Simulating urban transport for a week time horizon

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## Contents

1. **Introduction** 3

2. **State of the art** 4

3. **Week time horizon using MATSim** 5

   3.1 Base scenario 6

   3.2 Weekly model overview 6

      3.2.1 Initial demand modeling 6

      3.2.2 Iterative process 7

   3.3 Optimization strategy 7

      3.3.1 Full week iterations with end-of-week re-planning and scoring 8

      3.3.2 Daily iterations with end-of-day re-planning and scoring 8

      3.3.3 Full week iterations with end-of-day re-planning and scoring 9

      3.3.4 Full week iterations with within week scheduling 10

      3.3.5 Continuous planning 11

   3.4 Activities scheduling for a week 11

      3.4.1 Definition of weekdays and generation of weekends 12

      3.4.2 Definition of a full week schedule 12

      3.4.3 Definition of fixed and floating activities 12

      3.4.4 Continuous activity scheduling 13

4. **Conclusions and outlook** 13

   4.1 Methodology 13

**Bibliography** 16
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Abstract

MATSim is a large-scale multi-agent, activity-based transport simulation model. It can simulate each person in a urban area, managing millions of agents in reasonable computation times. Besides supply information, MATSim needs a planned activity schedule for every person as input data. Its time horizon is one day, and the activity-trip chains have to be fully defined before each simulation (start-time, duration, location, trip mode, and sequence for the entire day). MATSim scores the simulation, mutates agents’ plans and executes a new simulation many times, optimizing the macroscopic indicators and reaching user equilibrium conditions. However, the one day time horizon is a hard restriction for studying current transport planning challenges using MATSim. Recent studies show that the behavioral variety of travelers can not be well analyzed with only one day simulation results. Usual analysis procedures, like clustering the population according to their travel behavior, need multi-day information to account for intra-personal variability. Furthermore, longer time horizons allow to include restrictions like time and money budgets, and to simulate individual mode choice over time, identifying mode clienteles. Developments of advanced time consumption travel models require observations of at least a week for calibration purposes, because a complete cycle of work and leisure must be included. In conclusion, time consumption decisions that humans take inside a day depend on individual and collective behaviors. These behaviors only can be simulated and analyzed with longer term models.

Understanding the importance and pertinence of simulating transport with a multi-day time horizon, this paper discusses how MATSim can be expanded to execute one week time activity plans. The discussion is conceptual because no full implementation has been developed yet. The paper emphasizes two key aspects of the expansion: optimization strategies, and the generation of weekly plans. For each aspect alternatives are proposed, analyzed and compared. The impact of the proposed development on each step of the simulation process is taken into account. The problem of scheduling and re-scheduling and its relation to computational time in large-scale scenarios has to be kept in mind for weekly plans even more so than for daily plans. Activity plan generation procedures ranging from simpler, but faster methods to advanced ones, involving
econometric approaches or complex mental processes, are compared. Concepts like fixed and floating activities, activity agendas or shared activities (within households or with social networks) have to be evaluated for their impact. Furthermore, several options for performing the optimization of plans are presented, highlighting their advantages and disadvantages (e.g. full-week re-planning or end-of-day re-planning). Computing time and memory consumption are taken into account according to previous measures and expected indicators. It is easy to realize that the mobility simulation (traffic flow) module does not need significant changes when the total time is modified. However, if a within-week re-planning strategy is implemented modifications in this module and its implications are explained and evaluated as well. The paper concludes with a proposed methodology for developing this MATSim extension.

Keywords
Transport simulation, Week time horizon, Multiagent, Activities Scheduling, Transport optimization

Preferred citation style
1 Introduction

MATSim is a platform for simulating transport employing an activity-based, multi-agent approach. The software is designed to manage millions of agents; simulating their transport requirements in a common and limited transport supply. Each person in the region of interest must be modeled with socio-demographic characteristics and activity plans. In the beginning each agent (model of a person) starts with one schedule, called the initial demand. On a transport network a mobility simulation based on agent queues is performed. With these results, it is possible to know for each time step in the time horizon, what each agent is doing, and where. Within an evolutionary algorithm, this mobility simulation is repeated many times, scoring each agent and modifying some of their plans. This iterative process then gradually approaches user equilibrium conditions. The current time horizon of MATSim is one day. It means that initial demand plans are for one day; the agents manage daily schedules; the total time of the mobility simulation is one day; daily plans are scored; and the re-planning strategies are designed for mutate one-day schedules.

As MATSim (Meister et al. (2005)), activity-based travel demand models are based on daily activity chains at the most. Time use and urban transport studies are focused on a one day time horizon. The majority of travel diaries or households travel surveys are designed to cover this period of time. However, in the study of current transport planning challenges, this one day time horizon is a hard restriction. Recent studies present that the behavioral variety of travelers can not be well analyzed with single day simulation results. Usual analysis procedures like clustering the population according to their travel behavior need multi-day information to account for intrapersonal variability (Schlich (2004)). Furthermore, longer time horizons allow to include restrictions like time and money budgets, and to simulate individual mode choice over time, identifying mode clienteles (Kuhnsmhof and Gringmuth (2009)). Developments of advanced time consumption travel models require observations of at least a week for calibration purposes, because a complete cycle of work and leisure must be included (Jara-Diaz et al. (2008)).

The objective of this paper is to investigate how MATSim can be expanded to simulate and optimize weekly urban transport. The discussion is conceptual because no full implementation has been performed yet. First, the state of the art is presented followed by the MATSim modular structure review. Then, the paper emphasizes two key aspects of the expansion: optimization strategies, and weekly activity scheduling. For each one alternatives are proposed, analyzed and compared. First the estimated impact on the current MATSim implementation is taken into account. Then, comparisons of expected computational time and memory consume of the alternatives are performed, using the current Singapore scenario statistics. This model is being developed by the Module VIII of the Future Cities Laboratory for Singapore. Finally, the paper concludes with a proposed methodology for developing this MATSim extension.
2 State of the art

Understanding the necessity of simulating longer time horizons and being aware about the lack of multi-day information, procedures for generating accurate weekly time use information have been being developed. Munizaga et al. (2011) present a method for generating weekend schedules of a population given a weekday survey and several observations of weekend schedules. The method generates weekend schedules for each person in the survey population as a convex combination of some of the observed weekend schedules (a convex set).

Doherty et al. (2002) develops a complex algorithm for scheduling activities for a week, making decisions on-the-fly. Starting with a skeleton of routine activities, the model deals with planned activities, random events (e.g. extension of activities or travel times), and time windows for planning non-routine activities. The method can be adapted for execution by the MATSim mobility simulator, but one expects it to perform poorly in large scale scenarios, due to its complexity.

Kuhnimhof and Gringmuth (2009) present an algorithm that consists of two steps. Starting with the information of a multi-day, multi-period travel survey, an activity agenda is assigned to each agent according to their socio-demographic attributes. It is called an agenda because the activities don’t have specific information like location, start time or mode of travel, only preferred values and priority (that depend on their type and duration). The second step applies a greedy algorithm to generate the weekly schedules. Although the algorithm is simple, non-conventional restrictions, like time budgets, are taken into account. The more important point of this model is the accurate demand results. The problem is that, as the scheduling process is performed before the simulation, unexpected events can not modify the activity plans of the agents.

With the introduction of need-based theory by Arentze and Timmermans (2006), Märki et al. (2011) drops iterative optimization, that builds on stochastic user equilibria, and moves to a continuous planning approach. With this model agents take decisions on the fly according to their primary needs and the effects that the performed activities have on the rest of their needs (secondary). Early implementations show capacity of calibration and reasonable computation resources when these ideas are implemented in large-scale scenarios using a distributed environment. The problem is that the input information required for executing it is massive. For example daily or weekly increasing and decreasing needs rates have to be defined for each type of activity, and each corresponding period. But not all the agents have the same life cycles, therefore, not all the agents present the same rates.
3 Week time horizon using MATSim

The Figure 1 represents the MATSim-T process. From information obtained about a specified case study an initial demand must be obtained. It is composed of a list of activity plans where each agent has at least one plan assigned. For generating this list MATSim needs (i) socio-demographic attributes of each agent; (ii) information about the places where these people perform the activities (facilities); (iii) information about the transport supply like a road network, public transport schedules, traffic lights and road pricing; and (iv) which activities, when and where the population wants to perform.

Then, an evolutionary algorithm is executed. First a mobility simulator, based on queues of vehicles, processes all the agents in a shared and limited transport supply. Then, the mobility results are scored and re-planning modules mutate some agents’ plans. The agents save in their memories a fixed number of plans; upon reaching this limit through plan generation by re-planning modules, the lowest scoring plan is discarded. To ensure a score for each plan, a plan is always executed and scored once generated by re-planning. If an agent hasn’t had any new plans generated during re-planning, a plan is stochastically selected from their memory, the likelihood of selection being proportional to each plan’s score. Selected plans are executed again by the mobility simulator. This process is repeated as many times as needed to reach user equilibrium conditions. User equilibrium means that the average score of all the agents’ plans doesn’t increase significantly when the plans are mutated. Finally, as it is possible to know the location and the activity of any agent at any time with the result of any mobility simulation, analysis tools can be used for presenting aggregated or disaggregated mobility statistics. More details about the MATSim process can be found in Balmer (2007) and Rieser (2010).

Figure 1: MATSim process (3 steps)

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1Multi-Agent Simulation Toolkit, MATSim-T, MATSim Toolkit and MATSim are typically used synonymously.
3.1 Base scenario

The module VIII of the Future Cities Laboratory is simulating Singaporean urban transport using MATSim. A 25% sample was executed with 670720 agents (travelers and public transport drivers), up to 5 plans per agent, more than 150000 locations, 3.3 activities per plan, a road network with almost 80000 links, and a public transport system with 362 lines and more than 1000 routes. For re-planning purposes four modules were employed: Time allocation (Random), Re-route (Best response), Subtour mode-choice (Random), Secondary activity location mutator (Best reponse where the proximity is based on a time budget). The simulation was executed on 40 Intel Xeon 2.4GHz cores (fully used in the replanning stage), 80 GB of RAM (full population with several plans per agent needed 19.3 GB, the mobility simulator used up to 45 GB) and the computation time was 48 minutes per iteration on average (Figure 2).

Figure 2: Computation times

3.2 Weekly model overview

Now, as the aim of this work is to simulate a week time horizon, overviews of the extensions in the initial demand modeling, and in the iterative process are presented below.

3.2.1 Initial demand modeling

In the transport supply information it is important to model differences between weekdays and weekends in the public transport schedules, traffic lights and road pricing. The current facilities model allows different opening times for different days in the week. If it is required, due to new optimization strategies or new ways of scheduling activities, new attributes would have to be added to the persons in the population. As a key point, more information for establishing weekly
transport demand will be needed. It is possible that the structure of the plans will have to be changed. In the section 3.4 strategies for generating these weekly schedules are treated.

3.2.2 Iterative process

Although, in the first instance no changes have to be made to the mobility simulator (it only has a different total time), within week re-planning approaches would have a big impact on its implementation. The scoring process shouldn’t present any change. An executed weekly plan of an agent would be scored in the same way as a daily schedule (utility of performing activities plus disutility of traveling). Re-planning modules could have to be adapted to mutate weekly plans. For more details, alternatives to optimize the transport problem with a week time horizon are discussed in the section 3.3.

3.3 Optimization strategy

Either for user equilibrium or system optimum conditions, the optimization strategy in a transportation problem is the most critical aspect. The macroscopic transport measurements must arrive to stable values demonstrating that the transport demand is being satisfied in a limited transport supply. As it was mentioned before, MATSim uses an evolutionary algorithm to reach this state. The city transport must be simulated many times, scoring the result and applying changes to the plans of the agents after each iteration. The score depends basically in the time expended performing activities (utility), the time expended traveling (disutility) and some penalties according to fixed schedules (late arrivals). A commonly used utility function is described by Charypar and Nagel (2005).

Computational time is the most important issue. With a specified number of agents, it varies according to the quality of the initial demand and the type and quantity of the re-planning strategies. Although the mobility simulator is parallelizable, it has an optimum number or threads that depends on the network morphology and ranges from 3 to 5 threads, and then, given an appropriate computation server, its computational time is only related to the population size. As the initial demand depends on the quality of the given information, the selection of the re-planning strategies depends on it as well. You have to apply re-planning strategies to the aspects in which your initial demand is weak. Random modules present faster processing times, but more iterations are needed. Best response modules need more time per iteration, but the accurate mutations of the plans allow to reach equilibrium conditions in less iterations. The re-planning modules are fully parallelizable due the independence of agent plan mutation. Servers with more cores allow to mutate more agents at the same time.

Memory is an additional important constraint. Some MATSim objects will require more memory
like the Transit Schedule or the Facilities. But the most critical memory issue is the size of the plans. Currently, agents have a memory where they save up to a fixed number of daily plans. From this set they select which plan will be executed in the next iteration and, if the memory is full, which plan is erased. With a higher maximum number of plans the search space of the optimal solution is bigger. Then, the optimization process is more efficient, but more memory is required. Now, in a week time horizon, some optimization strategies are proposed, analyzed and compared:

3.3.1 Full week iterations with end-of-week re-planning and scoring

A whole week is simulated in Mobsim. Each agent saves in his memory up to a fixed number of weekly plans. Re-planning modules have to apply mutation strategies to the whole weekly plan. Although score increasing is guaranteed, for the nature of the algorithm, and the impact in the MATSim model (architecture and modules) is minimal, the computational time would be at least seven times the current one. This means that an optimization process with the described scenario and one hundred iterations would last 23.3 days. In the first instance, agents memory size would be seven times the current size as well, because each weekly plan is seven times bigger (135.1 GB for the described scenario). Plans with intensive definitions (e. g. saving for a certain activity the times when it is performed) can be designed to reduce this size.

3.3.2 Daily iterations with end-of-day re-planning and scoring

It is the simplest way of implementing an optimization strategy with the current state. A weekly plan of an agent is composed of seven daily plans. Then, the whole evolutionary algorithm is applied for each day of the week. It is as simple as to run MATSim seven times with different schedules and re-planning modules. Only the MATSim controller would have to be modified. There are two ways for running this alternative. In parallel: the memory needed is seven times the current amount (135.1 GB for the described scenario), and the computational time would depend only on the re-planning modules if the server has enough cores to parallelize the mobility simulator (for the presented scenario 4 cores were assigned to the mobility simulator, then 28 cores would be enough). In serial: The population memory needed is the same than the daily MATSim (19.3 GB), and the computational time is seven times (23.3 days). Although it is possible to expend less resources with this alternative, it has a critical problem, the sum of optimal days is not an optimal week. It means that it is possible to generate better scored weekly plans with the first alternative because, in the second, different and independent optimization problems are being solved.
Figure 3: Optimization strategies for a week time horizon

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3.3.3 Full week iterations with end-of-day re-planning and scoring

This is an intermediate alternative. The idea is to simulate the mobility of one day, score the plan, use random re-planning strategies, and advance to the next day. This strategy would be applied
to weekdays (5 optimization iterations in a week) while weekends would have a different and slower optimization process (2 optimization iterations for Saturdays and Sundays). As the total number of iterations will depend on weekends, advanced re-planning modules for secondary activities location must be applied. In [Horni et al. (2009)] and [Horni et al. (2011)] descriptions of the current methods for location choice in MATSim are presented. For more general purposes, days in the week have to be categorized in working days and leisure days, or even more general categories. It should be configurable which days of a week belong to each category for each agent due to not everybody has the 5-working-2-leisure week structure. For each category should be possible to define specific re-planning strategies. Thus, computational time will depend on the number of iterations needed to reach equilibrium in the category with the lowest number of days (leisure on average). The memory of an agent would be composed of a set of plans for each category. Computational time and memory size would be lower than the first alternative and higher than the second, but with the concept of category the optimization problem would be solved faster iterating several times a day within the week (e.g. 5 working days and 2 leisure days). In the third part of the Figure 5 a week composed of 3 categories is illustrated. In the first category, Monday, Tuesday, Wednesday and Thursday are optimized together, scoring and re-planning in the end of each day (only plans for one day are saved). In the second, Friday and Saturday are optimized together, but only in the end of the Saturday scoring and re-planning processes are applied (plans for two days are saved). Only Sunday belongs to the third category and it has its own optimization process. Thus, an agent with these categories would save plans for 4 days in memory (Mon-Thu, Fri, Sat and Sun), and the number of iterations would depend on the second and third category due to their slower optimization process compared with the first.

3.3.4 Full week iterations with within week scheduling

In the first instance, this strategy is very similar to the first one. Full weeks are simulated and the agents save plans for full week schedules. The difference is the addition of heuristic techniques to accelerate the optimization process. These techniques are based on executing demand generation processes within the mobility simulation, and suppressing long re-planning processes at the end of days or at the end of the whole week. Each agent would save one weekly base plan (without re-scheduling) that is lighter than a normal plan, and a set of extensions generated by the within week demand generation modules. With intensive definitions the plans sizes can be reduced even more. Computational time would increase, then, parallelization techniques have to be applied to continue processing events in a given time while some agents are scheduling activities. The forth part of the Figure 5 represents a week schedule of an agent. At some times in the week, within the mobility simulation, scheduling techniques would be applied using the current state of the city, and then, generating better plans in only one iteration. The scheduling processes could be based on the concept of needs and would use the techniques presented by
Märki et al. (2011), or in the complex mental process proposed by Doherty et al. (2002). The important aspect is that the decision has to be taken on the fly. More details are presented in the next section. The development of this strategy would have a big impact in MATSim. The initial demand generation would be changed to establish agents needs parameters and to calibrate activities’ effects. As mentioned before, the mobility simulator would be aware about agents’ demand generation within its execution. The re-planning process would be dropped, but week iterations would be performed to allow the generation of within day demand for selected agents while other agents execute previous plans.

3.3.5 Continuous planning

Starting from the ideas of Märki et al. (2011), one alternative is to drop the iterative optimization strategy and simulate a week only once. They propose to construct all the activity chains on-the-fly, based on agents’ needs. Although no iterations would be executed, a one-week simulation would need a distributed environment for making its development possible. The complex mental processes of an agent should be independent from the others allowing a better distribution. Another challenge is that the information needed per agent is very complex (e.g. time-dependent rates of increasing and decreasing needs values) therefore new techniques for obtaining this data must be designed. No executions have been performed with the described algorithms in a large scale scenario. Anyway, the mental process that agents use for taking decisions allows to find local optima for each one. According to some authors (Schlich (2004) and Simon (1955)) in reality people can not find global optima, because they don’t know all the alternatives or they don’t have time to calculate it.

3.4 Activities scheduling for a week

A critical issue about a weekly simulation is the quantity of input information needed. An agent daily plan consists on average of 3 to 4 activities specifying times, locations and 2 to 3 journeys with times, mode and routes. One million daily plans have an approximate size of 1GB in MATSim xml format. This size can be easily multiplied by 7 supposing a similar quantity of activities in weekends (not very true) obtaining files of 7GB per million of agents. Size is not the only issue. The generation of this initial demand requires much more external information. Surveys must be designed to retrieve the differences between weekends and weekdays and secondary activities must be better modeled for weekends. Next, some strategies for the weekly activity scheduling are described, each strategy can be optimized by one or more of the optimization strategies threatened in the previous section:
3.4.1 Definition of weekdays and generation of weekends

First, if there is no time-use weekly information, it is necessary to generate it using a common daily survey. Munizaga et al. (2011) present a method for generating weekend schedules of a population given a weekday survey and several observations of weekend schedules. The method generates weekend schedules for each person in the survey population as a convex combination of some of the observed weekend schedules (a convex set). For applying these techniques it is obviously necessary to perform a small time-use weekend survey.

3.4.2 Definition of a full week schedule

Either with multi-day survey as the one presented in Kuhnminhof and Gringmuth (2009) or applying the previous strategy, the idea is that in the simulation full weekly plans are given for each agent. With the current implementation of the mobility simulator, to execute these plans is straightforward. The problem is that the quantity of memory required to manage these plans is seven times the current memory used by MATSim. Saving intensive definitions of plans can mitigate the problem because of the repetition of activities and journeys in a weekly schedule. For example a work activity in a certain location and at the same time in five different days can be only described once, and its repetitions have only to be specified.

3.4.3 Definition of fixed and floating activities

By creating two categories of assigned activities in the weekly schedule (fixed and float), it is possible to give an incomplete plan to an agent composed of fixed activities and a set of float activities. The time windows defined by the complement of the fixed activities can be filled with float activities with re-planning processes or within the mobility simulation. A reduction in the plans file is obvious, fixed activities have to be saved once, and configurations of the floating activities must be saved and scored in an iterative optimization strategy. Intensive definition of plans can be applied as well reducing plan sizes. The definition of the floating activities can be performed in the beginning of the week, at the end of the previous day or on-the-fly. For the last option the greedy algorithm presented by Kuhnminhof and Gringmuth (2009) could be applied for this definition taking the list of float activities as the needed agenda. Another option is to implement the algorithm presented by Doherty et al. (2002) where an agenda is needed as well, but its complexity should result in low computational performance for large scale scenarios.
3.4.4 Continuous activity scheduling

Starting from need-based theory (Arentze and Timmermans (2006)), a full weekly schedule can be generated by each agent while the simulation is running using the algorithms of Märki et al. (2011). For this purpose (i) primary needs; (ii) activities that can decrease these needs; (iii) secondary needs (secondary effects) that these activities affect; (iv) locations where these activities can be performed; and (v) time-dependent increasing and decreasing need rates (within days and within the week) must be defined for each agent. With the hypothesis that people with similar socio-demographic characteristics have similar behaviors, procedures for performing this assignment can be design and implemented. The execution of this simulation would require a distributed environment and the continuous planning optimization strategy presented in the previous section (it means that it is designed to be executed once).

4 Conclusions and outlook

This paper presented a study of the aspects to take into account when implementing an extension of the MATSim-T to simulate urban transport with a week time horizon. After an overview through simple modifications, it focused on alternatives for developing a new optimization strategy and the weekly activities scheduling. The conceptual analysis was based on statistics from the Singapore model that is currently developed for the module VIII of the Future Cities Laboratory in that city. Now, a methodology for implementing this extension is described below and future results will be presented.

4.1 Methodology

1. Model structures for managing multi-day transport supply data (public transport, traffic lights and road pricing);
2. Generate a small scenario with full week plans;
3. Simple simulation of the third optimization strategy;
   (a) Design data structures for full weekly activity plans (extensive and intensive);
   (b) Model the categorization of days proposed in the third optimization strategy;
   (c) Develop a MATSim Controller that allows the simulation of the third optimization strategy;
   (d) Run and test the small scenario with the third optimization strategy.
4. Generate a small scenario with incomplete week plans;
5. Simple simulation of the fourth optimization strategy;
   (a) Design data structures for incomplete weekly activity plans and model the proposed
categorization of activities (fixed and float);
(b) Develop a MATSim Controller for simulating the fourth optimization strategy;
(c) Modify MobSim and develop the parallelization technique for simulating the fourth optimization strategy;
(d) Implement one simple and one complex within-week scheduling algorithms;
(e) Extend the population model to manage the information needed by the algorithms;
(f) Run and test the small scenario with the fourth optimization strategy, using the two implemented within-week scheduling algorithms.

6. Use continuous travel diaries like Zimmermann et al. (2001) or the one presented in Kuhnimhof and Gringmuth (2009) for generating a large scale scenario with full week plans. If the data can not be accessed, design and perform a small survey in Singapore for time use on weekends and use techniques presented in Munizaga et al. (2011) to generate a large scale scenario with full week plans;

7. Run and test the large scenario with the third optimization strategy;

8. Generate a large scale scenario with incomplete week plans;

9. Run and test the large scenario with the fourth optimization strategy, using the two implemented within-week scheduling algorithms;

10. (Optional, depending on future results) Implementation of continuous planning strategy.
   (a) Use need-based theory for implementing the continuous scheduling algorithm;
   (b) Extend the population model to manage the information needed by the continuous scheduling algorithm;
   (c) Run and test a small population scenario;
   (d) Calibrate the model for a large scale simulation;
   (e) Run and test a large scale population scenario.
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