
A Multi-Modal Network for MATSim

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Abstract

Explicitly multimodal simulation in MATSim exists since several years, but so far separate networks were usually used to simulate public and private transport. New questions and challenges in transport planning however, require the simulation of the competition for capacity between different modes. This paper presents a new software package that can create a MATSim network that enables public and private transport to share the network and therefore to compete for slots.

The software package is designed in a modular approach that allows quick and easy exchange of single functions to provide improvements, new options or abilities. The package creates the network and the schedule for Switzerland from entirely open data. The network is built from Open Street Map data and the schedule from the publicly available SBB HAFAS data. The package uses only MATSim data structures for the communication between modules, thus other data sources could be integrated easily.

The final package and the network and schedule it produces are tested and analysed to confirm proper functioning. These analysis reach from visual comparison of the network with previous standards at IVT to simulations with performance comparisons to other MATSim public transport solutions. The results of these analysis show that the package produces valid networks and schedules that can be the basis for new, fully-multimodal simulations in MATSim.

Keywords

MATSim, Multi-Modal, Network, OSM, Mapping

1. Introduction

Economic and population growth cause settlement pressure in Switzerland. In recent decades this pressure has been addressed mainly by constructing in new areas. In recent years however, this urban sprawl has led to increasing discontent in society and corresponding political initiatives. As examples may be mentioned the national referendum Zweitwohnungsinitiative (NZZ, 2012) or the Kulturlandinitiative in Zurich (Hotz, 2012). The suggested solution is urban densification. Urban densification means that in already built-up areas old buildings with a low space utilization are replaced by newer ones with higher utilization. This compression however, has a direct impact on the traffic load on accessing road network. Higher utilization means more living space and / or jobs and thus more traffic per area.

These developments, economic and population growth with the accommodating higher demand for mobility combined with a trend towards urban densification, increase the pressure on urban road networks. Congestion problems are, where not already being felt, predictable. Today in Switzerland however, infrastructure measures to increase capacity become more and more difficult and expensive, especially in urban areas (Axhausen, 2014). Short-term measures to increase capacity must therefore take the form of improved utilization of the existing infrastructure.

In this context, the SVI project NetCap was conducted at the IVT, ETH Zurich, together with the LUTS, EPF Lausanne. The topic of NetCap was the capacity optimization in urban areas. The capacity was to be maximized by an optimized balance between transport modes. The modal split in turn has been adjusted indirectly via a modified public transport (PT) offers. Macroscopic fundamental diagrams (MFDs) (Geroliminis and Daganzo, 2008) were used to calibrate and control of the effects of traffic flows and modal split adjustments. From the project was also to emerge in how far MFDs are generally suitable for such applications. Downtown Zurich was used as the test area.

In NetCap VISSIM and MATSim were used in combination study the effects of the measures and to apply the MFDs. The IVT group for transport planning was responsible for the generation of representative traffic demands at different PT service levels using MATSim. The research question of traffic demand under different PT regimes however, explicitly requires that the modes in MATSim mutually affect each other and compete for the limited infrastructure capacity. This is a special request as in previous MATSim scenarios (at IVT) PT and private transport used entirely separate networks. So far the buses in MATSim did not get stuck in a traffic jam, and the cars were not slowed down by stopping buses.

Therefore, as part of NetCap, the move to fully-multimodal networks and scenarios for MATSim was done at IVT. This means that PT and private transport share the same network. Also part of this development was the step from proprietary data to public data as the data source for the creation of networks and schedules. The new networks for MATSim should not

only be fully-multimodal, but also based on Open Street Map (OSM) data. The schedules should be created from the publicly available SBB HAFAS data.

This paper first presents the software package that allows the creation of fully-multimodal networks and schedules from open data (section 2). In the second part different analysis are presented which confirm the proper functioning of the package (section 3).

2. Implementation

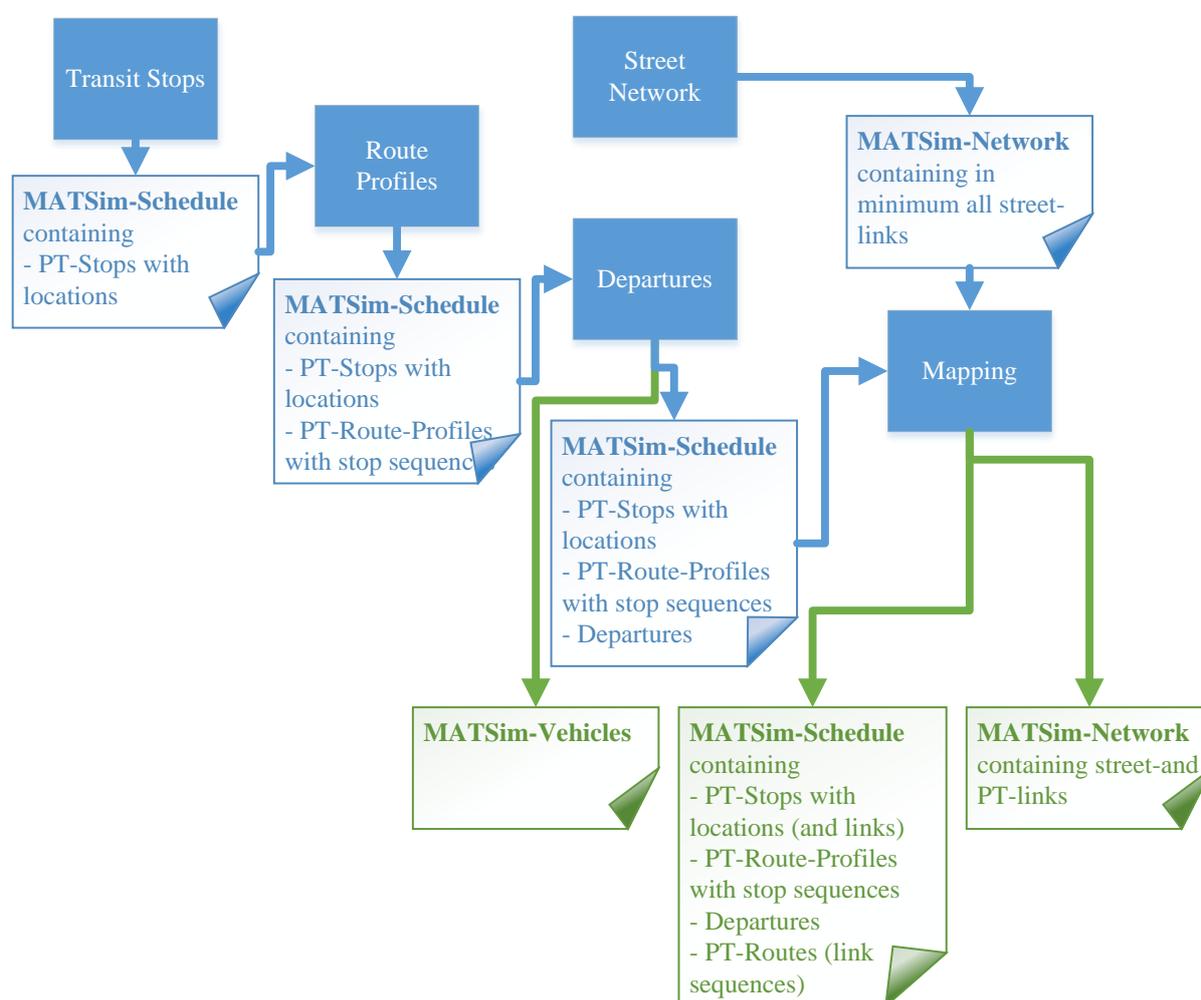
2.1 Modular Approach

The package for the creation of fully-multimodal networks should be designed for an iterative process. This would allow even for small changes in the package to review the results and give feedback. Also, and more importantly, this allows to respond quickly and effectively to possible future changes in the database or on changing requirements for the package. In the present case this is particularly important, since, as mentioned in the introduction, the maps derived from OSM should serve as data base. OSM data can be adjusted and corrected by anyone anytime. On the one hand, this leads to an ever-improving data base, but on the other hand also to an ever-changing data base.

The goal of an iterative approach was achieved with a modular approach in the package design. The various process steps of the overall package are implemented separately, each in an own module. The modules are connected only via well-defined data interfaces. MATSim data formats, such as for example the MATSim Network or the MATSim Schedule, are used for these data interfaces. As long as the interfaces of the modules are met, individual modules can be replaced independently by newer, enhanced or customized versions, which corresponds to the iterative procedure.

Figure 1 presents the modular structure of the software package. Four modules provide the data base, while the fifth module, Mapping, connects the data to the actual product. Two types of data are generated. On the one hand the infrastructure data, that is the road network and the bus stops, and on the other hand, the schedule data, that is the route stop sequences and the timetables for the various PT lines. As an overall package, together the modules create a network that contains roads and PT links. Where PT lines share the infrastructure with private transport, PT is mapped on to the shared network. These are above all the bus lines. Also, the package produces a PT schedule and a definition of the PT vehicles. In combination these three files constitute a valid, fully-multimodal infrastructure model for MATSim.

Figure 1 Modular design of the program package and interactions between modules.



2.2 Infrastructure Modules

2.2.1 Road Network

The road network module interface requires only that the road network module provides as output a MATSim network that contains the relevant road network for the scenario. How and from what data the road network is created is irrelevant from the perspective of the interface. The road network module may already add PT links to the network, if the data for this is already available. To fulfil the interface contract however, this is not required.

In its current implementation, the road network module generates the road network from OSM

data. The module is a slightly adapted version of M. Rieser's MATSim class to convert OSM data into MATSim networks¹.

OSM data is structured in the XML format. It distinguishes between nodes, ways and relations. OSM nodes and ways cannot be transferred directly to MATSim nodes and links however, because they represent different concepts. Nodes in MATSim are pure connectors of links, while in OSM they represent all sorts of geographical points of interest. Links in MATSim correspond to parts of transport ways and thus to links in the typical transport planning sense. Ways in OSM however, represent any geographic object that can be represented as a polyline. Relations in OSM connect nodes and ways to higher structures that represent complex concepts (for example roads or buildings).

The road network module analyses the OSM data for road network segments and transforms them into a MATSim network. Street characteristics (capacity, free-flow speed, etc.) are specified by default settings where they cannot be read from OSM directly.

The current implementation allows to convert only geographical sub-areas of a given OSM map into a MATSim network. These sub-areas can be specified as geometric shapes (currently rectangles or ellipses) or with SHP-files. The sub-areas can also be distinguished for different road categories. This allows, for example, to connect the European highway network with the fully detailed Swiss road network.

2.2.2 Transit Stops

The transit stop module interface requires that the output of the module is a MATSim schedule, in which all transit stops are included with identification number and coordinates. How and from what data this is created is again irrelevant from the perspective of the interface. Explicitly not required yet, but of course possible if the relevant information is already available, is the connection of the stops to network links. This link connection defines for each station via which MATSim-network link this station can be reached by the PT vehicles.

The current version of the transit stop module reads the required information from the file BFKOORD_GEO of the SBB HAFAS package. This file defines the transit stops with HAFAS identification numbers, WGS84 coordinates and their common names. From this data the MATSim stops are generated and added to a MATSim schedule. Additional data needed when creating MATSim stops, such as for example if a stopping vehicle blocks the road or not, is provided via default values.

¹ The MATSim class `org.matsim.core.utils.io.OsmNetworkReader.java` written by M.Rieser.

2.3 Schedule Modules

2.3.1 Route Profiles

The route profile module interface requires as input the output of the transit stop module, which is a schedule file that contains all transit stops. As output, the module has to generate a schedule file, which contains the transit stops and the PT routes with the stop sequence for each route (route profiles). These route profiles also include the arrival and departure times for each stop of any route profile.

The current implementation of the route profile module reads the required data from the file FPLAN of the SBB HAFAS package. In FPLAN however, the route profiles are directly coupled with the departure times. For this reason, in the current implementation, the route profiles are created together with the departures in the departures module, which is described in the next section.

2.3.2 Departures

The departures module interface requires as input the schedule created by the route profile module. The schedule should therefore already contain the transit stops and the route profiles. The output of this module is a schedule too. Compared to the input it contains additionally the departure times. A second output of this module is a MATSim vehicle file which defines all PT vehicles needed at the departures. How and from what data the required information is generated is again irrelevant for the interface.

In its current implementation, the departures module requires as data base the SBB HAFAS files FPLAN and BITFELD. The file BITFELD defines within the validity period of the timetable for each route in HAFAS the days on which it operates. The module analyses the BITFELD file for the busiest Tuesday or Wednesday of the validity period. This day is used as the reference date and only routes that operated on that day are read from HAFAS.

After the reference date is chosen, the file FPLAN is read. The file FPLAN contains every departure of every route of the entire Swiss PT network for the full validity period. It contains for each route the full route profile (stops sequences as well as arrival and departure time at each stop), the initial departure time and, if it is a clock-face schedule route, the number of cycles and the departure interval. Also included in FPLAN are the PT vehicle category and, if existing, the common name of the route. This data is read for each route and, if it operates on the reference date, a corresponding entry in the MATSim schedule is created including all departures of that route.

For each departure a vehicle of the specified vehicle type is created. In congestion situations this may result in excessively many PT vehicles in the simulation (new vehicles start with new departures while in reality the corresponding vehicle might still be stuck in congestion on the

previous route). It facilitates the scheduling process enormously however, as the distribution of a limited number of vehicles on all departures on all routes is a very complex problem already in itself.

In the current version of SBB HAFAS for many routes each departure is defined as a separate route. If this were directly translated to a MATSim schedule, this would lead to excessively many routes and thus to very long simulation times (explained in section 4.1). To avoid this, HAFAS routes with identical route profiles are merged. Routes which have the identical route profile as any earlier route will be integrated into this earlier route. It must be noted here that the equality of route profiles is determined based on the stop sequence only. The arrival and departure times at stops are ignored. This can sometimes lead to deviations in the arrival and departure times (see section 3.3).

2.4 Mapping

The goal of the mapping module is the mapping of the stops and routes on the infrastructure. Infrastructure in this context means the road network, on which PT and private transport share and compete for physical space (e.g. for buses), and the separate PT network (e.g. railways). Where PT uses a separate network, this must be generated if it is not already included in the input network (see section 2.2.1).

The mapping module interface requires as input a MATSim schedule and a MATSim network. The schedule file should be completely defined except for the link connection of the stops and for the travel routes. Travel route means the link sequence in the MATSim network, which PT vehicles have to follow on a particular transit route. The schedule file provided by the departure module satisfies these requirements. The required MATSim network corresponds to the output of the road network module. The output of the mapping module consists of a complete and valid MATSim schedule associated with the provided MATSim network. Together with the MATSim vehicle file from the departure module this output corresponds to the product of the overall package.

In the current implementation of the mapping module, road-based PT forms (e.g. buses) are processed first. The transit stops they use are connected to the nearest link. The nearest link is identified via the nearest end node. If within a defined search radius around the stations' coordinates no suitable node and thus link can be found, a new node is created for the station. This node is connected with an artificial link to the end node of the link of the previous stop. If the current station is the first stop of the stop sequence, a null link is generated to and from the new node. Subsequently, the station is connected to the link found or created. This approach allows to generate PT exclusive links to complement the road network. It can however, also lead to artificial PT links even when the corresponding road link exists, if the link's end node is outside the search radius. An analysis of the influence of the search radius on the mapping is

presented in section 3.1. After all transit stops are connected to the network, the travel route is identified. In the current implementation the travel route is defined as the shortest route from each stop to the next. A fast-A-Star routing algorithm is used to find this shortest route. Currently only the free flow travel times are considered for routing.

After the road-based PT forms, a separate network is created for the non-road-based PT forms (e.g. trains). This is done analogously to the generation of PT exclusive links for road-based PT forms. As this procedure directly creates the travel routes, no separate routing for non-road-bound PT forms is required.

After this mapping the various files are provided as output. The schedule is validated by calling the `TransitScheduleValidator`². The result of this check is reported.

3. Analysis

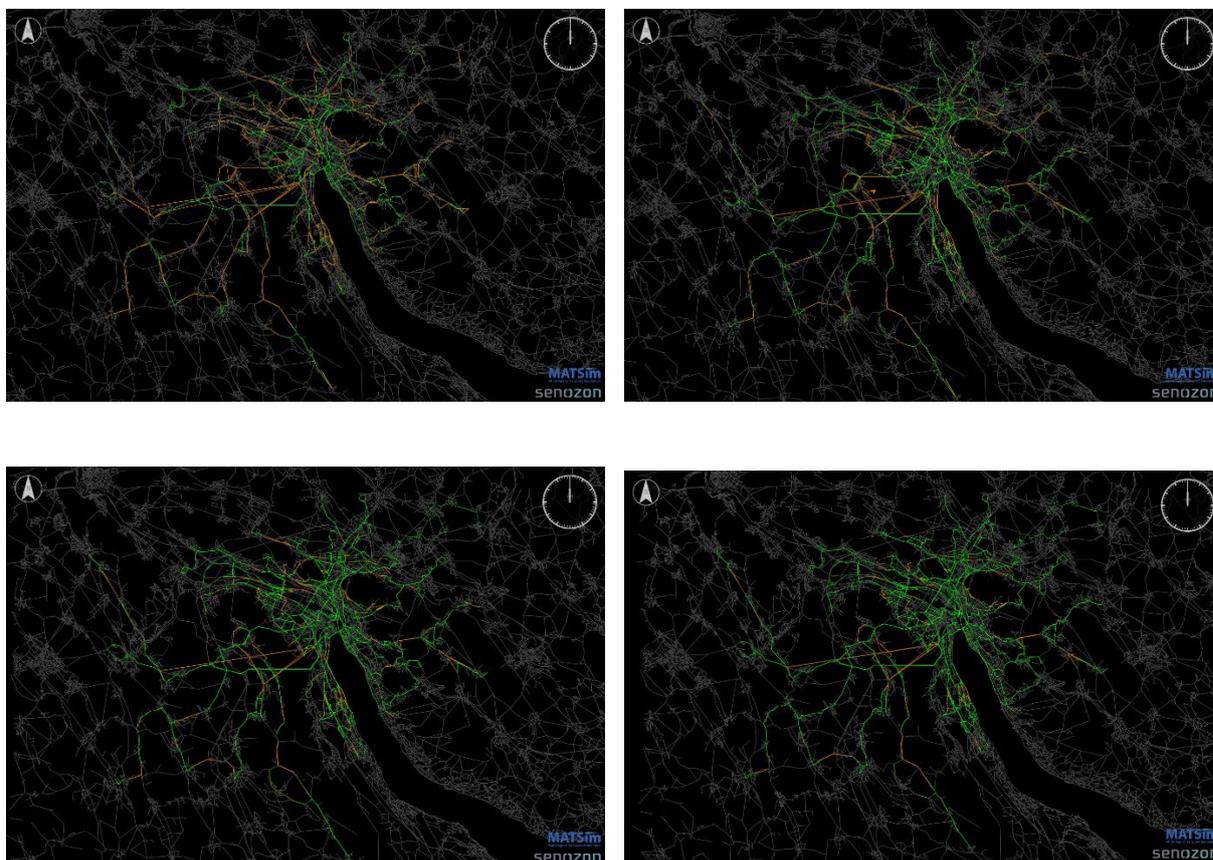
3.1 Mapping Radius

When linking transit stops to the road network, the great challenge is to write an algorithm that automatically identifies the correct link but also realizes if this link does not exist in the network yet. In the current implementation of the algorithm (section 2.4) this is achieved with a search radius. If around a transit stop's coordinates a suitable link exists within the search radius, the stop will be connected to this link. If no such link can be found within the radius, artificial links are created. It is clear that the size of the search radius has a fundamental influence on the correct mapping of PT lines on the network.

For different search radii (50m, 100m, 150m and 200m) mappings were done for the city of Zurich. The results are shown in Figure 2. They show that with a 50m radius many unnecessary, artificial links are created. With a 200m radius however, an over-mapping can be observed. Unnatural connections are made at places where artificial links are clearly needed, such as for example ETH Honggerberg.

² The MATSim class `org.matsim.pt.utils.TransitScheduleValidator.java` written by M.Rieser.

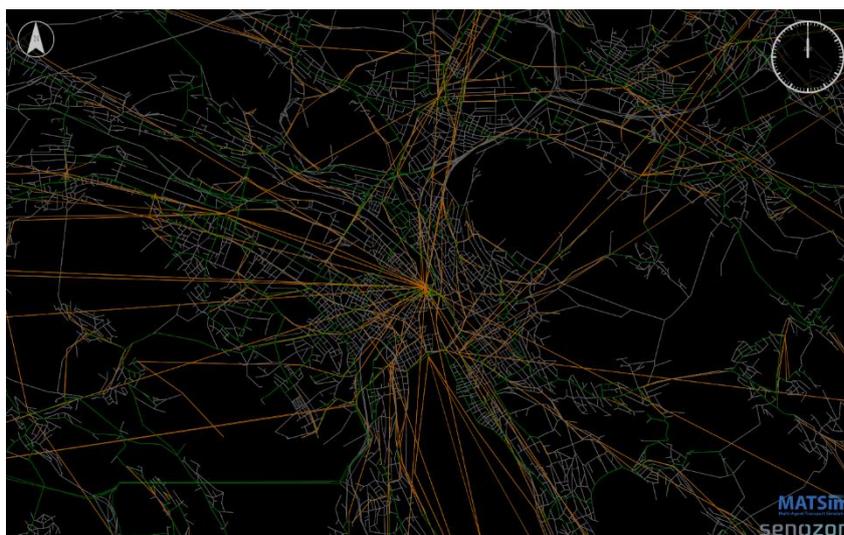
Figure 2 Visualization of the mapping results for different search radii (from top left to bottom right: 50m, 100m, 150m, and 200m). Bus routes were mapped for Zurich. Green links indicate a successful connection to the road network, orange links show artificially generated PT-exclusive links.



3.2 Network Visualization

In 2013 a new MATSim network with new MATSim schedules (incl. vehicles) was created at the IVT. It was based on the UVEK national transport model (ARE, 2010). This full Switzerland model was generated by A. Stahel (2014). Until then this was the most comprehensive and detailed model of the Swiss road and PT network available to the IVT. It had two main deficiencies however. First, the road and the PT network were still modelled completely separate. Second, PT – particularly in the urban areas – was created with heavily simplifying assumptions. To show the progress in mapping achieved with the new package and to illustrate the difference between the new fully-multimodal network and the network of 2013, a visual comparison of the two Zurich networks is presented in Figure 3.

Figure 3 Above the network based on the 2013 UVEK national transport model, below the network newly created with the software package presented in this paper. In both visualizations, the road links are coloured grey, the PT links orange and shared links green.



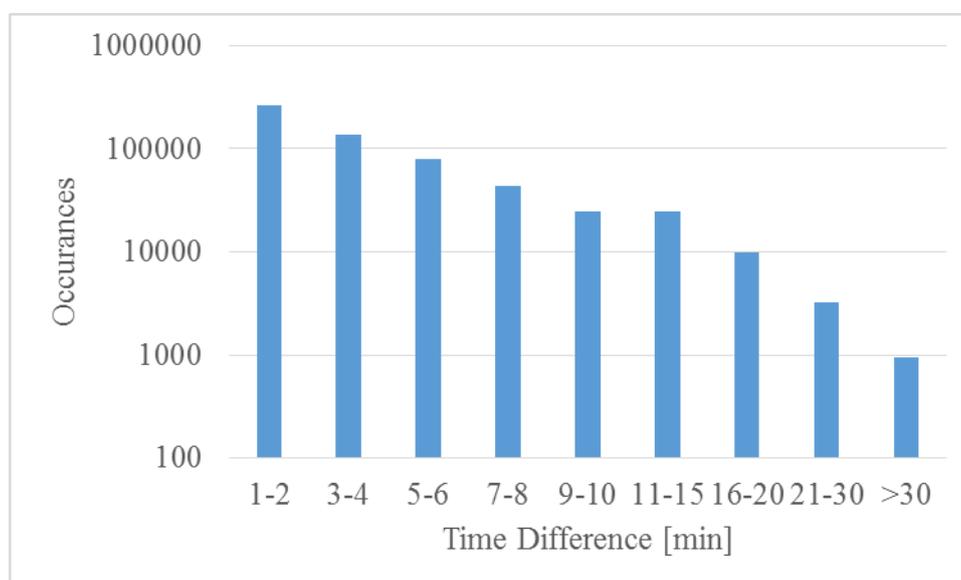
The train routes, especially for long-distance trains, correspond to a large degree between the two networks. The urban PT however, is resolved with completely different approaches. In the 2013 model the city districts have only one stop each. These stops are then radially linked. In the new network the bus lines are mapped on the streets and, even though the tram network is still on a separate network, at least the tram stops correspond to the real locations.

3.3 Arrival-Offsets

The departures module (section 2.3.2) merges PT routes with identical route profiles. In this merging process only the route profiles are currently considered as a merging criterion. Different arrival and departure times at transit stops, which are part of MATSim route profiles, are neglected. This can lead to time differences when throughout the day routes are served with identical profiles but varying schedules.

Statistical data on the occurring time differences was collected to quantify and assess these time differences. For all calculations the absolute values of the differences were used. With the current implementation a total of 45'208.9 hours of time difference occur on the entire Swiss PT network. This difference occurs at a total of 587'825 stopping procedures. This results in an average deviation of 4.61 minutes per affected stopping procedure. If the not-affected stopping procedures are taken into account too, the time differences occur over a total of 2'282'327 stopping procedures. This results in an overall average deviation of 1.19 minutes per procedure. Figure 4 shows a histogram of the time differences.

Figure 4 Histogram of the time differences due to route merging.



3.4 Routings

If the MATSim schedule is generated from the SBB HAFAS data for 2015, the BITFELD analysis identifies the 03.03.2015 as the reference date. To test the schedule, 33 random PT

trips were routed in MATSim, queried on Google Maps³, and the resulting routes subsequently compared. A PT trip consisted of origin coordinates, destination coordinates and a departure time.

In MATSim the routing process created 70 stages from the 33 PT trips. These 70 stages were compared with the respective stages from Google Maps. When querying from Google Maps, the settings were set so that the "best routes" were searched and that there was no preference for a particular type of PT. The date was set to the 03.03.2015. The results of the comparison are presented in Table 1.

Table 1 Results of the comparison MATSim HAFAS to Google Maps. In total 33 trips with 70 stages were compared.

Match	Description	Number of Stages	Percentage of Stages
Very Good	Same choices	35	50.0 %
Good	Same route, but one departure earlier or later	8	11.4 %
Satisfactory	MATSim stages that are walked in Google	3	4.3 %
Unsatisfactory	Different routes	24	34.3 %

The reasons for the 24 stages with different routes were identified as follows:

- 7 x Walking Behaviour: In MATSim agents like walking much less than assumed by Google, and if they walk, they walk slower. As a result, routes which include long walk stages are avoided much more in MATSim. If walking stages are absolutely necessary, MATSim misses connections respectively chooses later connections than Google.
- 4 x Tight Connections: In MATSim no or only a very small minimum time for a transfer is considered. This allows for extremely tight connections. This phenomenon is accentuated by the arrival and departure times changed by the merging process (sections 2.3.2 and 3.3) as they sometimes even result in connections which would require a negative transfer time in reality.
- 2 x Instant Start: In MATSim it makes no difference for agents if they have to wait at the start of a trip, or during transfers while on a trip. For them, a trip is simply

³ Homepage, accessed 08.04.2015, <https://www.google.ch/maps>.

the complete door-to-door time. Google apparently prefers routes which start later, but have shorter transfer times. This allows people to start later and to reduce long waiting times at transfers while still arriving at the same time.

- 11 x Unknown Reason: The route is not suggested in Google. Often even all proposed alternatives of Google are faster than the MATSim route. The exact reasons for the differences could not yet be identified for these routes.

3.5 Simulations

An existing and calibrated scenario was used to test the new OSM-based network and SBB HAFAS based PT schedules in a simulation. The scenario was created and calibrated by T. Dubernet and is used for education purposes at the IVT (Ciari and Waraich, 2014). In the simulation test the configuration values of the original scenario were kept wherever possible. The scenario is a 10% -Zürich scenario, which means that 10% of the population were simulated for the greater Zurich area for one day (24 hours). The scenario includes also freight traffic and transit. The presented values are based on the events of the 150th iteration of the simulation, which corresponds to a well-relaxed state of the system.

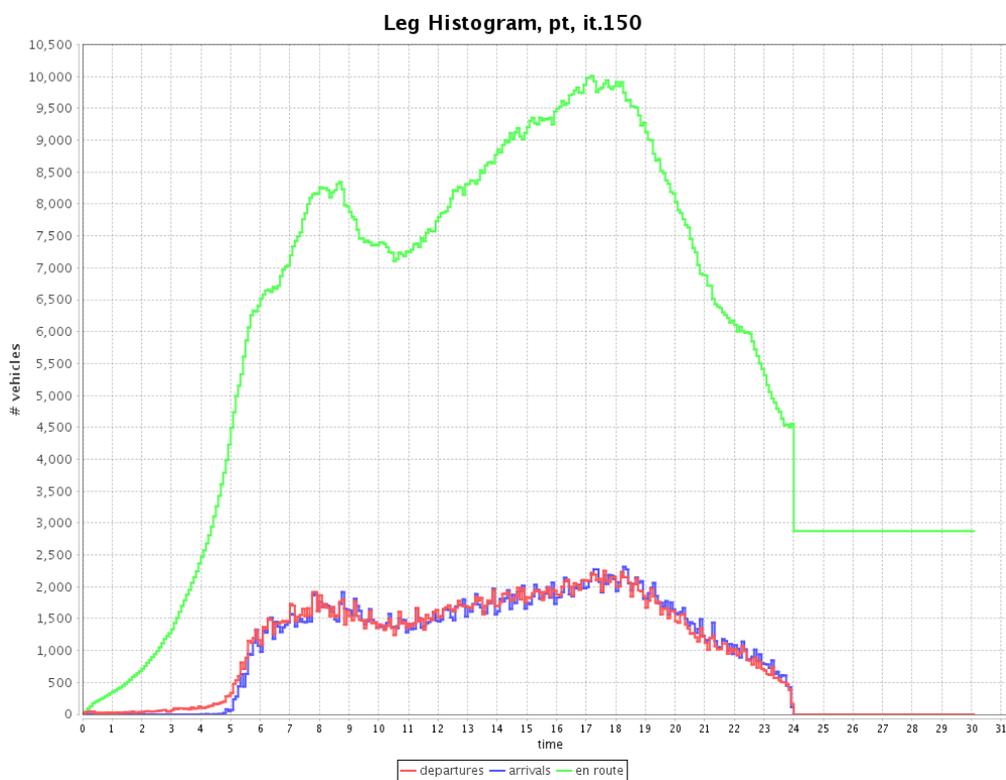
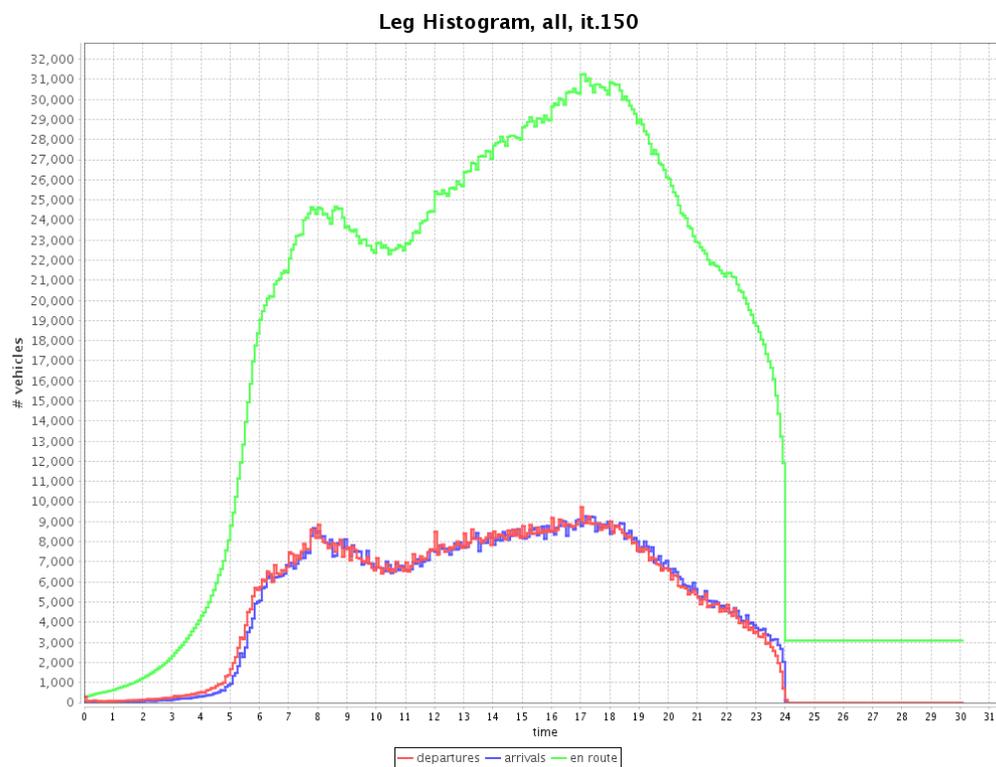
The simulation resulted in the following basic outputs:

- Number of Trips per Person and Day: 3.4 (Microcensus (MC) 2010⁴: 5.58)
- Modal Shares:
 - PT: 25.3% (MC2010: 19.9%)
 - Slow modes: 25.8% (MC2010: 52.2%)
 - Car: 48.9% (MC2010: 27.9%)
- Modal share of PT by activity:
 - Work: 23.2% (MC2010: 26.7%)
 - Leisure: 27.8% (MC2010: 17.6%)
 - Shopping: 29.2% (MC2010: 14.2%)
 - Education: 32.8% (MC2010: 26.7%)

Figure 5 shows for the simulated day the number of agents that are en route in total (above) and by PT (below). One can very well recognize the morning and the evening peak representing the respective rush hours.

⁴ BFS, Mikrozensus Mobilität und Verkehr 2010, Synthesetabellen 2010 (evaluated for the Zurich region), accessed 09.04.2015, <http://www.bfs.admin.ch/bfs/portal/de/index/news/01.Document.155249.xls>.

Figure 5 Leg-Histogram for all legs (above) and only PT legs (below).

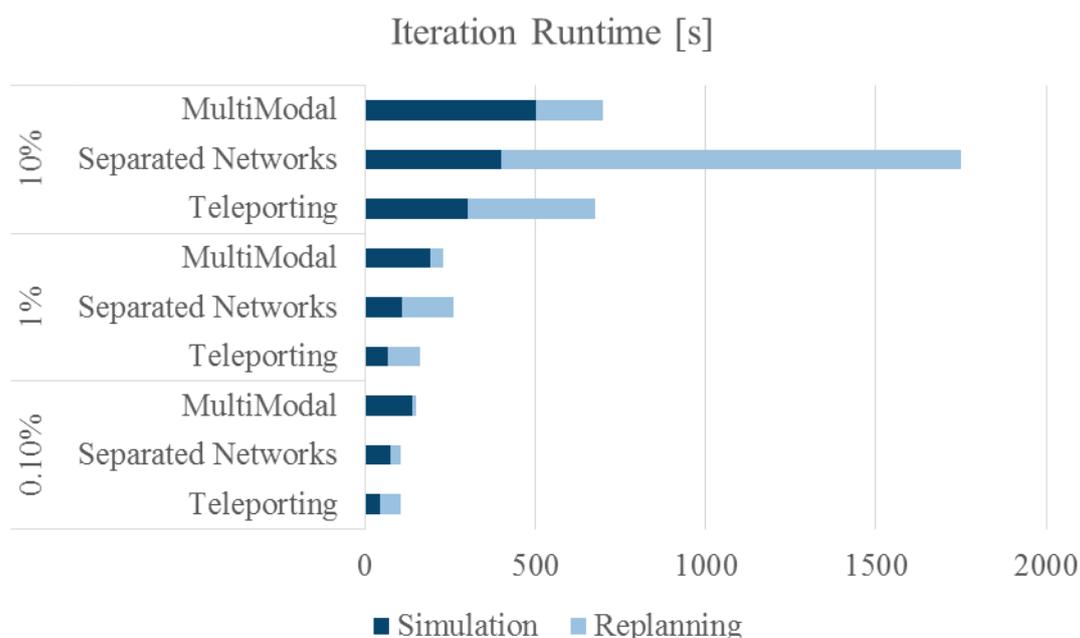


3.6 Performance

Increased level of detail means for simulations usually increased computational cost. It is one of the challenges in modelling to find a balance between these two contradicting requirements. The influence of the increased accuracy in PT representation on the simulation performance achieved with the new package was investigated for this paper.

Three different population samples were examined for three different PT representations. The different population samples are 0.1%, 1% and 10% of the total population. The different representations are first the fully-multimodal network and schedule (hereinafter "MultiModal") created with the package presented in this paper, second, the existing standard network and schedule of IVT, which has separate networks for PT and private transport ("Separated Networks") presented in section 3.2, and third, the a version where PT users are teleported and PT is not explicitly simulated ("Teleporting"). All nine scenarios use the same configuration parameters and the same basic data (the scenario presented in section 3.5) as far as the different set ups allow. Figure 6 shows the typical simulation and replanning times for one iteration for these combinations.

Figure 6 Typical simulation and replanning times per iteration for the different scenarios. The percentage values represent the population share that is simulated. The scenario names describe the form of PT representation used.



4. Discussion

4.1 Implementation Issues

During the implementation and application of the software package several stumbling blocks have emerged that could be of interest for potential users. For example, it is important that throughout the process the same geographical coordinates are used. This reads seemingly self-evident, but given the number of modules and data sources special care is suggested.

Within reason attention should be paid to generate only a small number of routes in the final schedule. The current implementation of the MATSim PT router generates between all routes and stations a separate transit link, if they allow for connections. The more routes, the more such transit links, and the worse the performance of the simulation.

Last but not least, an SBB HAFAS specific concept deserves a special comment: PT is usually organized on two levels, lines and routes (Ordonez and Erath, 2011). MATSim follows this structure. Lines summarize different but very similar routes. In contrast, in HAFAS the two levels represent management and departures. Management summarizes all departures of one administrative unit, e.g. PostAuto Schweiz or the Busbetriebe Aarau. If this difference in concepts is considered however, a transfer from HAFAS management to MATSim lines and from HAFAS departures to MATSim routes is possible, and also currently implemented in the software package.

4.2 Analysis Results

As mentioned in section 3.1, in the current implementation of the package, the mapping radius has a fundamental influence on the quality of the mapping of PT on the road network. It should therefore be chosen as carefully as possible. Currently, a visual inspection of the mapping is made for various critical points of the network. Based on these investigations, a search radius of 150 m was determined as the currently best compromise. Future developments should, however, allow for a quantitative determination of the optimal radius, unless a fundamentally different approach is taken and no search radius is needed anymore (section 5.1).

As expected, the – in comparison with alternative models – more complex and detailed modelling of the PT network and schedule (section 3.2) results in increased simulation time per iteration (Section 3.6). Surprising are however, the extremely short time replanning times in the case of the fully-multimodal network. The exact reason for this observation is the subject of current investigations. Based on other results (sections 3.4 and 3.5) however, a malfunction of the simulation caused by the network or the schedule can most probably be excluded. The currently pursued hypothesis is that the small number of lines in the schedule, which for MATSim is unusually small as here they represent administrative units and not similar routes

(section 4.1), leads to the very short replanning times.

The analysis of the arrival offsets (section 3.3) suggests potential for improvement in the selection of the departure and arrival times in the route profiles. Currently the arrival and departure times of the first occurrence of a route profile will be applied to all future occurrences of the route profile. One could, for example, imagine that an optimal compromise between all arrival and departure times of a single route profile is selected. This could possibly minimize the many relatively small time differences. The few large time differences could probably only be eliminated through the division of the profiles into different routes. This in turn would however, result in lower simulation performance. A compromise must be found.

The review of individual routing (section 3.4) suggests some potential for improvement too. This is, especially in the case of the too costly walk mode, supported by the simulation results (section 3.5). The slow modes, which include bike and walk, have a much too low share of the modal split in the simulation results.

4.3 Alternative Approaches

The current implementation of the package has focused on the creation of a fully-multimodal MATSim network covering Switzerland. It should be created from open data only. Therefore it was assumed that OSM is available for the network creation and the public SBB HAFAS data for the schedule. At the IVT however, alternative efforts and experiments were made by N. Rieser to create not only the network, but also the schedule entirely from OSM. This would allow the creation of fully-multimodal networks and schedules without additional data for cities and regions other than Switzerland. This approach is not pursued at the moment however, as it has turned out to be very difficult to implement.

Also, a semi-automatic solution (Ordóñez and Erath, 2011) was developed by IVT Singapore to map the PT routes based on GPS points collected by PT passengers. Because of the different requirements (open data vs. GPS-points) however, the Singapore package could not be used without adaptation. A possible solution to bridge the gap and unify the two packages could for example be to create artificial PT GPS points from OSM data and then map the PT routes to the OSM network using the Singapore solution.

5. Outlook and Conclusion

5.1 Outlook

Various additions, extensions and refinements are planned for the program package. Some of them are already in the process of implementation.

- **Review and correction of the road routes and stops positions with the information from OSM:** In OSM the passing PT routes are noted for many links. This information can be used to correct the link sequences in the schedule and for an improved routing (e.g. that the routing on such links is cheaper than on other links for lines which are noted on the link). Also many PT stops are more precisely placed in OSM than in HAFAS. This additional accuracy could be utilized to correct and to improve the linking of the transit stops.
- **Refinement of the identification of the nearest links for transit stops:** For example, every few meters (e.g. $\frac{1}{4}$ the search radius) of a link a virtual node is to be generated. These virtual nodes would then be included in the search for the nearest link. This should allow to identify as nearest links also links that pass very close to the stop but which have their end nodes far away from the stop (and which are therefore currently not recognized as "near").
- **Automatic adjustment of the free-flow speeds and flow capacities of the links based on the environment:** The idea that should be implemented here is that if for example more buildings are close to the link, traffic is usually slower on this link. Experience shows that this is currently not reflected in MATSim. Agents achieve – especially in urban areas – in tendency too high average speeds.
- **Combine linking and routing:** If several links are possible candidates for the linking of a transit stop, the current implementation selects the nearest. If the routing were combined with the linking of the transit stops however, it could be possible to identify those links as best that allow for an overall shortest route. They could then, for example, be selected with a higher probability than those requiring longer routes.
- **Ban U-Turns:** In the current routing implementation U-turns are allowed for PT vehicles. In reality, this is hardly realistic. Therefore, it would make sense to ban this when routing.

Also, the combination of the present solution with the Singapore approach (as indicated in section 4.3) should be checked.

5.2 Conclusion

The approach presented in this paper enables the generation of fully-multimodal MATSim networks and schedules from open data. Several tests have shown that this generation can be applied successfully. Nevertheless, there is still potential for improvement and different ideas for further development have already been formulated.

Only fully-multimodal networks allow the simulation of competition for road capacity between PT and private transport. They are therefore a necessary part of transport simulations in a time when limited road capacity is an issue not only but especially in urban areas. The immense effort that must be invested in any road capacity expansion today, and which is more and more difficult to justify given environmental and social trends, exacerbates the problem and makes it even more relevant.

Projects such as NetCap search for alternative approaches to solve this problem. An optimization of the PT supply can lead to capacity increase, but it must be implemented with political sensitivity. The support and review of this optimization with new approaches, such as MFDs in NetCap, enable new solutions.

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⁵ Dr. M. Rieser, Senozon, <http://www.senozon.com/about-us>.

⁶ Dr. N. Rieser, Ernst Basler + Partner AG, <http://www.ivt.ethz.ch/people/scnadine>.

⁷ M. Balac, IVT, ETH Zurich, <http://www.ivt.ethz.ch/people/balacm>.

⁸ T. Dubernet, IVT, ETH Zurich, <http://www.ivt.ethz.ch/people/thibautd>.

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