agent might also try switching travel mode for example to public transit to improve its utility.

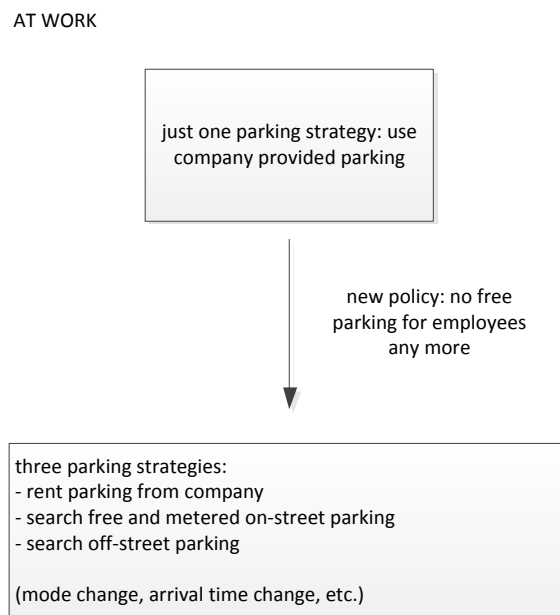


Figure 4: Example for parking policy change

4. Discussion

4.1 Strategy Evaluation

Both PARKAGENT and SUSTAPARK try to assign the most suitable parking type to an agent by running the simulation just once: For example in PARKAGENT the agent first tries finding an on street parking and if it does not find any on-street parking for 10min, it drives to a paid off-street parking. Although this approach might give as output the correct parking type choice (agent uses a paid off-street parking, as no on-street parking is available), it gets the search time wrong: A person which gets home late, will learn over time, that probably it is best for him to drive directly to an off-street parking, as in the scenario all parking places are occupied during the night. For such a person the parking search time should be zero, but in the implementation the search time is at least 10 min. This argument also holds for the SUSTAPARK model, which also tries to capture the parking type with just one run, by switching between strategies and also gets the search time wrong (although similarly it might get the selected parking type right). This problem was also recognized by Steenberghen *et al.* (2012), where it is mentioned that although an addition of a

parking garage in SUSTAPARK does reduce walking distance, the search time of the agent does not. This problem is just a consequence of the fact, that the strategies are executed in sequence rather than ran separately for themselves. The proposed algorithm in this paper avoids this problem, by evaluating all strategies separately several times over the iterations. This approach could also be used by the existing models to avoid unrealistic/too high search times.

4.2 Utility Function

At the moment the score assigned to each parking selection is just added to the overall score of the agent's daily plan in MATSim. Although by doing so, MATSim can react to parking bottlenecks, e.g. by changing travel mode, this score could be used more effectively, if the replanning modules in MATSim would make use of it. For example: Instead of just randomly changing the travel mode of a trip, such a replanning module could change the mode of such trips with higher probability, which have a consistently bad parking score (indicating, that no favourable parking option to the agent is available at the given destination).

Although, we did not assume any specific search strategy in this paper, the individual utility function of the agents gives a good starting point to create new search strategies, e.g. if a parking option A with a high cost is available close to the destination and a parking option B with a medium cost is available at medium distance, one might look for free one-street parking, while keeping option B as a last resort and trading off with option A. This means one can continue searching on-street as long as the disutility of reaching B from the current location is still lower than the selection of option A.

4.3 Simulation Detail vs. Performance

The PARKAGENT and SUSTAPARK models are quite detailed, a level of detail which cannot be achieved by the proposed parking search model, unless underlying micro-simulation of MATSim is changed. Although no simulation time numbers can be found in PARKAGENT, it says that a "practically unlimited number of drivers" can be simulated. The reason, why one can believe this statement, is that PARKAGENT does not have a complex traffic simulation such as MATSim but therefore also lacks some essential features like mode choice. In SUSTAPARK a run time of 6 hours is reported for 14'000 agents, but SUSTAPARK it is also more complex on both the parking search and overall traffic simulation side than PARKAGENT.

As one cannot have both detailed modelling and good performance, our proposed model also has to make trade-offs. Whereas the overall traffic simulation in MATSim has far more features than SUSTAPARK, the modelling on the roads is less detailed than both in PARKAGENT and SUSTAPARK. This leads to better performance especially for large scale scenarios with millions of agents on high resolution networks (Waraich *et al.*, 2009; Dobler and Axhausen, 2011).

Waraich and Axhausen (2012) is left out of the discussion above, as it does not contain parking search but only parking choice. There might also be use cases for this simulation, where parking search is not required, but only parking capacity constraints need to be accounted for. In such cases Waraich and Axhausen (2012) has possibly a better performance than the proposed parking search model in this paper.

Although introducing parking search strategies through within-day replanning into MATSim is additional computational burden, parallel event handling during replanning is available, which allows usage of several processors/threads of the computer. Furthermore the user can reduce the computational burden by taking boundary conditions of the system into account. E.g. if one knows that an agent has a private parking available, there is no point to add strategies for street parking search, etc. as this would just increase the time without adding any quality to the model.

5. Conclusions and Future Work

The proposed parking search model is the first to find optimal parking according to utility maximization theory, which can also influence choice mode and other long-term decisions of agents based on local parking conditions. Furthermore we have proposed an algorithm, which is able to evaluate parking strategies avoiding overestimation of parking search time.

At the moment the implementation of this algorithm and its application on a real-world scenario is being prepared for the city of Zurich. Special attention is given to individual attributes, so that for the first time parking search components dependent on personal attributes, such as income or age of agents are used in the micro-simulation. At the moment, it is unclear, how much influence such individual heterogeneity has on the overall traffic system and therefore this needs to be tested.

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