Switzerland in a box: An agent-based model of travel demand and traffic flow

KW Axhausen and M Balmer

June 2008
Agent-based simulation of travel demand: Structure and computational performance of MATSim-T

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Structure

Software:

• Open-source project under GNU public licence

Coordination:

• Kai Nagel, TU Berlin

Data:

• Public sources, where available
• Private sources, when needed or as occasion arises
Current team

Strategy:

• Kai Nagel, TU Berlin
• Kay Axhausen, ETH Zürich
• Fabrice Marchal, LET, Lyon

Coordination of the implementation and project management:

• Michael Balmer, ETH Zürich
• Marcel Rieser, TU Berlin
Current team: Implementation (1/2)

- Michael Balmer, ETH
- David Charypar, ETH
- Yu Chen, TU Berlin
- Francesco Ciari, ETH
- Dominik Grether, TU Berlin
- Jeremy Hackney, ETH
- Andreas Horni, ETH
- Johannes Illenberger, TU Berlin
- Gregor Lämmel, TU Berlin
- Michael Löchl, ETH
Current team: Implementation (2/2)

- Fabrice Marchal, LET
- Konrad Meister, ETH
- Kai Nagel, TU Berlin
- Andreas Neumann, TU Berlin
- Marcel Rieser, TU Berlin
- Nadine Schüssler, ETH
- David Strippgen, TU Berlin
- Rashid Waraish, ETH
Task and solution methods
Understanding scheduling

- Budget constraints
- Capability constraints

- Generalised costs of the schedule
  - Generalised cost of travel
  - Generalised cost of activity participation

  - Risk and comfort-adjusted weighted sums of time, expenditure and social content
What does MATSim-T do?

```
"Scenario"

Competition for slots on networks and in facilities

k(t,r,j)_{i,n}

Mental map

Activity scheduling

Population β_{i,t,r,j,k}

q_i ≡ (t,r,j)_{i,n}

Demand q are the \textsuperscript{i\text{th}}movements of person p from the current location at time t on route (connection) r to location j. The resulting generalised costs k are used to adjust the schedules and to change the capacities C and prices P of facilities f.
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Classification criteria

• Steady state (equilibrium) ?

• Aggregate demands ?

• Complete and perfect knowledge ?

• Optimised schedules ?

• Degrees of freedom and detail of scheduling

• Modelling of capacity restrictions (movement, activities) ?
MATSIM-T: Steady-state version

- Scale: 7.5 mio agents, 1 mio facilities, 1 mio links and nodes
- Continuous time resolution;
- Spatial resolution: individual facilities;
- Shared time-of-day dependent generalised costs of travel and activity participation
- Best-response models for schedules and routes
- (Random) imputation of mode and location
- Queuing for slots for movement (and activities)
Preferred configuration: Initial demand generation

- Number and type of activities
- Sequence of activities

- Start and duration of activity
- Composition of the group undertaking the activity
- Expenditure division
- Location of the activity

- Connection between sequential locations

- Location of access and egress from the mean of transport
- Vehicle/means of transport
- Route/service
- Group travelling together
- Expenditure division
Preferred configuration: (Iterative) activity scheduling

- Number and type of activities
- Sequence of activities
  - Start and duration of activity
  - Composition of the group undertaking the activity
  - Expenditure division
  - Location of the activity
  - Connection between sequential locations
    - Location of access and egress from the mean of transport
    - Vehicle/means of transport
    - Route/service
    - Group travelling together
    - Expenditure division
Preferred configuration: Competition for slots

Movement:
• Queue-based simulation of car traffic
• (Traffic signal can be explicitly represented)
• No cycling, walking, public transport networks or timetables yet

Activities
• No competition for facilities yet
• Type- and location-specific opening hours
• Capacities are known
Result of each iteration: Plan

<person id="22018">
  <plan score="157.72" selected="yes">
    <act type="h" x="703600" y="236900" link="5757" end_time="07:35:04" />
    <leg num="0" mode="car" dep_time="07:35:04" trav_time="00:16:31">
      <route>1900 1899 1897</route>
    </leg>
    <act type="w" x="702500" y="236400" link="5749" dur="08:12:05" />
    <leg num="1" mode="car" dep_time="16:03:40" trav_time="01:10:22">
      <route>1899 1848 1925 1924 1923 1922 1068</route>
    </leg>
    <act type="l" x="681450" y="246550" link="2140" dur="01:20:00" />
    <leg num="2" mode="car" dep_time="" trav_time="00:34:35">
      <route>1067 1136 1137 1921 1922 1923 1925 1848 1899</route>
    </leg>
    <act type="h" x="703600" y="236900" link="5757" />
  </plan>
</person>
Iterative learning and its (schedule) utility function
Utility function: Individual schedules

\[ U_{\text{plan}} = \sum_{i=1}^{n} U_{\text{act},i} + \sum_{i=2}^{n} U_{\text{trav},i-1,i} \]

\[ U_{\text{act},i} = U_{\text{dur},i} + U_{\text{late.ar},i} \]
Example scenario
Why MATSim-T scales (roughly) linearly?

- Initial demand ~ $N_{\text{agents}}$
  - Location choice ~ $N_{\text{agents}} \times [N_{\text{facilities}} \text{ or } R_{\text{prism}}^\beta]$
  - Mode choice ~ $N_{\text{agents}} \times N_{\text{modes}}$

- Optimising times and durations ~ $N_{\text{activities}}^\alpha$
- Shortest paths ~ $N_{\text{nodes}}^\gamma$

- Event-oriented traffic flow ~ $N_{\text{agents}} \times N_{\text{links in a route}}$
- Time-step traffic flow (1sec) ~ $N_{\text{links}}$

In principle, scale all processes by $1/N_{\text{CPU}}$
Example scenario: Study area and population
Example scenario: Problem size of the 10% sample

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directed links</td>
<td>60’492</td>
</tr>
<tr>
<td>Nodes</td>
<td>24’180</td>
</tr>
<tr>
<td>Agents within the study area</td>
<td>181’693</td>
</tr>
<tr>
<td>Average number of trips/agent</td>
<td>3.1</td>
</tr>
<tr>
<td>Trips (agents) crossing the study area</td>
<td>5’791</td>
</tr>
<tr>
<td>Number of modes/activity types</td>
<td>5/17</td>
</tr>
<tr>
<td>Number of homes (facilities)</td>
<td>1'313'337</td>
</tr>
<tr>
<td>Number of out-of-home activity facilities</td>
<td>382'979</td>
</tr>
<tr>
<td>Number of additional facilities abroad</td>
<td>880</td>
</tr>
</tbody>
</table>
Computing times by step

![Graph showing computing times by step](chart.png)

- **route optimization**
- **mobsim**
- **time optimization**
- **other computation**
- **dump all plans**
Score by iteration

![Score by iteration graph]

- avg score - executed plans
- avg score – worst plans
- avg score – all plans
- avg score – best plans
- avg trip duration
### Computing times by step

<table>
<thead>
<tr>
<th>Operation</th>
<th>Unit</th>
<th>Units/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial demand</td>
<td></td>
<td>0.12h</td>
</tr>
<tr>
<td>Scheduling (fixed components)</td>
<td></td>
<td>14.40h</td>
</tr>
<tr>
<td>Scheduling (planomat)</td>
<td>Agent</td>
<td>100</td>
</tr>
<tr>
<td>Scheduling (routing)</td>
<td>Agent</td>
<td>1000</td>
</tr>
<tr>
<td>Time-step based traffic flow simulation</td>
<td>Agent</td>
<td>300</td>
</tr>
<tr>
<td>Learning</td>
<td>Agent</td>
<td>250’000</td>
</tr>
<tr>
<td>Total iteration (with I/O)</td>
<td></td>
<td>0.22h</td>
</tr>
<tr>
<td>Total run (with I/O) (100 iterations)</td>
<td></td>
<td>23h</td>
</tr>
</tbody>
</table>
Validation
Agents flowing to and from a link arriving at 16-17:00
Home locations of the agents using a link from 16-17:00
Current tasks: Functionality

- Improving the realism of the scenario (e.g. parameter distributions)
- Parameter estimation for the utility function
- Switzerland scenario in 12h to steady state
- Functional expansion the planomat (mode choice, destination choice – sequencing of activities)
- Multi-modal traffic flow simulation
Future tasks: Functionality

- Integration of social network data structures
- Explicit social network-based choices
- Interface to UrbanSim *et al.*
- Addition of supply agents (car sharing, demand responsive transport, retail location, parking pricing, road pricing) (Traffic control)
More information

www.matsim.org

www.vsp.tu-berlin.de

www.ivt.ethz.ch/vpl/publications/reports
Utility function: Travel

\[ U_{\text{trav},i-1,i} = \begin{cases} \beta_{\text{trav}} \cdot t_{\text{trav},i-1,i} & \text{if } t_{\text{trav},i-1,i} \geq 0 \\ 0 & \text{else} \end{cases} \]

\[ \beta_{\text{trav}} = -12 \text{ Euro/h} \]
Utility function: Late arrival

\[ U_{late.ar, i} = \begin{cases} 
\beta_{late.ar} \cdot (t_{start,i} - t_{latest.ar,i}) & \text{if } t_{start,i} \geq t_{latest.ar,i} \\
0 & \text{else}
\end{cases} \]

\[ \beta_{late.ar} = -18 \text{ Euro/h} \]
Utility function: Activity performance

\[ U_{dur,i} = \begin{cases} 
\beta_{dur} \cdot t^* \cdot \ln\left(\frac{t_{dur,i}}{t_{0,i}}\right) & \text{if } t_{0,i} \leq t_{dur,i} \\
0 & \text{if } 0 \leq t_{dur,i} < t_{0,i} \\
\alpha \cdot t_{dur,i} & \text{else } (\alpha > 0) 
\end{cases} \]

\[ \alpha = 10 \text{ Euro / h} \]
\[ \beta_{dur} = 6 \text{ Euro / h} \]
Approach

- Physical (VISSIM)
- CA (TRANSIMS)
- Q (Cetin)
- Q event (MATSIM)
- Meso (METROPOLIS)
- Parallel Q event (MATSIM)
- Macro (VISUM)
Q-event: Approach without gaps

Link 1

Link 2

\( t \)

\( v_{\text{free}} \)
Q-event: Approach with gaps

Link 1

Link 2
Q-event: Implementation details

- Squeezing to avoid grid-lock
- Inflow capacity = 110% of outflow capacity (1800 veh/h* lanes)
- Vehicles are served in order of arrival at the junctions
- C++ with binary data interface to MATSim-T
Q-event: Fundamental diagram
Q-event: Integrated domain decomposition
Q-event: Parallelisation

The diagram shows the relationship between the number of processors and the speedup factor. The solid line represents the microsimulation speedup, and the dashed line represents the linear speedup. As the number of processors increases, the speedup factor also increases, indicating improved performance with parallelisation.
CH: Car availability (Census)
CH: Car availability (modelled)
CH: Season ticket ownership (modelled)
CH: tour based mode use – car (modelled)
CH: Tour-based mode use – public transport (modelled)

Legend

**public transport mode**

- 0% - 0.09%
- 0.10% - 0.11%
- 0.12% - 0.14%
- 0.15% - 0.22%
- 0.23% - 0.34%
CH: Mode choice – Observed share public transport