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Modelling disasters – First experiments with an agent-based simulation

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MATSim
Multi-Agent Transport Simulation

Overview

- Motivation
- MATSim
- Within Day Replanning
- Simulation approach for evacuations
- Future developments and features
- Conclusions and outlook

Motivation

Why modelling disasters?

- Disasters typically occur only with a very low probability – but if they do, they have a major impact on transportation systems.
- Development of strategies how to (re-)act when such exceptional events occur can help to reduce their impact and aftermath significantly.
- Existing models cannot handle such scenarios or at least require major adjustments, including support of
  - unexpected changes in the network infrastructure.
  - people who behave without foresight due to time pressure, herding and fear.

MATSim

What is MATSim? A very short overview

- Multi-Agent Transport Simulation Toolkit
- Open source software package for multi-agent-microsimulations based on a queue model
- Developed by teams at the ETH Zurich and TU Berlin
- MATSim uses an iterative optimization process to reach a stable state of the system where all persons have optimal daily plans.
  - Replanning of the routes is done between the iterations.

Multi-agent simulation

- Every person in the simulated scenario is represented by an agent.

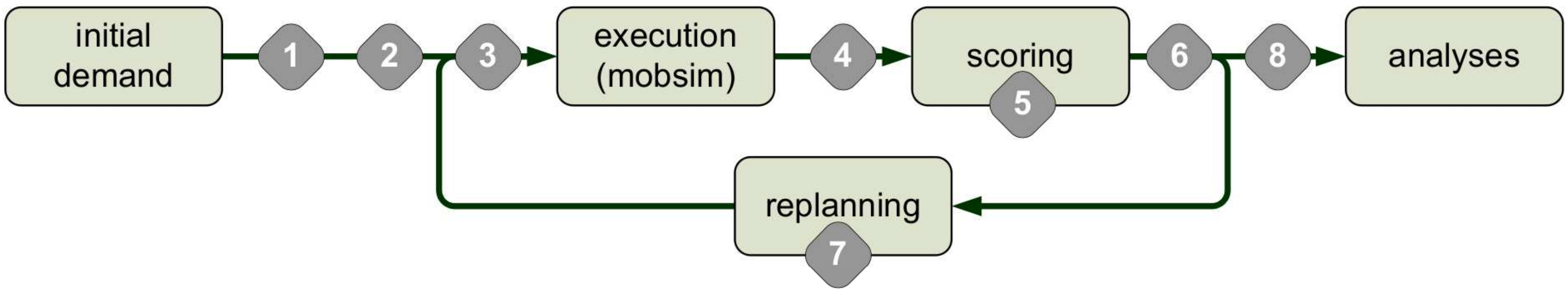
- Each of this agents has individual attributes, preferences and scheduled activities and trips, which connect those activities.

- In MATSim typically each agent hosts multiple plans which are created as a result of the iterative optimization process.

Representation of a person in MATSim

```xml
<person id="103" sex="f" age="25" license=“yes" car_avail=“always" employed="yes">

  <plan selected="yes">

    <act type="home" link="110" facility="1" x="60.0" y="110.0" start_time="00:00:00" dur="08:43:35" end_time="08:43:35" />

    <leg mode="car" dep_time="08:43:35" trav_time="00:05:00" arr_time="08:48:35">
        <route dist=„4467.0" trav_time=„00:05:00" >1442 1623 3553 1321</route>
    </leg>

    <act type="work" link="104" facility="2" x="310.0" y="70.0" start_time="08:48:35" dur="08:00:00" end_time="16:48:35" />

    <leg mode="car" dep_time="16:48:35" trav_time="00:05:00" arr_time="16:53:35">
        <route dist=„4467.0" trav_time=„00:05:00" >1322 3552 1622 1443</route>
    </leg>

    <act type="home" link="110" facility="1" x="60.0" y="110.0" start_time=“16:53:35" dur="07:06:25" end_time="24:00:00" />

  </plan>

</person>
```

MATSim iterative optimization loop



Simulation Events

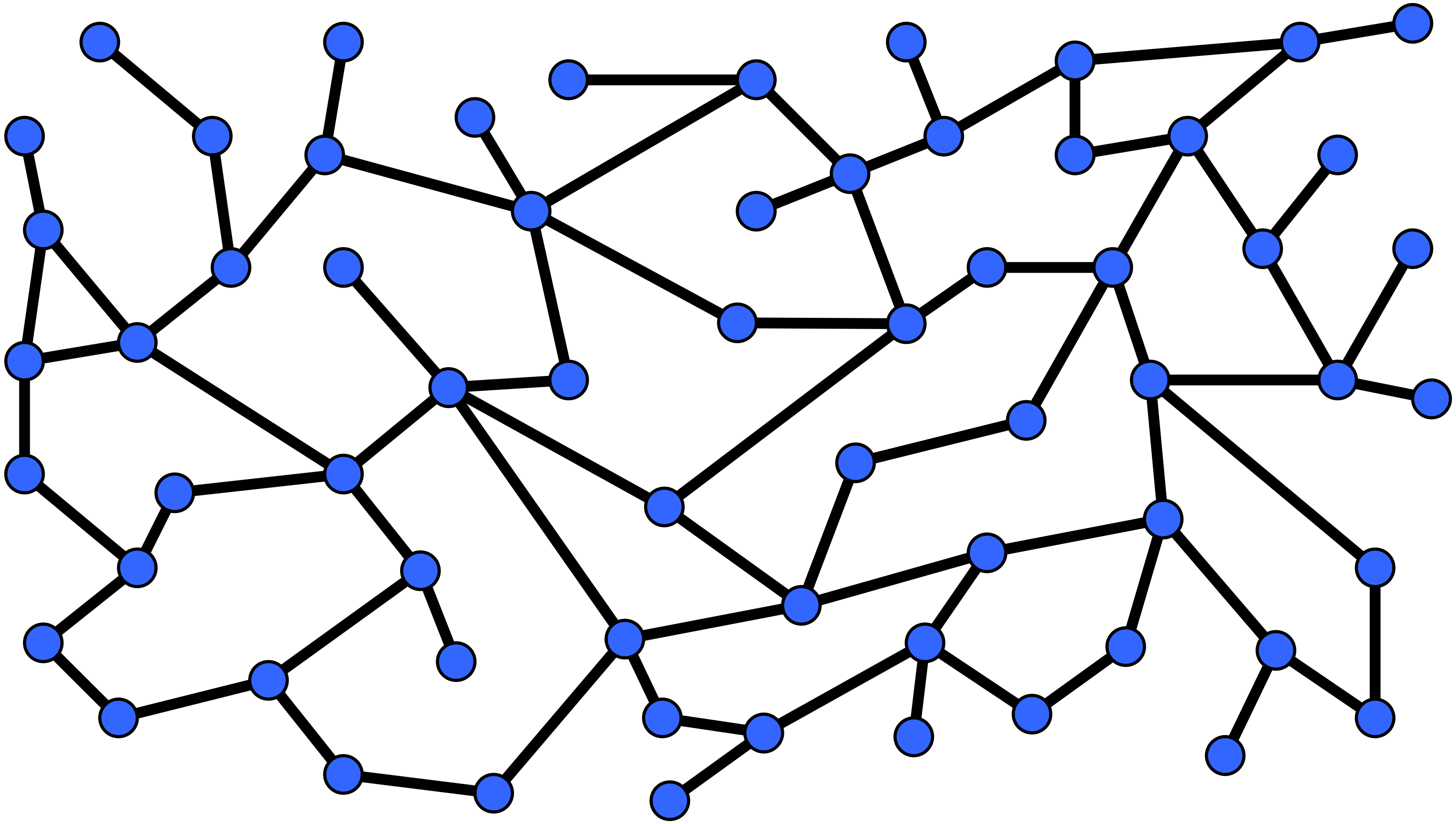
1 **Simulation Starts**	3 **Before Mobsim**	5 **Scoring**	7 **Replanning**
2 **Iteration Starts**	4 **After Mobsim**	6 **Iteration Ends**	8 **Simulation Ends**

MATSim and exceptional Events?

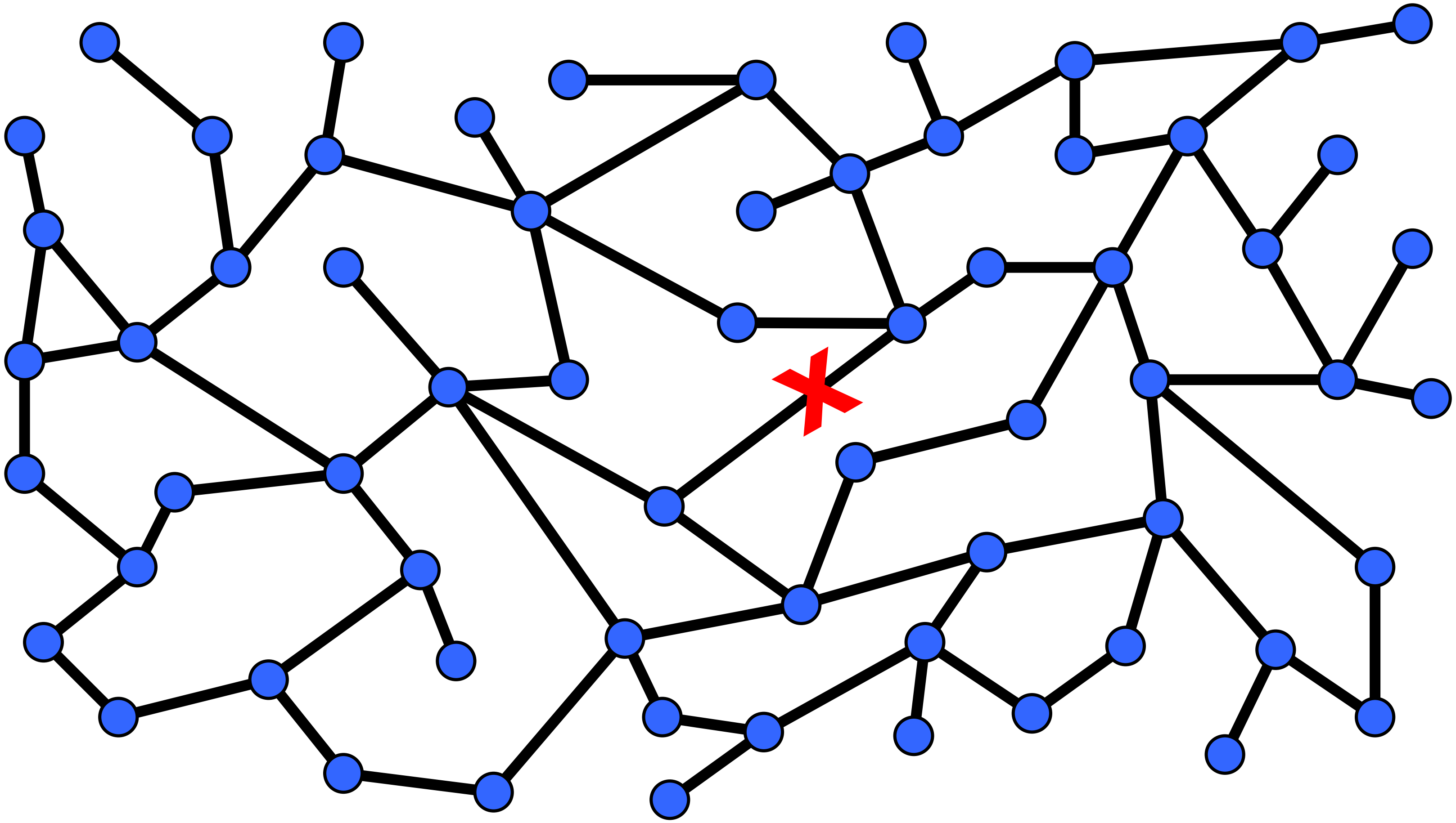
- MATSim uses an iterative simulation approach
  - Agents use information from previous iterations when creating new plans.
  - Meaningful for “typical day” scenarios.

- But how to simulate scenarios with exceptional events (e.g. large incidents, heavy weather conditions, disasters, …)?
  - Can an iterative approach be used to simulate scenarios with exceptional events?

Exceptional events in MATSim – network



Exceptional Events in MATSim – occurring Event



X Event that blocks a link

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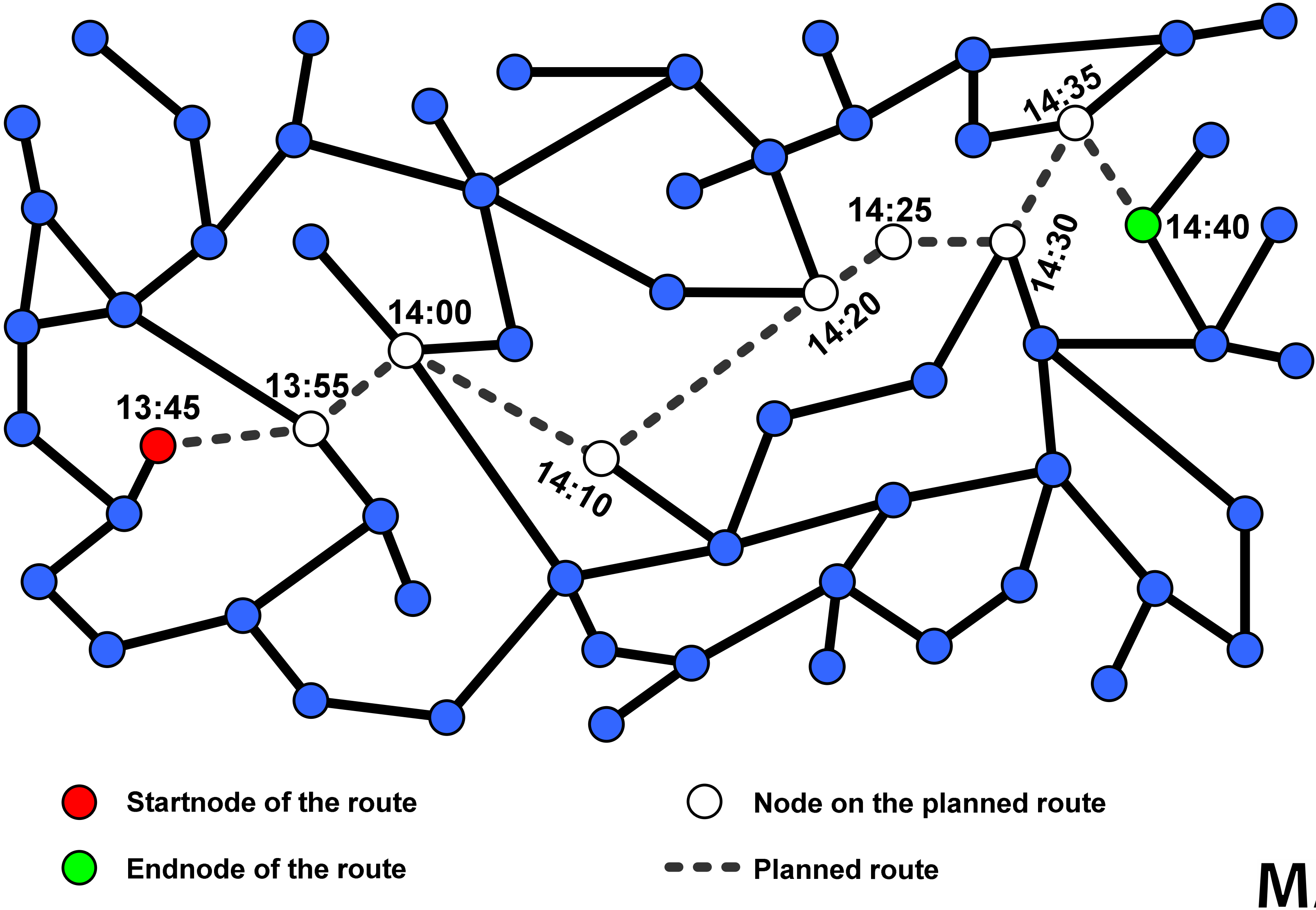
Exceptional events in MATSim – planned trip



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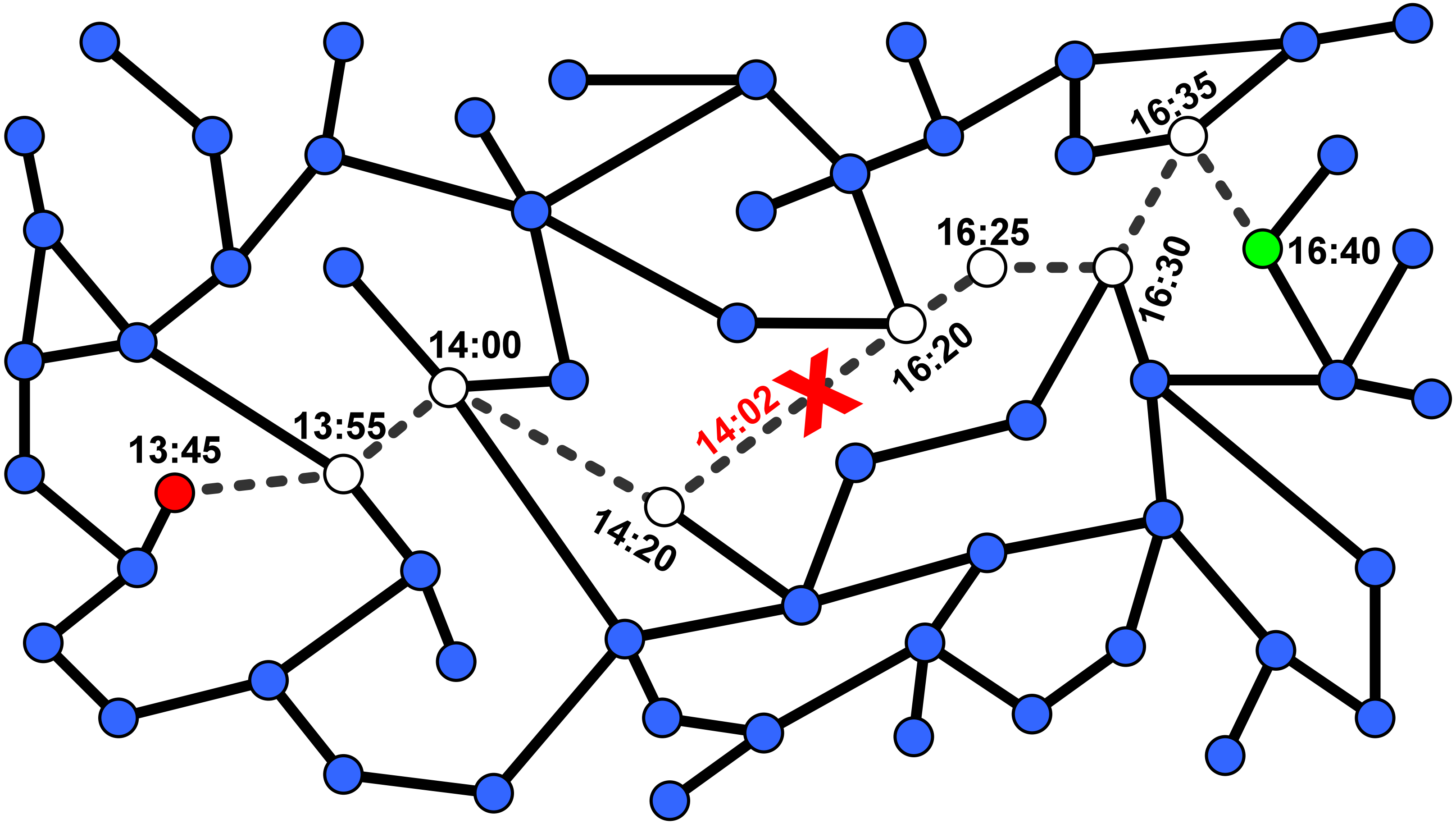
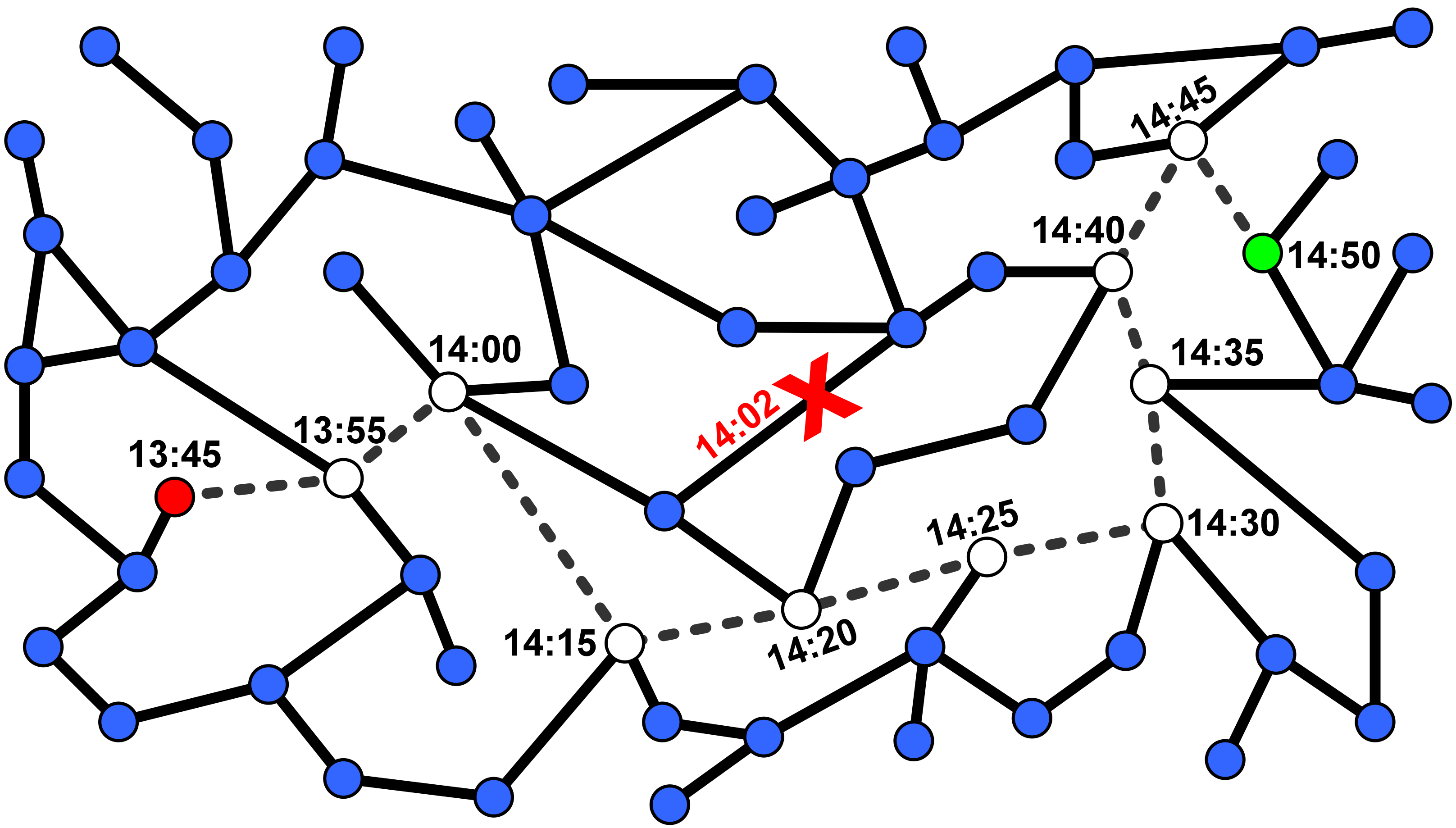
Exceptional events in MATSim – real trip



⇒ Trips duration is much higher than expected and therefore the executed plan will get a very bad score.

Exceptional events in MATSim – iterative approach



⇒ Iterative approach: the agent decides that another route will be faster.
BUT: The new route differs from the original one even before the event has happened!

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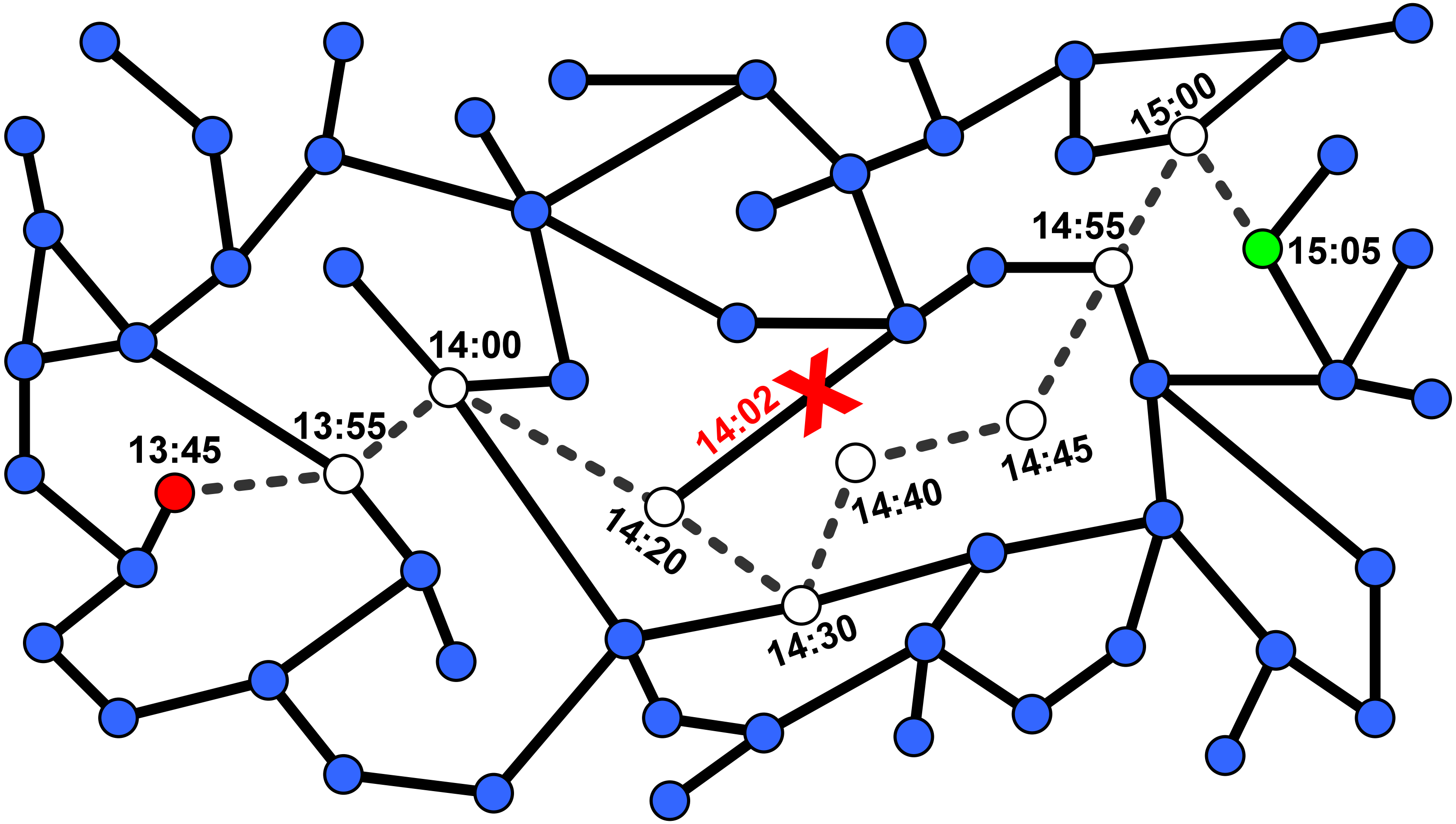
Exceptional events in MATSim – within day replanning approach



⇒ Within day replanning approach: the agent reaches the blocked link, recognizes its congestion and adapts his route.

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Exceptional events in MATSim – conclusions

- Using an iterative simulation approach will result in illogical behaviour – not only in combination with MATSim.
- A reasonable way to avoid those problems is using a simulation approach without iterations.
  - The agents have to adapt their plans during the simulation using information from past events.
  - Spreading of information can be respected – e.g. it may take some time until an agents recognize changes in network conditions.
- Develop an extended simulation module for MATSim that allows within day replanning.

Within Day Replanning

Within Day Replanning – objectives

- Simulation of unpredictable, dynamic scenarios with changes in the
  - network structure and capacities of the links.
  - desires of the people.
  - amount of available (traffic) information.
  - traffic volumes.

Within Day Replanning – requirements

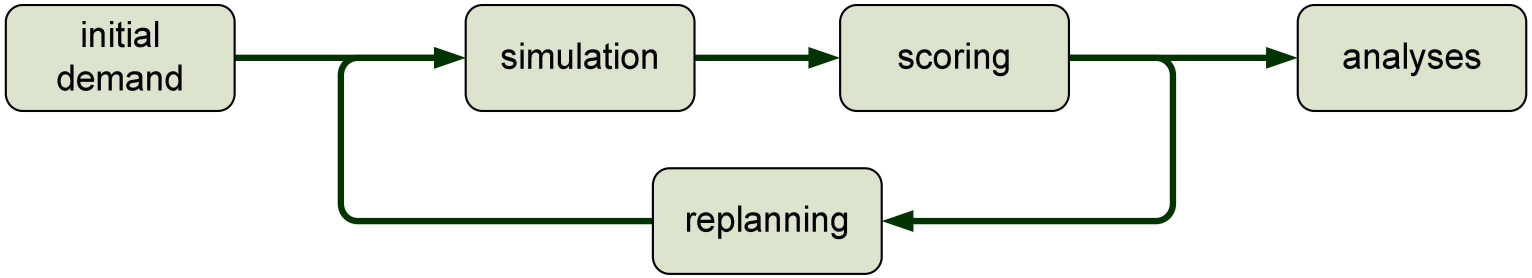
- Individual replanning strategies and parameters for each agent, depending on facts like
  - When is the replanning carried out?
  - How is the replanning triggered?
  - Which information is available for the router?

- Adaption of current and future routes, adding and removing of activities.

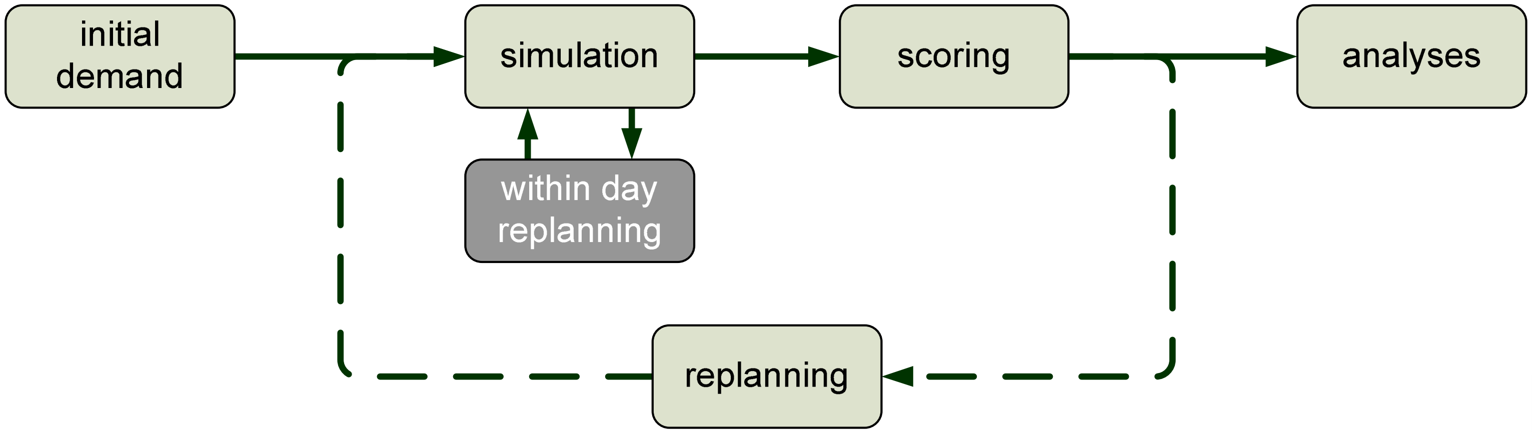
- Parallel replanning of multiple agents at a time using parallel threads.

How to implement Within Day Replanning in MATSim?

- Adaption of the iterative MATSim structure
  - traditional structure



  - within day replanning structure



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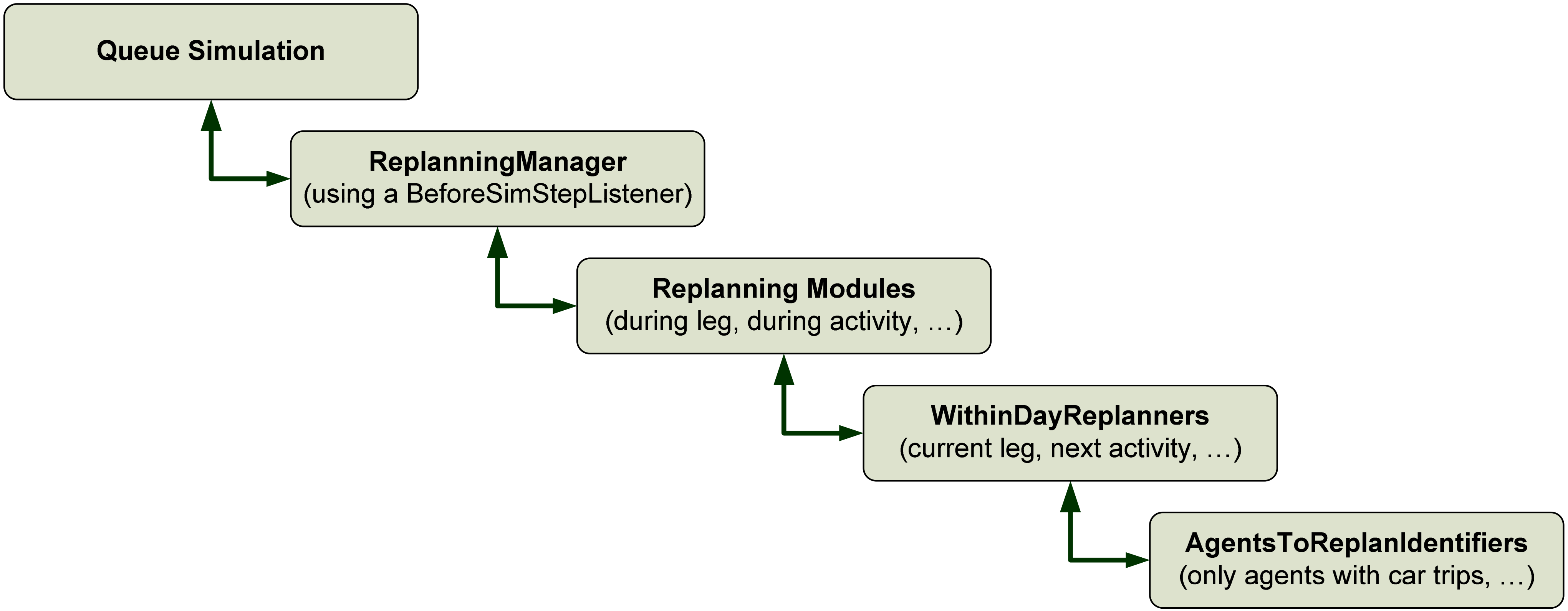
Implementation in MATSim



Replanning Manager

- Manages the interactions between the *Queue Simulation* and the *Within Day Replanning* modules.

- The *Queue Simulation* uses a time-step based approach. At various points of a simulated time-step interactions with the simulation are possible (e.g. before and after the time-step is simulated).

- The *Replanning Manager* is a so called *BeforeSimStepListener.*
  - All used *Within Day Replanning Modules* have to be registered at the *Replanning Manager*.
  - During the simulation the manager informs all registered modules that they should check, whether they have to do a replanning.

Replanning Modules

- Three different situations, where an agent can perform a replanning – each represented by a separate *Replanning Module*. Replanning …
  - initially before the simulation is started.
  - during an activity.
  - during a trip is performed.

- Every *Replanning Module* hosts at least one *Within Day Replanner* which implements a replanning strategy. (e.g. adapt the duration of an activity, change the destination of a trip, …).

Within Day Replanner

- Every replanning strategy is implemented in a separate *Within Day Replanner*.

- Various replanning strategies are possible
  - during an activity is performed
    - adapt departure time, next trip's route or next destination
  - during a trip is performed
    - adapt route or next destination

- Each of these *Replanners* uses at least one *Agent to Replan Identifiers*.

Agents to replan identifiers

- Identifies those agents that need an adaption of their plan.

- Identification can depend on various attributes, e.g.
  - mode used (e.g. only car or everything except walk)
  - age, gender or income of the agents.
  - destination of the current trip.
  - remaining duration of the current activity.
  - current position in the network.

Sample applications for Within Day Replanning

- Simulation of scenarios with exceptional events
  - Evacuations
  - Disasters

- Modelling and validation of traffic control systems and traffic forecast systems

- In combination with iterative MATSim runs
  - Parking search
  - Car-sharing / collective taxis

Combination of Within Day Replanning with iterative MATSim runs

- Parking search using iterative approach
  - Agents plans to park at a certain parking area
  - What happens, if there is no space left, when the agent arrives?
    - The agent may wait until another vehicles departs – but maybe there are free parking spaces just a couple of meters away…
    - Ignore the capacity restriction of the parking area but add a penalty to the parking activity.

- Parking search using iterative approach in combination with Within Day Replanning
  - Agent enters the link where the next activity is scheduled.
  - If there is a free parking space, the agent parks there – otherwise the agent can decide where to look for a free parking lot.

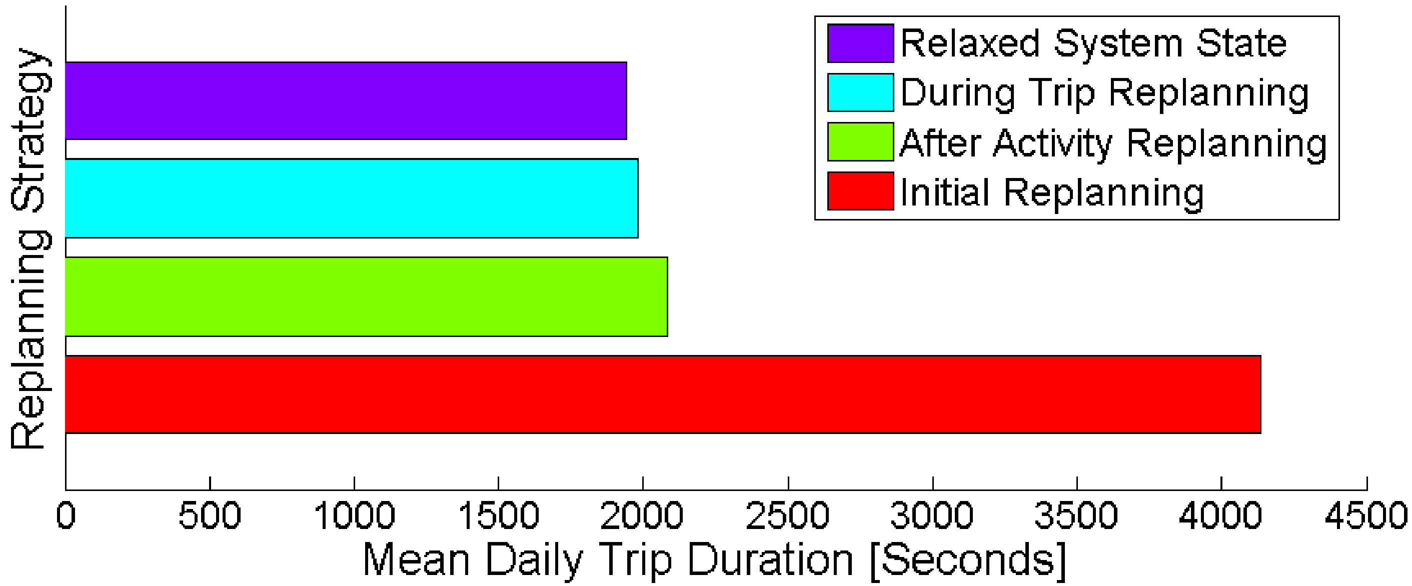
Combination of Within Day Replanning with iterative MATSim runs

- Taxis driving around and looking for passengers using iterative approach
  - Really hard to implement – how to plan that a certain taxi is at a given time at a given position to pick up an agent there?

- Taxis driving around and look for passengers using iterative approach in combination with Within Day Replanning
  - Very simple to implement – the agent that wants to take a taxi waits at a link until an empty taxi enters that link.
  - The taxi drivers recognizes the waiting person and adds a “pick up passenger” activity to his plan
  - Finally the taxi reaches the passenger, picks him up and sets the passengers desired destination as next activity point.

Proof of concept – Sample results using Within Day Replanning

- Sample Canton Zurich scenario using different replanning strategies
  - Relaxed system state using iterative approach
  - Within Day Replanning at the end of each activity or multiple times during a trip is performed
  - Initial replanning on an empty network



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Simulation approach for evacuation scenarios

Simulation approach for evacuation scenarios

- Starting with a simple modeling approach
  - ignore social relations between agents
  - all agents act rational, start the evacuation immediately and have total knowledge of the traffic situation

- Agents react differently depending on…
  - where they are:
    - in- or outside the evacuated area.
  - what they are doing:
    - performing an activity.
    - performing a trip.

Simulation approach for evacuation scenarios

- Agents who are…
  - performing an activity in the evacuated area will
    - end the activity immediately and reschedule their Plan to get to the safe area.
    - replace all not yet performed activities by a new (rescue) activity outside that area.
  - performing a trip in the evacuated area will
    - replace the destination of the trip with the position of a (rescue) facility.
    - remove all other remaining activities from their scheduled plan.

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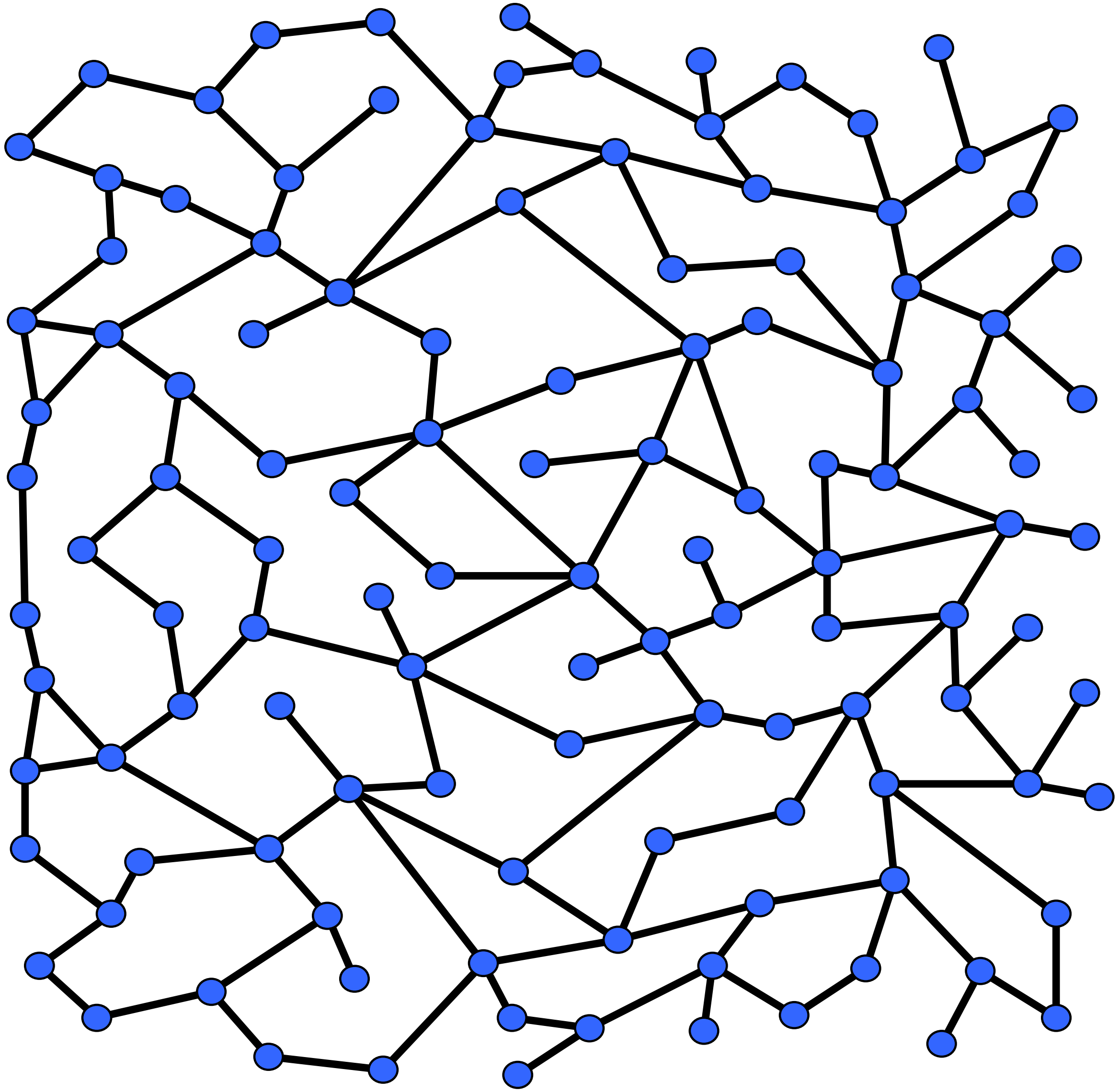
Simulation approach for evacuation scenarios

- Agents who are…
  - performing an activity in the secure area will
    - stay there until the end of the simulation.
    - remove all other remaining activities from their scheduled plan.
  - performing a trip in the secure area will
    - end their trip on the current link and perform a new (waiting) activity there.

Network



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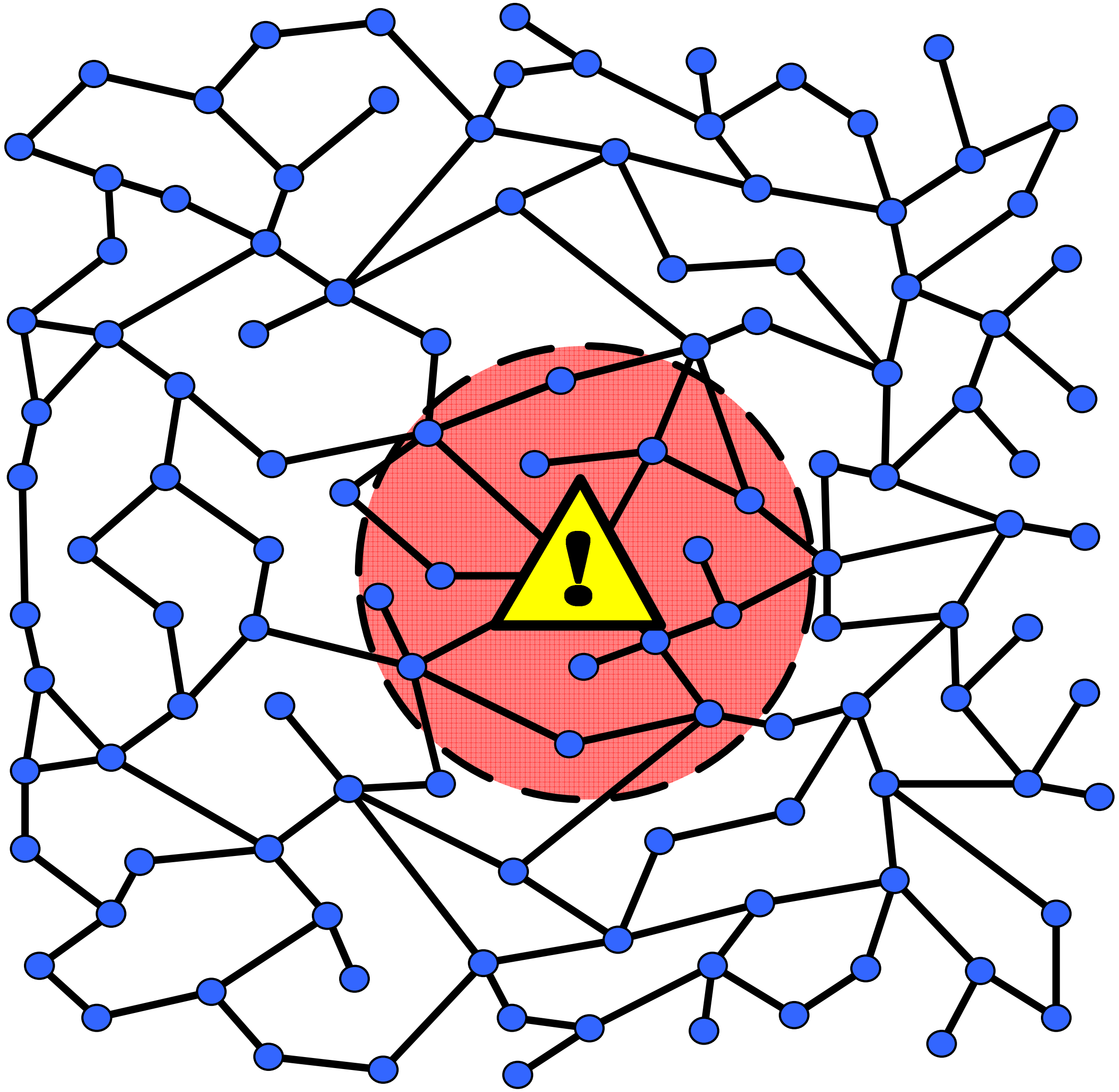
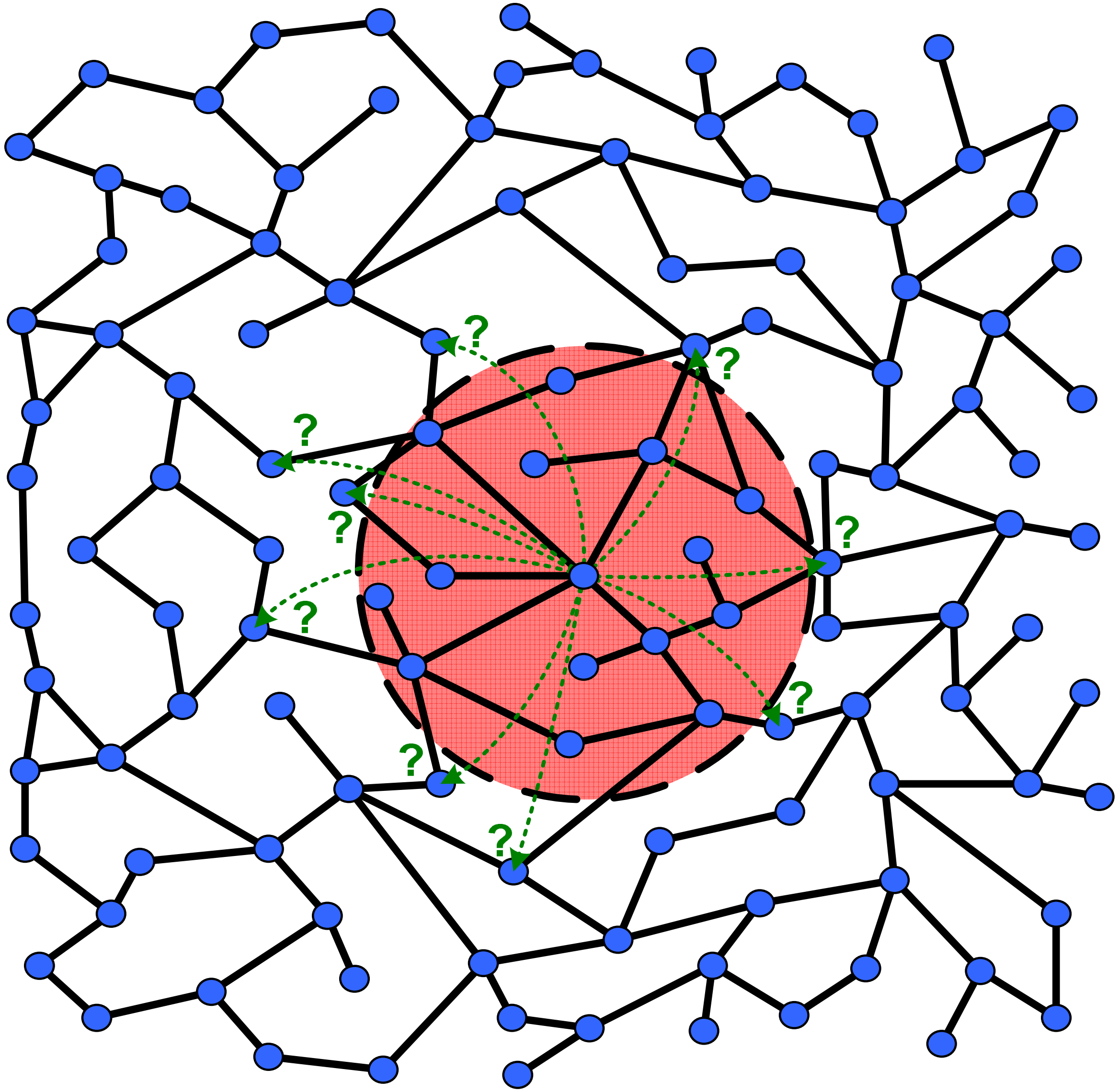
Region to be evacuated



Complexity – where to go to?

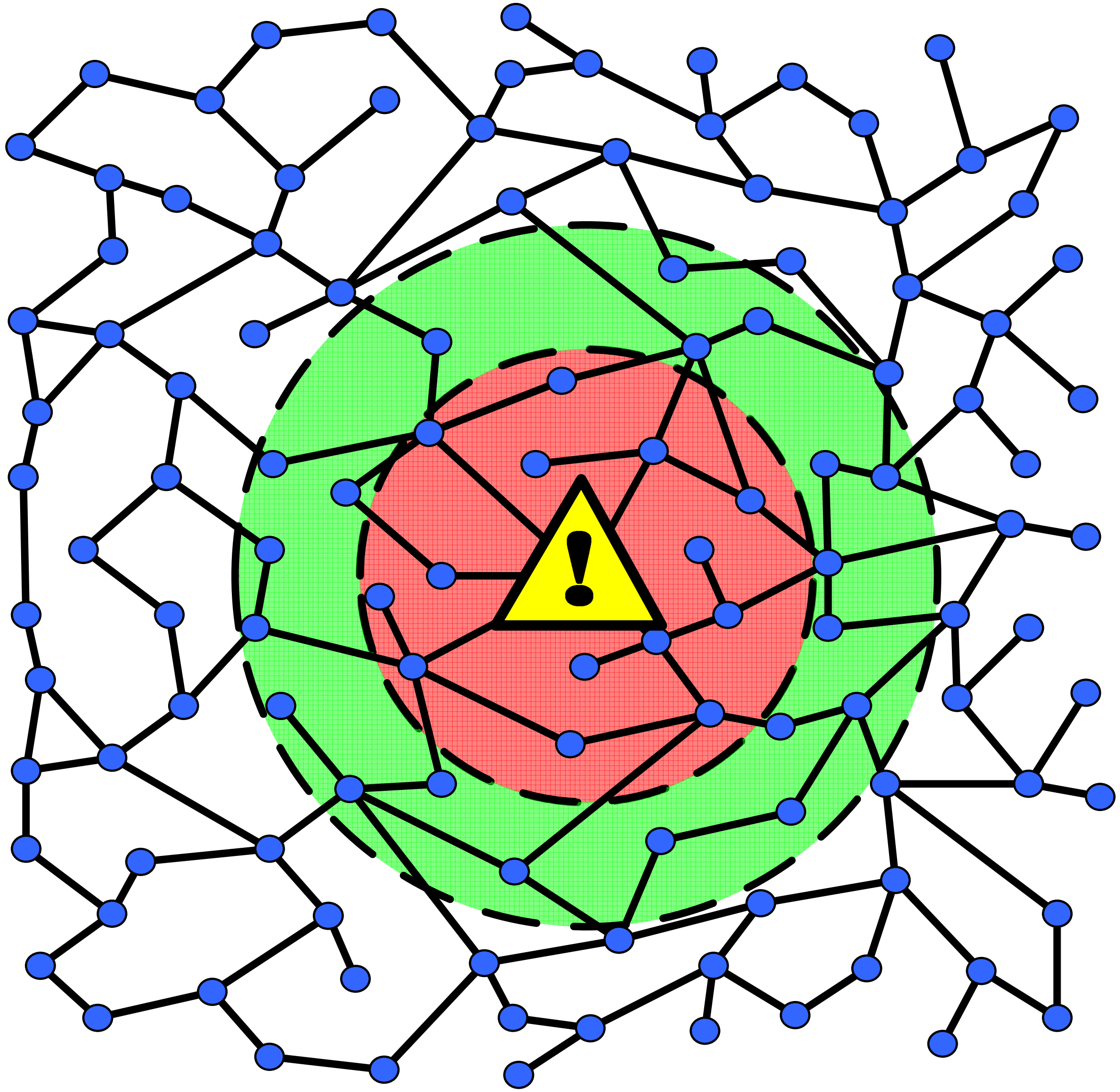


Complexity – where to go to?

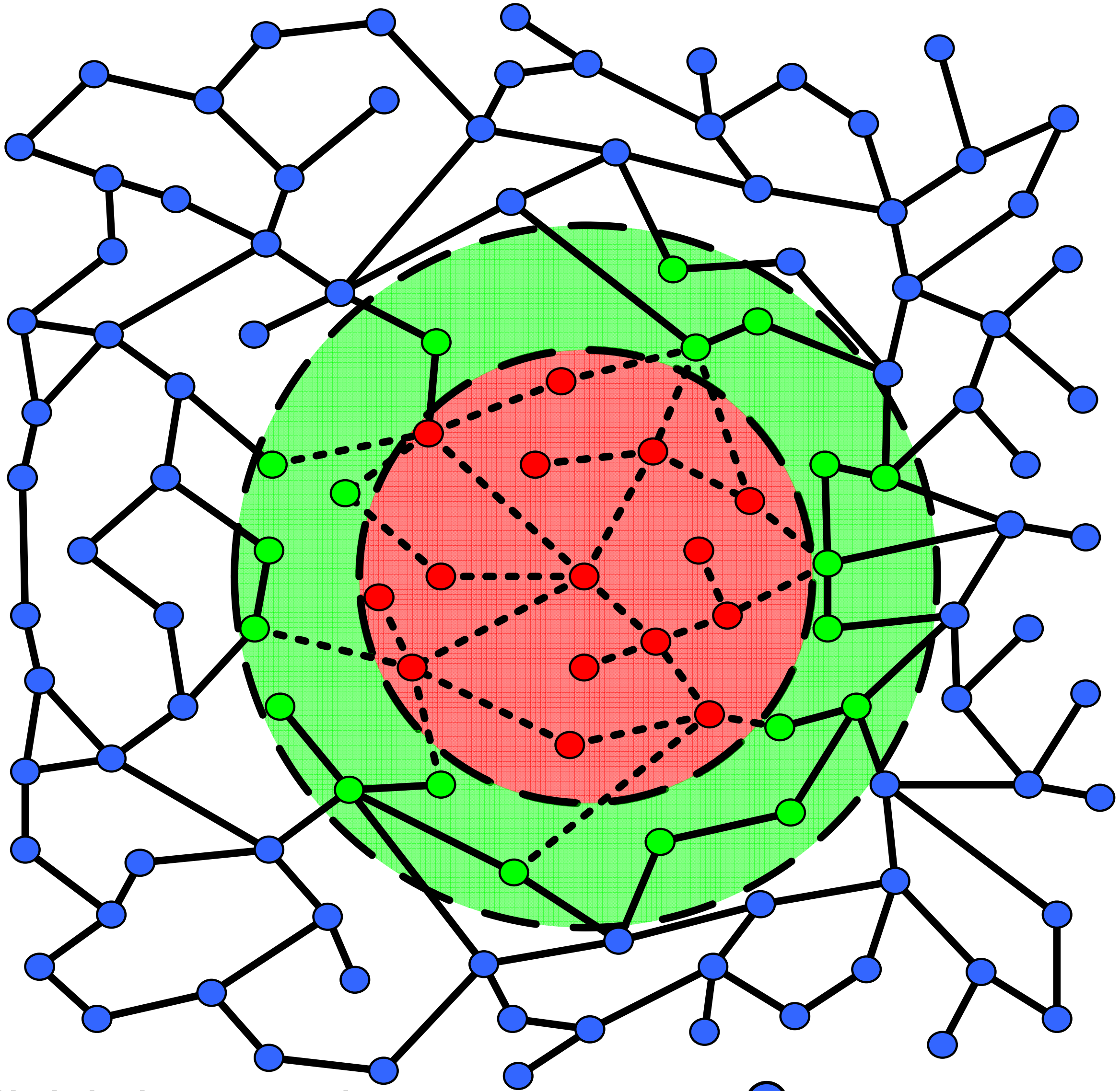
- Problem: extremely high computing costs
  - Where an agent should travel to?
  - Which secure place can be reached in the shortest time?
  - Calculation of many shortest paths to the secure area for each agent.

- Solution:
  - Approach introduced by Yuan et al and implemented by Lämmel and Flötteröd

Handle complexity



Handle complexity



Node in the evacuated area

Secure node next to the evacuated area

Node in the secure area

Link that is evacueed

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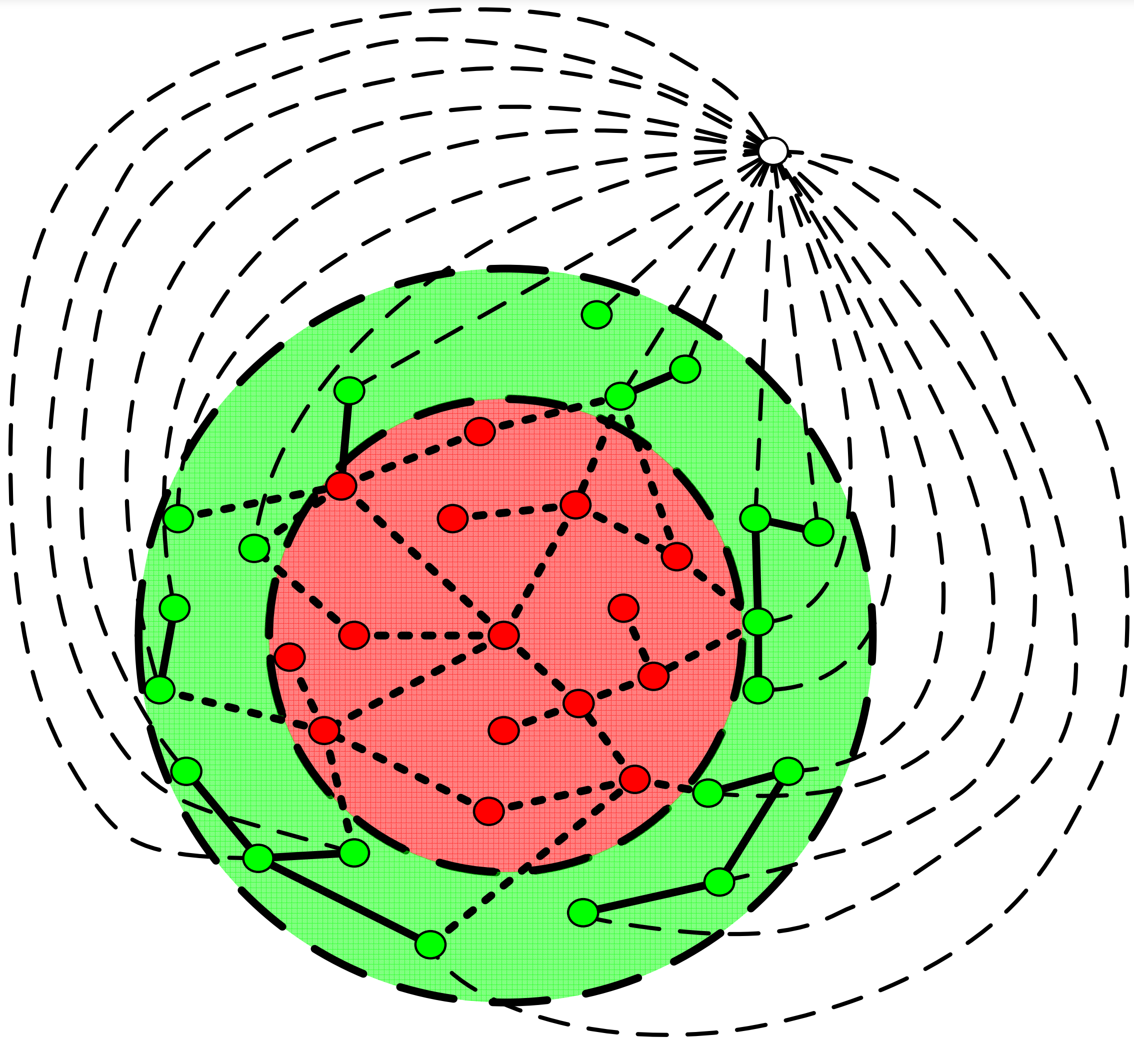
Handle complexity – only one destination left



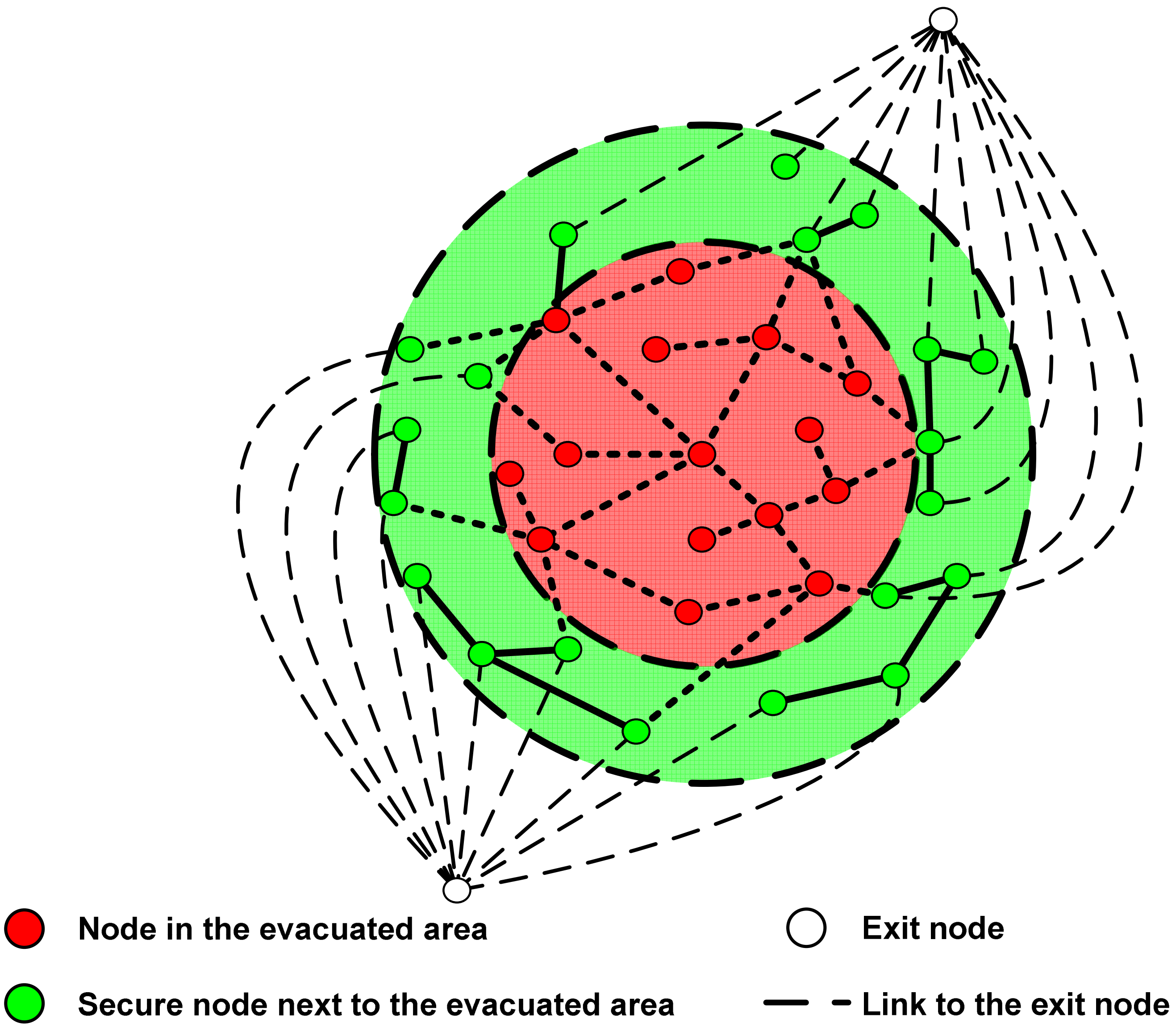
Node in the evacuated area

Exit node

Secure node next to the evacuated area

Link to the exit node

Handle complexity – still multiple destinations possible



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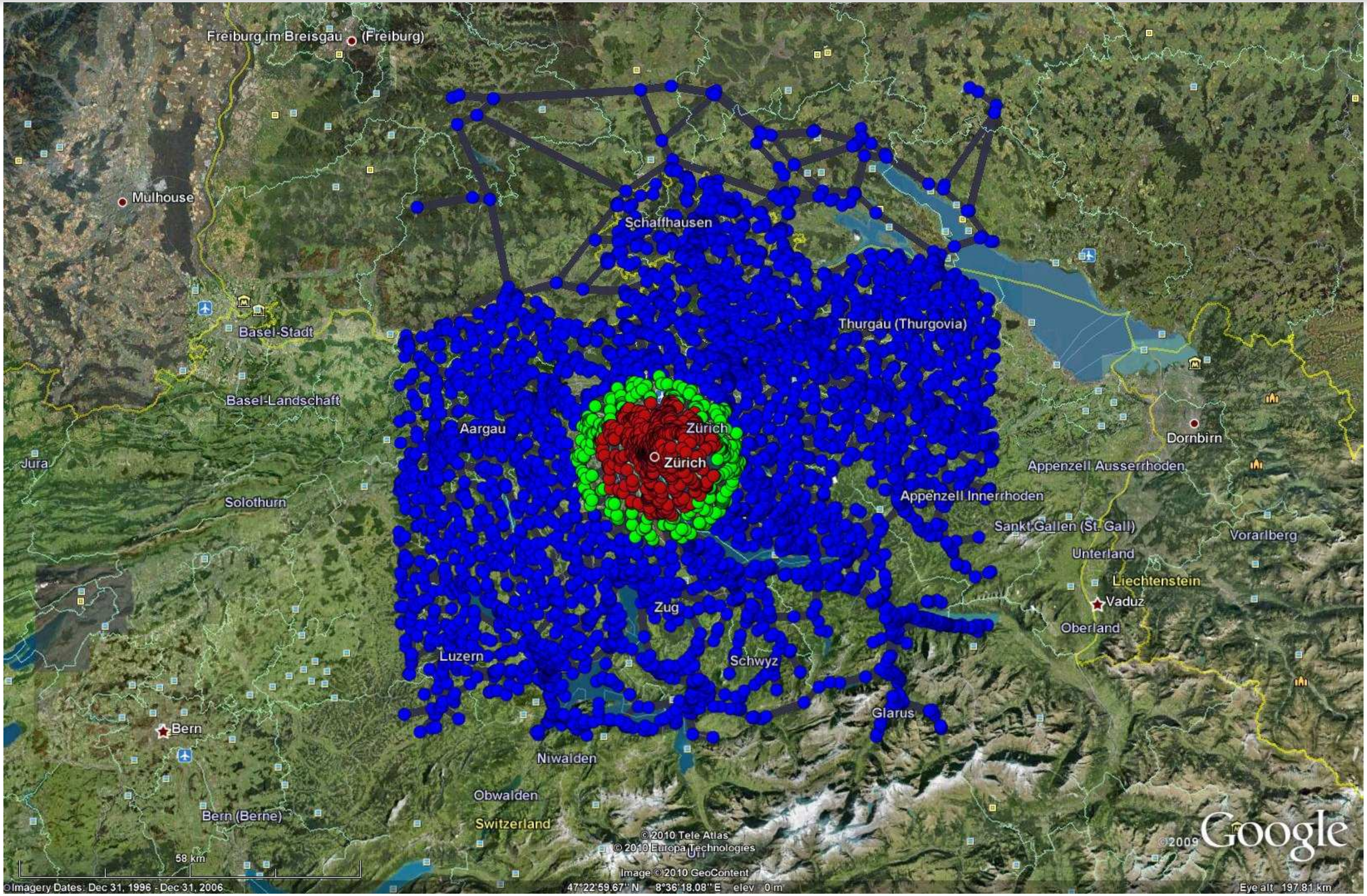
First results – Sample scenario

- 10% sample scenario of Canton Zurich
  - Entire scenario is scaled down to 10%
    - only 10% of the population are simulated
    - only 10% of the network capacities are available
- ~ 90k simulated agents
- Only car trips included
- Evacuation of a 10km radius around Bellevue
- Start of the evacuation at 8:00 AM

Sample scenario



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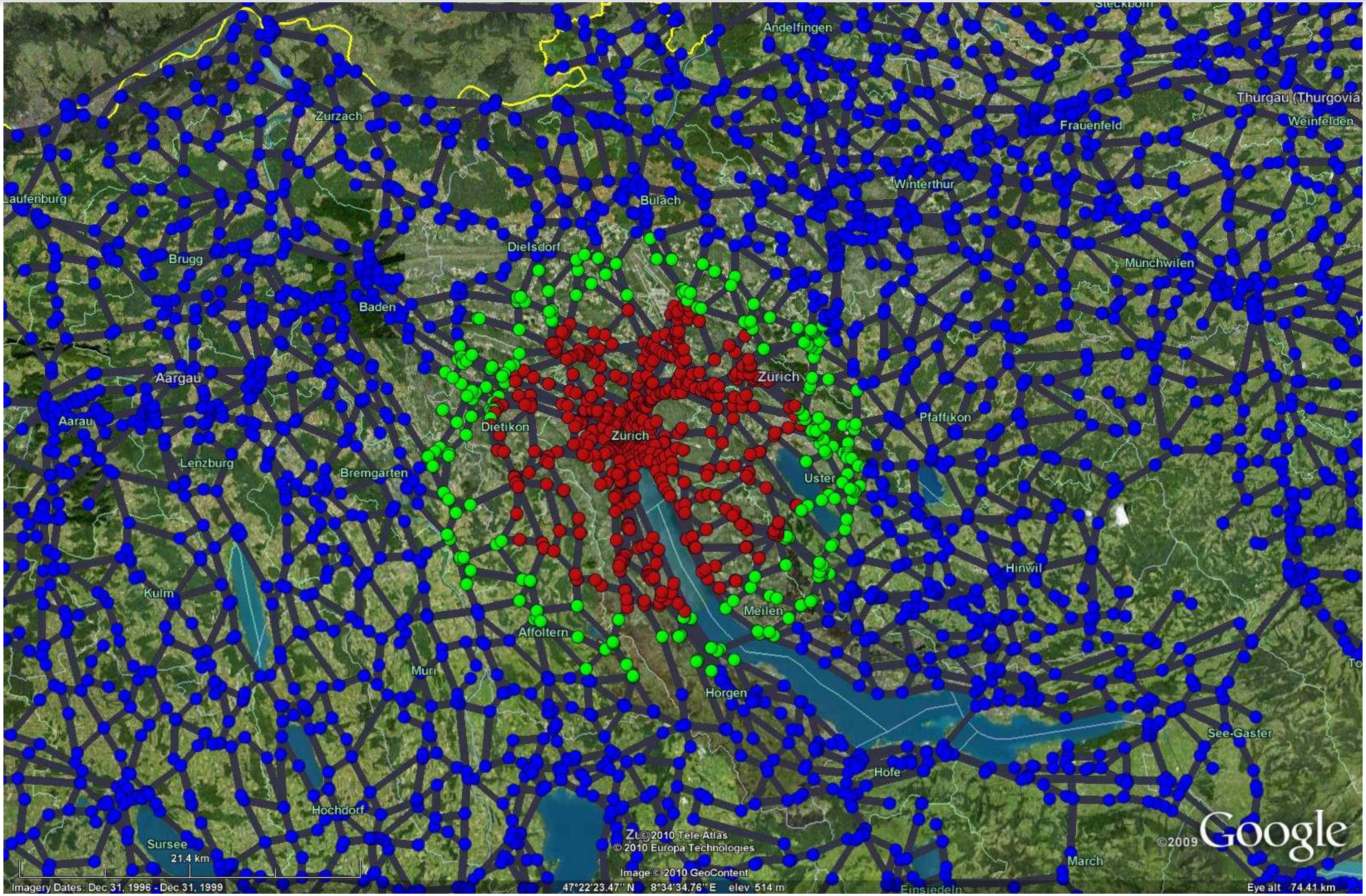
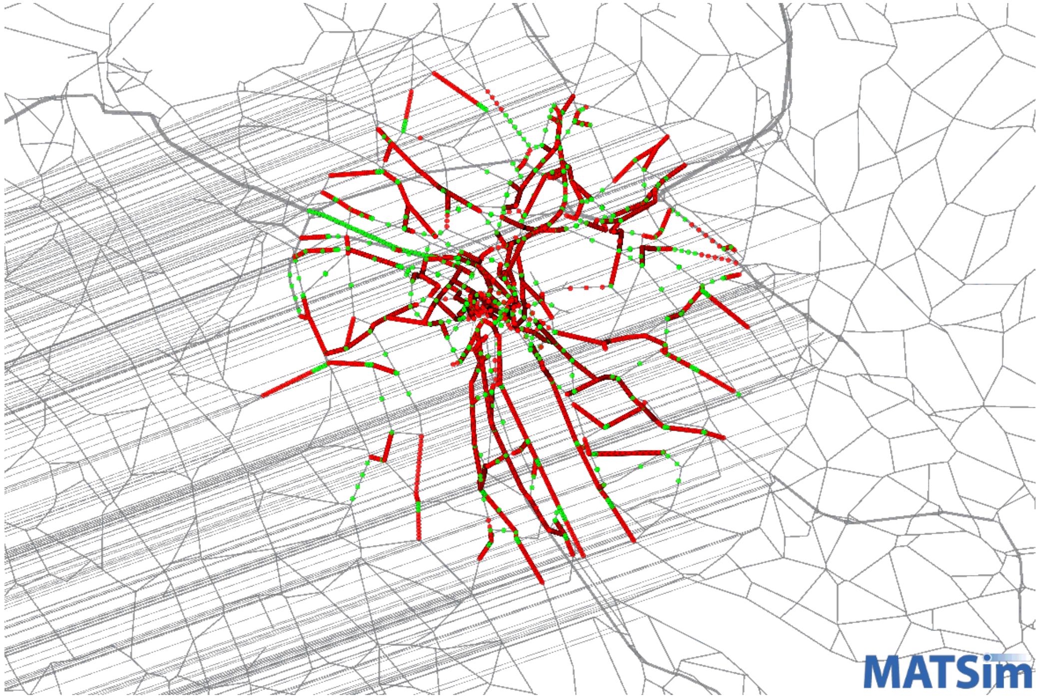
Sample scenario

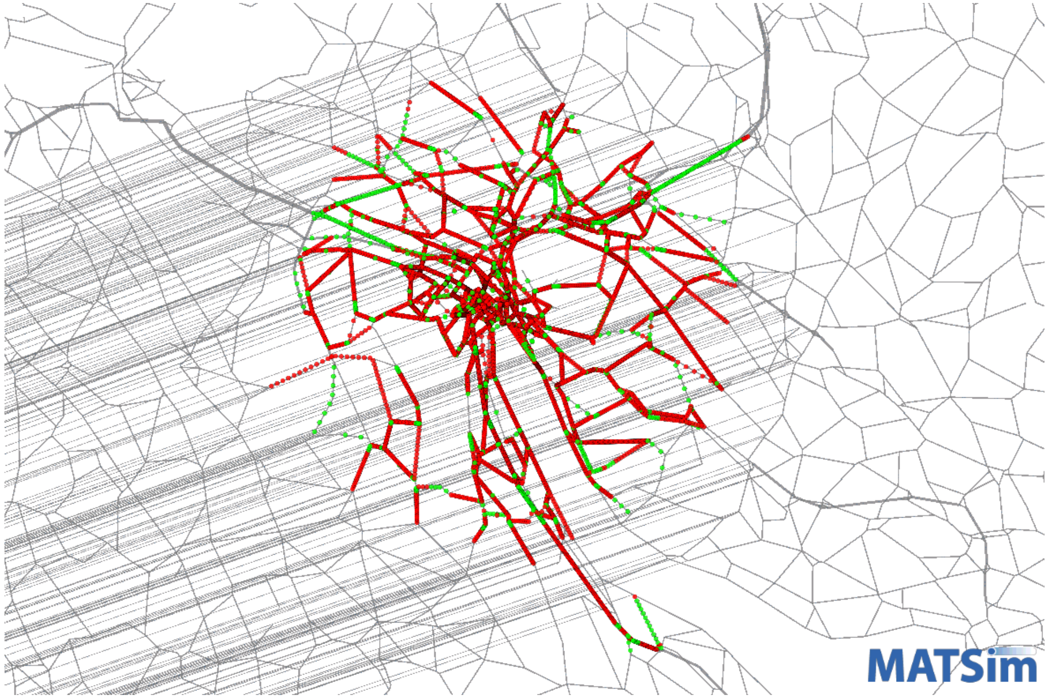


Sample scenario

Results – OTFVis

- Two different replanning strategies





Planning of the routes when the evacuation starts using actual travel times.

Initial planning of the routes and additional replanning during the evacuation.

Results – Leg histogram – typical day without evacuation

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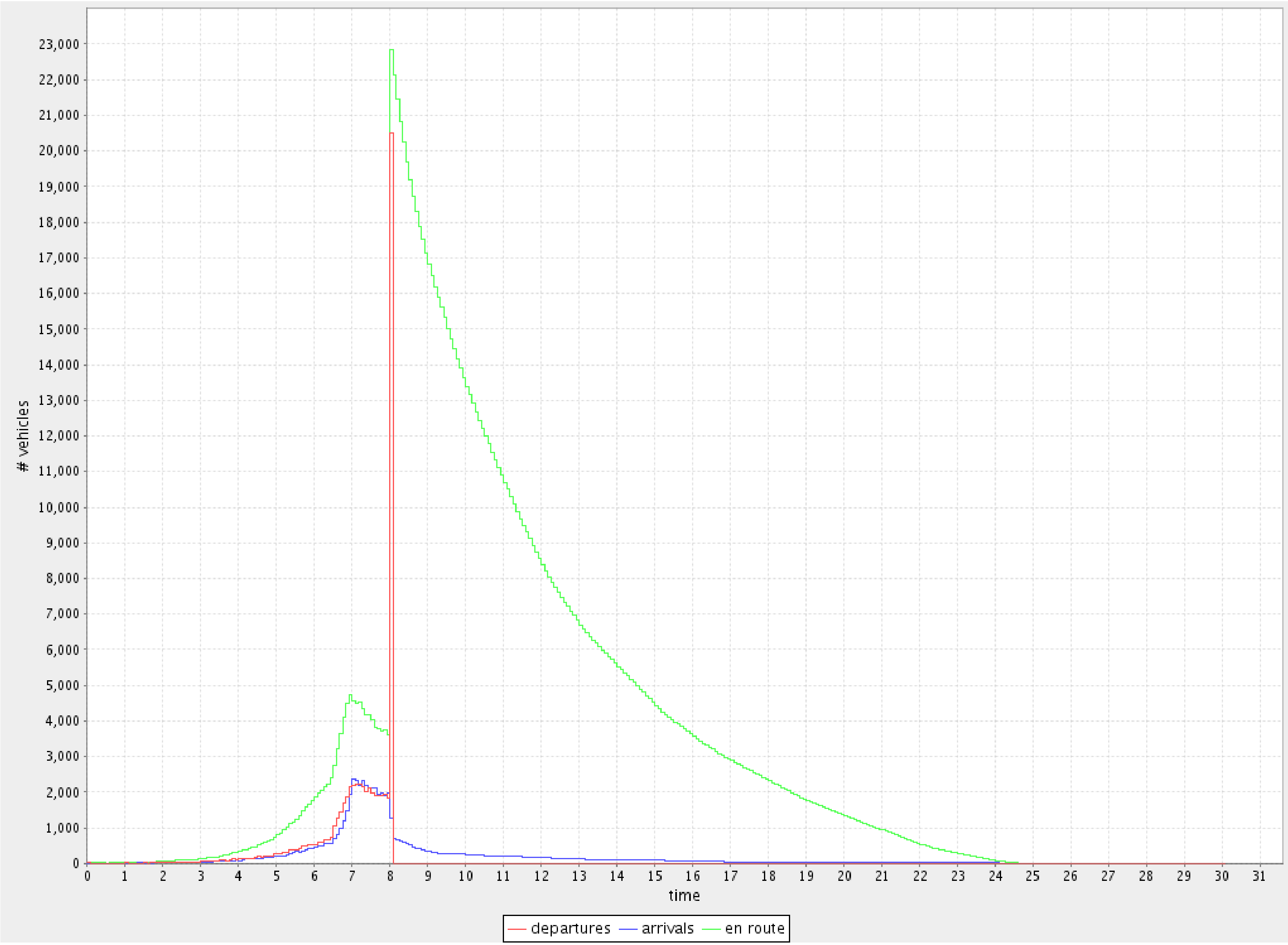
Results – Leg histogram – Evacuation, routes planned when evacuation starts



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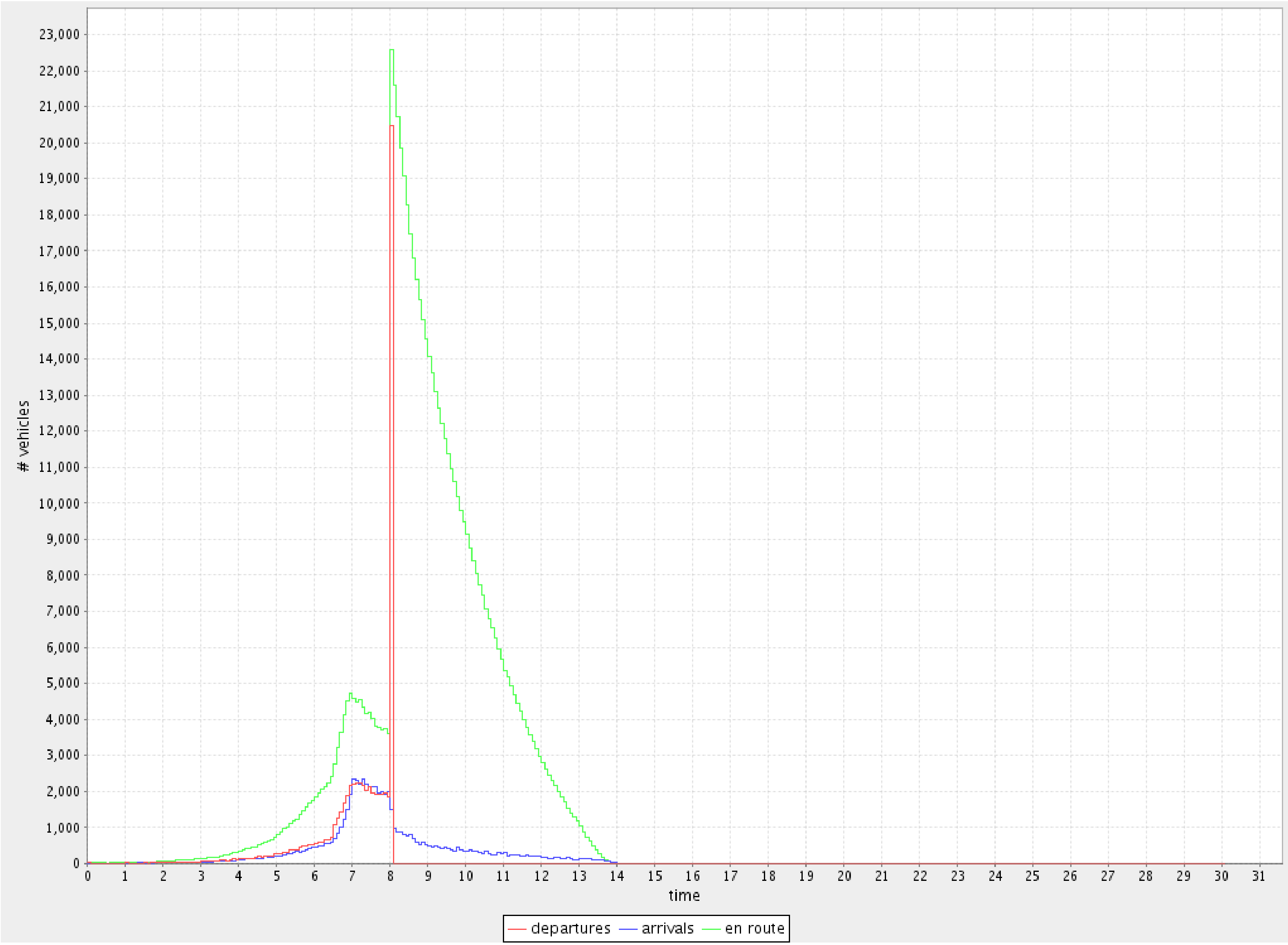
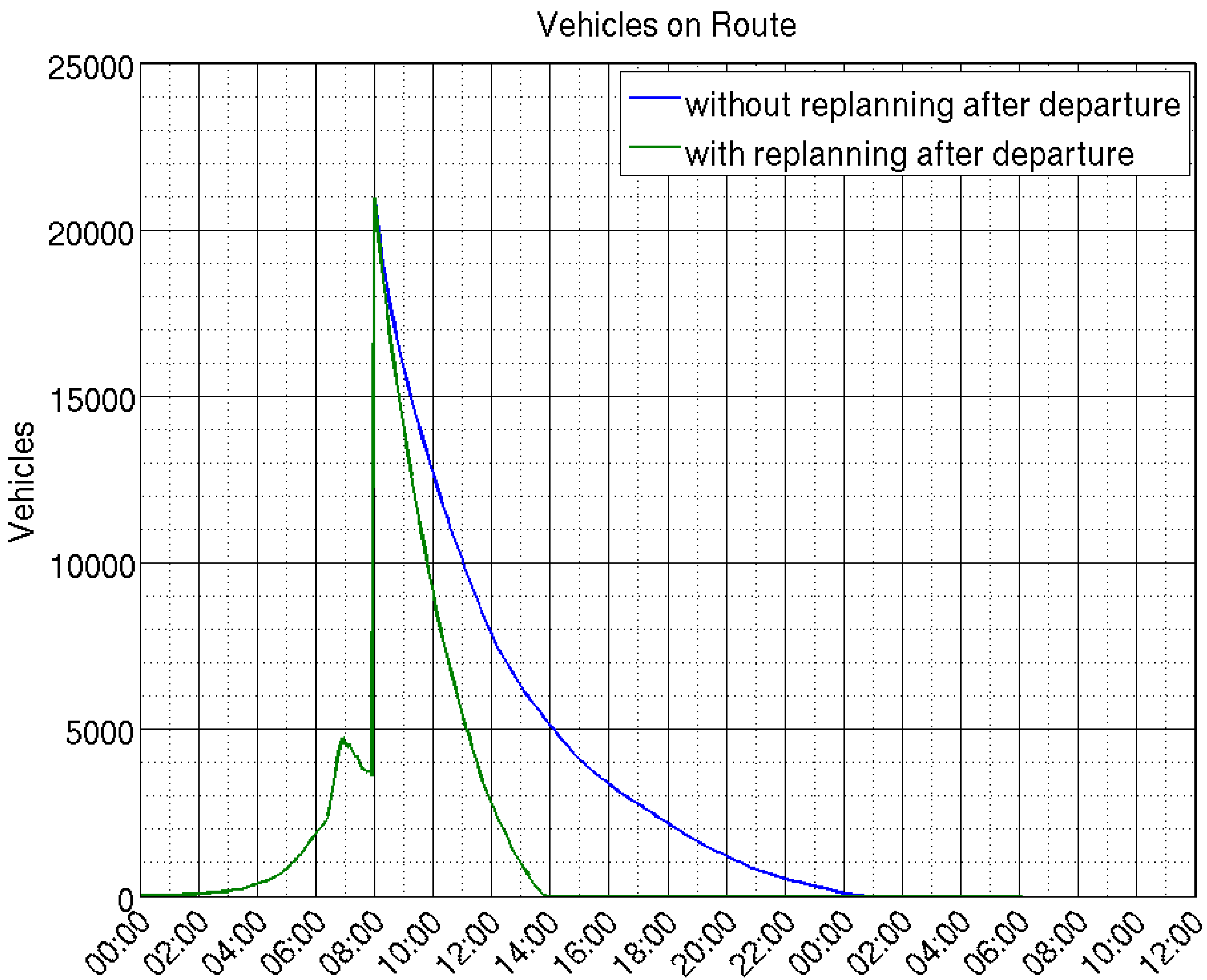
Results – Leg histogram – Evacuation, interactively replanned routes



Results – Leg histogram - comparison



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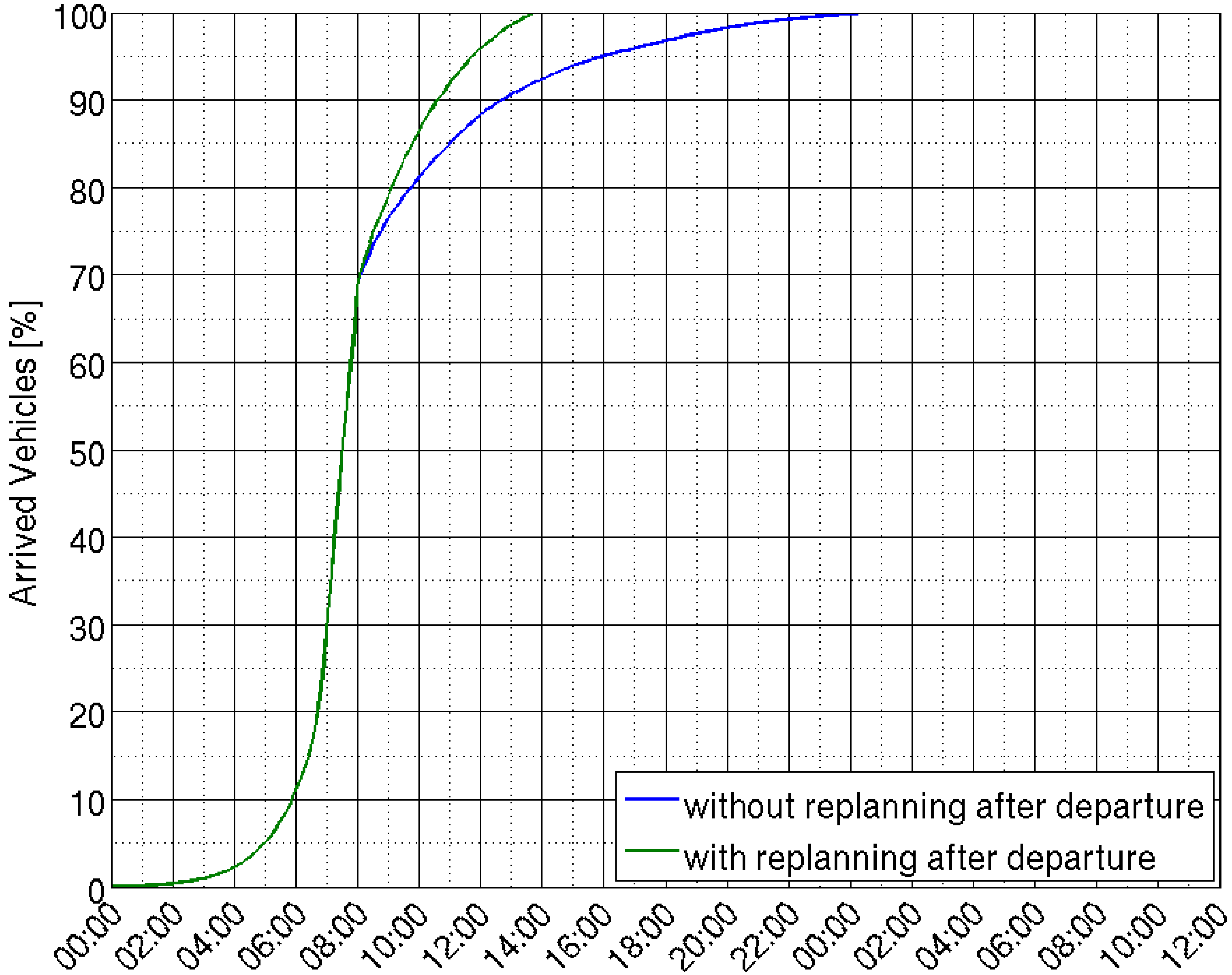
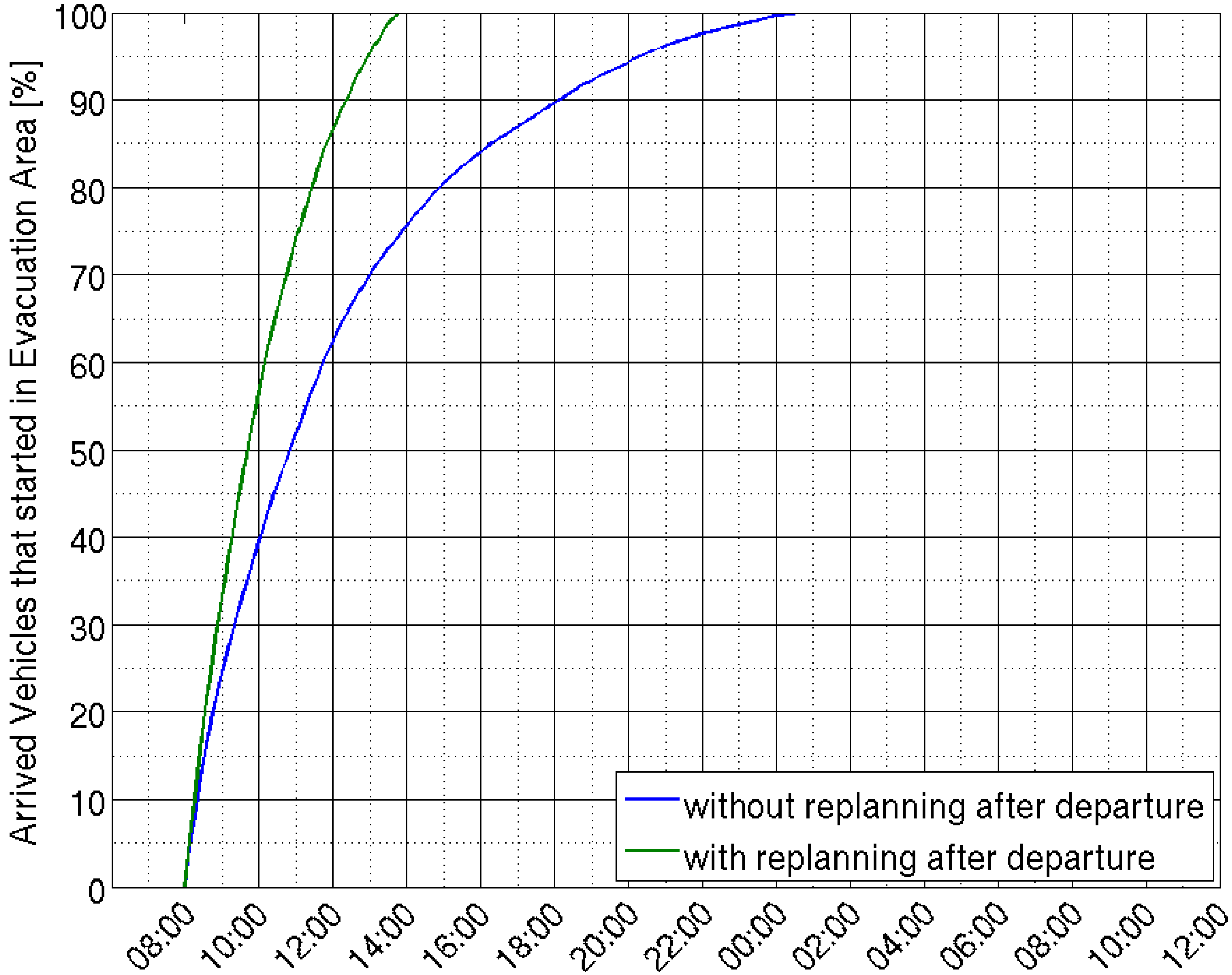
Results – Comparison arrived vehicles



Results – Comparison arrived vehicles after evacuation has started



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Future developments and features

Future Developments and Features

- Improve detail level of the simulated scenario, e.g. include…
  - other transport modes (public transport, walk, bike, …) and their behavior (e.g. buses leaving their designated routes to reach a secure area)
  - availability of cars and car-sharing
  - cars picking up walking agents or agents who leave their cars behind on congested links
  - (interactive) adaption of the network structure (e.g. contra flow lanes) and capacity
  - traffic control methods

Future developments and features

- Improve detail level of the simulated scenario, e.g. include…
  - households, social networks and their interactions
  - vehicles and their specific attributes like capacity
  - agent’s driving behavior, influenced by factors like stress or bad driving conditions

- Analyze results of Nash Equilibrium vs. System Optimum
  - Considerable differences between the results?
  - How can a system optimal state be achieved?

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Conclusions and outlook

Conclusions and outlook

- The presented Within Day Replanning Framework is still under development. Work will be finished and the framework added as package to org.matsim.

- First simulation runs show promising results – Within Day Replanning modules and evacuation strategies have successfully been implemented in MATSim.

- Simulation of a more realistic scenario, including contraflow lanes, other transport modes and strategies how to handle them.

- Analyze and compare results of Nash Equilibrium vs. System Optimum.