MATSim, an agent based traffic simulator

Concepts, framework, and applications
PART 1: The multi-agent microsimulation toolkit
MATSim at a glance

Agent and activity based simulation of transportation demand (Scheduling) and transportation supply (Network).

- Java-Implemented
- Open source (GNU license)
- Jointly developed at ETH Zurich and TU Berlin
- www.matsim.org
The actors of the modeled system are represented at individual level and act in an artificial environment, according to given rules, pursuing a given goal and having learning capabilities.
The actors of the modeled system are represented at individual level and act in an artificial environment, according to given rules, pursuing a given goal and having learning capabilities.

The behavior of the system „emerges“ from the simulation as a consequence of individual agents‘ behavior.
Traffic is the consequence of the need of persons to perform activities at different places.
Traffic is the consequence of the need of persons to perform activities at different places.

If we can model activities of persons we can obtain the transportation demand as „side-product“ of the simulation.
MATSim Framework

- initial demand
- execution
- scoring
- analyses
- replanning
Persons:

- Attributes (i.e. Age, Gender, Driving license, Car ownership, etc.)
- Primary activities („Home“, „Work“, „Education“)

Source: Census, Synthetic Population

Demand:

- Initial Day-plans

Source: Travel diaries survey
Execution

- “Physical” Simulation of the day-plan
- Interaction among agents
- Basis for the calculation of the utility (score) of the plan for the person

**ActEnd**

**AgentDeparture**

**Wait2Link**

**LeaveLink**

**EnterLink**

**AgentArrival**

**ActStart**
**MATSim Utility function:**

\[
U_{\text{plan}} = \sum_{i=1}^{m} U_{\text{act},i} + \sum_{j=1}^{n} U_{\text{travel},j}
\]

\[
U_{\text{travel}} = \sum_{j=1}^{n} \alpha_j + \beta^1_j \cdot TT + \beta^2_j \cdot Cost_j \cdot Dist
\]

- Available modes: Car, PT, Bicycle, Walk,
Scoring

- Initial demand
- Execution
- Scoring
- Analyses
- Replanning

@home → travel → @workplace → @lunch

Workplace opening time
Replanning

Routes

Mode

Starting time

Location
High resolution navigation network, including turning rules
Facilities

„Facilities“:

• Building location
• Activity options
• Capacity, Opening time

Source:
Enterprise register, Building register
Performance - Scenario

- Transportation system in Switzerland
- 24 h of an average Work-day

- 5.99 Mio Agents
- 1.6 Mio Facilities for 1.7 Mio Activities (5 Types)
- Navigation network with 1.0 Mio Links
- 4 Modes
- 22.2 Mio Trips
- Routes-, Time-, (Subtour-)Mode- und „Location“-Choice

→ One Iteration in ca. 4.5 hours
Output (2)
PART 2: Applications
Working with MATSim…

• Users
  • Black-box use

• Super-users
  • Add new features

• Developers
  • Add new fundamental features
Current scenarios

- **Zurich and Switzerland**
  - Switzerland 7.6 Mio Agents
  - Navigation road network with 1 Mio Links

- **Berlin**

- **Munich**

- **Germany/Europe – Main road network**
  - 435 000 Links

- **Padang, Indonesia**
  - Simulation of a Tsunami evacuation

- **Tel-Aviv, Israel**

- **Gauteng, South-Africa**

- **Kyoto, Japan**
  - MATSim for the Optimization of the demand
  - Own detailed Traffic simulation with driving behavior

- **Toronto, Canada**
  - Network from EMME, Demand from TASHA

- **Caracas, Venezuela**

- **Singapore**
Current research themes (1)

• **Simulation of Public Transport**
  ◦ Improved Routing, Multimodal Simulation

• **Replanning improvement: Planomat, Planomat X**
  ◦ Reduce the number of iterations
  ◦ Add other choice dimensions

• **Simulation of Traffic lights and Lanes**
  ◦ Focus on adaptive Signal-control

• **Queue Simulation**
  ◦ Parallelisation

• **Location Choice for Secondary Activities**
Current research themes (2)

• Simulation with „Withinday Replanning“
  ◦ Simulation of Evacuations, Accidents, Parking search

• Modelling of the vehicle fleet
  ◦ Calculation of emissions

• Introduction of Land-use
  ◦ Integration with UrbanSim

• Location choice of Retailers
  ◦ Addition of Supply-side Agents

• Car-Sharing
  ◦ Carsharing as additional modal option
Example 1: Adding carsharing as modal option
Motivations & Goals

Motivations

- Carsharing and shared vehicle systems are growing fast but there are no models able to predict the demand for such systems

Goals

- Introduce carsharing as new modal option for the agents
- Show that the fundamental aspects of carsharing use are captured by the model
Representation of Carsharing travel

<table>
<thead>
<tr>
<th>Car 1</th>
<th>Car 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>8am - 9.30am</td>
<td>10am - 1pm</td>
</tr>
<tr>
<td>12pm - 14pm</td>
<td>3pm - 4.0pm</td>
</tr>
<tr>
<td>5am - 10pm</td>
<td>4.30pm - 7pm</td>
</tr>
</tbody>
</table>

Out: 4.51pm  In: 5.15pm
Out: 5.03pm  In: 9.28pm
Out: 9.31pm  In: 9.37pm
Out: 4.58pm  Out: 7.25pm  Out: 9.15pm
Out: 5.03pm  Out: 7.05pm
Out: 9.28pm  Out: 9.37pm
The modelled system

• The fee for carsharing is the sum of a distance fee and a time dependent fee

• Agents can pick up the cars only at predetermined locations (stations), and must bring them back to the same spot

• Agents are always choosing the closest station to the starting facility, stations are real car-sharing locations in the modeled area

• It is assumed that agents are walking to the pick-up point

• Car-sharing is available to everybody having a driving license (no membership is needed)

• An unlimited number of cars is available at the stations
Utility Function carsharing

\[ U_{plan} = \sum_{i=1}^{m} U_{act,i} + \sum_{j=1}^{n} U_{travel,j} \]

\[ U_{travel,i,cs} = \alpha_{cs} + \beta_{cost,cs} Cost_t * RT + \beta_{tt,walk} * (AT + ET) + \beta_{tt,cs} * TT + \beta_{cost,cs} * Cost_d * Dist \]

- The score for a Carsharing leg is calculated as the sum of normal walk legs and a car leg with the addition of a time dependent cost term.
Car Sharing Simulation: Test Scenario

Links: 236,000
Nodes: 73,000
Facilities: 373,000
Time resolution: 1 second
Agents: 161,000 (10%)
Simulation: Modal Shares

- Car
- Bike
- Walk
- Carsharing

Bar chart comparing MatSim and Census shares for different modes.
Validation with Mobility Swiss Data

- Mobility Swiss: 2350 Cars at 1200 Stations

- Data from 107 Stations in the area around Zurich and corresponding Trips and Customers data
  - Stations: Location (coords), # cars
  - Customers: Home location (coords)
  - Trips: Start and end time, distance
Tour duration

![Graph showing tour duration with lines for Mobility, Matsim, and Census.](image-url)
Distance to the station

![Graph showing cases percentage against distance (m) for MATSim and Mobility simulations. The x-axis represents distance in meters ranging from 0 to 1800, and the y-axis represents cases percentage ranging from 0 to 35. The graph includes data points for MATSim and Mobility, differentiated by symbols and color. The legend indicates MATSim (diamonds) and Mobility (squares).]
Trip purpose

Cases [%]

- Work
- Education
- Shopping
- Leisure

All Modes (Census)
Cs (Matsim)
Summary

• The model is still simple, yet capable to capture some of the most important aspects of carsharing usage

Future Work:

◦ Access to the stations with any mode
◦ Limited number of vehicles at stations
◦ Schedule for the vehicles
◦ Membership model
◦ Refined behavioural models (Survey)
◦ Further Validation (Mobility customers data)
Example 2: Improving location decisions of retailers using an agent based approach
Motivations & Goals

Motivations

- To have an agent-based system which allows the **dynamic interactions** of **demand** side and **supply** side agents

Goals

- Introduce **retail agents** which are able to relocate their stores
- Show that shops’ locations can be improved with this methodology
Retail agents

**Retailer:** “Person or entity having the control on one or more shopping facilities (retail stores)”

**Goal:** Maximize the number of customers

**Choice dimension:** Location of retail stores
Each retailer uses a **genetic algorithm** with the following objective function:

\[
\min \sum_{i}^{n} \left( \sum_{j}^{m} \frac{C_{ij}}{m} \right)
\]

- \(n\) = number of shops of the considered retailer
- \(m\) = the number of potential customers for the shop \(i\) at the given location
- \(C_{ij}\) = generalized cost of travel for the individual agent \(j\) to travel to location \(i\)
Simulation Scenario

- Area around Zurich

- Two retailers, with respectively 29 and 17 stores
- Initial locations of **two real Swiss retailers**, leaders in the grocery market.
- Locations available have been selected randomly, but accepted under some specific requirements. For each candidate location, an hypothetical caption area around it has been considered.
  - Potential customers above a given threshold in the area
  - Ratio potential customers/ shops capacity above a given threshold
Results (1)

![Graph showing the comparison between Optimized Relocation and No Relocation over iterations.](image-url)

- **Optimized Relocation**
- **No Relocation**

The graph illustrates the decrease in the number of customers over iterations for both Optimized Relocation and No Relocation scenarios.
<table>
<thead>
<tr>
<th></th>
<th>Retailer 1</th>
<th>Retailer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Shops</td>
<td>29</td>
<td>17</td>
</tr>
<tr>
<td>Stores Moved</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Stores Moved %</td>
<td>41%</td>
<td>35%</td>
</tr>
<tr>
<td>Customers (Move)</td>
<td>3541</td>
<td>2902</td>
</tr>
<tr>
<td>Customers (No move)</td>
<td>3199</td>
<td>2603</td>
</tr>
<tr>
<td>Increase %</td>
<td>10.6%</td>
<td>11.4%</td>
</tr>
</tbody>
</table>
Summary

• Retail agents in the simulation are able to increase the number of their customers by relocating their shops

Future work:

◦ Validation regarding the number of customers shopping in specific stores
◦ Run 100% Scenario
◦ Further agent types (transport operators, planners, public authorities, legislators, etc.)
PART 3: To conclude...
MATSim Summary

• Agents are software abstractions representing persons acting in an artificial world
  ◦ Personal attributes/behavioural rules
  ◦ Goal-oriented
  ◦ Learning ability (experience)

• They are traveling as a consequence of individual needs (shopping, work, leisure, etc.)

• Agents are competing for the infrastructure

• Iteratively (one day is iteratively simulated) until a steady state is reached.
Key Features

• **Fast Dynamic and Agent-Based Traffic Simulation**
  Uses a dynamic assignment and simulate whole days within minutes

• **Private and Public Traffic**
  Both private cars and transit traffic can be simulated

• **Supports Large Scenarios**
  MATSim can simulate millions of agents and/or huge, detailed networks

• **Versatile Analyses and Simulation Output**
  E.g. compare simulated data to real-world counting stations

• **Modular Approach**
  Easily extended with your own algorithms

• **Interactive Visualizer**
  See what each agent is doing during the simulation

• **Open Source**
  You get the Java Source Code, which runs on all major operating systems

• **Active Development**
  We add constantly new features and improve current ones
Team

- ETH Zürich, IVT
  - Prof. Dr. Kay W. Axhausen
  - Dr. Michael Balmer
  - Francesco Ciari
  - Christoph Dobler
  - Andreas Horni
  - Kirill Müller
  - Dr. Nadine Schüssler
  - Basil Vitins
  - Rashid Waraich

- TU-Berlin, VSP
  - Prof. Dr. Kai Nagel
  - Yu Chen
  - Dominik Grether
  - Johannes Illenberger
  - Benjamin Kickhöfer
  - Gregor Lämmel
  - Andreas Neumann
  - Thomas Nicolai
  - Michael Zilske

- Senozon AG
  - Dr. Michael Balmer
  - Dr. Marcel Rieser
• THANK YOU FOR YOUR ATTENTION!

• MATSim project: www.matsim.org