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

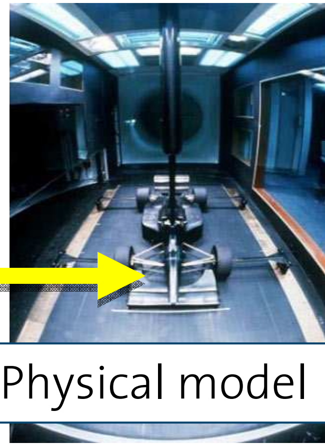
Macro-Simulation vs. Micro-Simulation

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

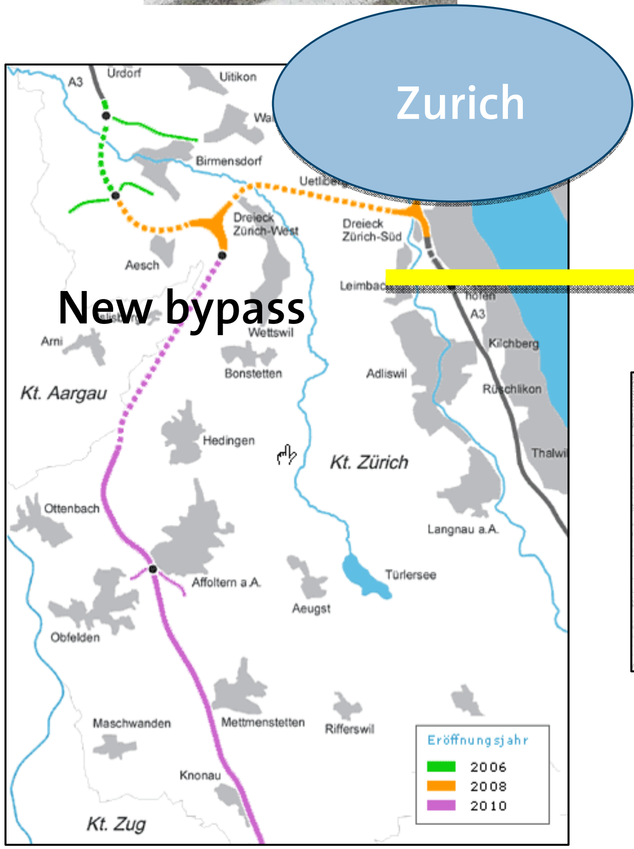
- Micro-Simulation
  - Population is modeled as a set of individuals
  - Traffic flows are based on the movement of single vehicles (or agents) and their interactions
  - Various traffic flow models, e.g. cellular automata model, queue model or car following model
  - Often high resolution networks (e.g.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

Transport Models

How to improve a front wing?

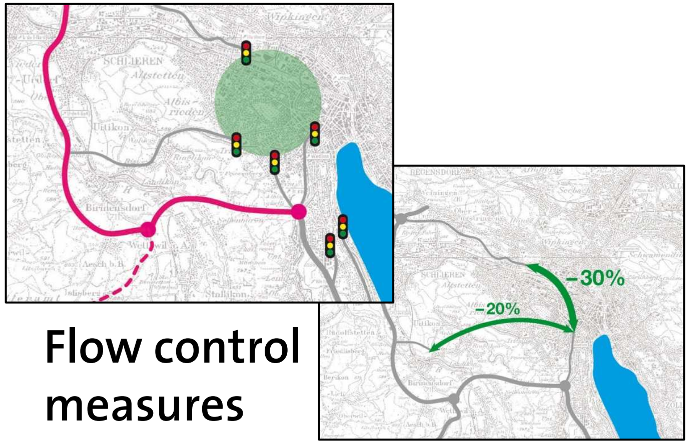


Physical model



How to improve the transport system?

Transport model for forecasting



Flow control measures

MATSim

PTV Visum, etc.

Traditional Approach: Four Step Process

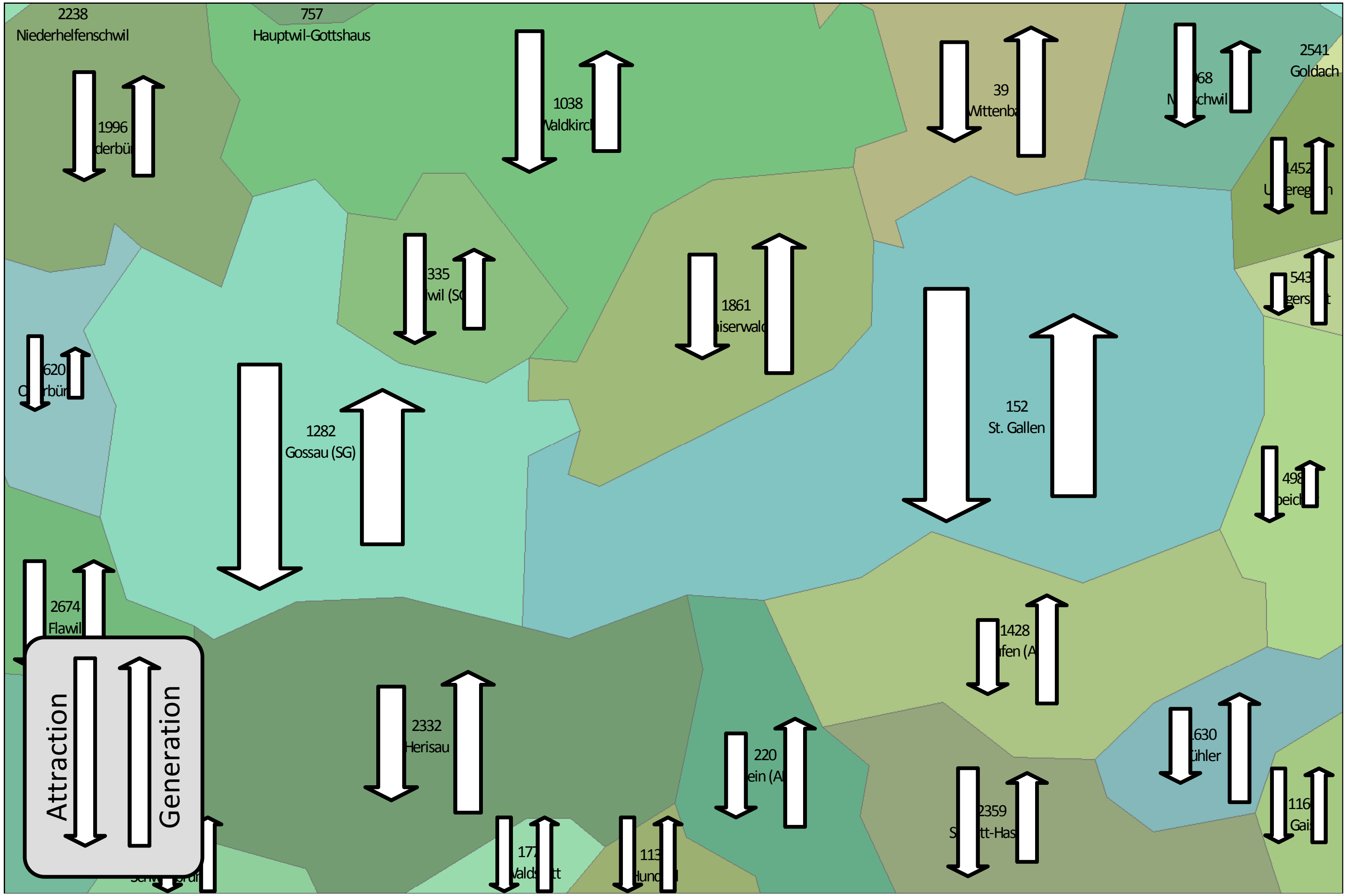
- Trip generation
  - Define number of trips from and to each zone.

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

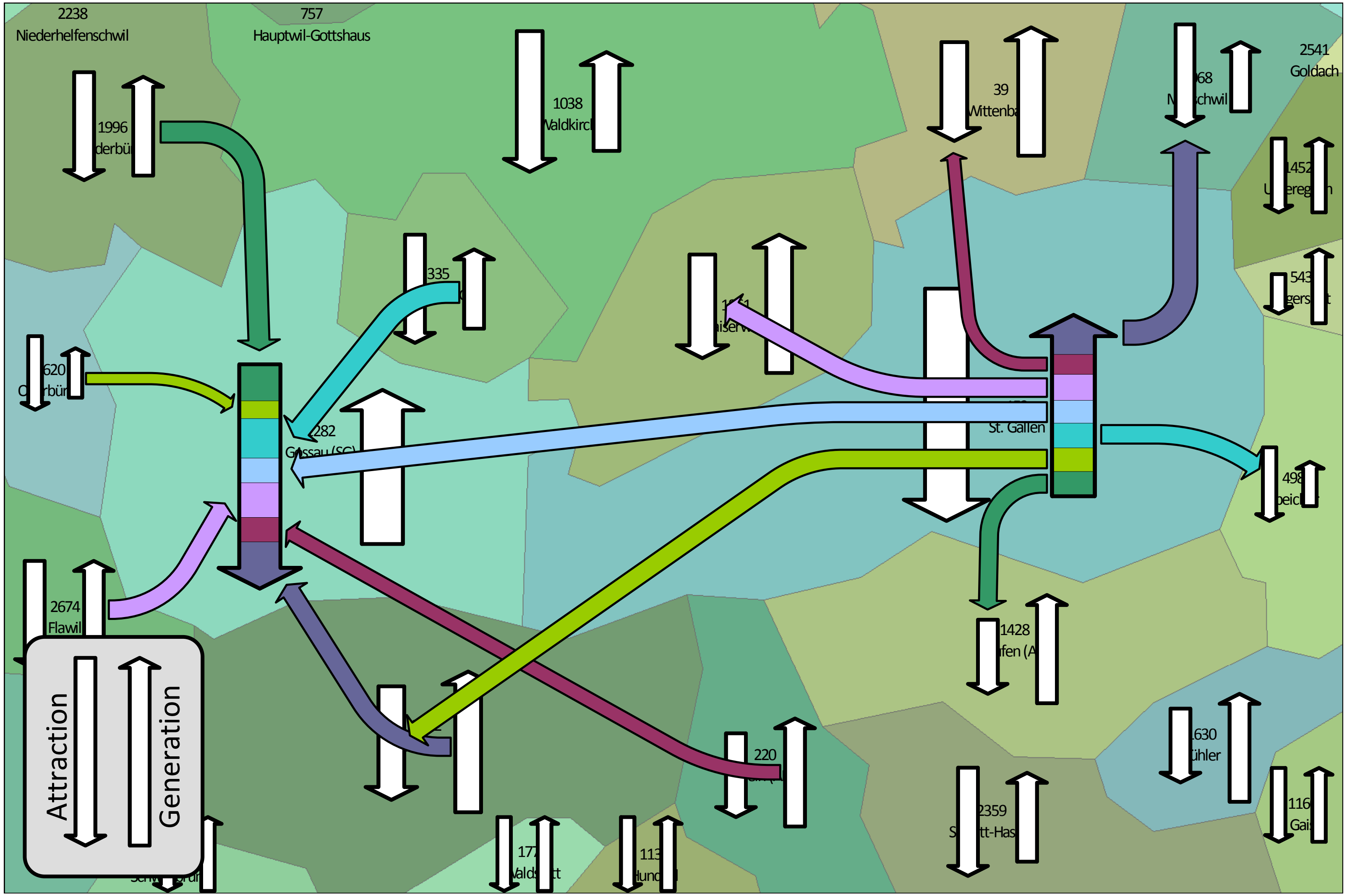
- Mode choice
  - Define transport mode for each trip.

- Route assignment
  - Assign a path to each route.

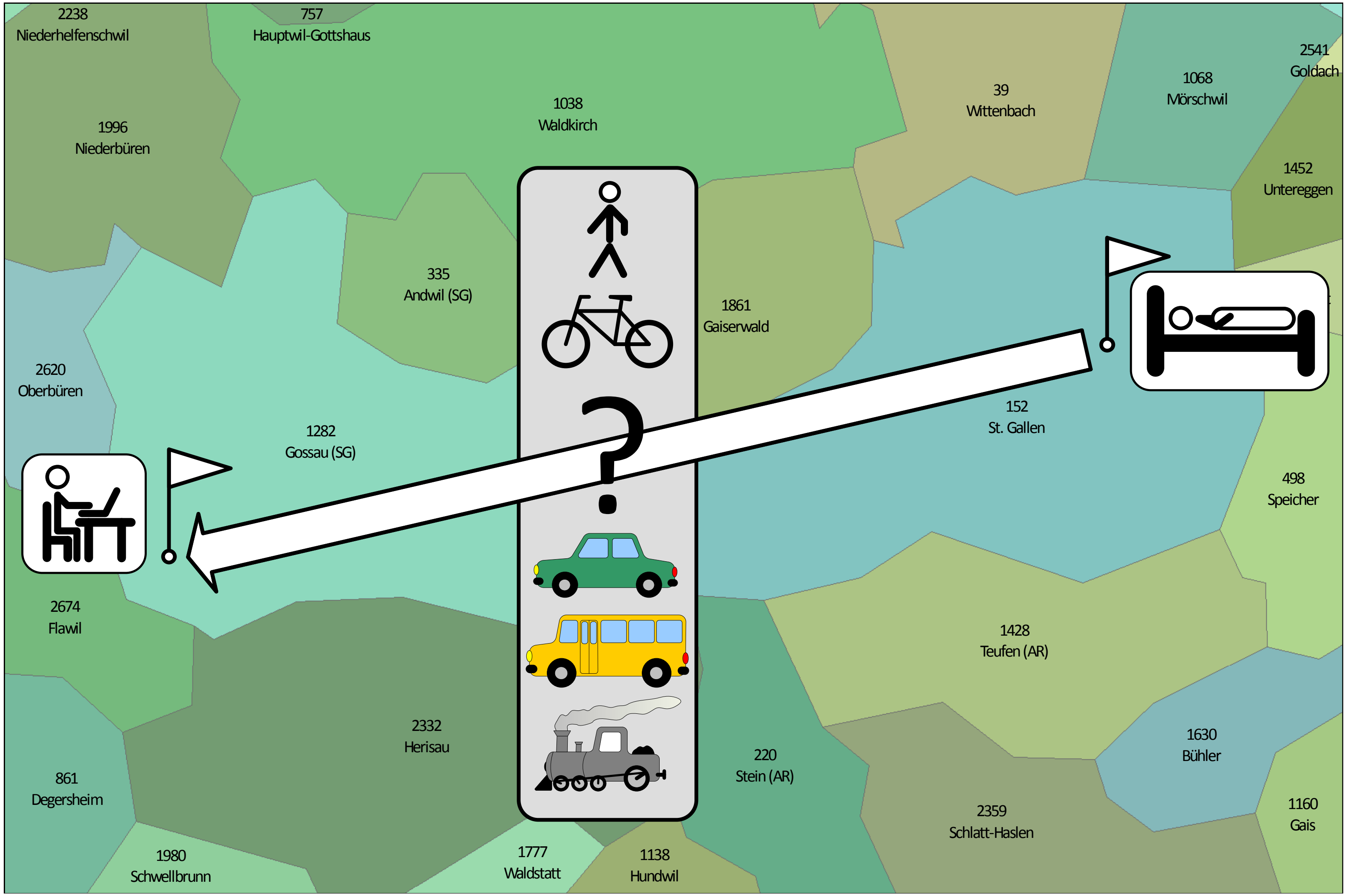
Four Step Process – Trip Generation



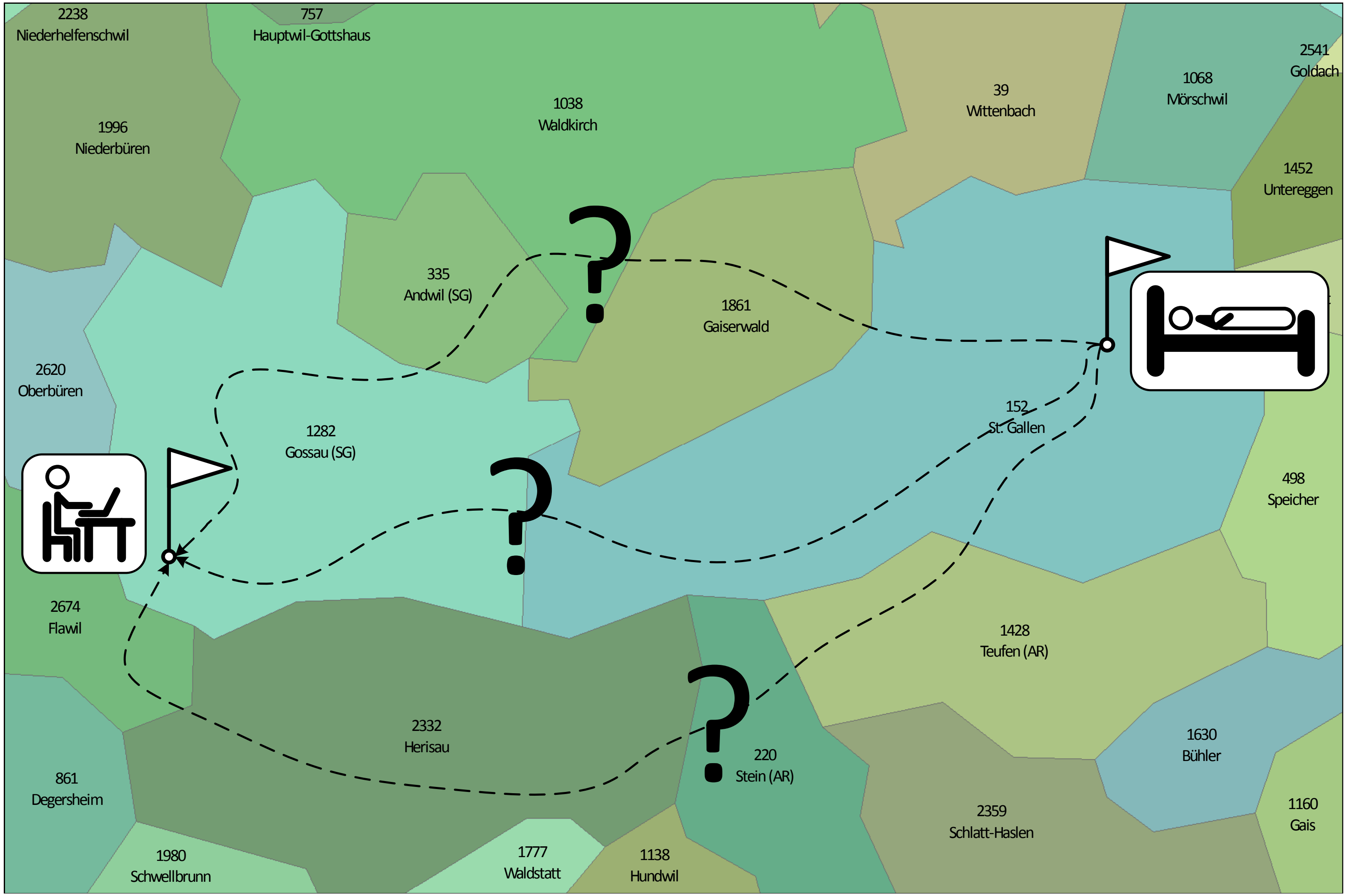
Four Step Process – Trip Distribution



Four Step Process – Mode Choice

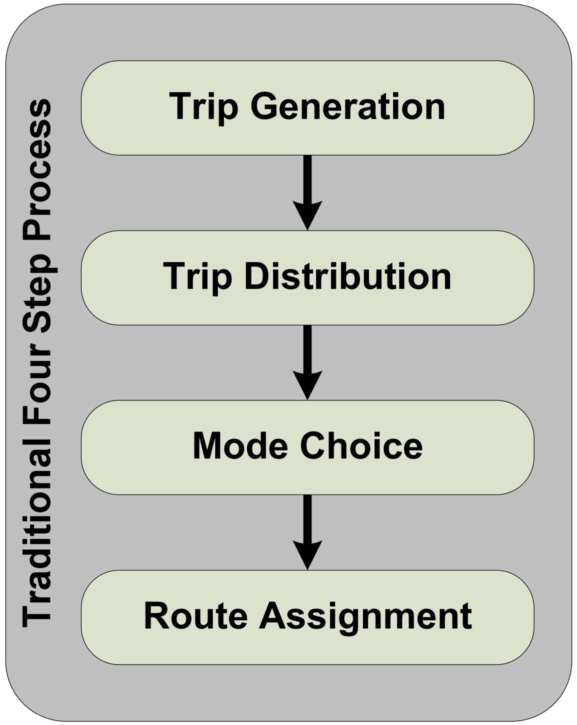


Four Step Process – Route Assignment



Traditional Four Step Process – Facts

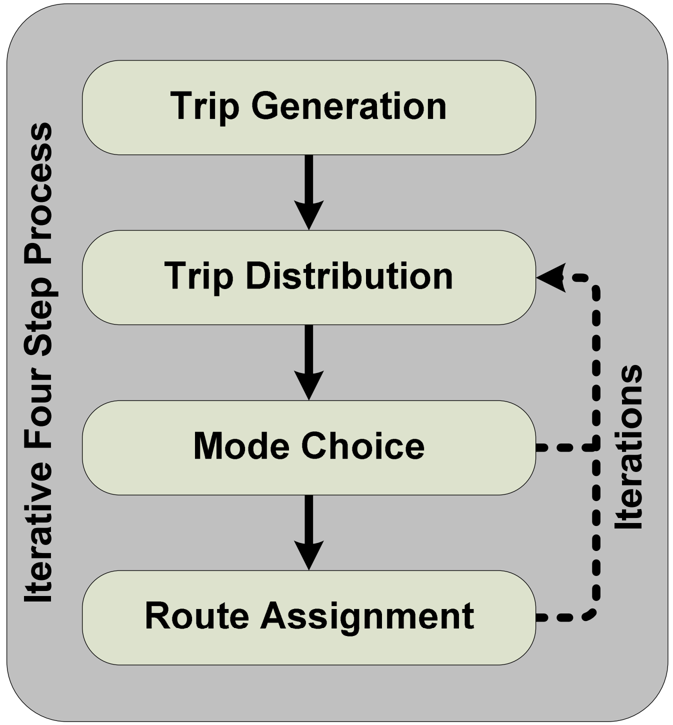
- Traditional approach in transport planning
  - Simple, well known and understood
- Sequential execution
  - Feedback not required, but desirable
- Aggregated Model
  - No individual preferences of single travelers
  - Only single trips, no trip chains
- Static, average flows for the selected hour, 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

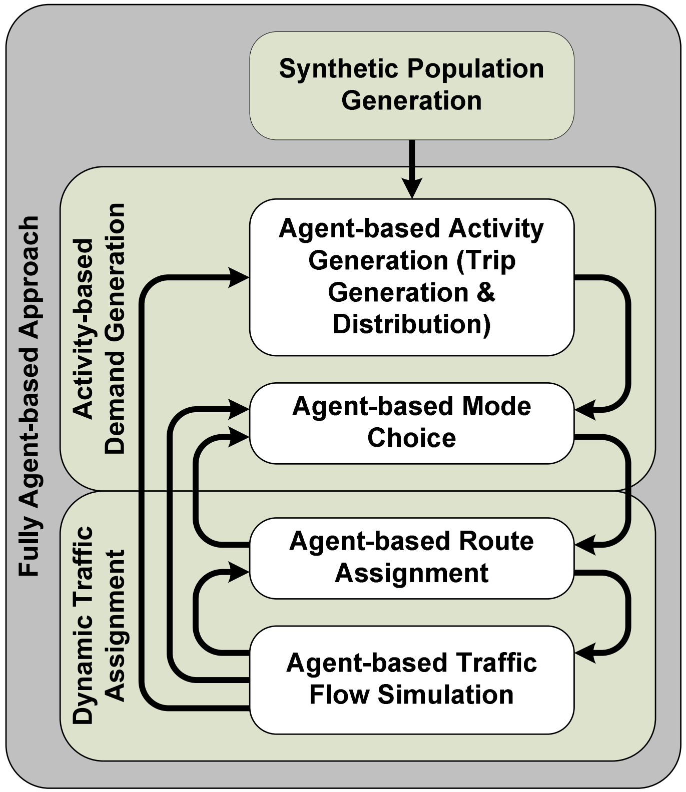
- Time dependent link volumes replace static traffic flows.

- 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

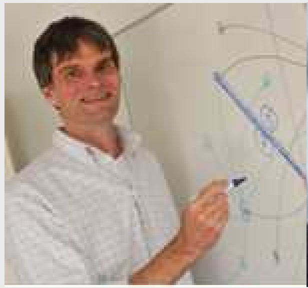
- Open source framework written in java (see www.matsim.org)

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

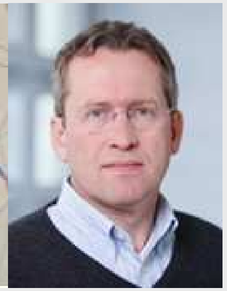
- Developed by Teams at ETH Zurich, TU Berlin and senozon

MATSim Team

Head



Prof. Dr.
K. Nagel



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T. Dubernet
A. Horni
K. Meister
B. Vitins
R. Waraich

... and others all over the world!

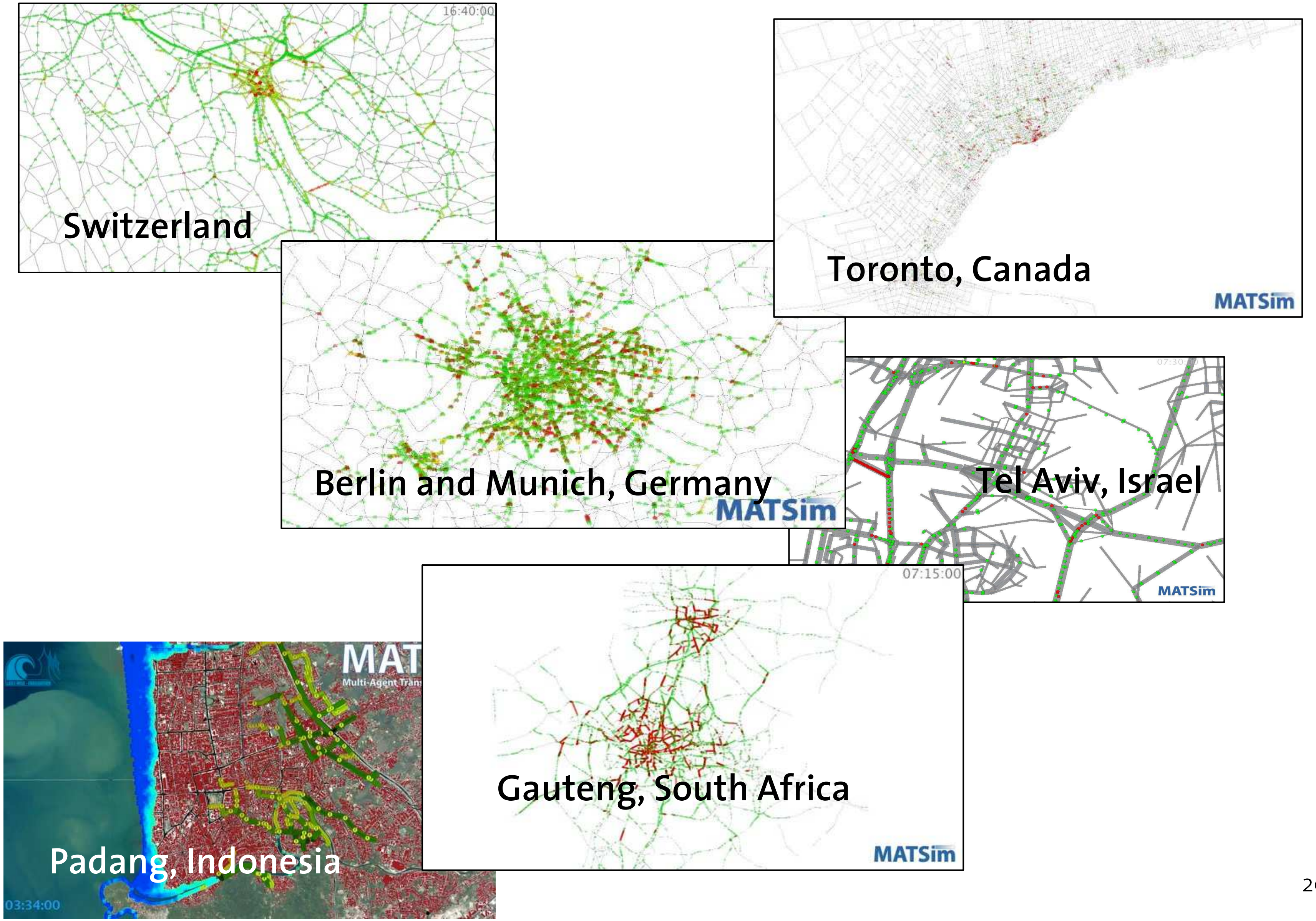
MATSim spin-off & consulting

senozon
understanding mobility

Dr. M. Balmer

Dr. M. Rieser

… we are not alone: MATSim Spreading



Day Plans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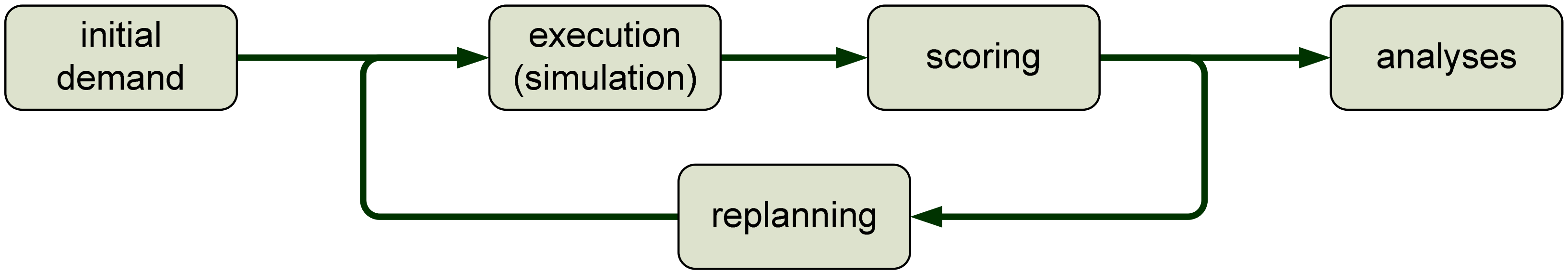
        <travelcard type="unknown" />
        <plan selected="yes">
                <act type="h11" link="22399" x="633714.0" y="127443.0" start_time="00:00:00" dur="06:45:00" end_time="06:45:00" />
                <leg num="0" mode="car" dep_time="06:45:00" trav_time="00:30:11" arr_time="07:15:11">
                 <route dist="12000.0" trav_time="00:30:11">7467 7010 7033</route>
                </leg>
                <act type="w10" link="22401" x="634366.0" y="127260.0" start_time="07:15:11" dur="10:00:00" end_time="17:15:11" />
        ...
</plan>
</person>
```

MATSim – Iterative Optimization Loop

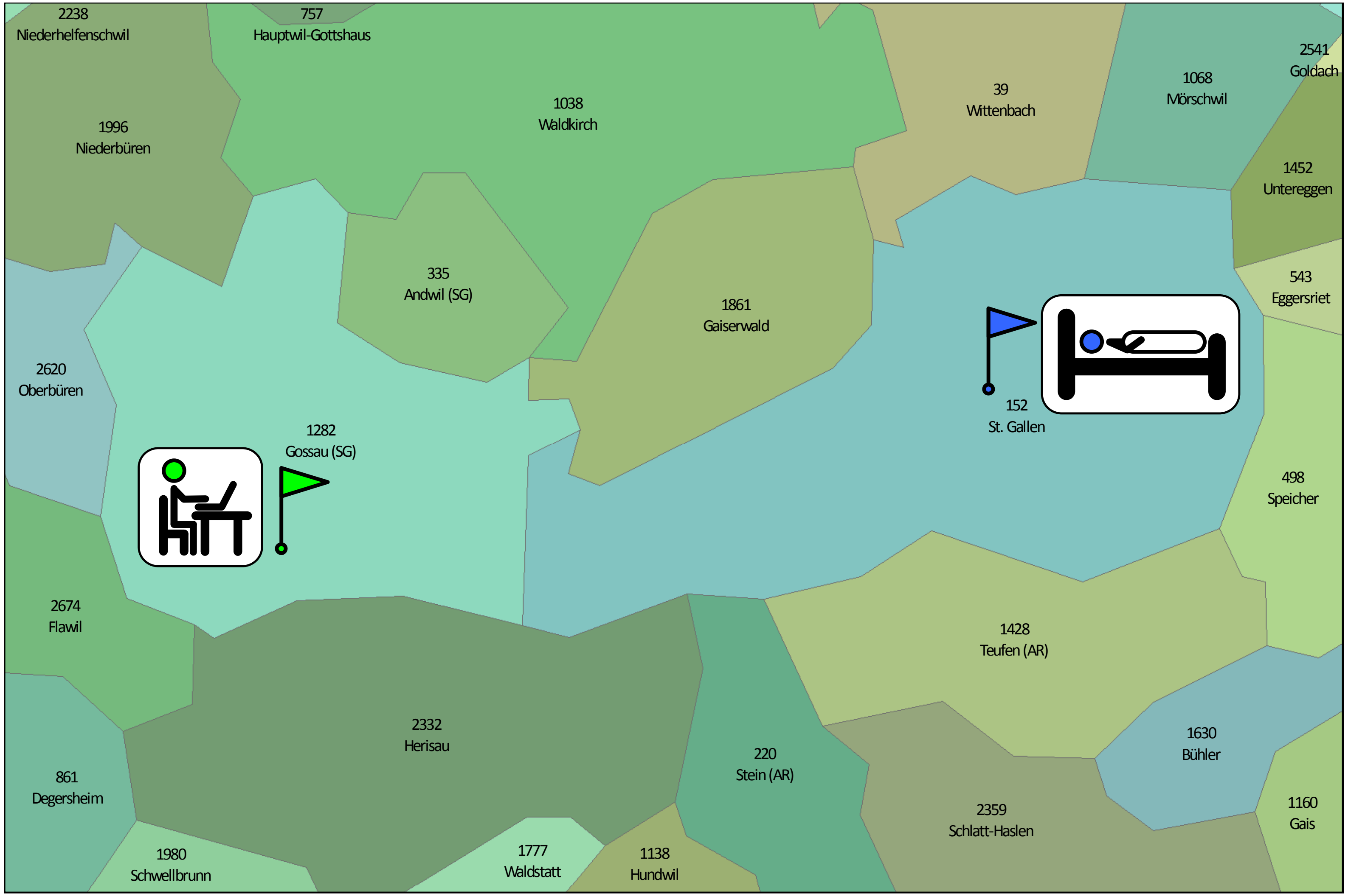
- Optimization is based on a co-evoluationary algorithm
- Period-to-period replanning (typically day-to-day)
- Each agent has total information and acts like homo economicus
- Approach is valid for typical day situations



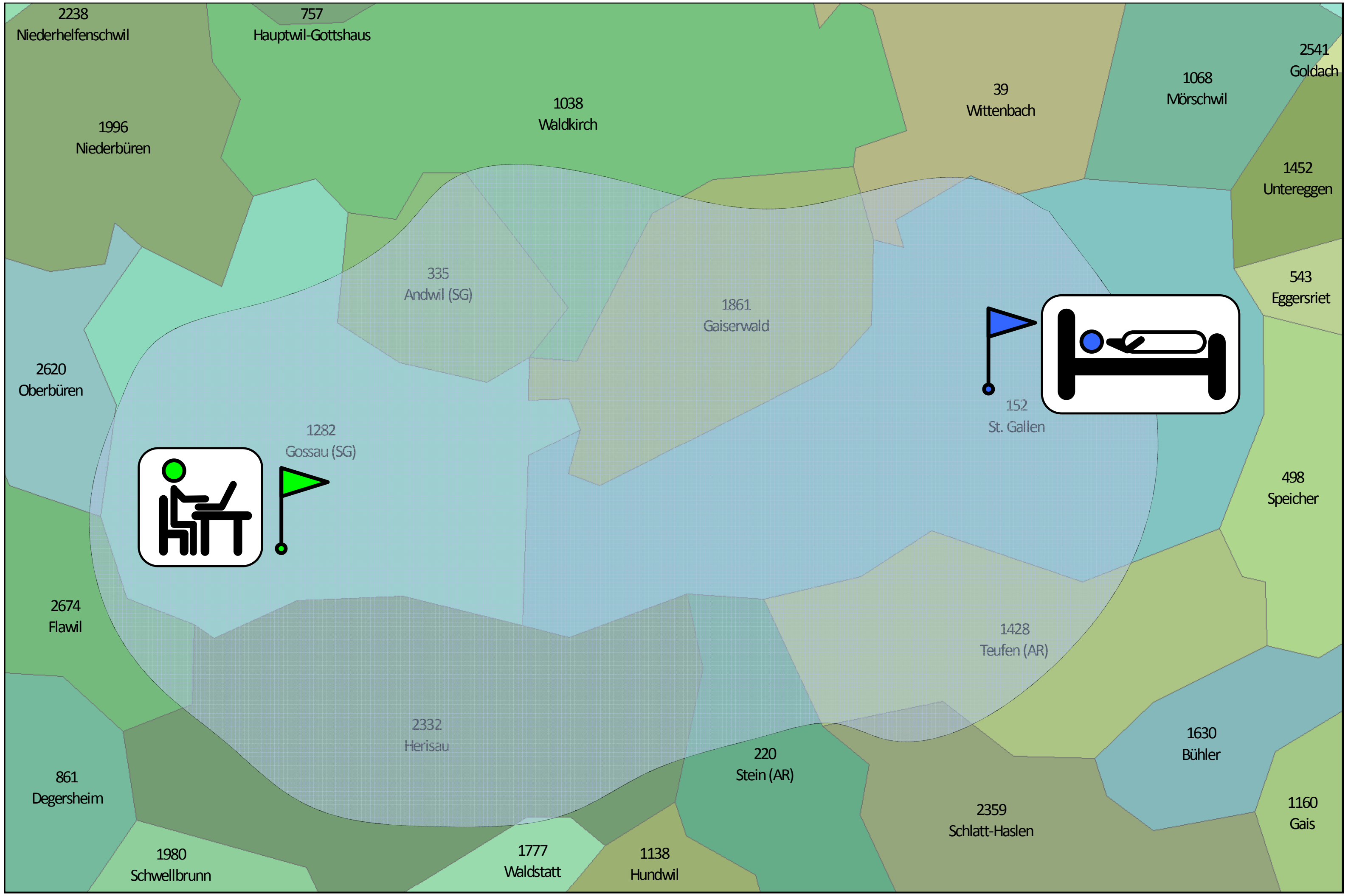
MATSim – Creation of the Initial Demand

- 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)

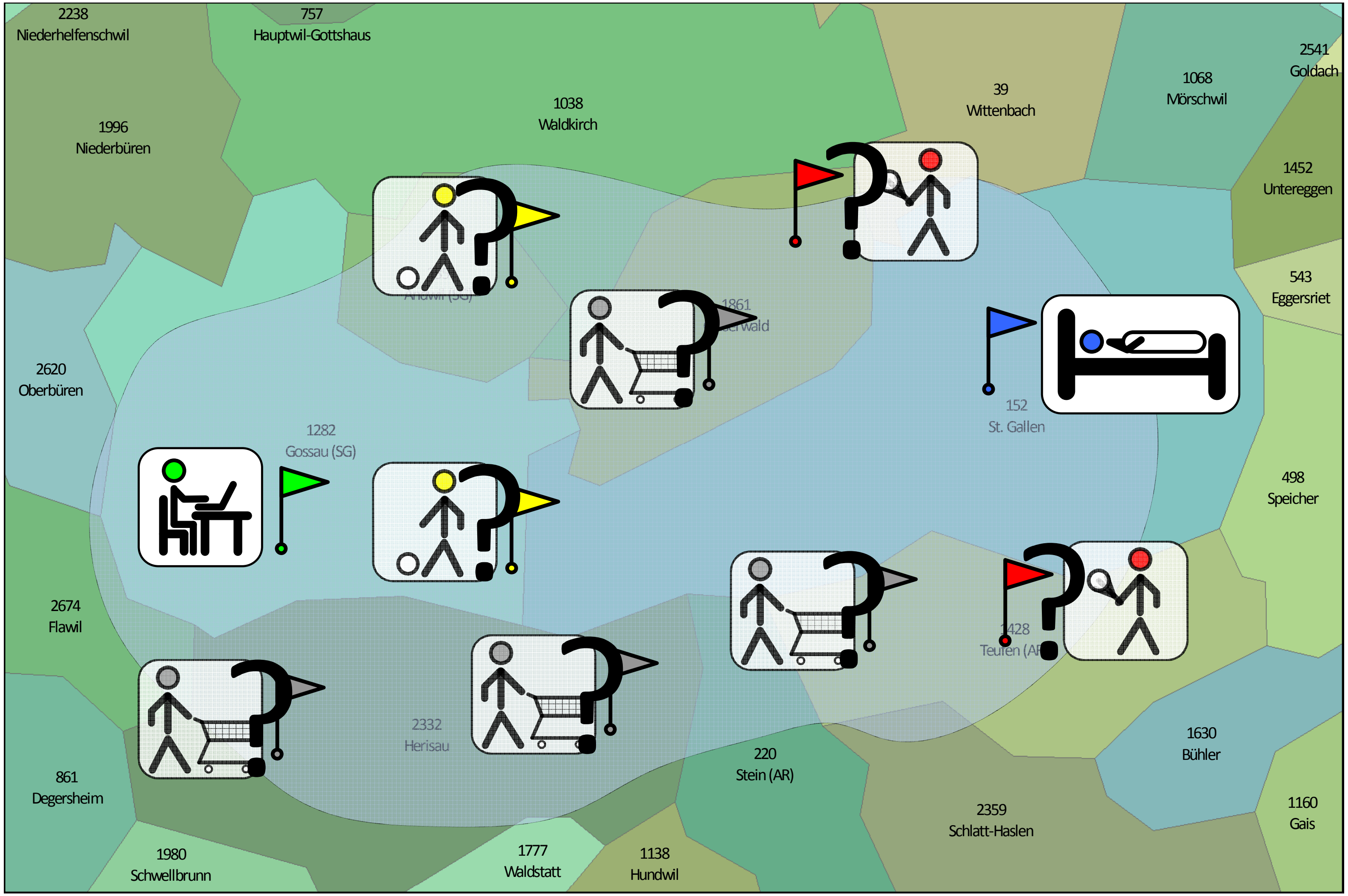
Home and Work Location from Census Data



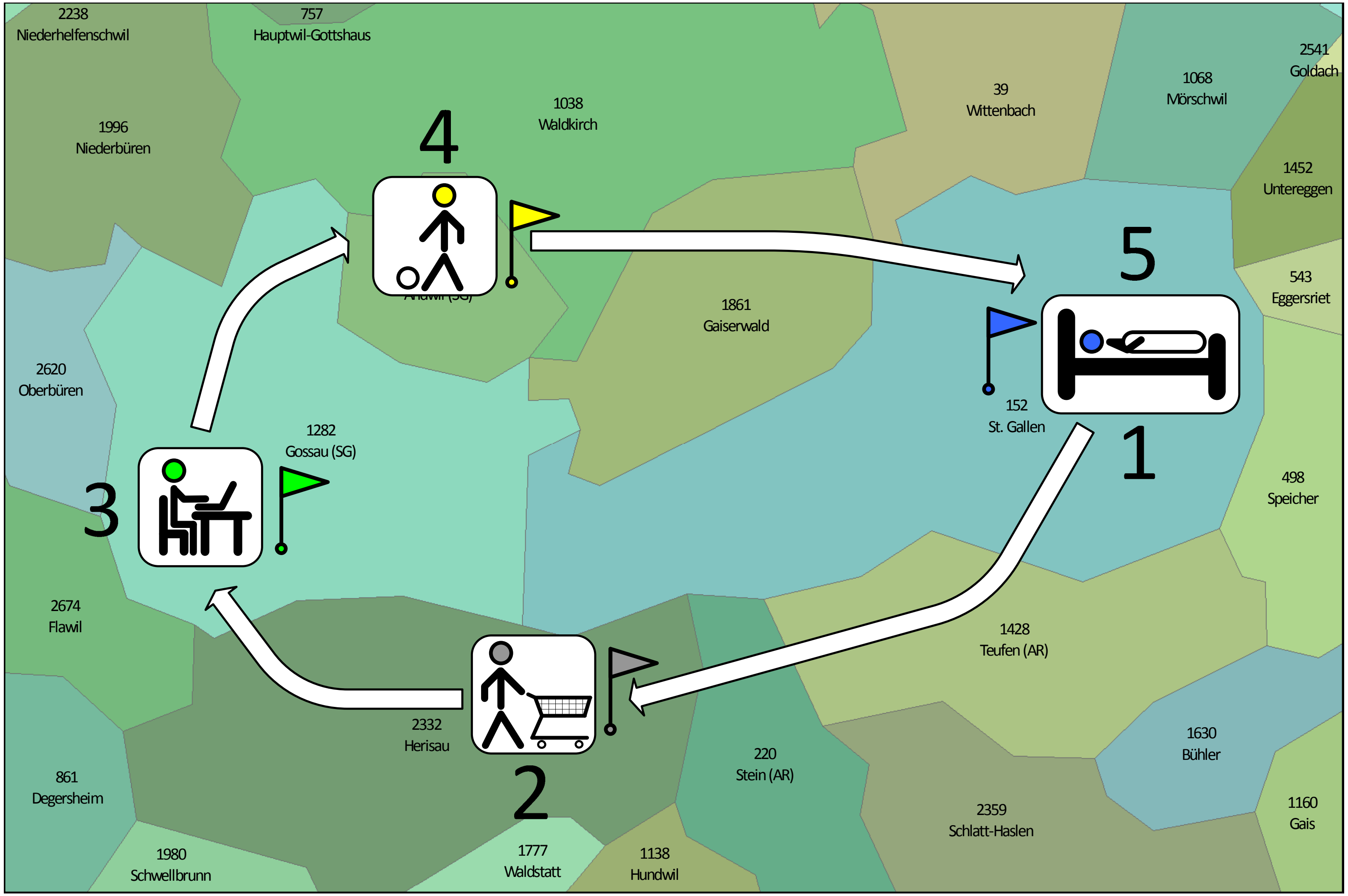
Area for Secondary Activities



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:

$$U_{plan} = \sum_{i=1}^{n} \left(U_{act,\,i} + U_{travel,\,i} \right)$$

- 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

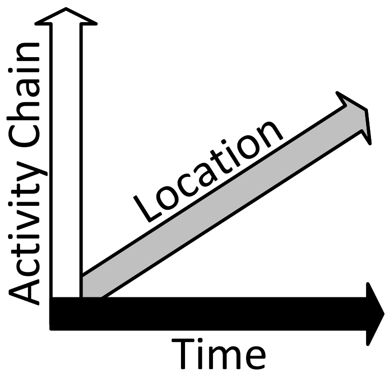
MATSim – Replanning Module

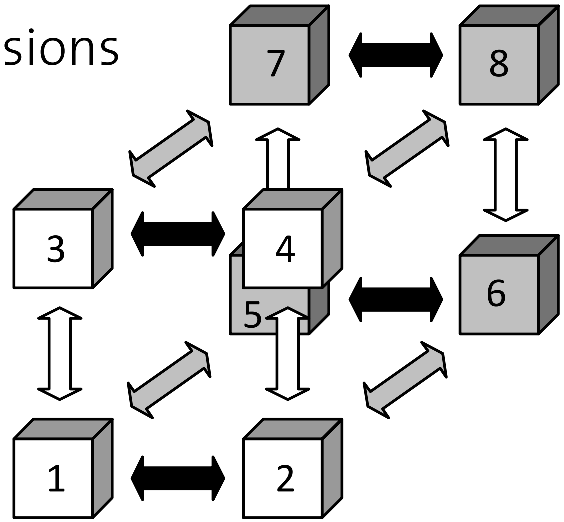
- Different replanning strategies are available to optimize an agent's daily schedule:
  - Activity chain choice
  - Time choice
  - Location choice
  - Mode choice
  - Route choice

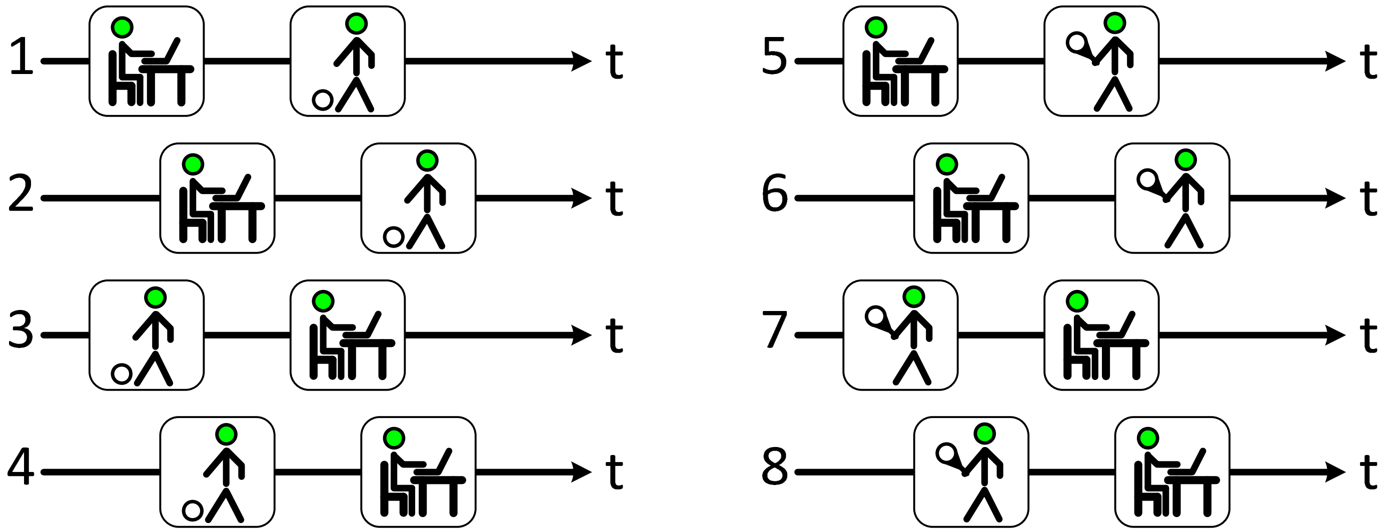
- The number of active replanning strategies defines the complexity of the optimization problem.

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
  - CO_2 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

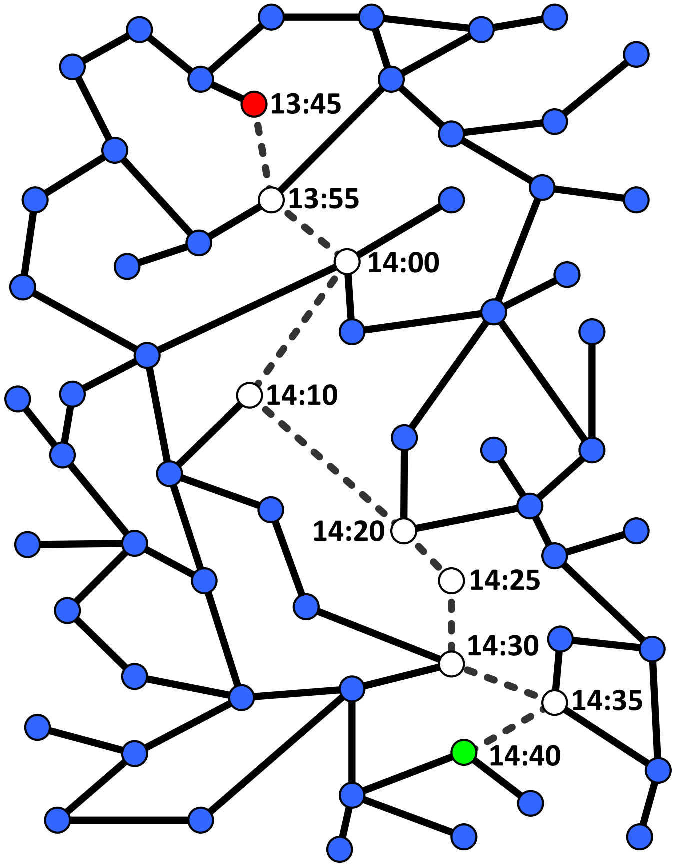
  - Transport system
    - Affected network structures
    - Availability of services (public transport, traffic signals, …)

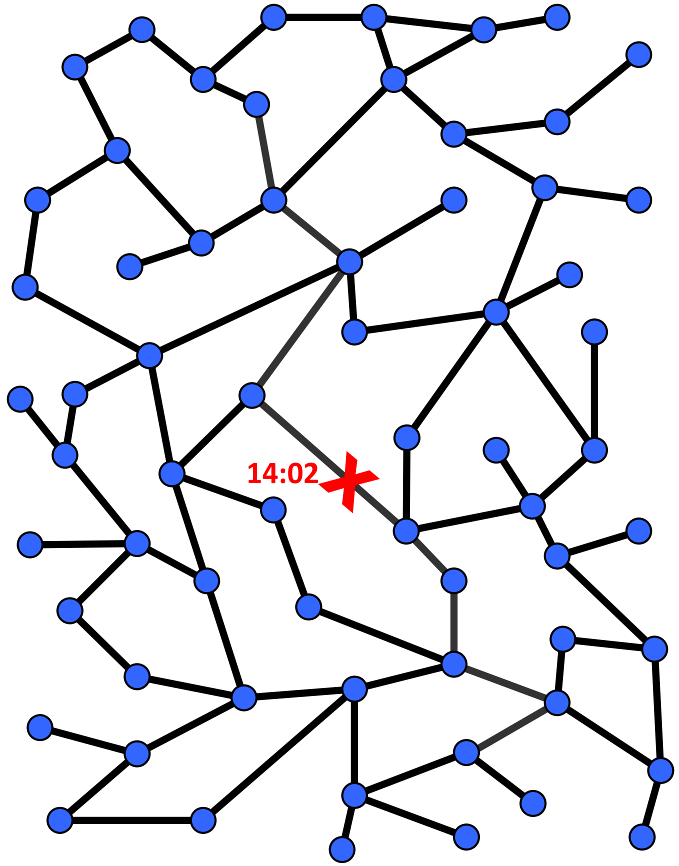
Extreme Events in Transport Simulations

- 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

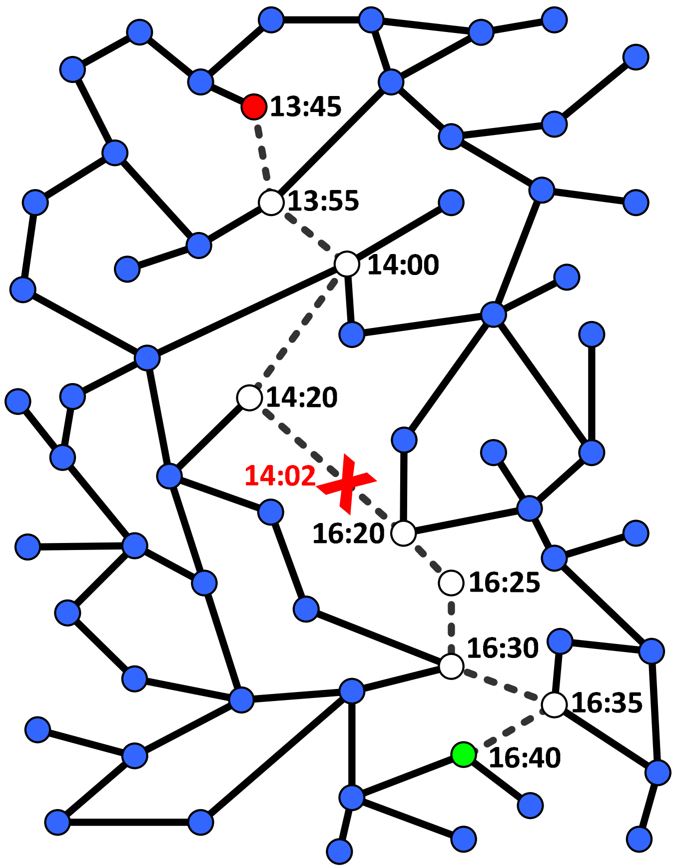


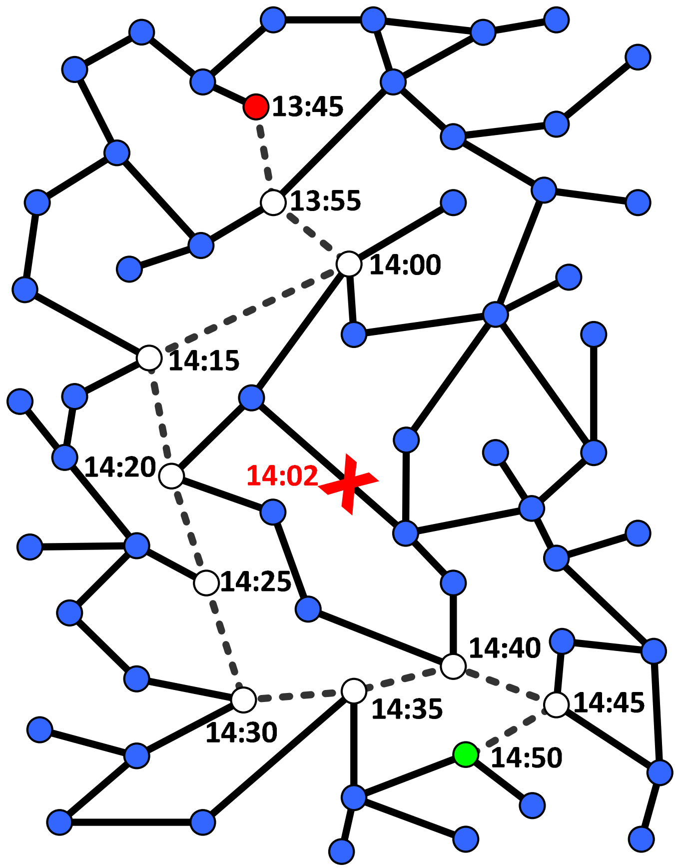


Startnode of the Route | Node on the planned Route | Endnode of the Route | Planned Route

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 agents 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, …)

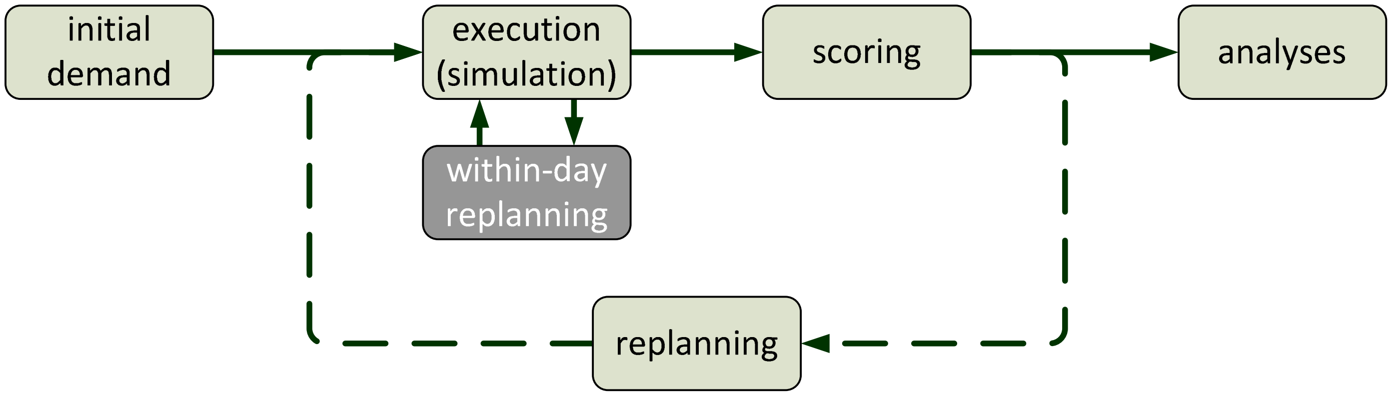
Findings from the Literature Review

- 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

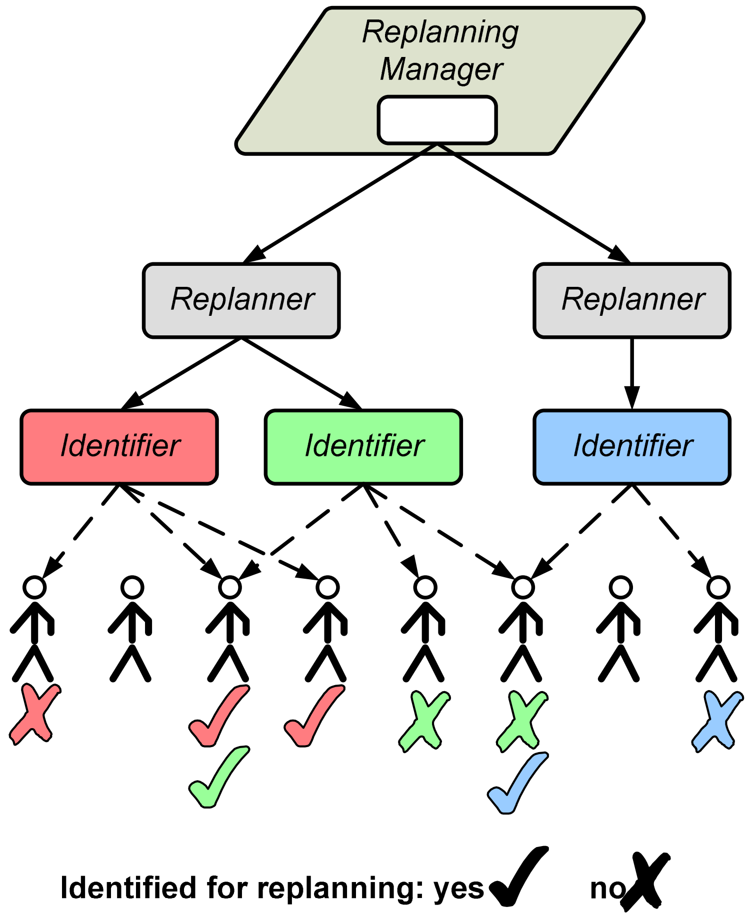
- People prefer homes of kin or friends to find shelter
- Social contacts are important for receiving and interpreting information on the evacuation
- A bright mass of people do not evacuate before an official order is given
- The more an evacuation order is confirmed, the more people participate
- Face-to-face 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 agent 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

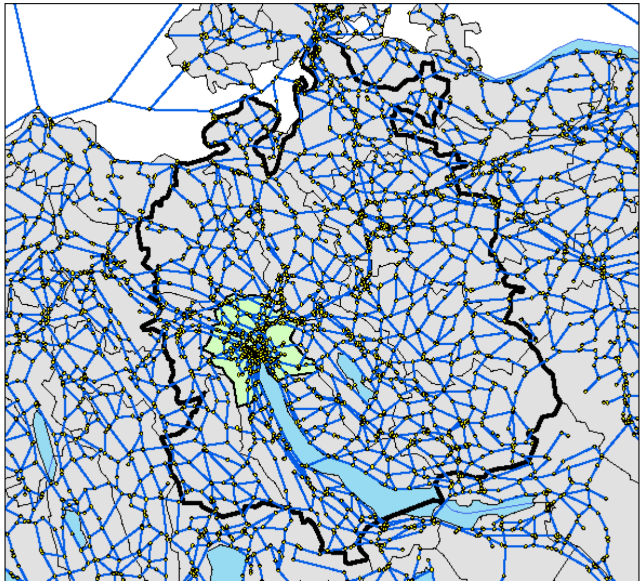
- How could a passenger know, which taxi will come?
- How could a taxi driver will know where to pick up a passenger?

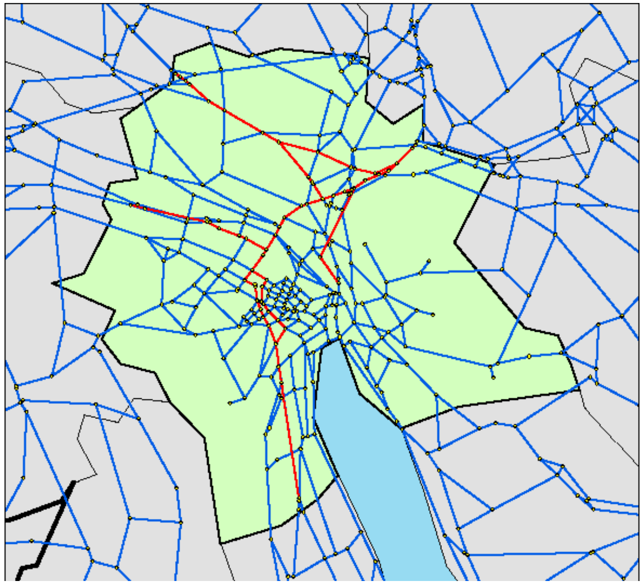
- Solution approach:
  - Passenger is waiting at the street and stops the next taxi that is coming by.
  - Taxi drivers look for passengers waiting on the street and pick them up.

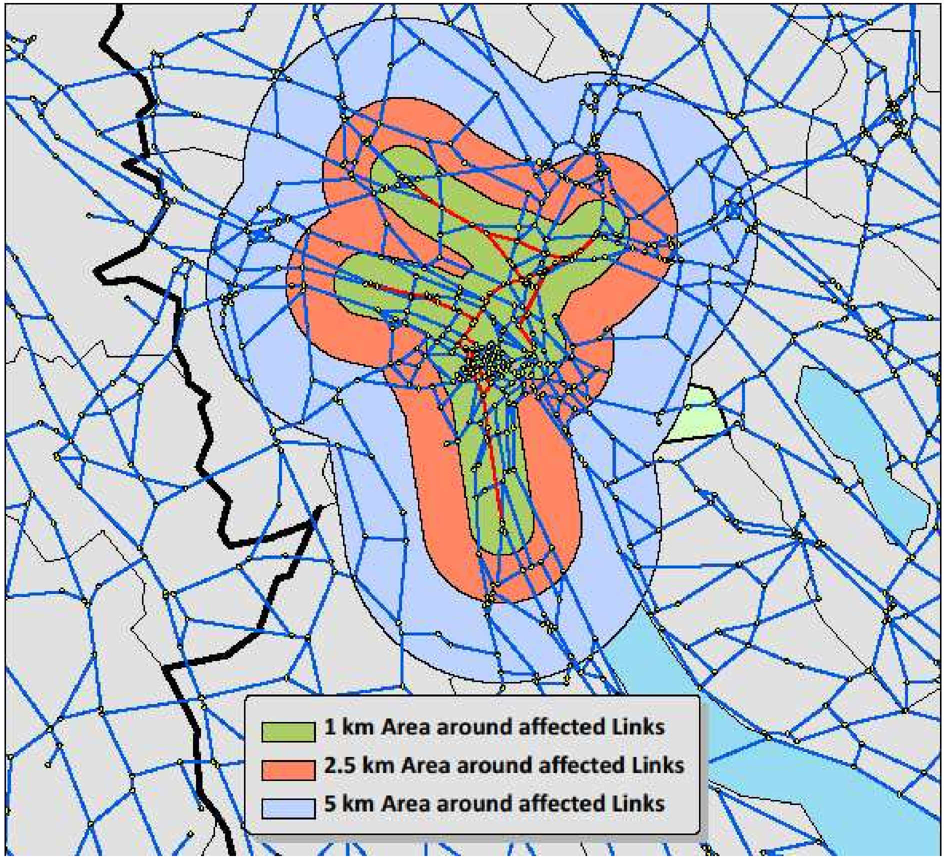
Extreme Traffic Events – An Example: Scenario Description

- 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

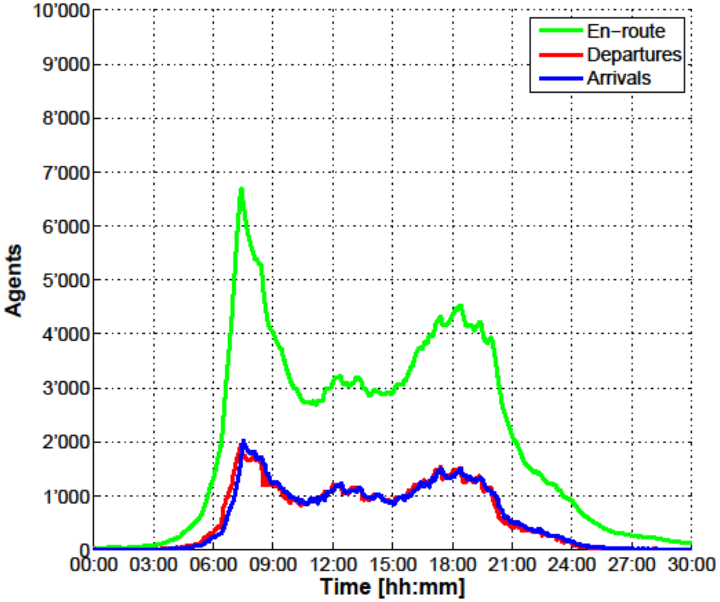
Scenario – Area and Affected Links

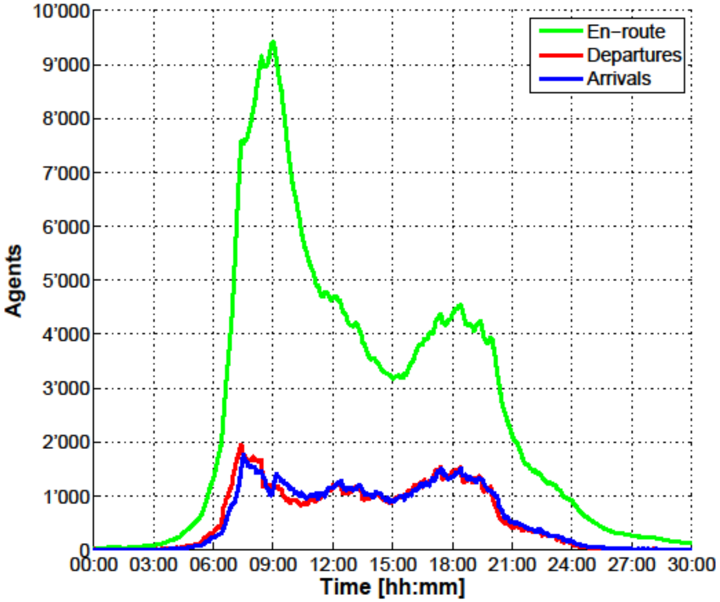


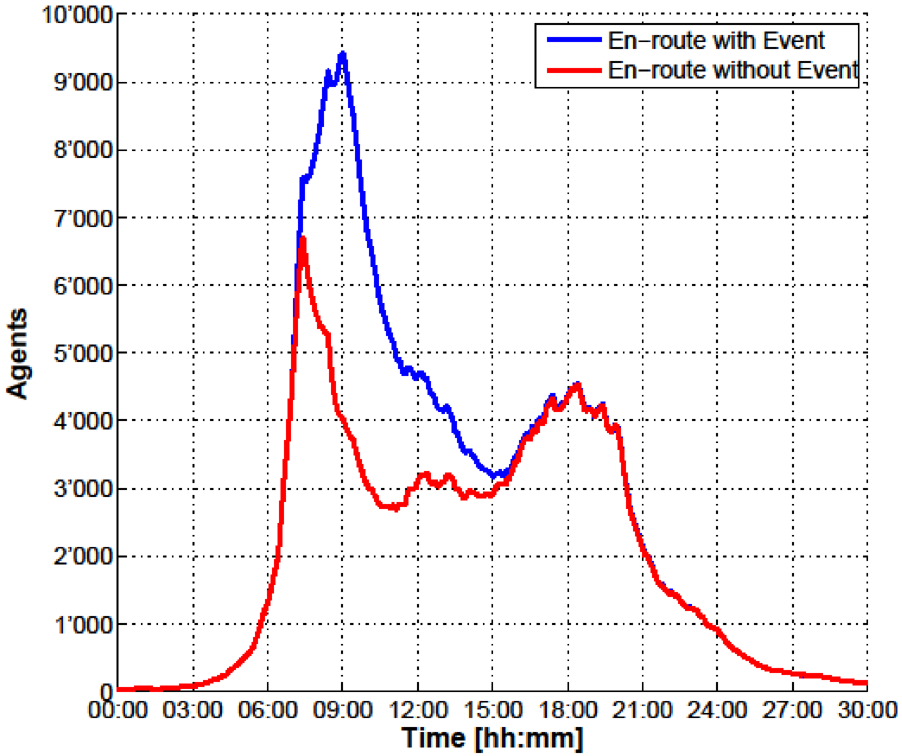




Scenario – With and Without Event





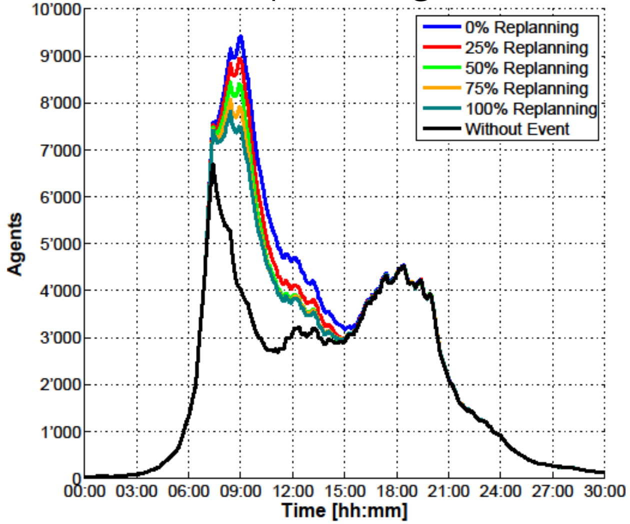


Scenario – Within-Day Replanning Setup

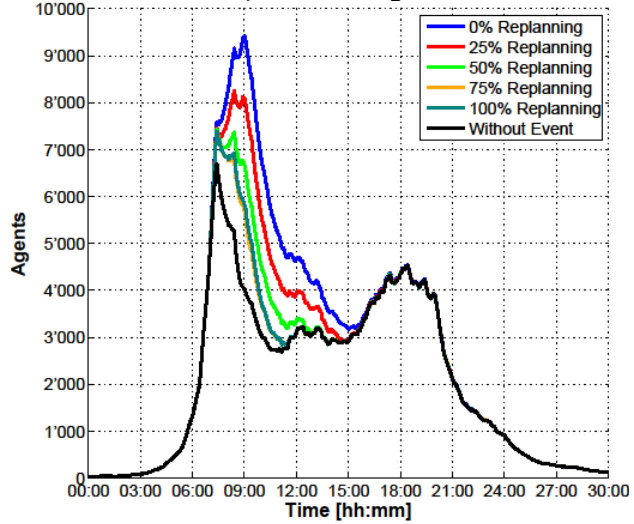
- Within-day replanning is enabled from 07:00 to 12:00
- Only replanning type is rerouting
- Replanning distances 0.0km, 1.0km, 2.5km and 5.0km
- Replanning share 0%, 25%, 50%, 75% and 100%

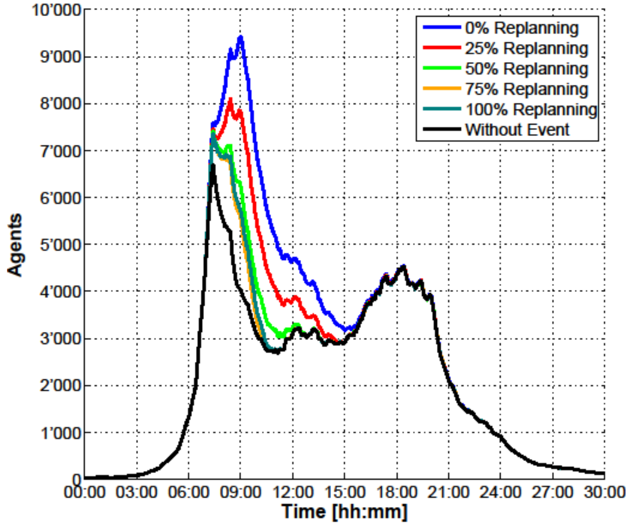
Scenario – Results – Replanning Buffers

0.0km replanning buffer

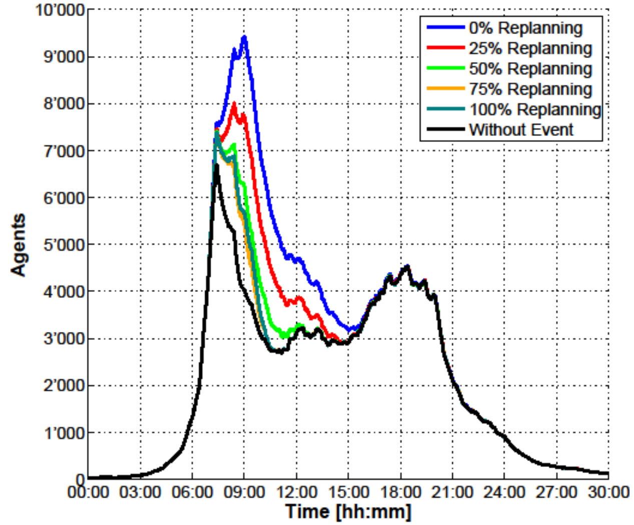


1.0km replanning buffer



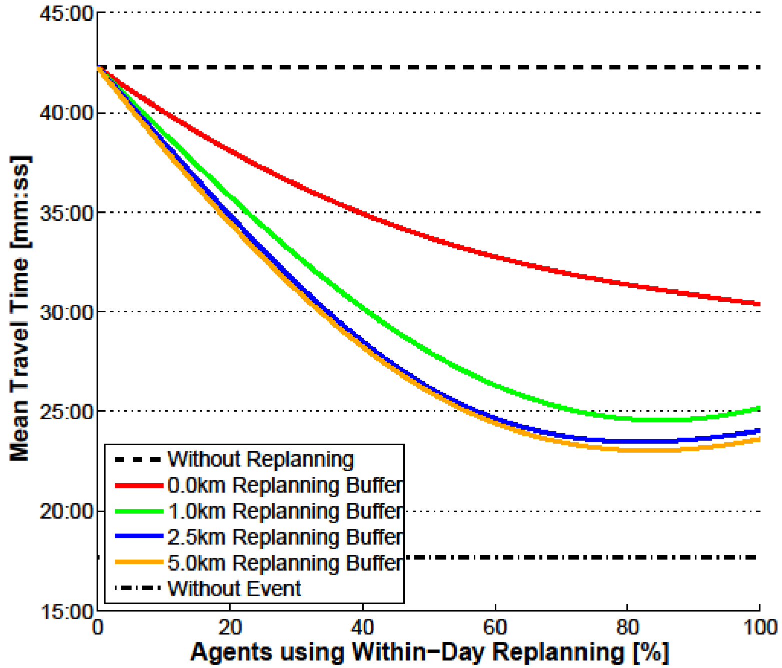


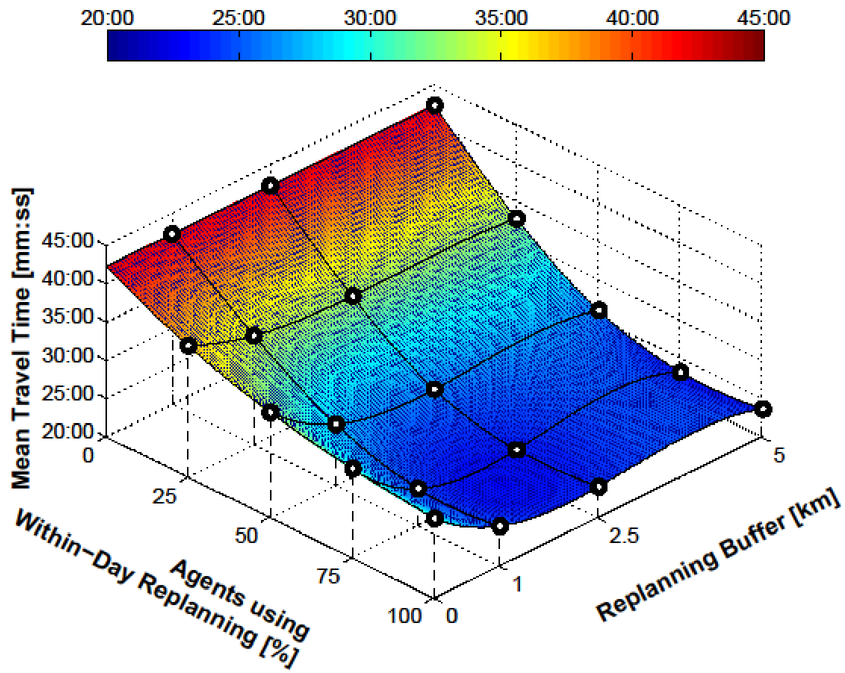
2.5km replanning buffer



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?