Location Choice for Shopping and Leisure Activities Implemented in the Activity-based Multi-agent Transport Simulation MATSim

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Abstract

This paper presents the concept and implementation of the MATSim (Multi-Agent Transport Simulation Toolkit) location choice module for shopping and leisure activities and shows first simulation results for the Zürich region of Switzerland using more than 60,000 people and 7,800 shop or leisure activity locations. MATSim is designed to handle large-scale scenarios. Thus, computational efficiency, that is fast convergence to a Nash Equilibrium, while maintaining behavioral precision is a fundamental objective. We show that to achieve this goal Hägerstrand's time-geographic approach can be incorporated easily and consistently into MATSim and into disaggregated location choice simulations in general. Our novel time-geographic algorithm, tailored for the use in MATSim, is derived from a potential path area algorithm. It is extended to handle chains of multiple shop or leisure activities between two anchored activities (i.e., those with fixed start times, durations and locations) by using recursion.

To improve both the behavioral precision and the stability of our model, we show how time-dependent capacity restraints can be incorporated explicitly into iterative disaggregated location choice simulations, as capacity restraints for activity locations have an effect on people's location choices, similar to the effect of road capacity restraints on people's route choices. To our knowledge, to date, only static activity location attributes, such as opening hours and loca-

tion size, are incorporated explicitly in disaggregated location choice simulations and thus our contribution is also meant to open up a discussion.

Keywords

location choice, Time Geography

1   Introduction

Behaviorally precise and computationally efficient modeling of people's location choice for shopping and leisure activities clearly is of great importance for not only science but also economy, where different disciplines such as transportation planning, marketing and geography, to name a few, benefit from improved location choice models. However, descriptive empirical data for shopping and leisure activity location choice exists only sparely, and moreover, they are spatially not easily transferable. Thus, behaviorally precise models have to include the underlying factors which drive the decision process, which is, at the end of the day, the objective of MATSim and its location choice module in particular. For the time being, our main focus is on the design of an efficient and easily parameterizable location choice module for large-scale scenarios.

MATSim, as a realization of an iterative utility maximizing method in transport planning, assumes that every person, while interacting with other persons in the infrastructure, has the goal to optimize its individual day plan by performing route, time and location choice until the system as a whole reaches a relaxed state, i.e. a *Nash Equilibrium*. The search space defined by the three above mentioned dimensions (route, time, location) is huge for real world scenarios and thus a relaxation process based on exhaustive search is expected to show impractically slow convergence. The paper addresses how location choice is instead performed based on local search by binding together location choice and time choice. This is realized by integrating a time-geographic approach based on Hägerstrand (1970) and Landau *et al.* (1982). Combining micro-simulation and time geography our work follows a similar concept to that in PCATS (e.g. Kitamura *et al.*, 2005) but with an emphasis on computational efficiency.

A person's choice of a shopping or leisure location is driven by a large number of influencing factors, which can be categorized as the persons' attributes, the activity locations' attributes and contextual or situational attributes (e.g. Simma *et al.*, 2002).

The large number of these factors is reflected in the number of articles concerning different attributes relevant for location choice. In addition to others, the impact of travel time and travel distance, store size and number of employees, range of products, price level and quality level have been investigated extensively (see for example Oppewal *et al.*, 1997; Brunner and Mason, 1968; Lademann, 2007).

To our knowledge, however, what has been neglected in simulations of location choice and in empirical surveys is the explicit treatment of capacity restraints of activity locations, which are induced by, for example, a limited number of parking spaces or tables in a restaurant or the availability of sales staff. In the next section, we present a method to include efficiently computable and easily parameterizable capacity restraints where their explicit incorporation increases both the accuracy and the stability of our algorithm by ensuring the boundary condition

of not having unrealistically overcrowded activity locations which is a theoretically possible but an infeasible state of our computation (e.g. Vovsha *et al.*, 2002).

Generally speaking, our model handles shopping and leisure activities the same way. While the leisure decision process for the time being only incorporates travel time and opening hours, the choice for a shopping location also depends on capacity restraints, where in principle capacity restraints can replace the explicit incorporation of opening hours. This approach is chosen as the strength of the capacity restraints vary much more between different leisure facilities than between different shopping activities. Thus, as soon as high resolution and large-scale data for leisure activities is ready to use, the capacity restraints can be incorporated for the leisure activity location choice too.

This paper is organized as follows. The following section, *Method*, provides an overview of MATSim, discusses the methodical implications and constraints of incorporating the time-geographic approach in MATSim and presents the implementation details of the location choice module. Furthermore, the scenario used to validate our module is described there. The next section, *Results*, presents the details of the four configurations of the simulation scenario. Conclusions and ideas for future research are presented in the last section.

2 Method

As mentioned, the base model of our location choice module is the activity-based Multi-Agent Transport Simulation toolkit, MATSim, whose main features are presented below.

2.1 MATSim

MATSim is an activity-based, easily extendable multi-agent simulation toolkit implemented in JAVA 1.5 and designed to handle large-scale scenarios. It searches iteratively for a Nash-Equilibrium (Nash, 1951) in terms of some reward that persons get by executing the activities of their daily activity chains. Thus, MATSim is a utility maximizing model as opposed to a sequential rule-based decision making model (e.g. Timmermans, 2001). In MATSim, the daily activity chains are represented by *plans* which consist of assigned scores determined by the activities, which in turn, are defined by the following attributes: start time and duration, location, position in the chain, group composition, route to the activity location and travel mode used to go to the activity location. Plans represent the *planned* or *desired* daily routine of an agent and thus do not necessarily reflect the *actual* situation on the simulated infrastructure.

The configuration of MATSim, as it is used at the moment, follows a variant of an evolutionary algorithm, more precisely an evolution strategy (see Rechenberg, 1970), where daily plans represent the individuals. The search space is defined by the three dependent dimensions: activity timing (i.e. start time and duration), location of shopping and leisure activities and the route between two subsequent locations.

In more detail, this means that in every iteration a *replanning step* is performed. This includes for every agent the probabilistic selection of one plan of its memory for execution in the next iteration and possibly modification before the execution. The selection probability is given as $p \propto e^{\beta S_j}$, where S_j is the score of plan j and β are empirical constants. Plan modification is done for a predefined share of the agents (usually 10 %). Time choice is done by either using local random mutation (e.g. Balmer *et al.*, 2005; Raney, 2005) or an additional inner loop of optimization based on a genetic algorithm (Meister *et al.*, 2006). For route choice, the A-star algorithm (Lefebvre and Balmer, 2007) is used. For the location choice of shopping and leisure activities (in our case *secondary activities*), Hägerstrand's time-geographic approach is followed as described below where we introduce our novel module which assigns locations to chains of secondary activities by making a choice from a recursively adapted implicit spatio-temporally constrained choice set.

The JAVA re-implementation of the micro-simulation in MATSim presented in Cetin (2005) provides exact event information (activity start or end time etc.), which enables the precise

computation of activity location load as described in more detail in the section *Capacity Restraints and Scoring*.

The MATSim utility function is compatible with micro-economic foundations. It is the sum of utilities of all activities plus the sum of all travel (dis)utilities (see Charypar and Nagel, 2005). With the implementation of location choice, a penalty term for overcrowded activity locations and a term, indicating that agents (in our model) generally associate a higher utility with a bigger store (e.g. Carrasco, 2008) is added (see section *Capacity Restraints and Scoring*).

For further details about MATSim please refer to Balmer (2007); Balmer *et al.* (2006, 2004).

2.2   Integrating the Time-geographic Approach: General Remarks

Home, work and education are defined as primary activities in our model and thus their activity locations are taken as fixed. Location choice for *secondary activities* (in our model, shopping and leisure) has to be implemented based on local search for efficiency reasons which is done by following Hägerstrand's time-geographic approach where the choice set for secondary activities performed between two primary activities is constrained by space-time prisms. As the temporal dimension of the primary activities and the activity duration of secondary activities are changed during in the course of the iterations, the trading of travel time against shorter activity participation at a more attractive but farther location (not covered by the travel time budget) is included implicitly in our model.

Our work extends the GIS-based algorithm introduced in Scott (2006). This shortest path-based algorithm serves the purpose of constructing an explicit location choice set for secondary activities performed between two primary activities, where the algorithm is designed to handle exactly one secondary activity at a time. This algorithm is tailored in the sense that we construct an implicit choice set for chains of arbitrary length for shopping and leisure activities by using it recursively and by only checking the feasibility of an alternative in terms of the given travel time budget after it is randomly and tentatively chosen as an activity location.

The behavioral interpretation of our model has the well known short-comings of all utility-maximization procedures. Besides this, the iteration process with respect to location choice seems quite realistic when modeling a person being new to a place, which after an exploration phase reduces, that is optimizes, his/her travel time budget.

2.3 Implementation

Implementation of the *secondary location choice module* in MATSim has two main foci: (i) the construction of the constrained location choice set as part of the agents' re-planning rule based on Scott (2006) and (ii) the definition of the capacity restraint function as an extension of the given scoring function that measures the success of an executed plan.

2.3.1 Construction of Constrained Location Choice Set

The algorithm proposed in Scott (2006) works as follows: Assume that we know the locations and the planned start and end times of the primary activities and the duration of the secondary activity. In turn, this means that the travel time budget t_{tb} is defined. The construction of the travel time based potential path area (PPA) algorithm has two stages. First, a distance-based approximative subset of links for possible inclusion in the PPA is chosen. Second, the network accessibility of the chosen links in terms of the given travel time budget is computed to identify the links of the PPA.

In detail, in the first step, all links lying inside the circle whose center is the point equidistant to the two primary locations and with radius $(t_{tb} \times v)/2$ are included in the subset of potential PPA links. v is chosen as a reasonable speed for that region. Activity spaces usually are approximated by elliptical regions. But, the existence of efficient implementations of spatial query methods for circular regions makes it advantageous to use a circle whose diameter is equal to the major axis of the underlying ellipse.

As mentioned above, a MATSim plan describes the planned course of activities in space and time. That is, for both primary and secondary activities, the planned locations and the desired start and end times are specified in principle. As for the the above algorithm, we take the locations and the start and end times of the primary activities as fixed whereas for the secondary activities only the desired durations are taken as fixed. Given the two primary activities and n secondary activities with planned activity durations $duration(act_{si})$, the rough idea is the following.

After having constructed the subset in the first stage, a location is chosen randomly out of it and the travel time is reduced by the time it takes to travel from the first primary activity to that location in the loaded network. As long as the total travel time is smaller than the travel time budget, the algorithm is applied recursively where the recently set secondary activity location is taken as the first anchor point. In case that the travel time budget is exceeded, the algorithm starts from beginning-that is, with the choice set generation for the first secondary activity, but with a different random seed. After a certain number of failed trials, the algorithm is initialized with a reduced travel speed (arbitrarily set to 10% reduction), as it is supposed that the assumed

average travel speed for that region has been set too high. The above mentioned number is fixed for the time being but could be made adaptive to the size of the current choice set. Termination of the algorithm is guaranteed by a random choice within the choice set after a certain maximum number of failed trials.

More precisely, the skeleton of our algorithm is given in pseudo-code as follows:

1: Set $act_1 \Leftarrow$ first primary activity and
2: $act_2 \Leftarrow$ second primary activity
3: Compute the total travel time budget as: $t_{tb} \Leftarrow starttime(act_2) - endtime(act_1) - \sum_{i=1}^{n} duration(act_{si})$
4: Set the total travel time $t_t \Leftarrow 0$
5: **for** $i = 1$ to n **do**
6:      Construct the subset of stage 1 for act_1 and act_2
7:      Randomly choose a location from the subset and set it as the location for act_{si}
8:      Update the total travel time: $t_t \Leftarrow t_t+$ time to travel from $location(act_1)$ to $location(act_{si})$
9:      **if** $i = n$ **then**
10:         $t_t \Leftarrow t_t+$ time to travel from $location(act_{sn})$ to $location(act_2)$
11:     **end if**
12:     **if** $t_t > t_{tb}$ **then**
13:         Start on line 1 again but using a different random seed
14:     **end if**
15:     $act_1 \Leftarrow act_{si}$
16: **end for**

where $location(act_i)$, $starttime(act_i)$, $endtime(act_{p1})$ means the location and start and end time of activity i respectively. t_t is the total travel time.

On line 7, the choice of an alternative from the constrained choice set is, for the time being, drawn randomly as opposed to choosing an alternative with probability dependent on its utility, which is expected to add another speedup in terms of the number of needed iterations of the relaxation process. The reason for this approach is twofold:

1. The utility of performing an activity is in MATSim dependent on the choices of the other agents and thus not defined in an exact way in the replanning phase.

2. Making a choice weighted by the attributes independent of other agents' choices requires the generation of an explicit choice set, which is, for the time being, avoided by our algorithm for computational efficiency, but which is stated as a point for future work (see below).

Possible future improvements of our algorithm are the following:

- The chronological ordering of the secondary activities is independent of the priorities of the activities. Our algorithm can be easily extended to handle the activities in the order of their priorities, where as long as we do not know the actual priorities the activity duration could be taken as an indicator.

- Routing is done during stage two of our algorithm, where a spanning tree is constructed. If computer memory is not the limiting factor, the spanning trees can be stored to recursively generate an exact and explicit choice set.

2.3.2 Capacity Restraints and Scoring

The activity location load, computed for time bins of 15 minutes, is derived from events that are delivered by the micro-simulation. After termination of the micro-simulation the executed plans get assigned scores (e.g. Charypar and Nagel, 2005) that respect the opening hours of the facilities. With the inclusion of the location choice module, a penalty term for crowded facilities is added, where the value of the penalty is computed with the well known Bureau of Public Roads capacity restraint function which is usually employed in static assignment methods. As persons clearly do not perceive an equal attractiveness for all stores of the universal choice set, we add an attractiveness factor logarithmically depending on store size to the scoring function, where the store size is available for all stores from the official census of workplaces (see Swiss Federal Statistical Office, 2001). Our model allows us to set a time-dependent capacity whose parameter setting is discussed in section *Parameter Setting*. Thus, the utility function is as follows, where its parameters are described in the section *Parameter Setting*:

The utility function of MATSim is the sum of all utilities U_{act} of all activities plus the sum of all travel disutilities U_{trav}:

$$F = \sum_{i=1}^{n} U_{act}(type_i, start_i, dur_i) + \sum U_{trav}(loc_{i-1}, loc_i)$$

where $type_i$, $start_i$ and dur_i is the type, the start time and the duration of the activity respectively. The utility of an activity is defined as follows:

$$U_{act,i} = (U_{dur,i} + U_{wait,i} + U_{late.ar,i} + U_{early.dp,i} + U_{short.dur,i}) \times f_{attr} \times Max(0, (1 - f_p))$$

where $U_{dur,i}$ is the utility of performing the activity, $U_{wait,i}$ denotes the disutility of waiting, $U_{late.ar,i}$ and $U_{early.dp,i}$ gives the disutility of late arrival and early departure respectively. $U_{short.dur,i}$ is the penalty for performing an activity for a too short time. f_{attr} is the store size

dependent attractiveness factor mentioned above and f_p is the penalty factor further discussed in Section *Parameter Setting*.

2.4   Simulation Scenario

The initial demand of our simulation scenario is derived from the Swiss census of population (Swiss Federal Statistical Office, 2000) and the national travel survey for the years 2000 and 2005 (Swiss Federal Statistical Office, 2006). For our scenario we draw a 10% sample of Swiss MIV that crosses the area delineated by a 30 km radius circle around the center of Zürich (Bellevue). The same initial demand, but additonally including border crossing traffic, is used in Balmer *et al.* (forthcoming). The activity location data set is computed from the Federal enterprise census 2001 (Swiss Federal Statistical Office, 2001). The network is an updated and corrected version of the Swiss National Transport model (Vrtic *et al.*, 2003). A similar setting is used in Balmer *et al.* (2008) where public transit and border crossing traffic are included additionally. A normal working day is simulated. In detail, the following data form the basis of our scenario:

- Total number of agents simulated: 61,480

- Zürich circle: total number of facilities for ...

    - **shopping** activities: 1,162
    - **leisure** activities: 6,662

- Total number of activities performed for ...

    - **shopping**: 25,896
    - **leisure**: 40,971

- Total number of persons doing ...

    - **shopping** activities: 22,639
    - **leisure** activities: 32,229
    - **shopping** or **leisure** activities: 42,962

- Activities ...

    - **primary**: home, work, education
    - **secondary**: shop, leisure

- Average number of trips per agent: 3.35

- Network: number of ...

    - **directed links**: 60,492

    - **nodes**: 24,180

The locations for the secondary activities are initially assigned randomly within the Zürich circle. The usage of capacity restraints in combination with the spatial characteristics of the population sample described above restricts location choice to the Zürich Area.

2.5 Parameter Setting

A number of parameters are used in our model and in the scenario. However, they are not empirically verified.
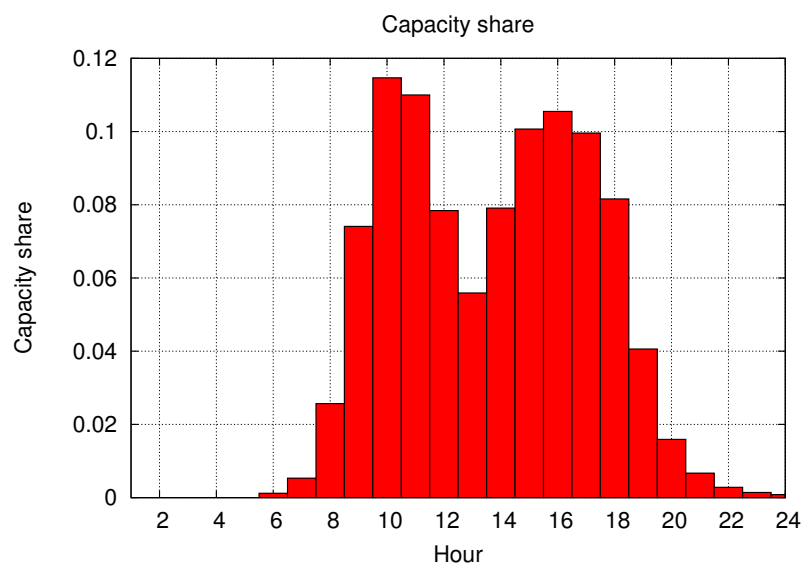
- The travel speed v used in the first stage of the algorithm is computed from the census where an average trip distance of 10.3 km and an average trip duration of 24.4 minutes for a normal working day regarding all trip purposes is given. Thus, a travel speed of 25.3 km/h results. As our simulation area is an urban region, the computed value is expected to be slightly too large. Nevertheless a reserve of 20 % is added to avoid too many false negatives.

- Time-dependent capacity values for shopping facilities can be assigned for every single facility. However, for the sake of demonstration, the capacities are derived from shopping trip information given in the national travel survey 2005 (see Figure 1). The aggregated daily capacity is set, such that the facilities of the Zürich circle (where location choice is done) satisfy the total daily demand with a reserve of 50 %. The capacity of a facility is logarithmically dependent on its size, which is given in 5 categories.

- Our BPR-like capacity restraint function looks as follows:

$$f_p = \alpha \times \left(\frac{load}{capacity} \right)^{\beta}$$

    with $\alpha = 1/1.5^{\beta}$, $\beta = 5$. f_p is the penalty factor which is applied during scoring as described above.

- The remaining scoring function parameters are set as described in Charypar and Nagel (2005).

Figure 1: Time-dependent capacity share

3 Results

To demonstrate the effect of applying our novel algorithm for location choice compared to random choice from the universal location choice set and to show the effects of capacity restraints for activity locations, the simulation results for the following four configurations are presented in this section:

- Configuration 1:

  - **Replanning**: Rerouting; Time choice

  - **Scoring**: No capacity restraints

- Configuration 2:

  - **Replanning**: Rerouting; Time choice; Location choice (universal choice set)

  - **Scoring**: No capacity restraints

- Configuration 3:

  - **Replanning**: Rerouting; Time choice; Location choice (universal choice set)

  - **Scoring**: Including capacity restraints

- Configuration 4:

  - **Replanning**: Rerouting; Time choice; Location choice (constrained choice set)

  - **Scoring**: Including capacity restraints

As mentioned in the section *Simulation Scenario*, all secondary activity locations are initially assigned randomly within the Zürich circle. During the replanning phase, location choice for configurations 2 and 3 is done by random choice from the universal choice set which contains the locations within the Zürich circle. Configuration 4 uses our novel algorithm, which constrains the choice set with respect to the agents' travel time budget. For configuration 1, no location choice is performed during the replanning phase.

The replanning step is performed for 10% of the agents in each iteration. No strict termination criterion exists yet for the evolutionary algorithm of MATSim. In order to show the effects of our location choice module, the scenario run is terminated after 500 iterations without having reached a relaxed state.

It is expected that applying our algorithm results in a faster decrease of the average travel times and distances and hence in a faster increase of the average plan's score than random choice from the universal choice set. The incorporation of capacity restraints is expected to slightly

increase the average travel times and distances as persons have to make an additional effort to avoid overcrowded activity locations. As described below, the simulation results meet these expectations.

As can be seen in Figure 2, for all four configurations, the objective value of the MATSim evolutionary algorithm, that is the average score, shows a strong increase during the first iterations followed by a short attenuation phase and finally a long phase of small increases. As this is the typical progress of evolutionary algorithms (see Eiben and Smith, 2003) this is strong evidence for the effective operation of the evolutionary algorithm of MATSim.

As can be seen, the major effect is caused by time choice and route choice, where the average trip travel time (see Figure 2(b), configuration 1) is strongly decreased while the average trip travel distance is only slightly decreased (see Figure 2(a), configuration 1) during the course of the iterations.

The effect of additionally performing location choice is revealed by the comparison of configurations 1 and 2. The average score is significantly higher for configuration 2 than configuration 1, which is caused by lower average trip travel times (amongst others caused by lower average trip travel distances) and higher rewards for activity participation at more attractive locations.

When comparing configurations 3 and 4, the effect on convergence of including the time-geographic approach can be clearly seen, where the effects are expected to scale with the scenario size. For both configurations, an identical scoring function is used. It can be seen that the convergence in terms of number of iterations is improved significantly for configuration 4 as it is expected that configuration 3 needs a vast amount of iterations to approach the results of configuration 4 (if the Nash Equilibrium is unique). After 400 iterations, both configurations are in the phase of small changes, where Figure 4 indicates that both approach the same Nash Equilibrium as there is a continuing reduction of the average travel distance. The reduction of configuration 3 is bigger, being caused by the larger distance from the Nash-Equilibrium to begin with.

As expected, the introduction of penalties for shopping locations increases the average travel time and travel distance (compare configurations 2 and 3). In Figure 3, it can be seen that the incorporation of capacity restraints has a substantial effect on time choice: the aggregated hourly load of activity locations is adjusted to the time-dependent capacity restraints (see Figure 3 compared to Figure 1). Furthermore it can be seen that people shorten their shopping activity due to the capacity restraints. A subject of future work is the aggregated and disaggregated analysis of the time-dependent activity location occupancy. Given that in our model capacity restraints reinforce the peaks for shopping and thus lower travel speed, separate analysis of the effects of making a detour, being stuck in traffic jams and location choice on the increased average trip travel distance and average trip travel time of configuration 3 compared

Table 1: Mean computation time (seconds) per iteration (computed using 1 CPU (Dual-Core AMD Opteron Processor 8218 with 2600 MHz and 1024 KB cache size) and 18 GB of RAM)
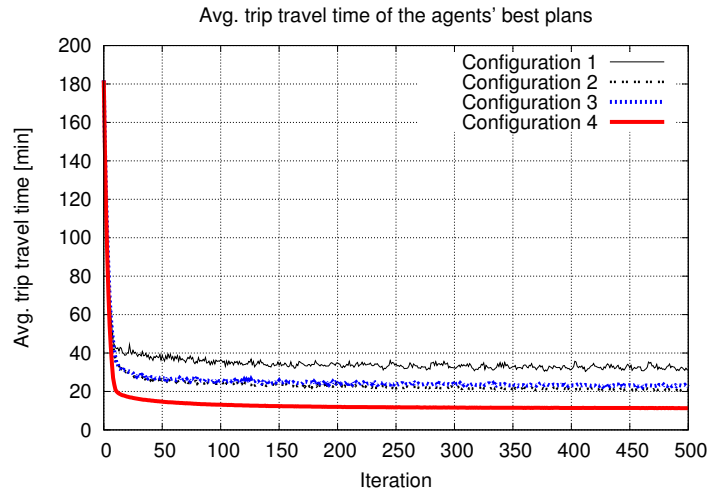
	Configuration	Mobsim	Replanning	Sum
1	Rerouting; time choice no capacity restraints	581	13	**594**
2	Rerouting; time choice; location choice no capacity restraints	498	49	**547**
3	Rerouting; time choice; location choice capacity restraints	529	50	**579**
4	Rerouting; time choice location choice improved capacity restraints	365	82	**447**

to configuration 2 has to be done. In other words, the effects of capacity restraints on time, route and location choice have to be analyzed separately.
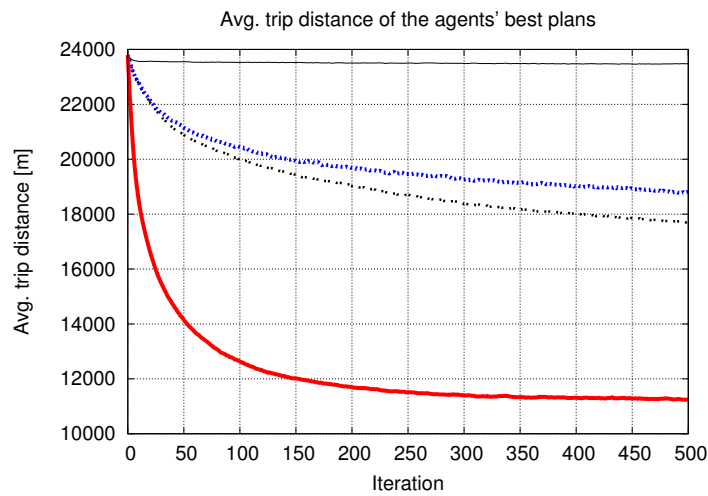
Table 1 gives the average computation times per iteration for the four configurations. It can be seen that the computation times are in general reduced by location choice (configurations 1 and 2). The reason for that is that including location choice shortens the routes which have to be handled in the micro-simulation. Furthermore, it can be seen that the additional replanning effort of configuration 4 is more than compensated by shorter micro-simulation computation times (compare configuration 3 and 4).

Figure 2: Avg. trip travel times and distances and plan score of the agents' best plan

(a) Avg. trip travel times

(b) Avg. trip travel distances

(c) Avg. plan score

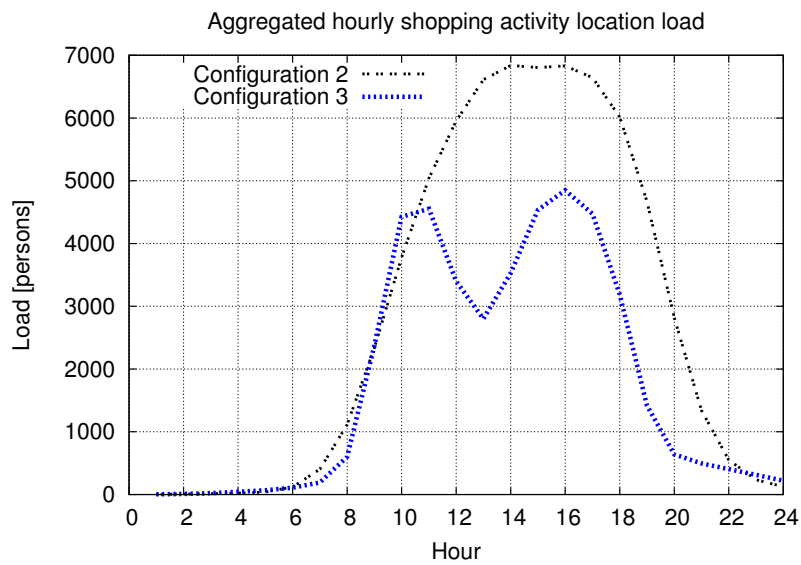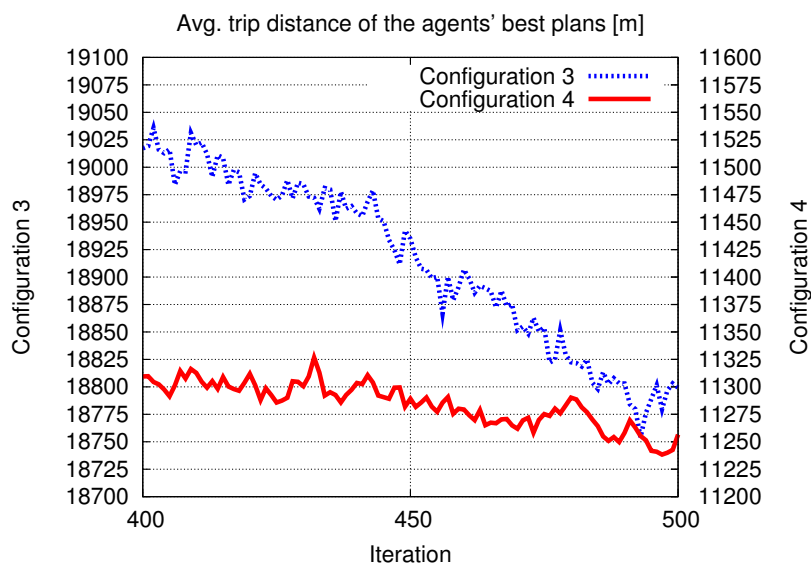Figure 3: Aggregated hourly load of the shopping activity locations

Figure 4:]

Travel distances for configuration 3 and 4 (Iteration 400-500) [m]

4 Conclusions and Outlook

Through the incorporation of location choice, MATSim is capable of modeling simultaneously time, route and location choice.

The results presented in the previous section give further evidence that location choice models of iterative micro-simulations can be advantageously combined with time geography for the sake of faster and possibly better convergence of the search process *and* reduced total computational effort per iteration. It is shown explicitly that random choice made from the universal choice set is not applicable for large-scale scenarios and improvement through the time-geographic approach is required in terms of computational feasibility which is particularly important when simulating a complete Switzerland scenario with more than 7.5 million agents and 1.7 million activity locations, which is the aim of MATSim. It is furthermore shown that the time-geographic approach can be integrated by using a simple, but efficient, recursive algorithm which successively generates an implicit choice set for shopping or leisure activities belonging to an activity chain bounded by two primary activities.

As mentioned earlier, our efficient and easily parameterizable location choice module has to be developed further in a next step. Starting with the empirical adjustment of the parameters concerning both the capacity restraints and the choice set generation algorithm, the range of attributes included in our utility function will be considerably extended, where we will draw on recent Swiss work estimating facility-specific grocery location choice models using the geo-coded national travel survey (Carrasco, 2008). As mentioned earlier, capacity restraints will be incorporated for leisure activities too, where the strength of the restraints is expected to vary much more than for shopping activities.

MATSim currently models five different activities where shop and leisure activities are defined as secondary activities. By using a more detailed specification of secondary activities in the near future the hierarchy of secondary activities to be considered when doing location choice is advantageously expanded accordingly. This can easily be incorporated into our algorithm.

In the near future, time-dependent aggregated and disaggregated facility usage will be the subject of further analysis, where the MATSim location choice module is designed to be easily extendable to provide capabilities for time-dependent catchment area analysis, similar to the common spider analysis performed for network links.

In conclusion, it can be said that the combination of micro-simulation and time geography has again shown to be a promising approach combining efficiency, behavioral precision and flexibility in terms of feature integration.

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