

Modelling Large-scale Evacuations – Experiments with an Agent-based Simulation and Future Developments

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Technische Universität Berlin



senozon
understanding mobility

MATSim
Multi-Agent Transport Simulation

Motivation – Why modelling Large-scale Evacuations?

- 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.
- Having an appropriate model will help to reduce the impact of such exceptional events.

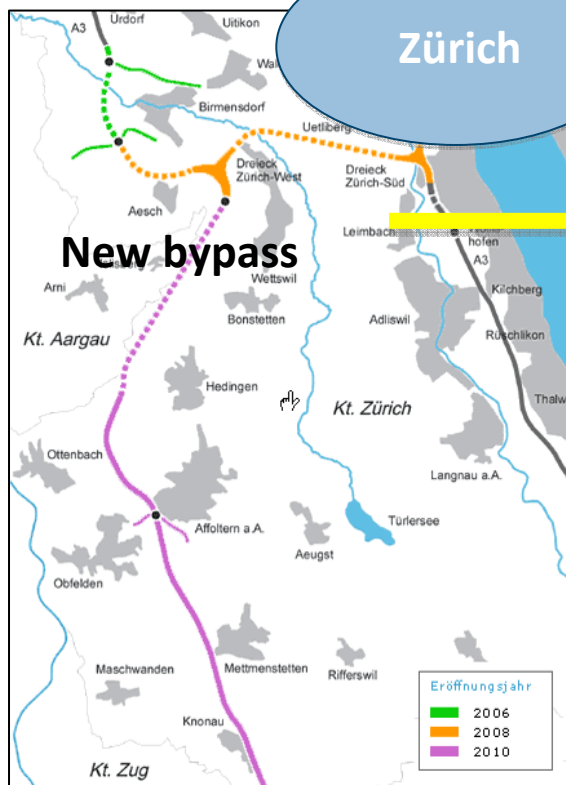
Transport Models



How to improve a front wing?

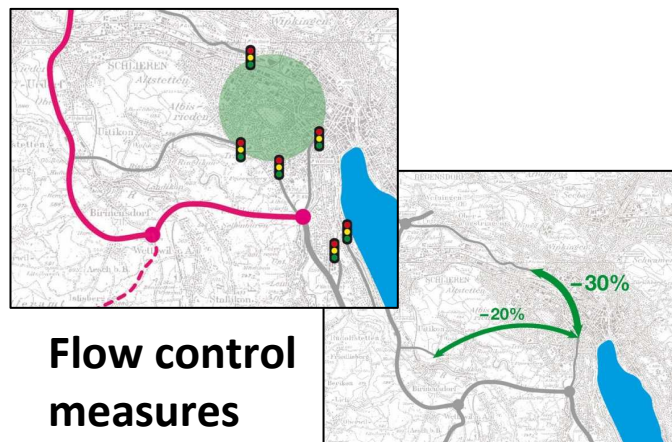


Physical model



How to improve the transport system?

Transport model for Forecasting



MATSim

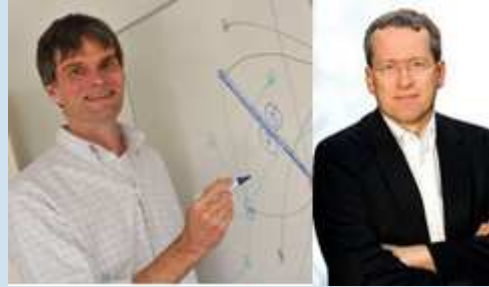
PTV Visum, etc.

MATSim

Multi-Agent Transport Simulation

MATSim – Team

Head



Prof. Dr.
K. Nagel

Technische Universität Berlin



Prof. Dr.
K.W. Axhausen



Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Project management

Dr. N. Schüssler

Developers

Y. Chen
D. Grether
J. Illenberger
B. Kickhöfer
G. Lämmel
A. Neumann
T. Nicolai
M. Zilske

F. Ciari
C. Dobler
T. Dubernet
A. Horni
K. Meister
B. Vitins
R. Waraich

MATSim spin-off & consulting

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Dr.
M. Balmer

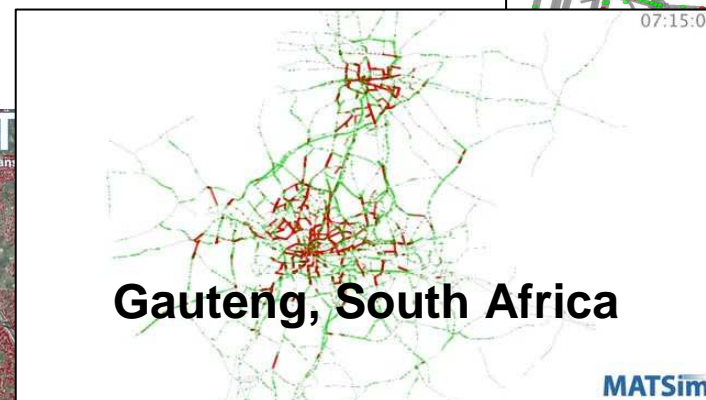
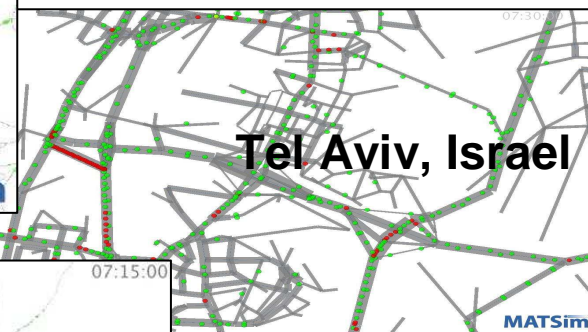
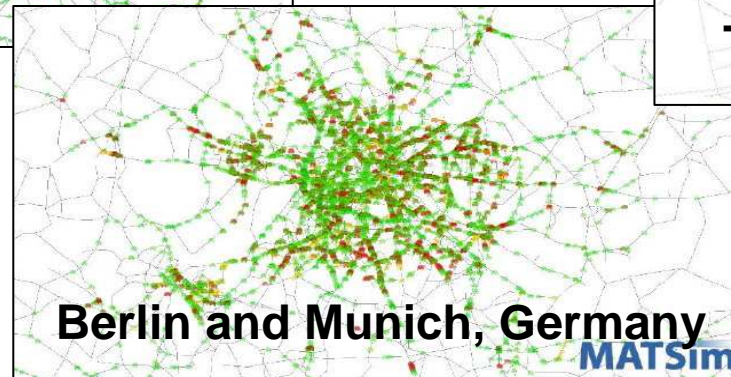
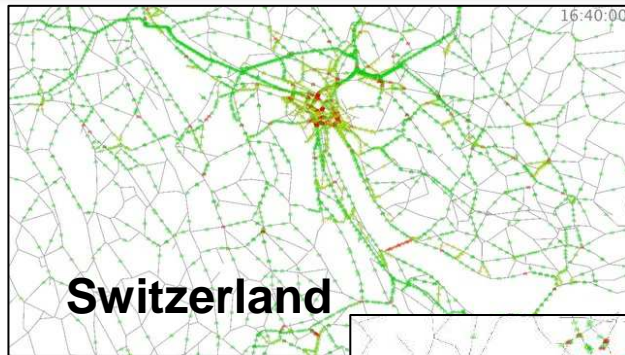


Dr.
M. Rieser

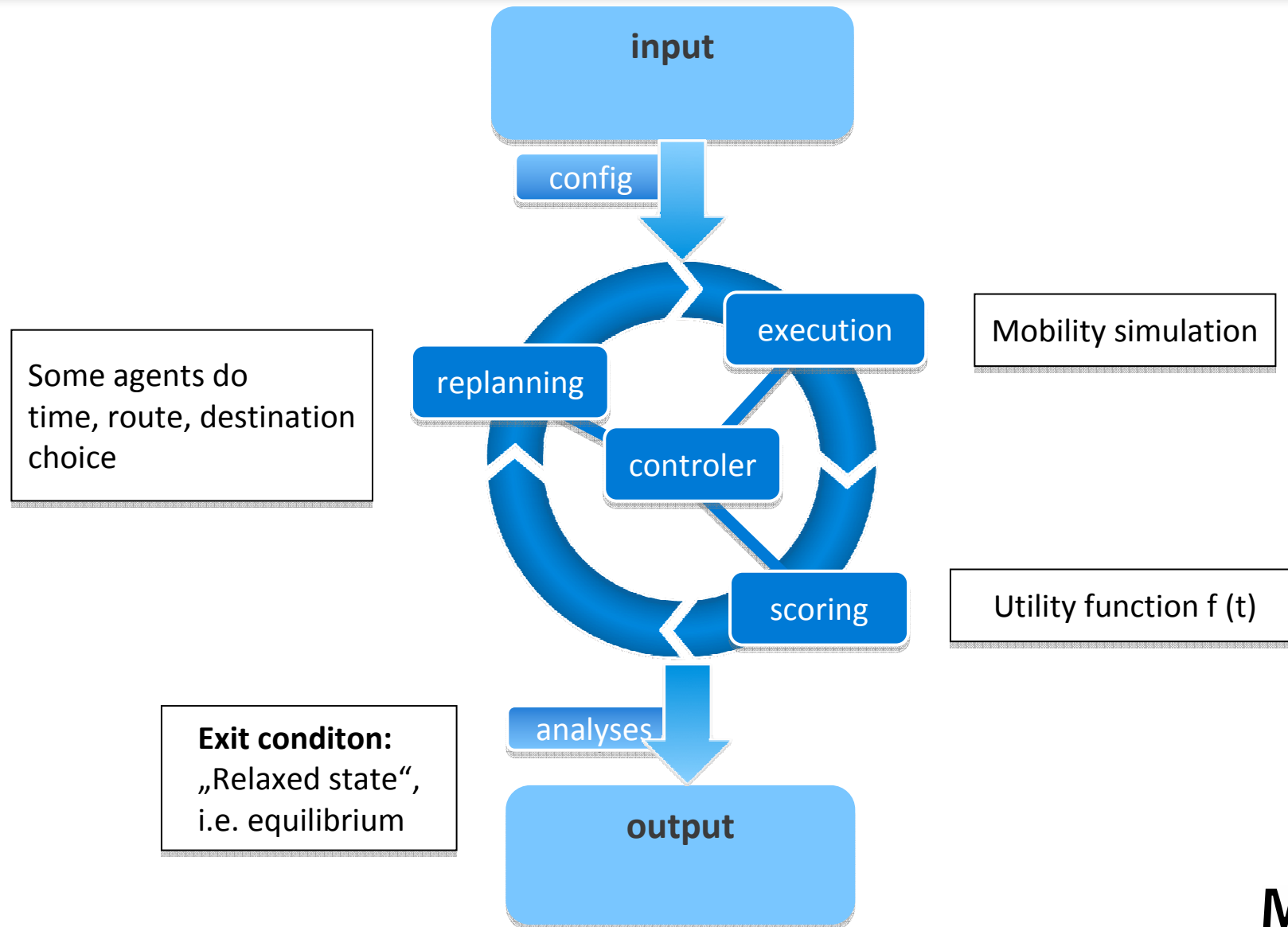
What is MATSim

- Transport modeling tool:
 - Disaggregate
 - Activity-based
 - Dynamic
 - Agent-based
- Free and open source: www.matsim.org -> www.sourceforge.net
- Started ~ 10 years ago
- Growing fast
- Written in JAVA 1.6, using state-of-practice software concepts and tools

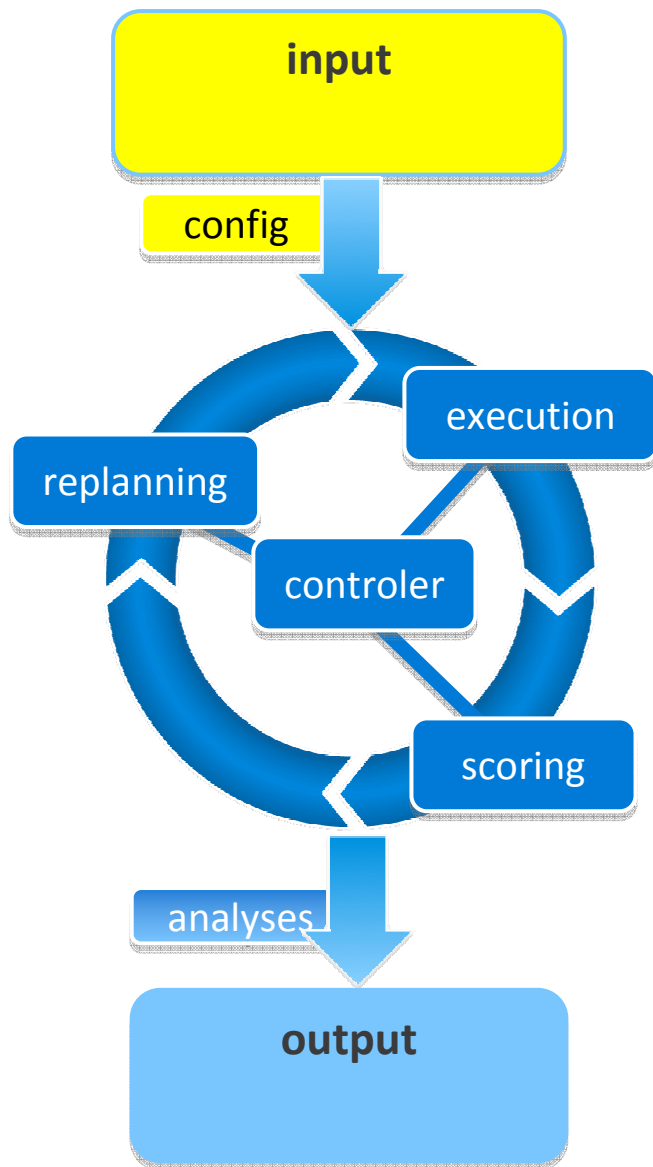
... we are not alone: MATSim Spreading



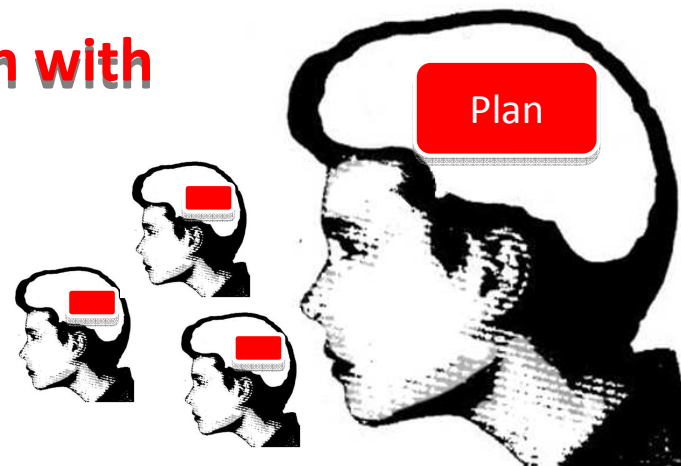
MATSim: Structure → Evolution



Input



Agent population with day plans



Input:

- Plans (demand)
- Config (parameters)
- Network (supply)

Day Plans

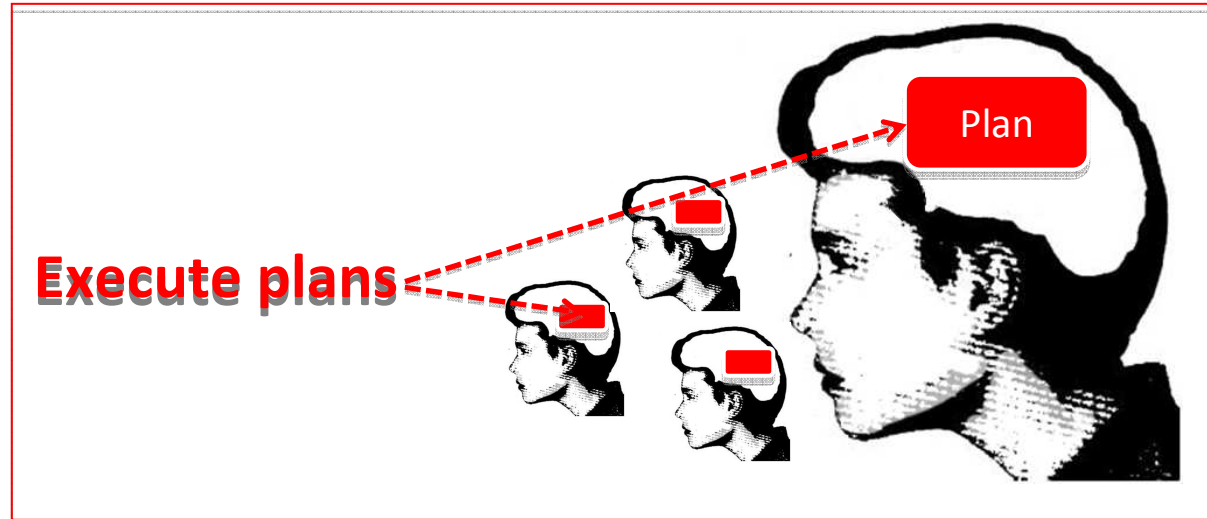
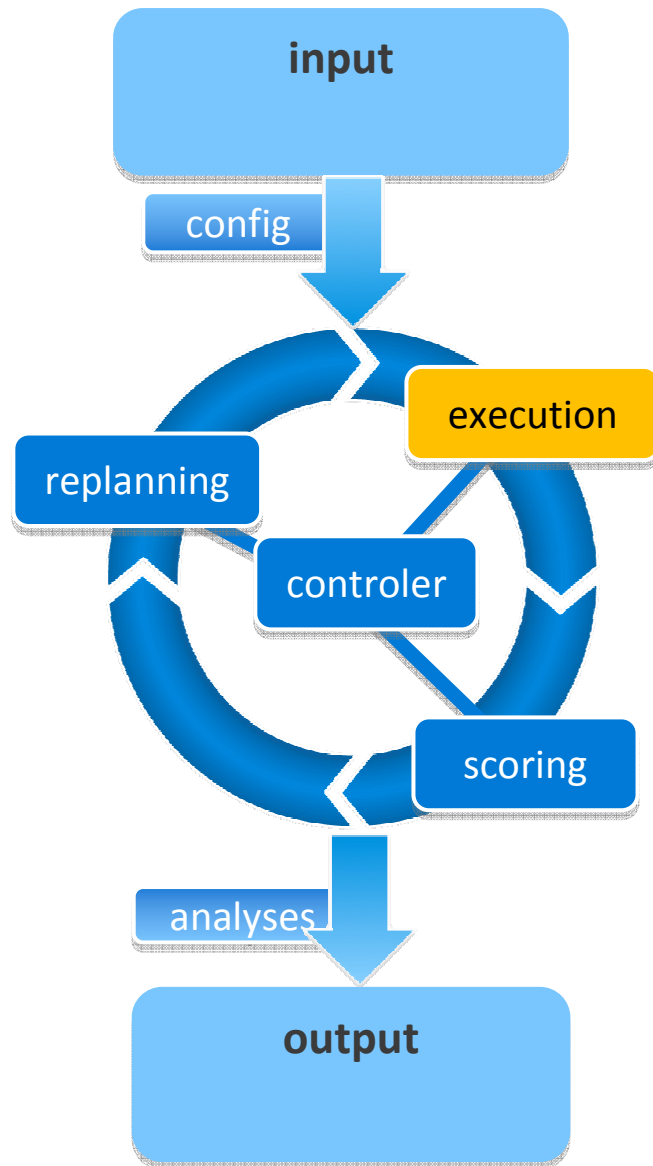


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  <plan selected="yes">
    <act type="h11" link="22399" x="633714.0" y="127443.0" start_time="00:00:00"
      dur="06:45:00" end_time="06:45:00" />
    <leg num="0" mode="car" dep_time="06:45:00" trav_time="00:30:11" arr_time="07:15:11">
      <route 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"
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    ...
  </plan>
</person>

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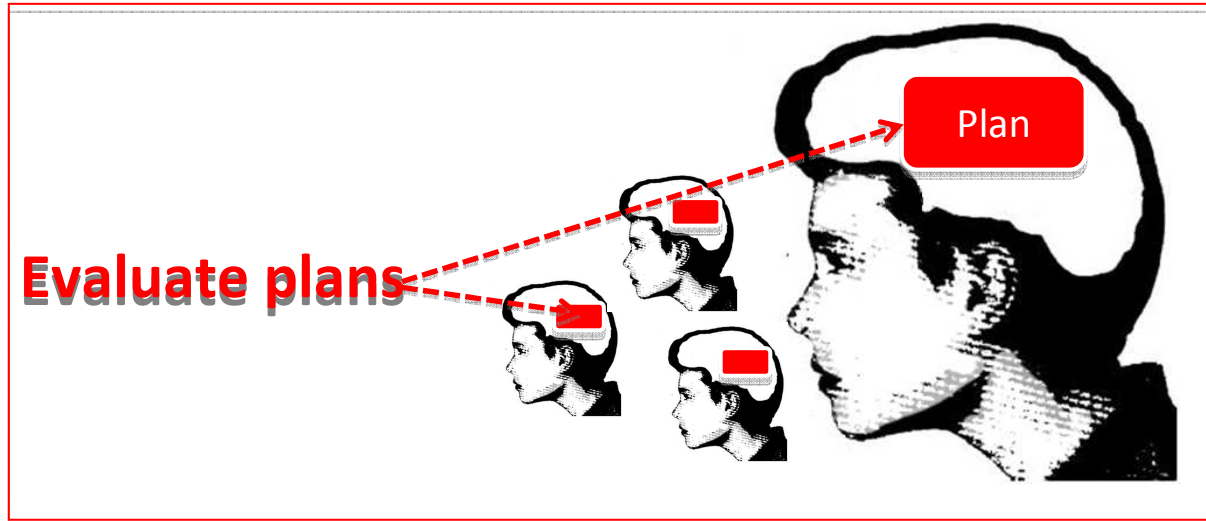
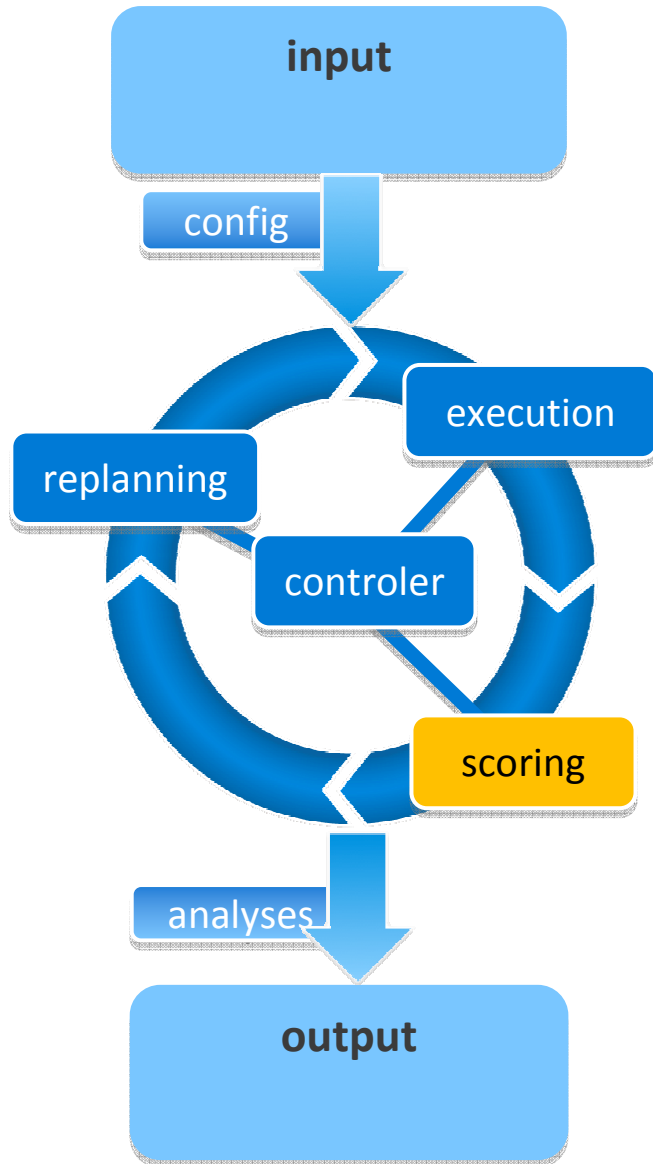
Mobility Simulation



Modes:

- Motorized individual traffic
- Public transport
- Bike (teleported)
- Walk (teleported)
- Experimental: ride

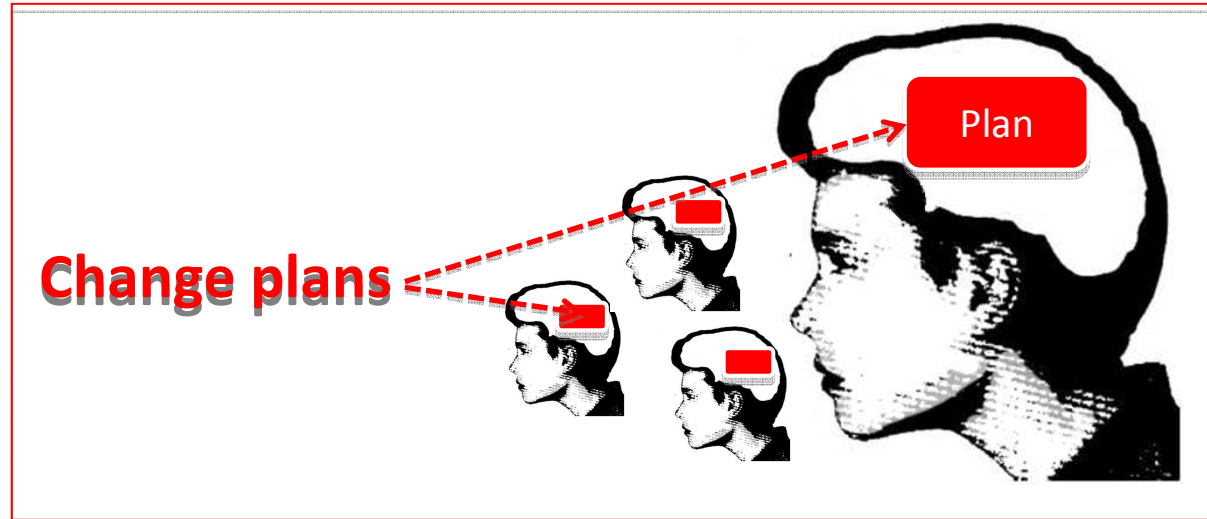
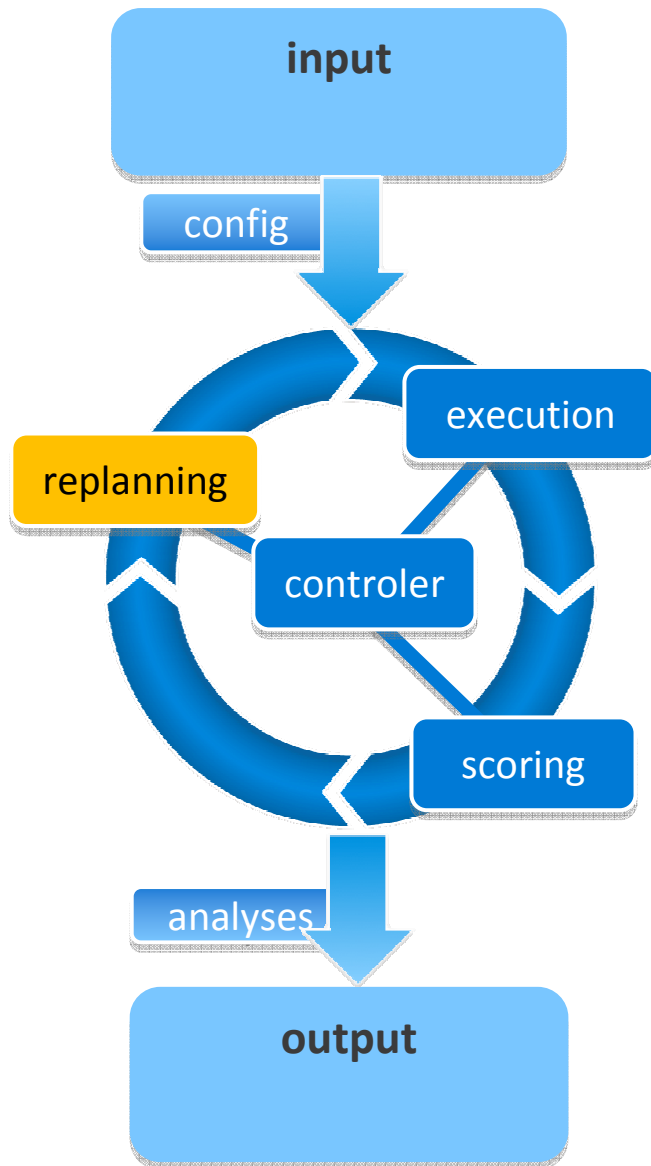
Scoring, i.e. Fitness Evaluation



Generalized costs:

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

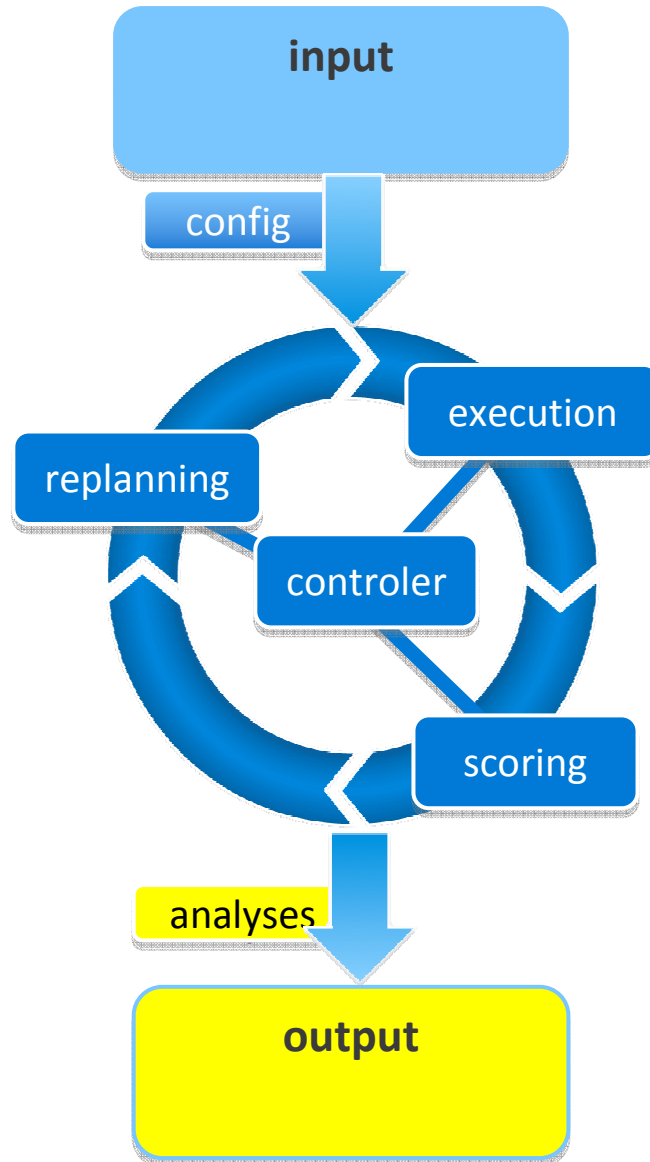
Adaptation



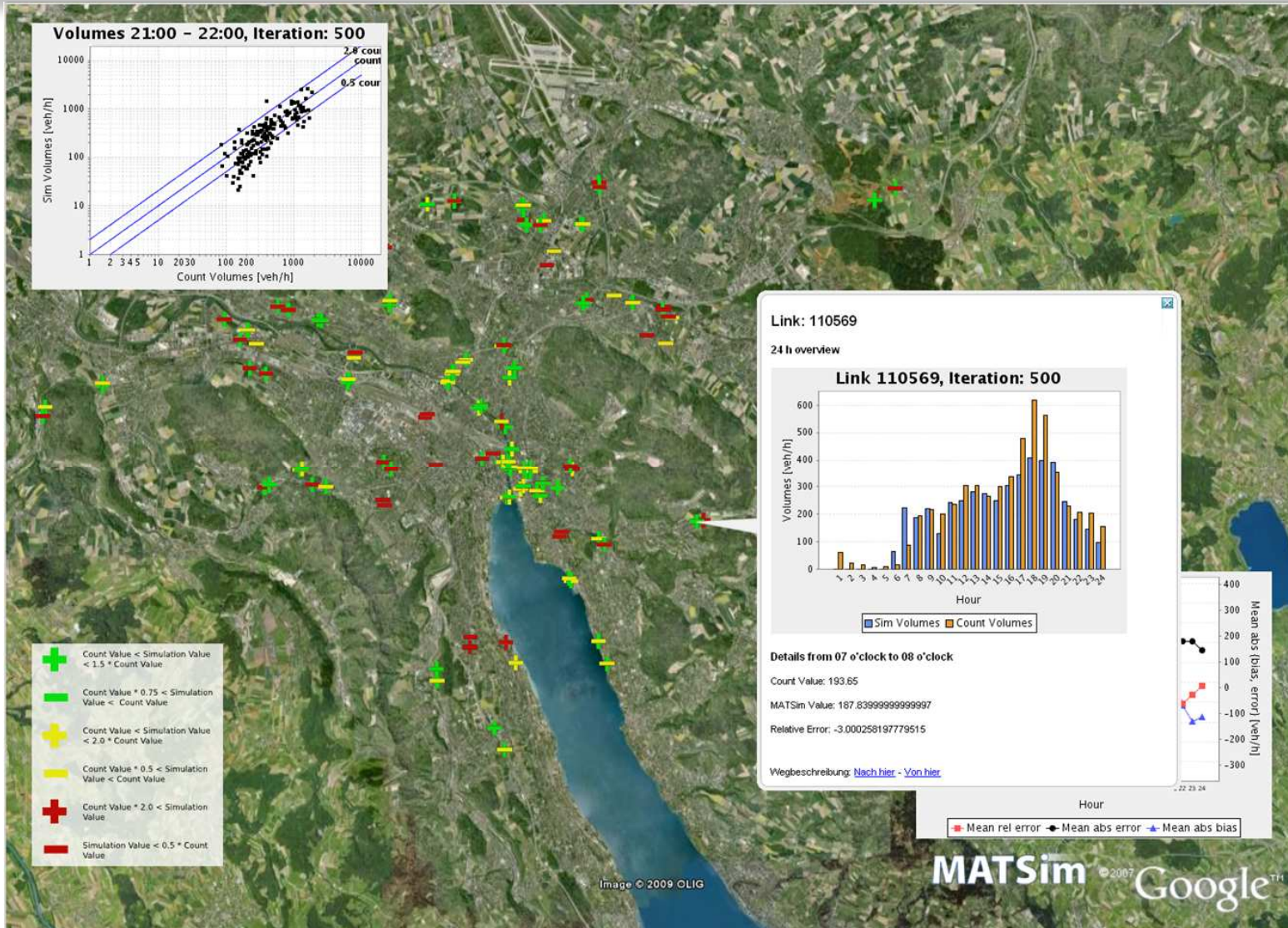
Decision dimensions:

- Time choice (local random mutation)
- Route choice (best response)
- Mode choice (experimental)
- Destination choice (experimental)

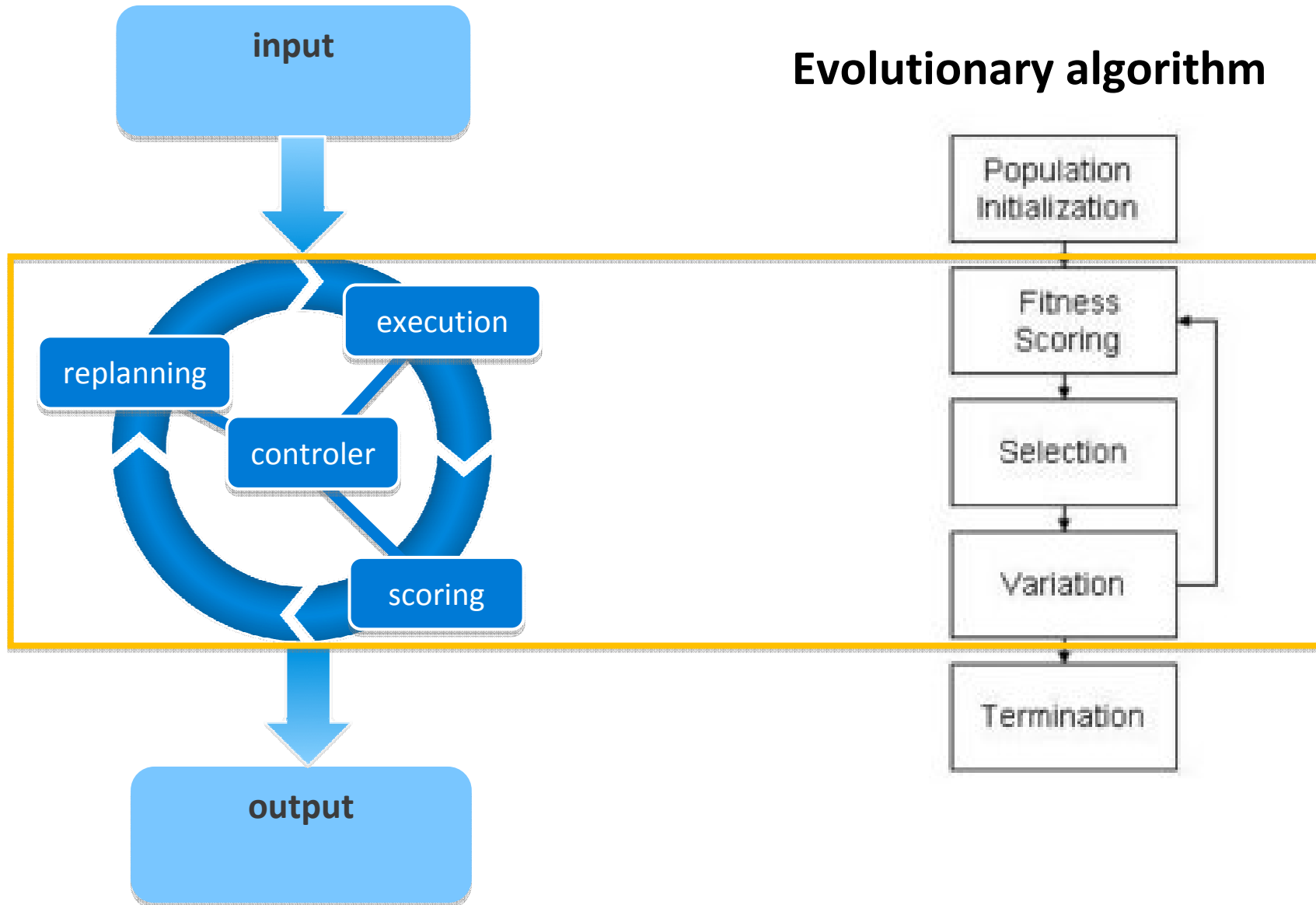
Output



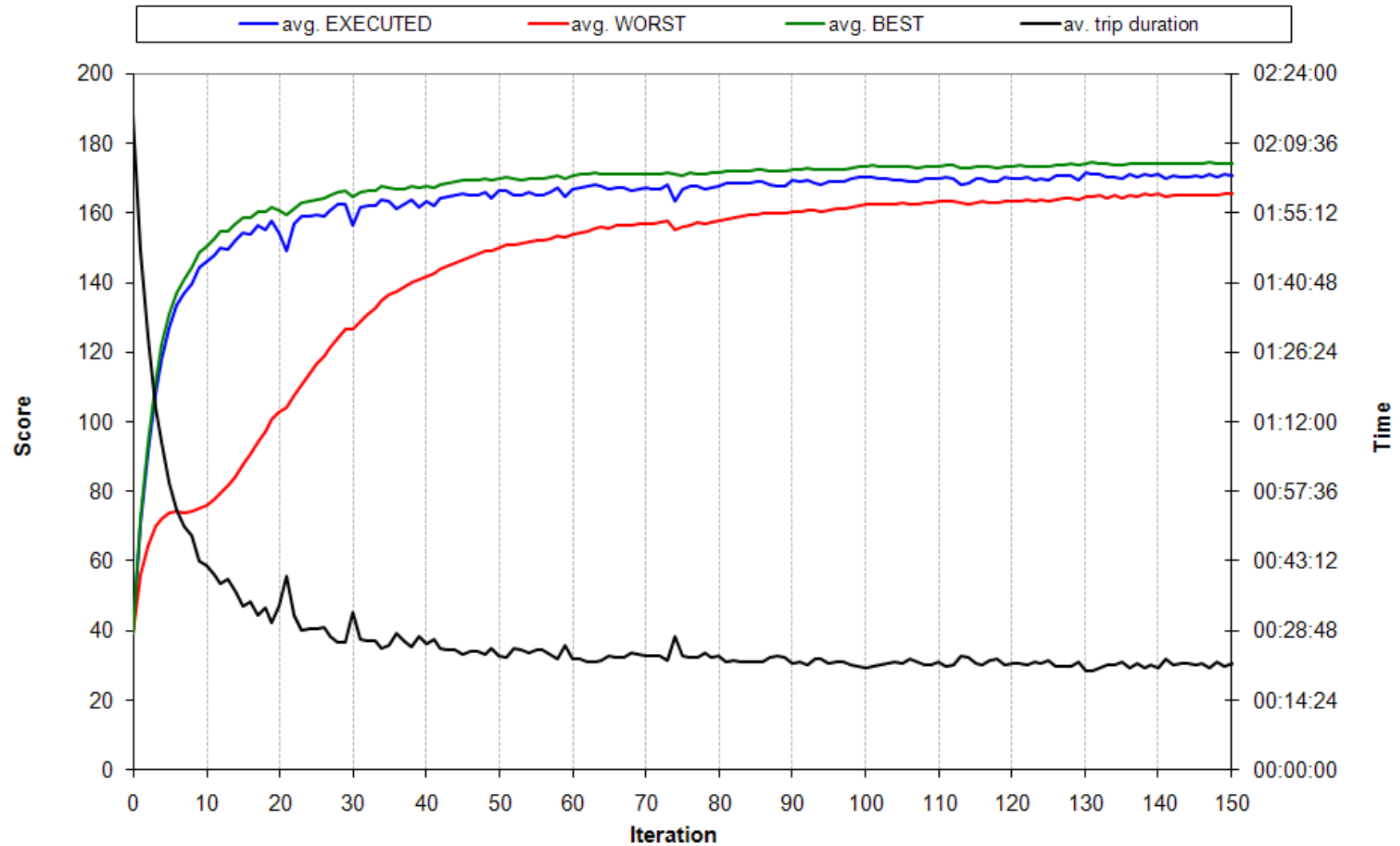
- Statistics
- Counts
- Plans
- Events -> post-processing e.g., in visualizer



An Evolutionary Algorithm ...



Score Development: Relaxed State



Ongoing Research and Future Features of MATSim

Destination choice

Activity chain choice

Car sharing

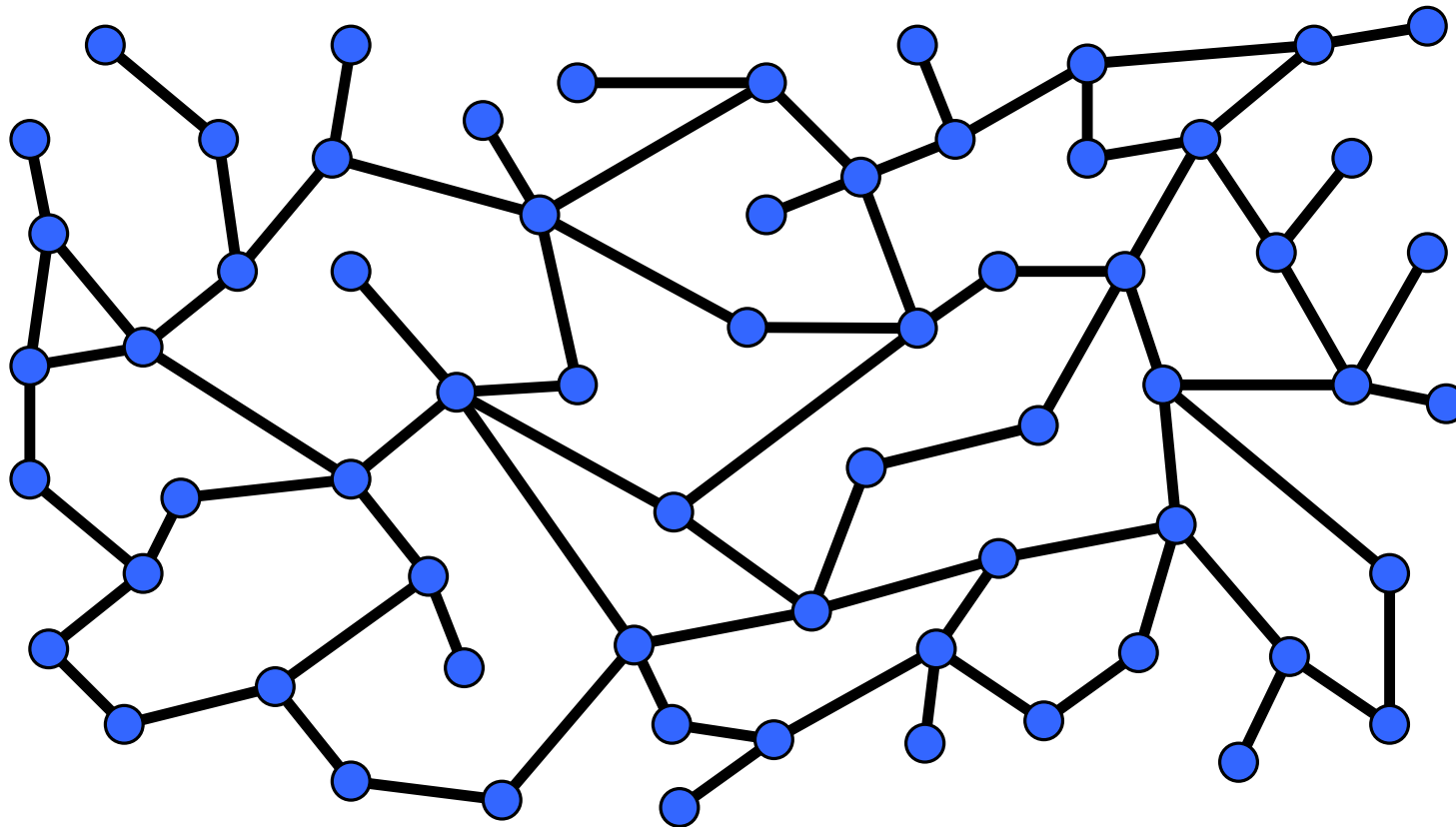
Wide area effects of green cars

Public transport and multimodal simulation

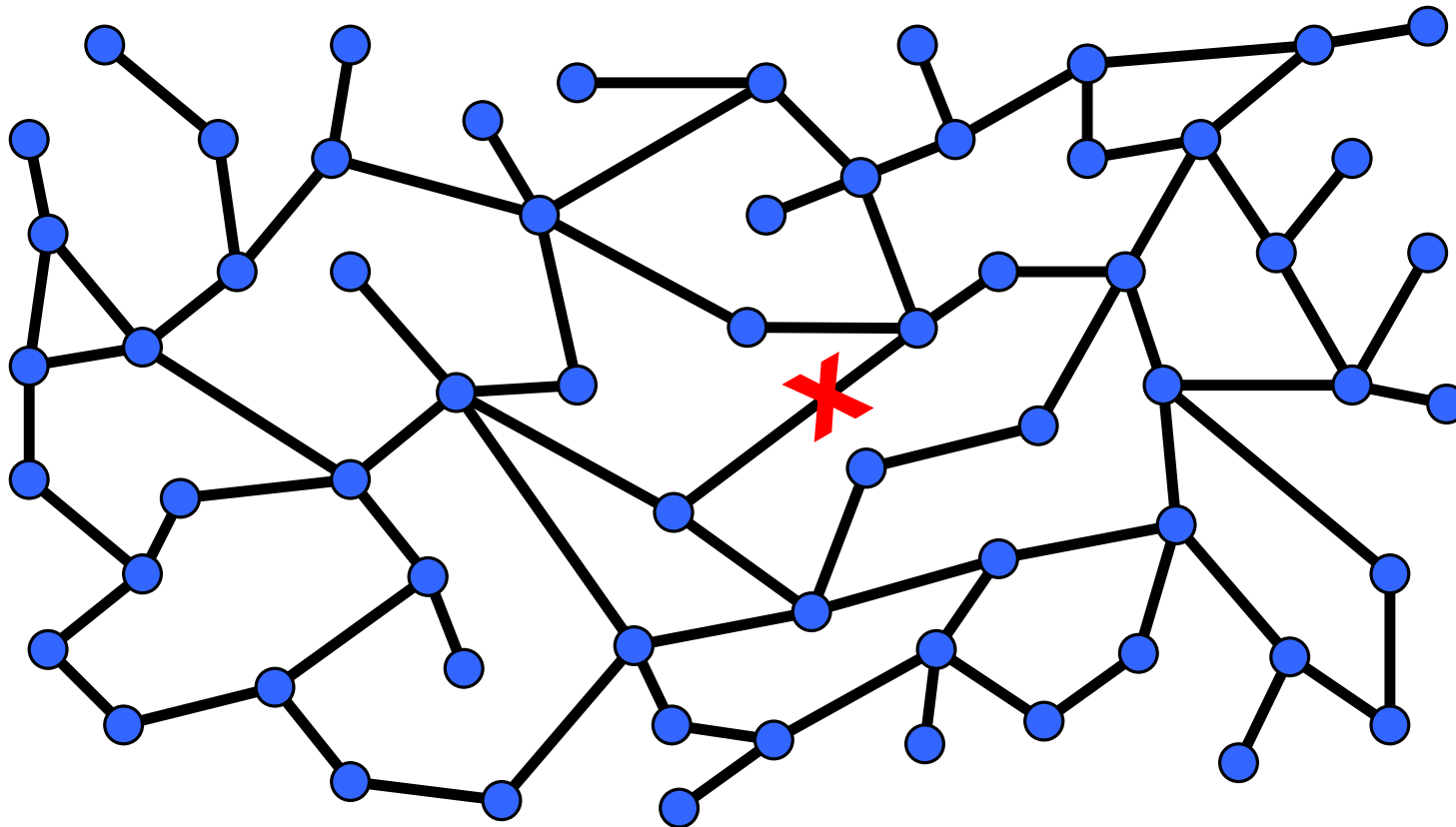
Exceptional Events

Exceptional Events – A Hard Problem for any Iterative Simulation Approach!

Exceptional Events – Road Network

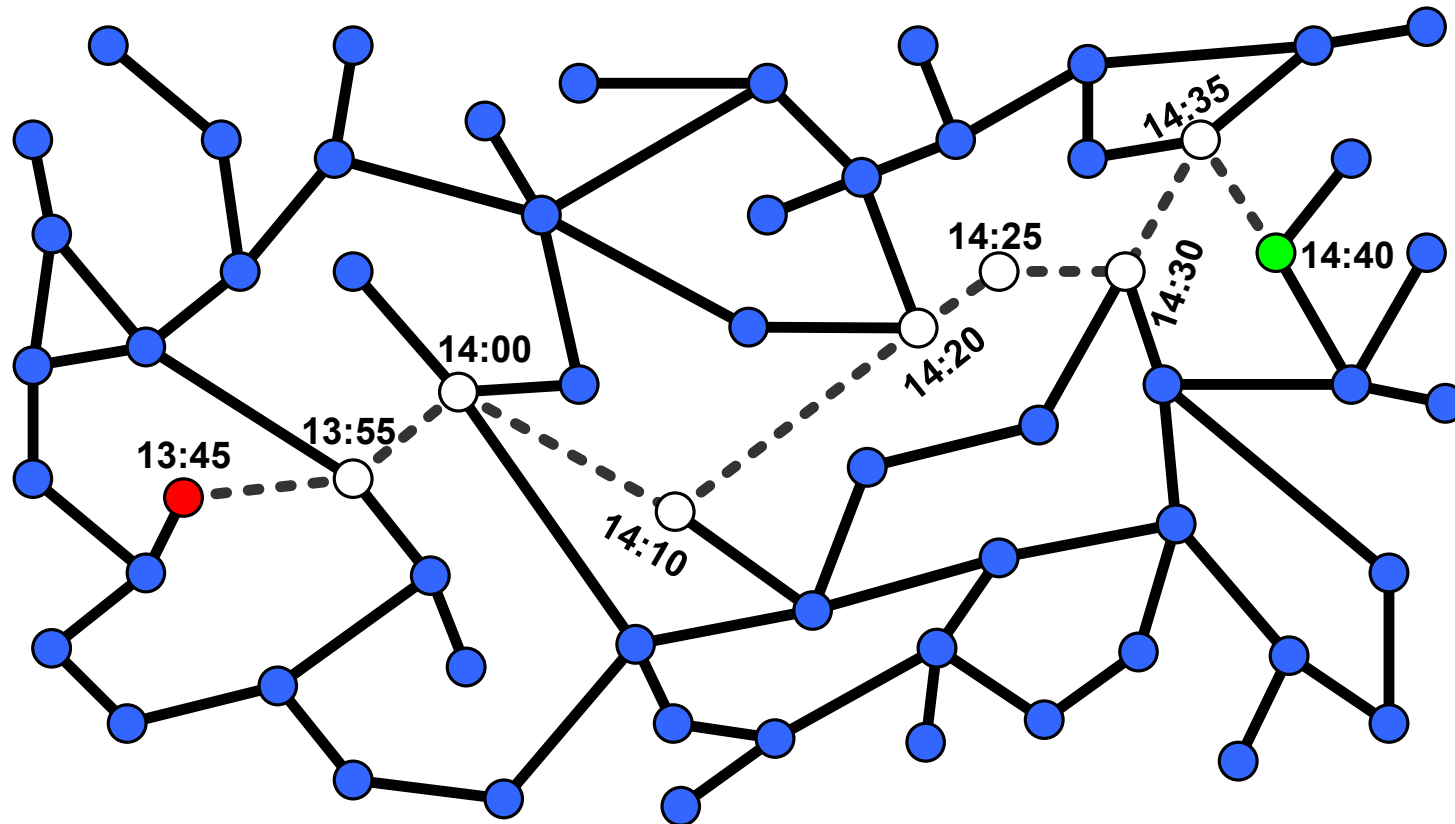


Exceptional Events – Occurring Event



X Event that blocks a link

Exceptional Events – Planned Trip



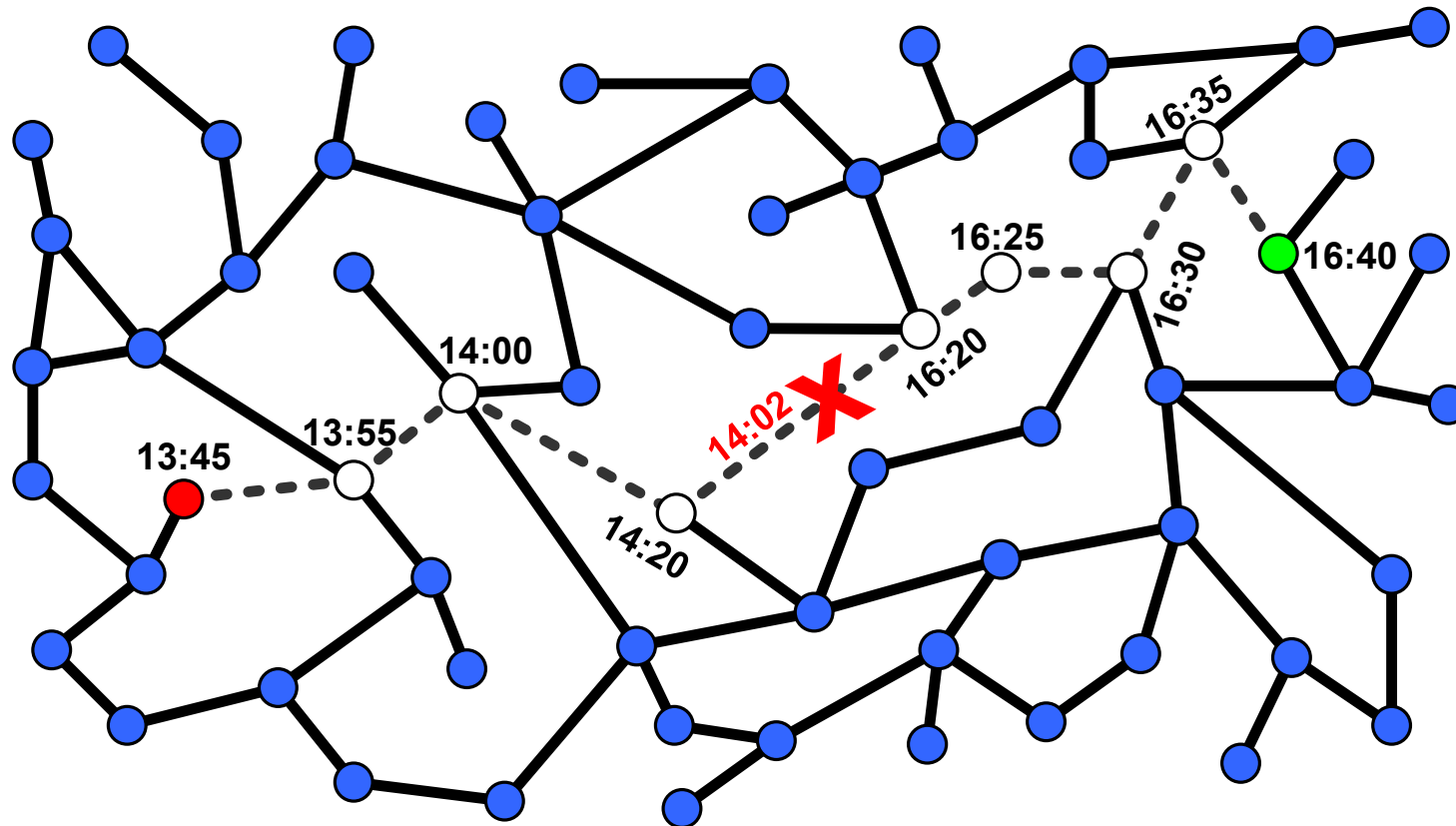
● Startnode of the route

● Endnode of the route

○ Node on the planned route

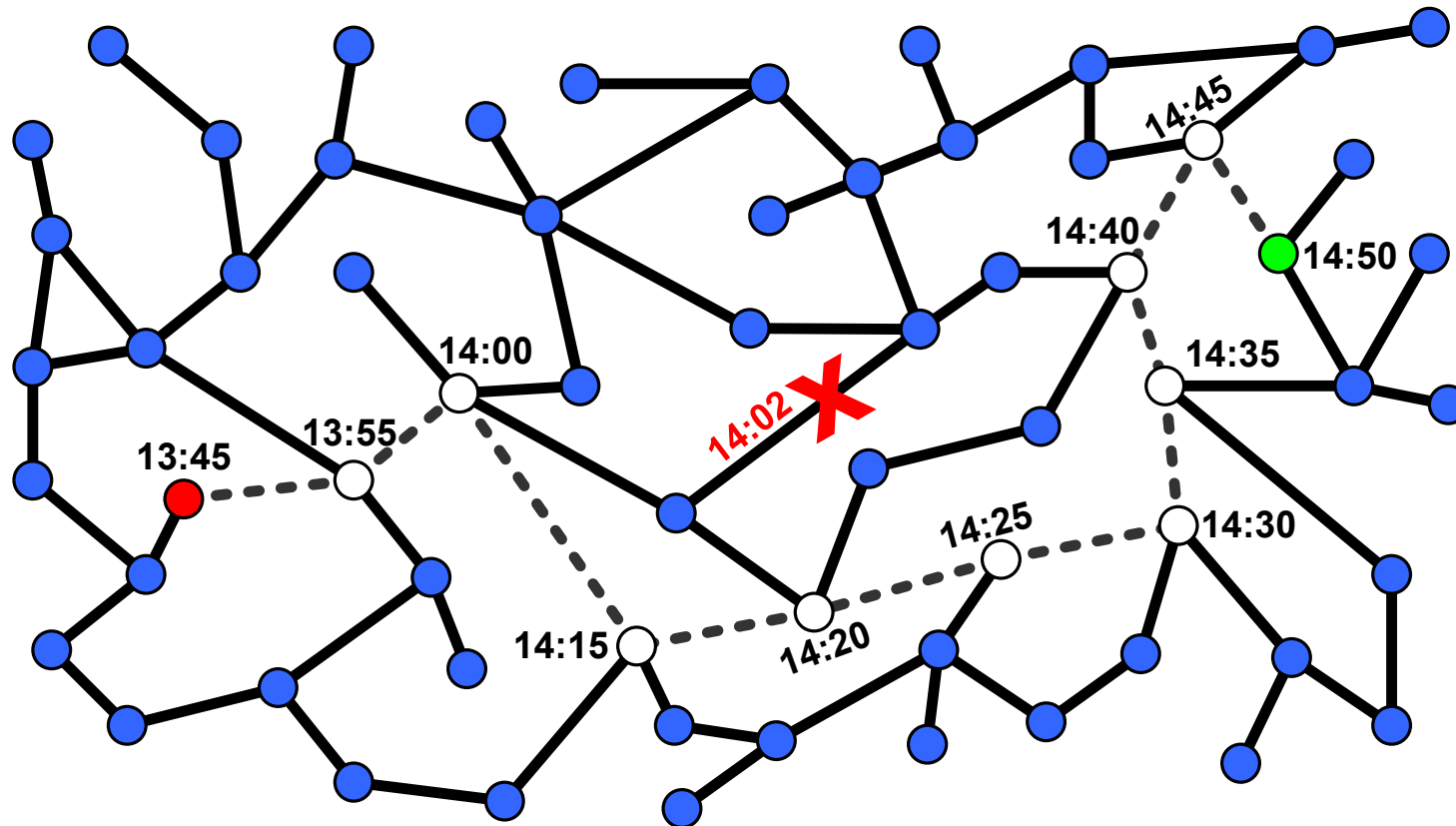
--- Planned route

Exceptional Events – Real Trip



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

Exceptional Events – Iterative Approach

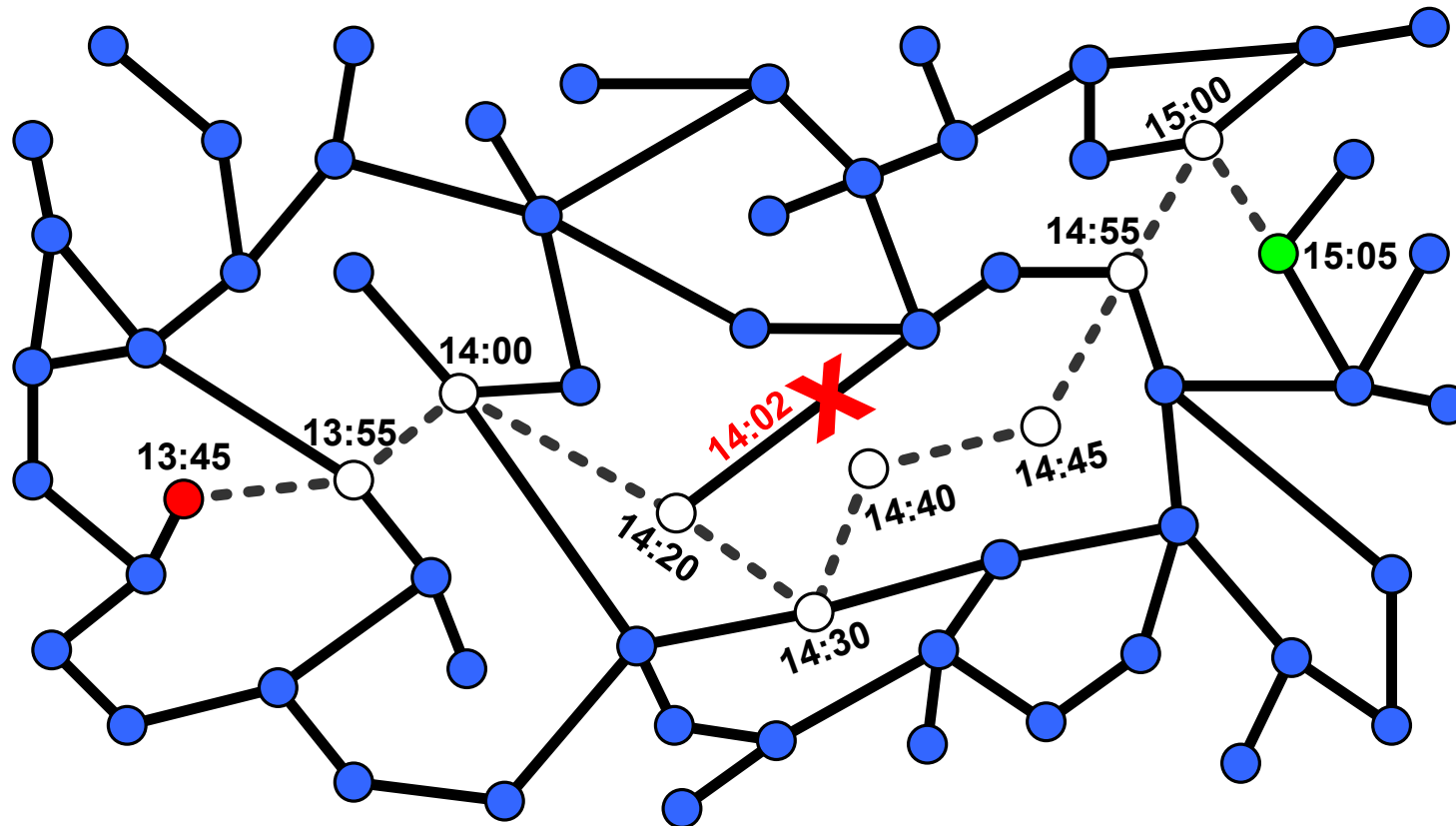


⇒ Iterative approach: the agent decides that another route will be faster.
BUT: The new route differs from the original one even before the event has happened!

Exceptional Events – Conclusions

- Using an iterative simulation approach will result in illogical behavior.
- Therefore, apply an 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.
- One way to solve this problem: *Within-Day Replanning*

Exceptional Events – Within-Day Replanning



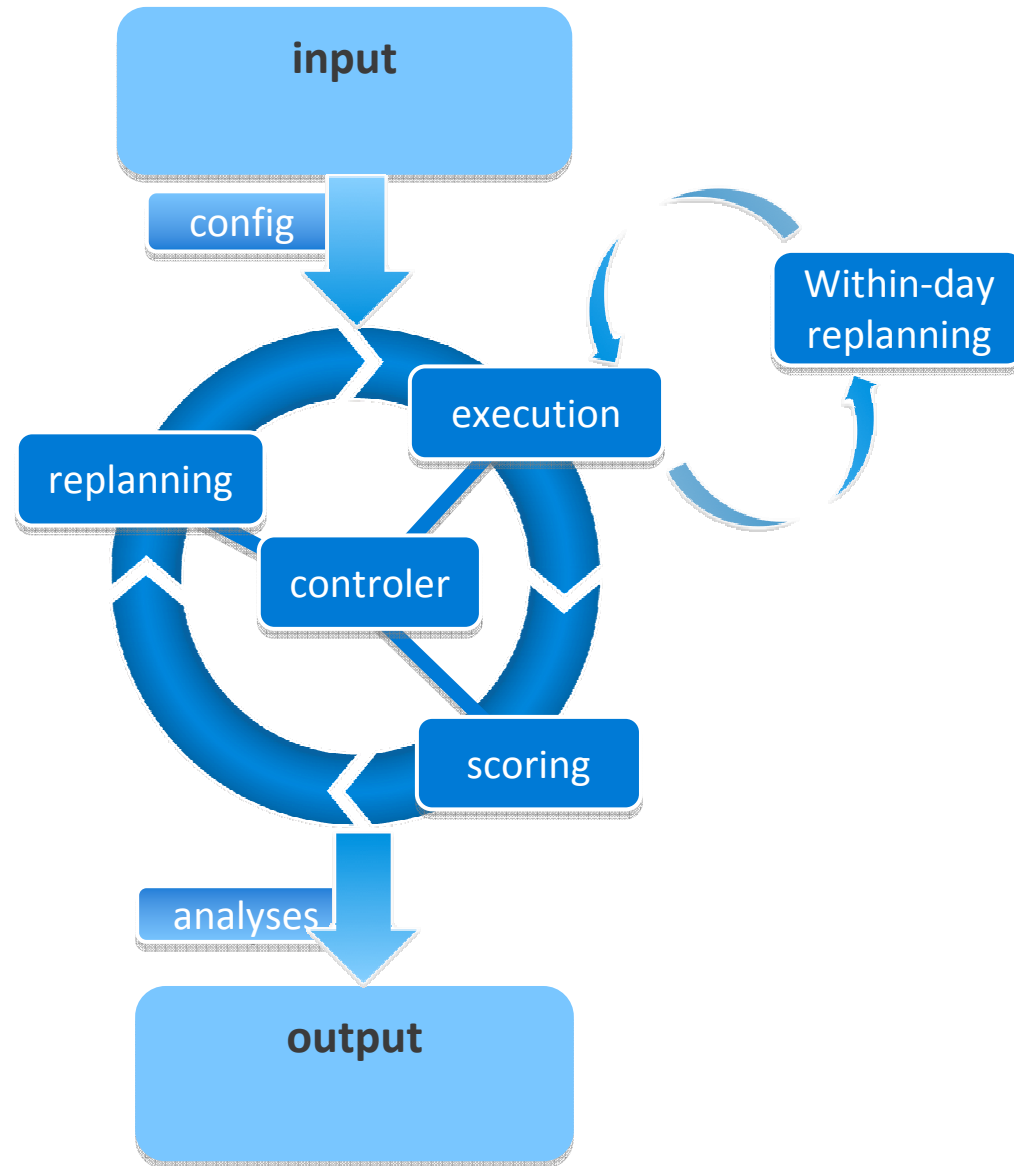
⇒ Within-day replanning approach: the agent reaches the blocked link, recognizes its congestion and adapts his route.

Within-Day Replanning – Features

- Simulation of exceptional events which affect the
 - network structure and capacities of the links.
 - amount of available (traffic) information.
 - traffic volumes.
 - desires of the people.
 - behavior of people when new information becomes available.

Within-Day Replanning – The Extended MATSim Picture

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Within-Day Replanning – Use Cases

- In iterative runs to keep the agents behavior consistent
 - Parking search
 - Taxis

- For scenarios with large scale events
 - Accidents
 - Disasters & evacuations

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:
 - Do not define an exact parking position in advance.
 - Agents use within-day replanning to select a free parking lot when they are close to their destination.

Within-Day Replanning – Taxis

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

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:
 - 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 & Evacuations

- How do people react if a disaster occurs and an evacuation is required?
- Does the disaster affect the network?
- Solution:
 - Model behavior of the rescue units.
 - Model governmental instructions.
 - Model individual reaction (waiting at home, meeting family members, evacuate, ...)

Within-Day Replanning – Proof of Concept

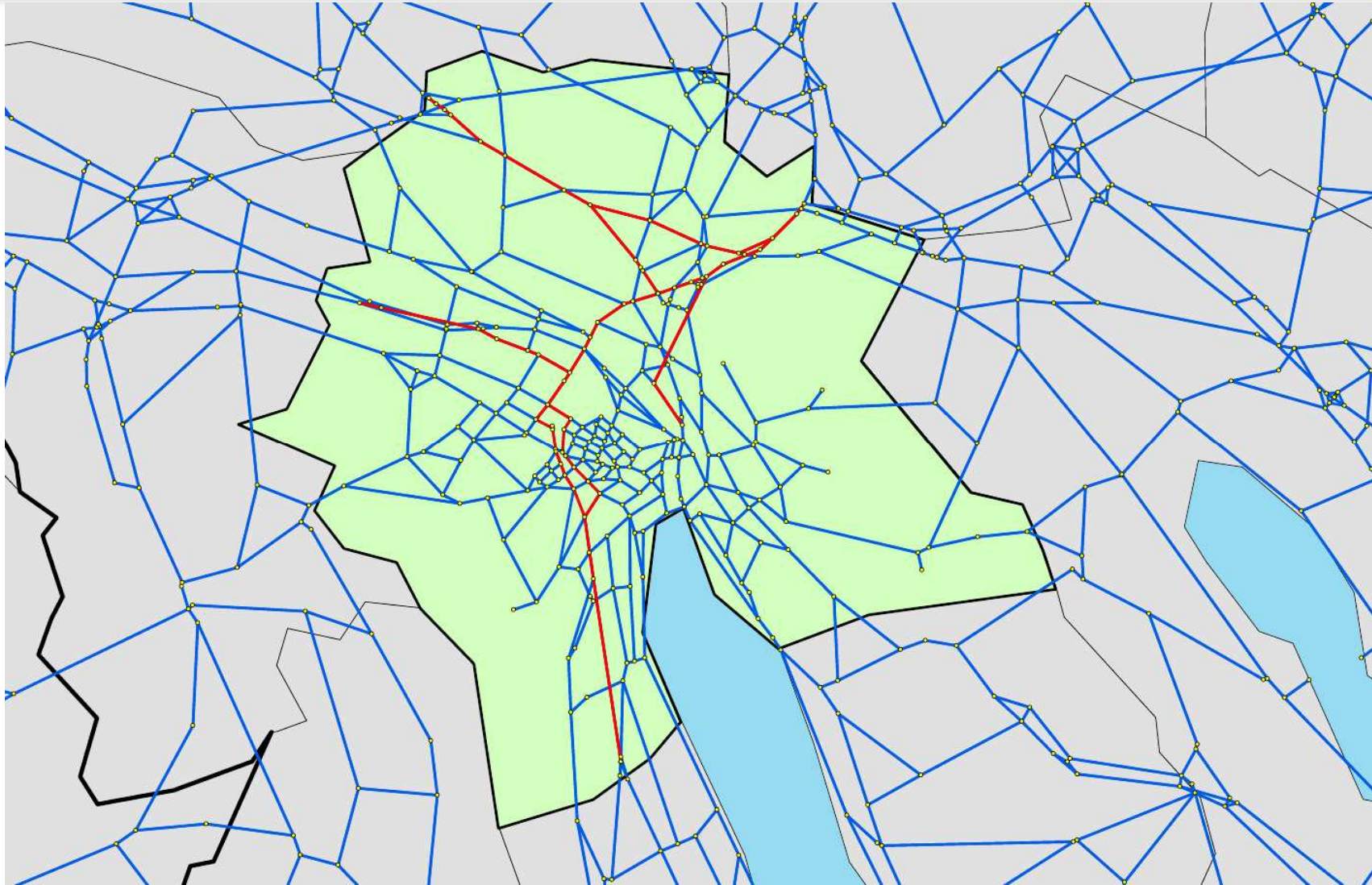
- Within-Day Replanning feature has been further developed and standardized
 - Now part of MATSim package, but still experimental
 - Project to simulate taxis has just started

- Scenario Setup
 - 10% Sample of Canton Zurich
 - Only car traffic
 - Planning Network
 - Capacity of several arterial roads in the City of Zurich is reduced to 15% between 07:00 and 09:00
 - Agents that would use that roads in that time can adapt their plans

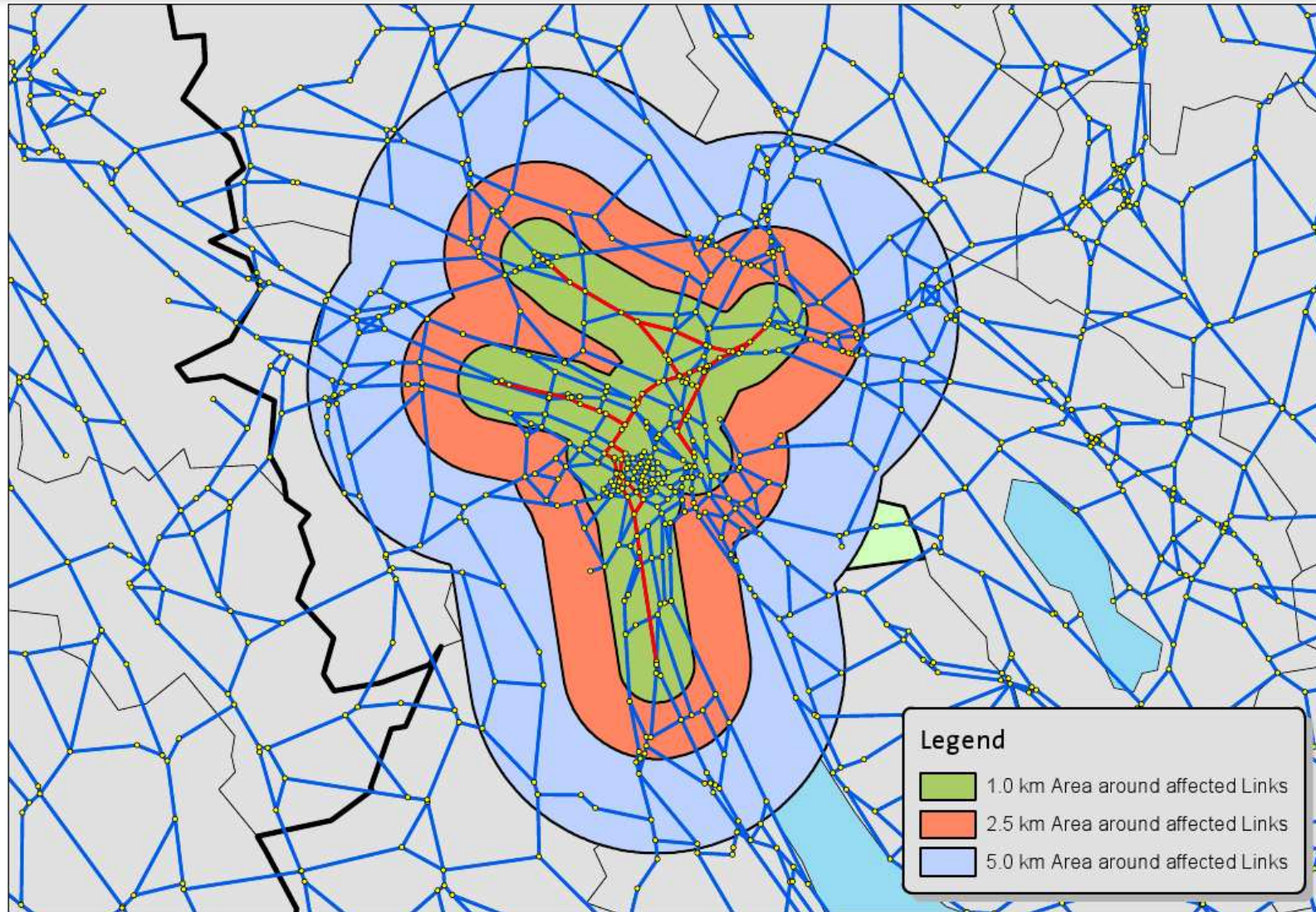
Proof of Concept – Scenario Area



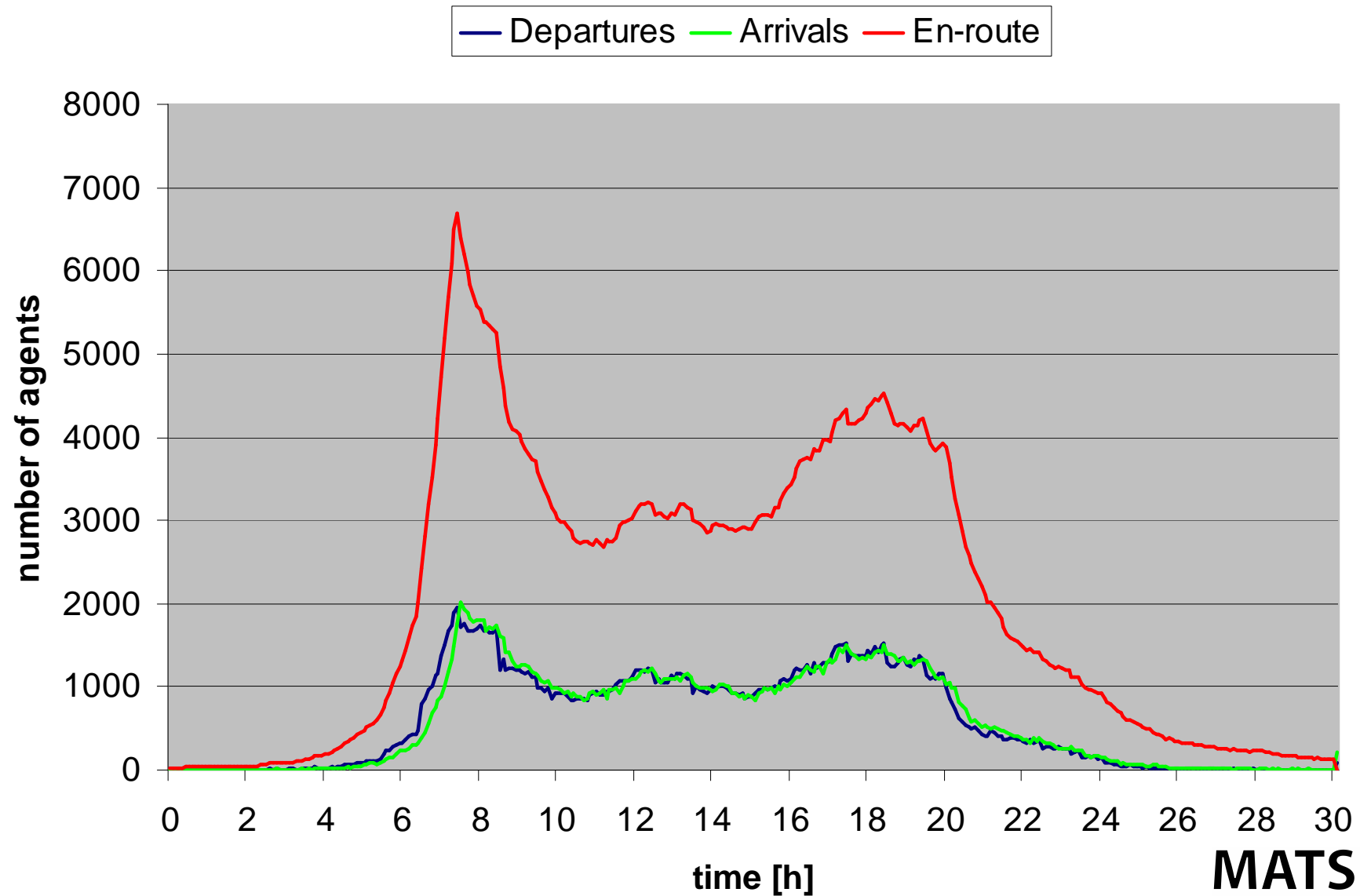
Proof of Concept – Affected Links



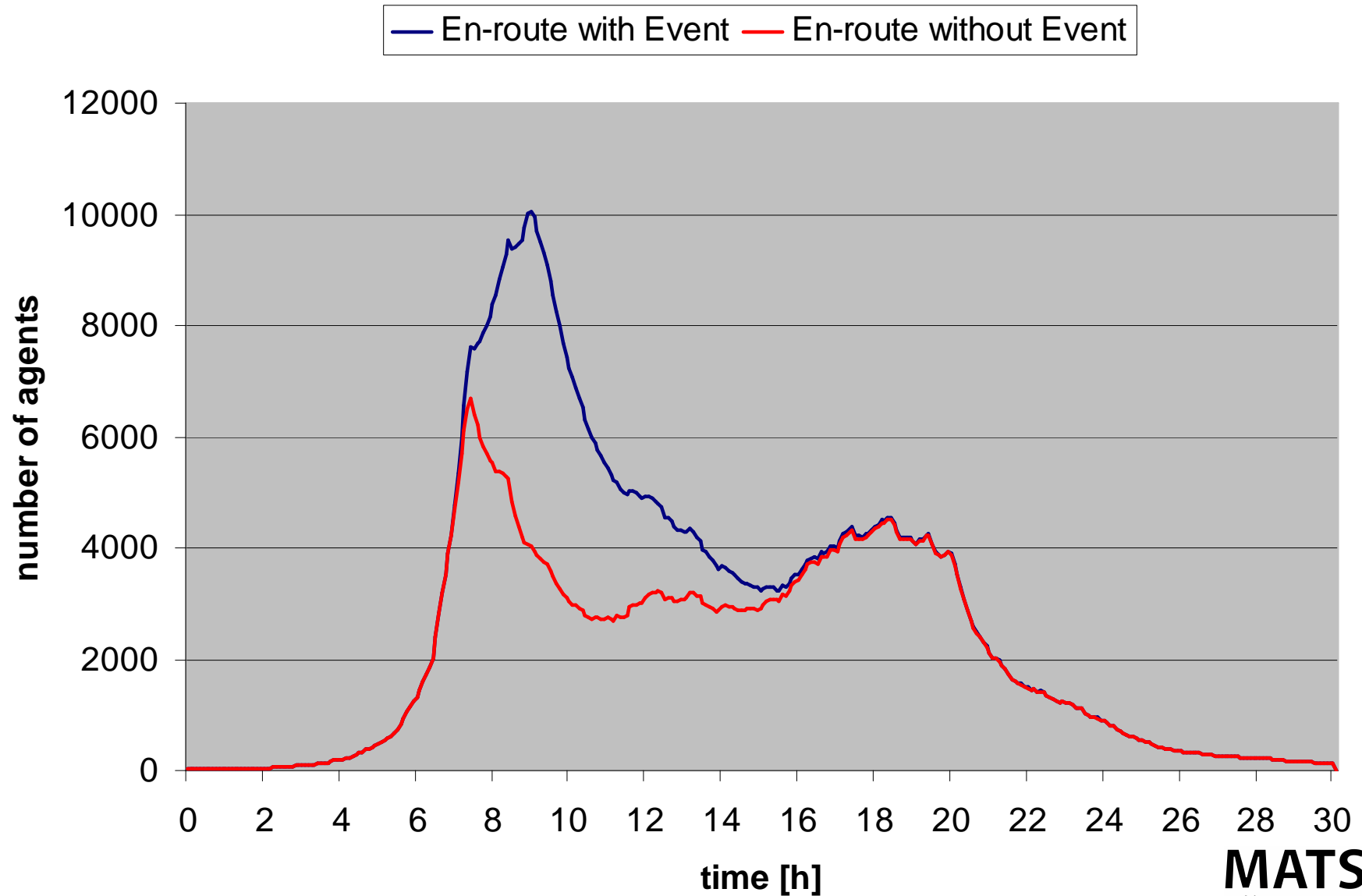
Proof of Concept – Replanning Buffers



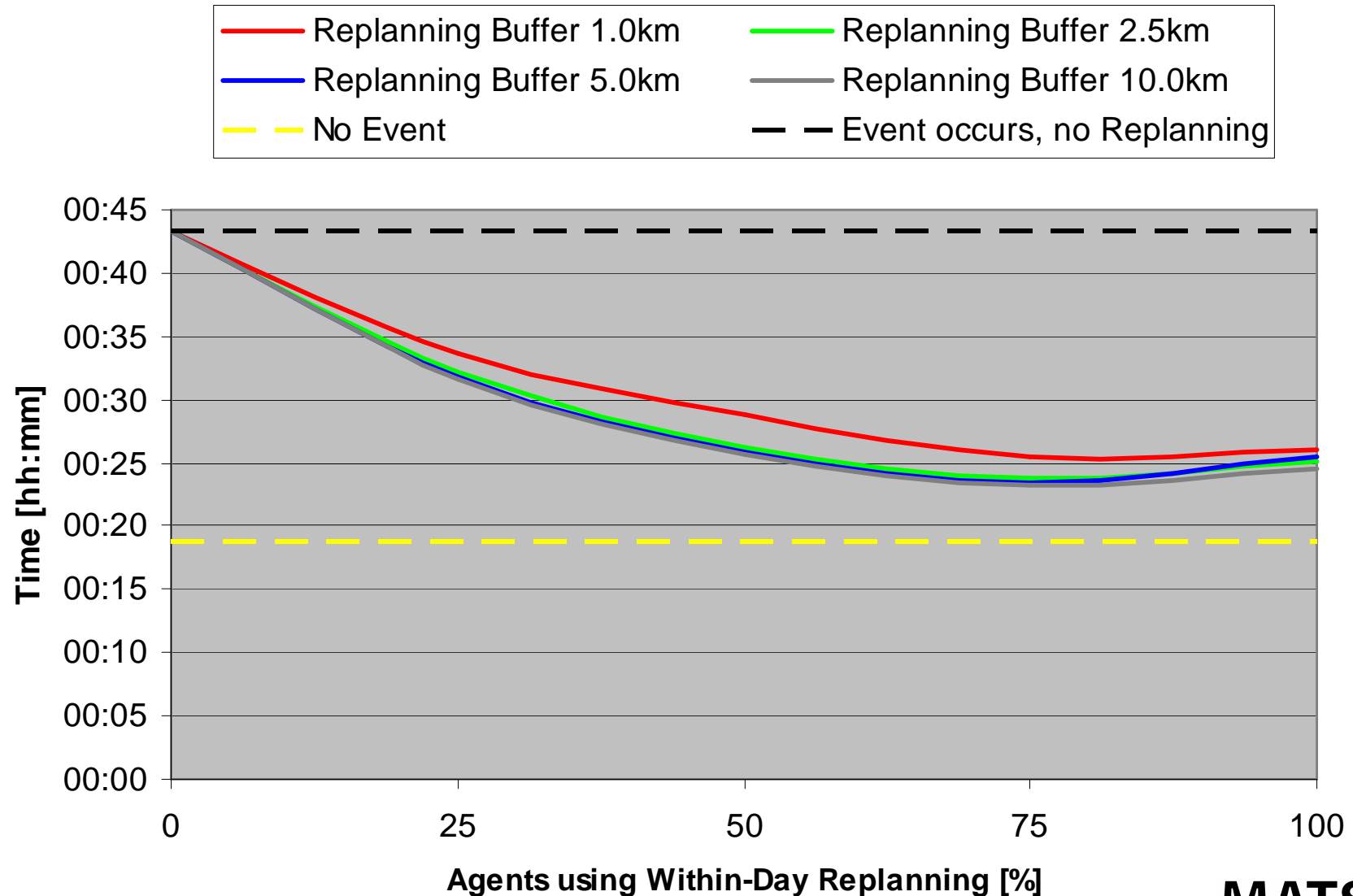
Proof of Concept – Leg Histogram



Proof of Concept – Compare En-route Agents



Proof of Concept – Travel Times of Affected Agents



Collecting data on evacuation behavior

Data collection aims to:

- Generalize the abstract behavior of an evacuating population
- Identify behavioral differences between concrete evacuation conditions

Restrictions

- The project exclusively focuses on:
 - 'Large-scale' evacuations; zones ≥ 1.5 km
 - Evacuations as exceptional rather than routine events
- The evacuation movement is limited to:
 - The begin of a thread and the point where (all) people left
- Evacuations resulting from all kinds of events are of interest:
 - Natural disasters
 - Industrial accidents
 - Social occurrences

Survey methodology and protocol

- Triangulation of different information sources:
 - Literature research
 - Expert interviews
 - Quantitative survey research

Literature research: Comparative analyses

- General findings:
 - The decision to evacuate is negatively related to the distance between home and disaster
 - Outside the evacuation zone (+ x km) the distribution of evacuees follows a distance decay function
 - Evacuees move in the direction they perceive as the safest
 - Even without official order few people start to evacuate

Literature research: Comparative analyses

- General findings:
 - The success of an evacuation is related to the perception of the threat
 - People prefer kin and core contacts to find shelter

Literature research: Comparative analyses

- Evacuation behavior and socio-demographics:
 - Children and females (mothers) are primary candidates
 - Nuclear families evacuate as units
 - Families with children are more likely to evacuate than childless or single households
 - Younger age cohorts are likely to evacuate, elderly not
 - Workers are often less likely to evacuate
 - There is a positive relation between socioeconomic status and evacuation behavior

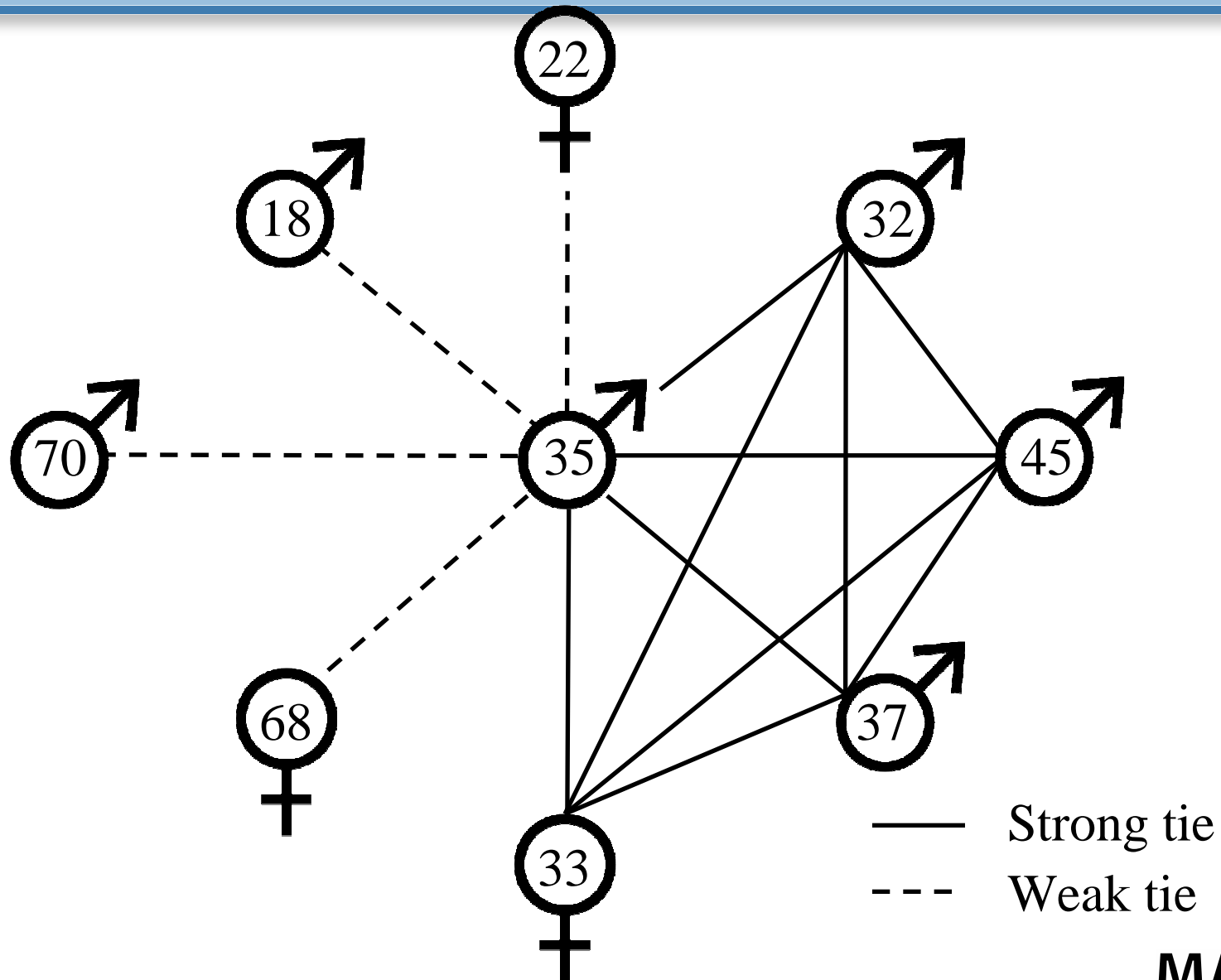
Literature research: Irrational behavior and panic

- Panic is a very exceptional event in evacuations
- Requirements for panic behavior:
 - A strong threat towards existence
 - A soon disappearing possibility to escape whether time or capacity related

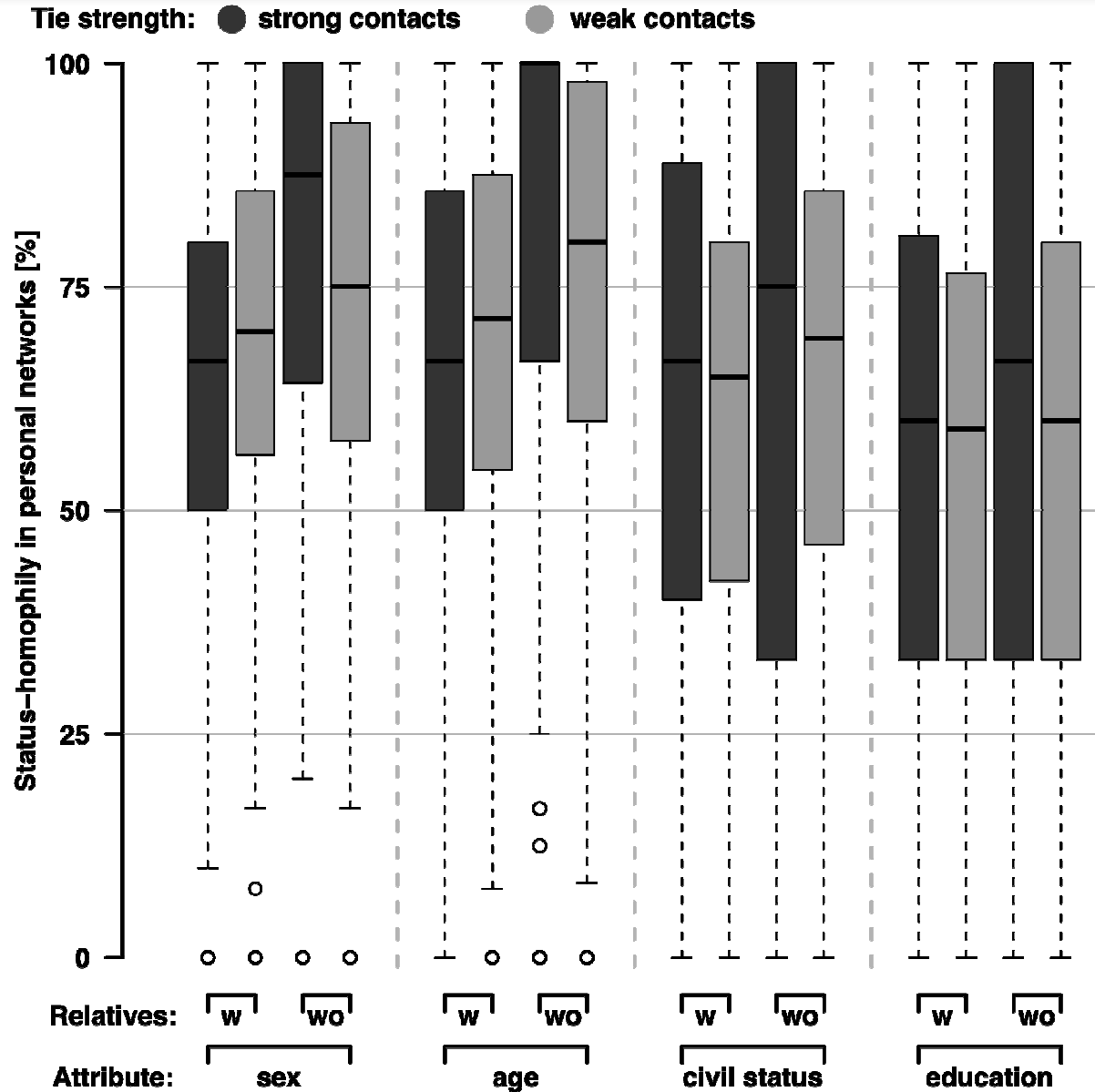
Interviews with experts (Pre-test)

- Challenge:
 - Who is considered as an expert?
- Approach:
 - Ask national/regional offices for civil protection to mention their experts
 - Use a sample of appropriate experts for interviews

Quantitative survey: Social network analysis

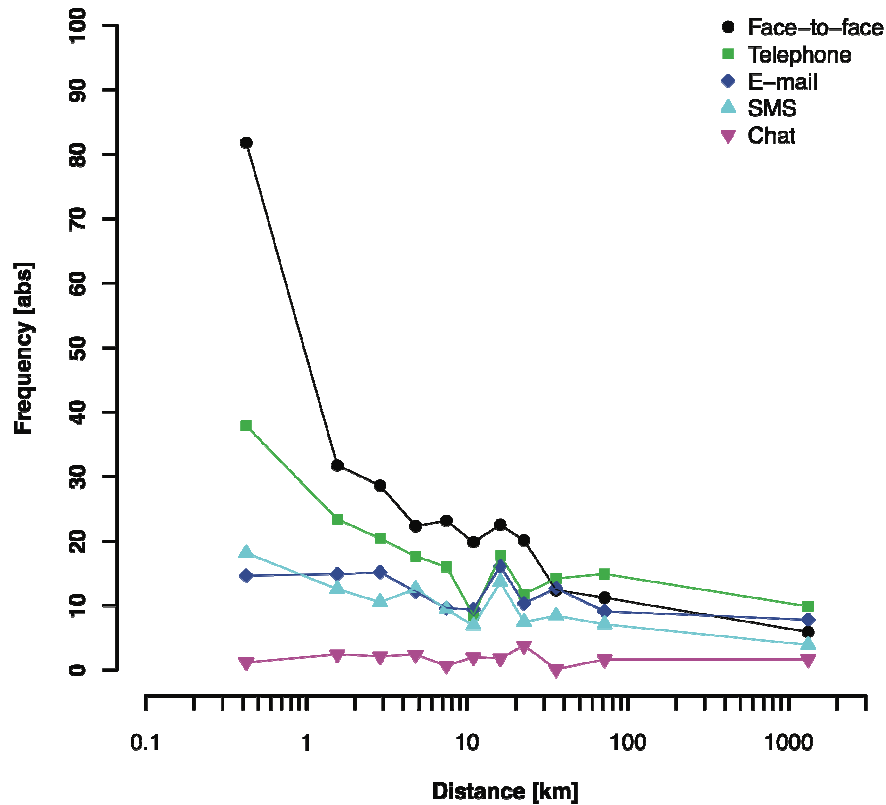


Quantitative survey: Social networks analysis

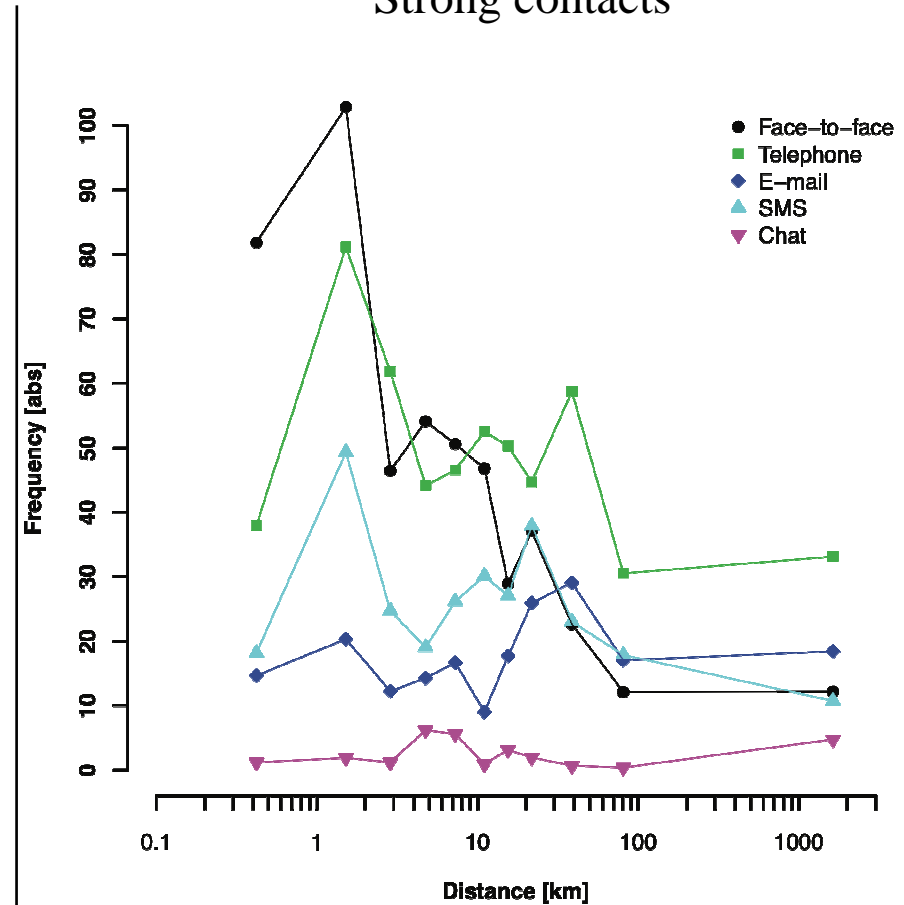


Quantitative survey: Social networks analysis

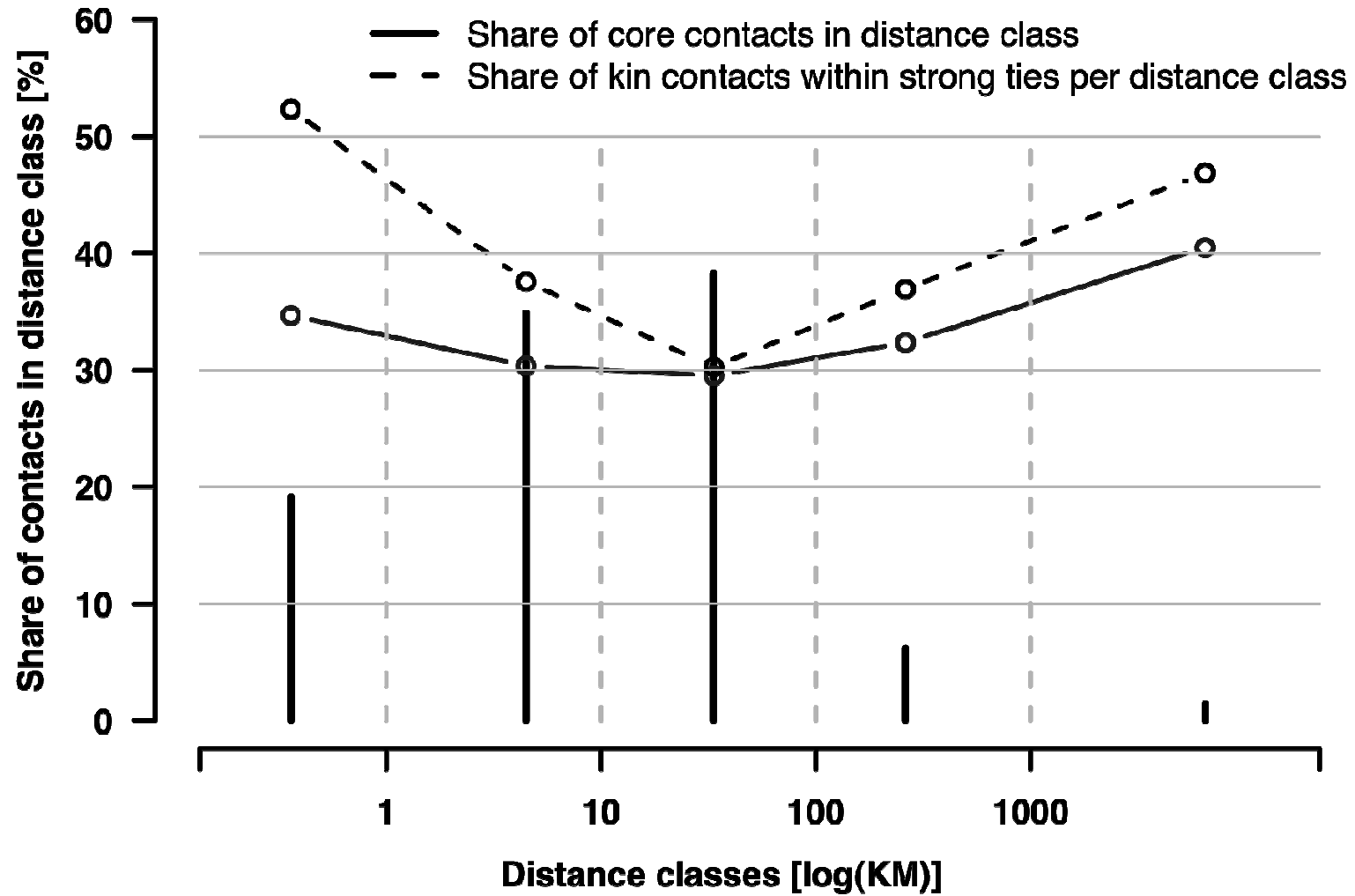
Weak contacts



Strong contacts



Quantitative survey: Social networks analysis



Multilevel logistic regression model on tie strength

Effects	Coefficient	t-value	Odd ratios
Threshold	3.031	10.445	
Continous effects on level 1			
Relation duration [years]	0.054	12.712	1.055
Face-to-face contacts [year]	0.007	4.339	1.007
ICT contacts [year]	0.013	11.570	1.013
Dummy effects on Level 1			
Sex homophily [y/n]	0.236	2.895	1.266
Alter is a kin contact [y/n]	0.758	5.760	2.135
Continous effects on level 2			
Children in household [number]	0.342	3.784	
Network size [number of alters]	-0.028	-2.946	
Residual variance	2.470	0.000	

Summary: Data on evacuation behavior

- There are various influences on peoples evacuation behavior
 - Perception of threat and source of warning
 - Socio-demographic characteristics
 - Distribution of social contacts

MATSim – Current Development and new Features

- Vehicles
 - Vehicle specific attributes like length and seat count

- Households
 - Use data from Census
 - Assign household members to the same home facility
 - Assign vehicles on household level
 - Allows modelling of decision making process on household level

Implementation of Evacuation Behavior Model

- Combine new MATSim features (Households and Vehicles) with results from evacuation behavior studies to model the behavior of the population during / after a large-scale disaster.
- Use Within-Day Replanning framework to model
 - Information distribution
 - Decision making process
 - Take socio-demographics into account

Evacuation Behavior Model Features

- Destination choice
 - Is home facility safe?
 - Life close friends in the secure area?
- Directive and decision to evacuate
 - Propagation of evacuation directive
 - Decision to accept or decline order based on socio-demographics
- Meet family members
 - Decision to meet and jointly evacuate or evacuate on a personal level and meet afterwards in the secure area.

Evacuation Behavior Model Features

- Mode choice
 - Decision of a household to evacuate conjointly in one vehicle or separated to have a fail back option and additional space for valuables.
- Perception of threat
 - Based on level of information of a person
 - Indirect information, e.g. from the media
 - Direct information, e.g. seen face-to-face

Conclusions & Outlook

- Work on the Within-Day Replanning framework is ongoing.
 - First results look very promising.
 - Feedback from test users will be used to further improve its applicability.
- Planned steps for the second half of 2011:
 - Fully include vehicles and households into scenario.
 - Implement interactions between agents using different modes.
 - First behavioral model for agents during / after a disaster in MATSim
 - Ongoing research to further improve behavioral model, e.g. by conducting expert interview

Questions?

