Simulation of Extreme Traffic Events I

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Transport Planning – A very short Introduction
Tasks of Transport Planning

• Optimal design of transport systems
  • Respect global utility and, as far as possible, individual preferences

• Strategic planning of network development

• Design (e.g. shape of a road) and configuration (e.g. green time fractions of traffic lights) of infrastructure

• Determine impacts of changes in the infrastructure

• Design infrastructure to reach a desired impact
User Equilibrium vs. System Optimum

• For both states it is assumed, that all people have perfect information (e.g. traffic flows, load of buildings, ...)

• User Equilibrium
  • Every person acts selfish, e.g. like a homo economicus
  • No person can improve its daily schedule further

• System Optimum
  • The global utility (e.g. the sum of all personal utilities) is optimized
  • Typically, most people will profit but some will also suffer
Macro-Simulation vs. Micro-Simulation

• Macro-Simulation
  • Based on aggregated data
  • Flows instead of individual movement
  • Often planning networks

• Micro-Simulation
  • Population is modeled as a set of individuals
  • Traffic flows are based on the movement of single vehicles (or agents) and their interactions
  • Various traffic flow models, e.g. cellular automata model, queue model or car following model
  • Often high resolution networks (e.g. in navigation quality)
Transport Models

How to improve a front wing?

Zurich

New bypass

Transport model for forecasting

PTV Visum, etc.

Flow control measures

Physical model
Traditional Approach: Four Step Process

- Trip generation
  - Define number of trips from and to each zone.

- Trip distribution
  - Define for each zone where its trips are coming from and going to.

- Mode choice
  - Define transport mode for each trip.

- Route assignment
  - Assign a path to each route.
Four Step Process – Trip Generation
Four Step Process – Trip Distribution
Four Step Process – Mode Choice
Four Step Process – Route Assignment
Traditional Four Step Process – Facts

• Traditional approach in transport planning
  • Simple, well known and understood

• Sequential execution
  • Feedback not required, but desirable

• Aggregated Model
  • No individual preferences of single travelers
  • Only single trips, no trip chains

• Static, average flows for the selected hour, e.g. peak hour
Iterative Four Step Process

- Improvement of the traditional approach
  - Iterations allow feedback to previous process steps
- Still an aggregated model
Modern Modeling Approaches

- Activity-based demand generation
- Dynamic traffic assignment
- Fully agent-based approach – combination activity-based demand generation and dynamic traffic assignment
Activity-based Demand Generation

• Models the traffic demand on an individual level.

• Based on a synthetic population that represents the original populations on a statistical level accurately.

• For each individual a detailed daily schedule is created, including descriptions of performed
  • Activities (location, start and end time, type)
  • Trips (mode, departure and arrival time)

• Activity chains instead of unconnected activities and trips.

• Represents the first three steps of the 4 step process.
Dynamic Traffic Assignment

- Time dependent link volumes replace static traffic flows.

- Typical implementations are simulation based.
  - Iterative simulation and optimization of traffic flows in a network on an individual level.

- Represents the fourth step of the 4 step process.
Fully Agent-based Approach

• Combines the benefits of activity-based demand generation and dynamic traffic assignment.

• Replaces all steps of the four step process.

• During the whole process, people from the synthetic population are maintained as individuals.
  • Individual behavior can be modeled!
MATSim – A Multi-agent Transport Simulation Toolkit

- Implementation of a fully agent-based approach as part of a transport modeling tool
  - Disaggregate
  - Activity-based
  - Dynamic
  - Agent-based

- Open source framework written in java (see www.matsim.org)

- Started ~10 years ago, community is still growing
  - Yearly developer and user meetings
  - Tutorials held all over the world

- Developed by Teams at ETH Zurich, TU Berlin and senozon
MATSim Team

Head

Prof. Dr. K. Nagel
Prof. Dr. K.W. Axhausen

Project management

Dr. N. Schüssler

Developers

Y. Chen  F. Ciari
D. Grether  C. Dobler
J. Illenberger  T. Dubernet
B. Kickhöfer  A. Horni
G. Lämmel  K. Meister
A. Neumann  B. Vitins
T. Nicolai  R. Waraich
M. Zilske

... and others all over the world!
... we are not alone: MATSim Spreading
Day Plans

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    </leg>
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  </plan>
</person>

...
MATSim – Iterative Optimization Loop

- Optimization is based on a co-evolutionary algorithm
- Period-to-period replanning (typically day-to-day)
- Each agent has total information and acts like homo economicus
- Approach is valid for typical day situations
MATSim – Creation of the Initial Demand

• Based on an activity-based demand generation approach

• Typically multiple data sources have to be combined

  • Census data (socio-demographic attributes, home and work locations)

  • Travel surveys (activity chains, transport mode, distance distributions)
Home and Work Location from Census Data
Area for Secondary Activities
Possible Locations for Secondary Activities
Final, Initial Daily Plan
MATSim – Simulation Module

- Simulation of the traffic flows based on a queue model (first in, first out, no overtaking)

- Time step based, i.e. the simulated time span is split up into time bins (typical duration: 1 second)

- So far, only simply dynamics at junctions

- Car traffic and public transport is simulated physically, walk and bike trips are estimated
MATSim – Scoring Module

• The quality of an executed plan is evaluated using a scoring function:

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

• \( U_{act} \) ... Utility of performing an activity. Depends on
  • Duration
  • Further constraints like opening times of buildings

• \( U_{travel} \) ... Utility of traveling. Depends on
  • Travel time
  • Travel distance
  • Transport mode
• Different replanning strategies are available to optimize an agent’s daily schedule:
  • Activity chain choice
  • Time choice
  • Location choice
  • Mode choice
  • Route choice

• The number of active replanning strategies defines the complexity of the optimization problem.
MATSim – Replanning Module

- Example with three binary replanning decisions
MATSim – Analyses

• Various default analyses are available, e.g.
  • Trip distribution (number of agents arriving, departing an en-route per 5 minutes time bin)
  • Score statistics over all iterations (best, worst, average score of all plans)
  • Travel distances
  • Mode share statistics
  • Traffic count comparison (simulation vs. real world counts)
MATSim – Analyses

• Moreover, problem specific analyses can be performed based on a log-file containing all simulation events

• Each state change of an agent is logged as an event (e.g. departure from home, move from link A to link B, …)

• For example
  • CO2 emissions of a vehicle based on vehicle type, travel distance and average speed
  • Load of buildings, e.g. shops
  • Mode share
  • People passing certain links or parts of the network
Extreme Traffic Events
Extreme Traffic Event – Definition

- An event that
  - cannot (e.g. an earthquake) or
  - only partially (e.g. a major sports events) be foreseen.

- Classification based on the impact of the event on the
  - Population
    - Number of affected people
    - Reaction of an affected person

- Transport system
  - Affected network structures
  - Availability of services (public transport, traffic signals, …)
Extreme Events in Transport Simulations

- Assumption that agents have full information is no longer valid.
  - Agents have to collect information to be able to estimate the traffic flows and the travel times in the network.
  - A model of the information flows has to be added to the simulation.

- Combination of exceptional events and an iterative simulation approach possible?
Problem: Extreme Events and Iterative Simulations

- Startnode of the Route
- Node on the planned Route
- Endnode of the Route
- Planned Route
- Event that blocks a Link
Problem: Extreme Events and Iterative Simulations
A Possible Solution: Within-Day Replanning

• Idea: Get rid of the iterations – perform only a single one!

• Use a system in a relaxed state as input scenario.

• Allow the agents to adapt their plans interactively during this iteration to be able to react to extreme events.
Within-Day Replanning: Requirements

• For every kind of extreme event, a specific behavioral model is required.

• Depending on the kind of event, an agent will no longer act as a homo economicus (as typical agent-based simulations assume), e.g. during an event that causes an evacuation of the affected area:
  • fathers that will try to rescue their family instead of leaving an evacuation area as fast as possible
  • people who are in panic might act illogical

⇒ A flexible behavioral model is required that can reproduce such reactions
A Flexible Behavioral Model: The BDI Approach

- Beliefs
  - Level of information of an agent
  - Not necessarily true

- Desires
  - What an agent wants to achieve
  - Desires can compete with each other

- Intentions
  - Describe how an agent plans to reach its desires
Literature Review: Behavior under Evacuation Conditions

- A large-scale evacuation is a extreme event with a high impact on the population as well as the transport system.

- Boundary conditions for the review
  - Large-scale evacuation, not small-scale like single buildings
  - Evacuation area > 3km diameter
  - Respect various events which trigger an evacuation (incident in a nuclear power plant, flooding, bush fire, ...)

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Findings from the Literature Review

- People tend to act in a rational way, panic is seldom
- Whenever possible, nuclear families evacuate as unit
- Women and children are more likely to participate than men
- People tend to evacuate by car, if one is available
- Young people participate more often than older ones
Findings from the Literature Review

• People prefer homes of kin or friends to find shelter

• Social contacts are important for receiving and interpreting information on the evacuation

• A bright mass of people do not evacuate before an official order is given

• The more an evacuation order is confirmed, the more people participate

• Face-to-face information is taken more serious than information from the mass media
Implementation – Adapted MATSim Loop
Implementation – Replanning Manager

- Replanning Manager:
  - Started once in every time step of the mobility simulation

- Replanner:
  - Each replanner implements one type of plan adaptation (e.g. re-routing, relocation of an activity, ...)

- Identifier:
  - Identifies agents that should be replanned by its replanner.
  - Can be seen as information distribution channel.
Within-Day Replanning – Use Cases

• For scenarios with extreme events
  • Accidents
  • Disasters
  • Evacuations

• In iterative simulations runs to keep the agents behavior consistent and feasible
  • Parking search
  • Car-sharing
  • Taxis
Within-Day Replanning – Accidents

• How do people react if an accident influences the road network capacities?
• Do they know that an accident has happened?

• Solution approach:
  • Reduce level of information of the agents.
  • Model information spreading.
  • Model individual reaction (willing to wait vs. searching for alternative route)
Within-Day Replanning – Disasters

• How do people react if a disaster occurs?
• Do they know that the disaster has taken place?
• Do they know whether the network infrastructure is affected or not?

• Solution approach:
  • Reduce level of information of the agents.
  • Model information spreading.
  • Model individual reaction.
Within-Day Replanning – Evacuation

• How do people react if an evacuation order is given?
• Do they know that the order is given?
• Are there any rescue units to support the evacuation?

• Solution approach:
  • Model behavior of the rescue units.
  • Model governmental instructions.
  • Model individual reaction (waiting at home, meeting family members, evacuate, ...).
Within-Day Replanning – Parking Search

• How could one agent exactly plan where to park?
• What would happen, if the planned parking lot is not free anymore?

• Solution approach:
  • Do not define an exact parking position in advance.
  • Agents use within-day replanning to select a free parking space when they are close to their destination.
Within-Day Replanning – Car Sharing

- How could multiple agents share one car?
- Will the driver wait, if some passengers are missing?
- Will the passengers wait, if the car has not arrived?

Solution approach:
- If the car has to wait, add a waiting activity to the driver’s plan.
- If the passengers have to wait, add a waiting activity to their plans.
Within-Day Replanning – Taxis

• How could a passenger know, which taxi will come?
• How could a taxi driver will know where to pick up a passenger?

• Solution approach:
  • Passenger is waiting at the street and stops the next taxi that is coming by.
  • Taxi drivers look for passengers waiting on the street and pick them up.
Extreme Traffic Events – An Example: Scenario Description

- 10% diluted cut sample of Canton Zurich (67’000 agents)
- Planning network (24’000 nodes, 60’000 links)
- Capacities of arterial roads inside the City of Zurich is reduced to 20% at 7:00 and reset to 100% at 9:00
Scenario – Area and Affected Links
Scenario – With and Without Event

![Graph showing the comparison between En-route, Departures, and Arrivals with and without an event.](image-url)
Scenario – Within-Day Replanning Setup

• Within-day replanning is enabled from 07:00 to 12:00

• Only replanning type is rerouting

• Replanning distances 0.0km, 1.0km, 2.5km and 5.0km

• Replanning share 0%, 25%, 50%, 75% and 100%
Scenario – Results – Replanning Buffers

0.0km replanning buffer

1.0km replanning buffer

2.5km replanning buffer

5.0km replanning buffer
Scenario – Results – Mean Travel Times
Conclusions

• Simulation of extreme traffic events is none of the common tasks of transport planning, therefore models and simulation software is very rare.

• Common modeling approaches cannot reproduce feasible traffic flows and population behavior for scenarios with extreme traffic events.

• An new approach to overcome this drawback is within-day replanning.

• A behavioral model for each different kind of extreme traffic event is required.
Questions?