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Within-Day Replanning of Exceptional Events (12-1586)

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After events like the disastrous tsunami that hit coastal regions around the Indian Ocean in December 2004, or the devastating earthquake and subsequent tsunami in Japan in March 2011, the interest in large-scale evacuation simulations has grown enormously. In transport planning and traffic management, this creates the necessity of simulating scenarios where unforeseeable exceptional events occur. This requirement conflicts with traditional simulation approaches that optimize traffic demand using an iterative approach where agents can rely on their experience from comparable situations, like previous iterations. Applying an iterative approach to a scenario with unexpected events results in problems like illogical agent behavior, producing false results.

Problem Definition

Exceptional Events

Basically defined, an exceptional event is an incident that cannot or only partially be foreseen. Different kinds of exceptional event have diverse impacts on population behavior. The number of people affected can vary and their reaction will depend on the kind of event. A small-scale incident, like an accident on a minor road, will affect only a few people and will result only in small changes of their daily schedules. In contrast, large-scale events, like natural or man-made disasters, that affect the majority of the population, will lead to major changes in affected people's daily schedules.

Behavior Under Evacuation Conditions

A review of large comparative studies on people's evacuation behavior has shown that the behavior of people depends on the kind of event that has occurred. Therefore, a behavioral model is either designed for a specific kind of event only, or becomes very complex if it is designed for arbitrary events.

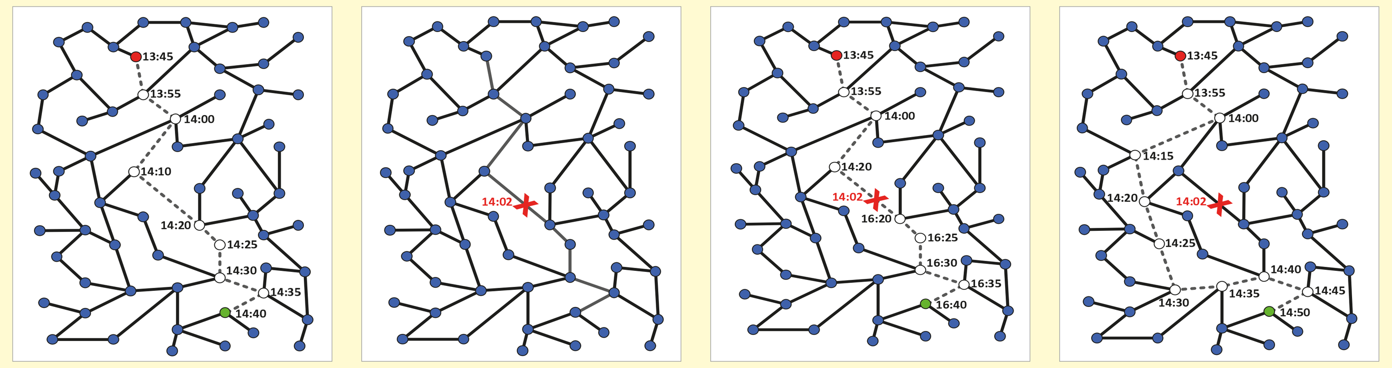
Simulation Approaches

Iterative Simulation Approaches

Starting point of an iterative simulation approach, as it is used in agent-based traffic flow micro-simulations, is the generation of an initial plan for each agent, including an intended schedule of activities and the trips that connect them. For each activity, its type (e.g. work, leisure or shopping), its location and the expected start and end time are given. A transport mode and a route specify a trip. In an iterative process, containing the three steps of plans execution, evaluation and adaptation, agents improve the quality of their scheduled daily plans using information from previous iterations.

The figures show an example scenario where an iterative approach would produce illogical and faulty results.

Endnode of the route · Planned route · Startnode of the route · Node on the planned route · X Event that blocks a link



Network with an agent's planned route including the times when the agent passes each node of the route.

Link where an event, like an accident, occurs, which blocks that link for two hours.

As a result, the agent reaches its destination two hours later than expected.

When this scenario is iterated, the agent recognizes that its route has a much higher travel time than expected and chooses a different route.

A closer look at the node where the optimized route deviates for the first time from the original one shows that this occurs even before the accident happened, which is unfeasible and illogical.

Within-Day Replanning Approach

A within-day replanning approach uses a significantly different strategy from that of an iterative approach. Instead of multiple iterations, only a single one is simulated. Thus, it is now essential that agents can adapt their plans during this iteration without having information from previous iterations available. To do so, they have to continuously collect information and take into account their desires, beliefs and intentions when they decide how to (re)act.

Therefore, the decision-making process of an agent becomes an important topic. In an iterative approach, each agent has total information and can thus select the best route. Due to limited available information, this is not possible in a within-day approach. As a result, a simulation will not converge to a user equilibrium. Decisions made during the simulated time period may seem to be optimal when they are made. However, evaluated retrospectively, an agent might realize that they were not.

Behaviour Modeling

Behavioral models used in the field of transport planning assume that a person tries to improve its daily schedule and the joint optimization of all people leads to a user equilibrium. However, especially for large-scale exceptional events such a behavioral model is not appropriate anymore and more complex models, like the BDI (beliefs, desires and intentions) approach, are required.

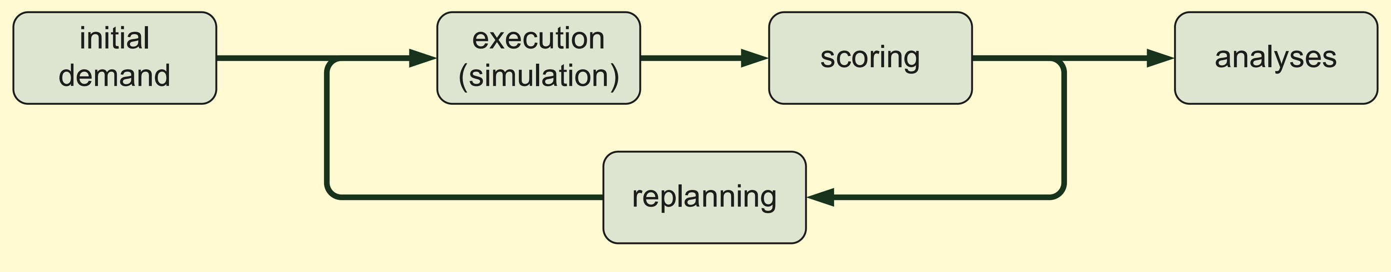
In the BDI approach, the level of an agent's information is represented by its beliefs, e.g. about traffic flows in a certain region. As the term belief indicates, some information might be wrong or misinterpreted. People's desires describe what they are trying to reach. Typically, a person has multiple desires that can conflict with each other. Therefore, people have to prioritize their desires. Finally, the intentions of a person describe what the person plans to do. In general, beliefs, desires and intentions of a person interact and change over time. A person might get new information that alters beliefs and re-prioritizes desires, resulting in changed intentions.

MATSim Framework

MATSim is a framework for iterative, agent-based transport systems micro-simulations. It is currently being developed by teams at ETH Zurich and TU Berlin as well as senozon AG, a spin-off company founded by former members of both institutes. Because of its agent-based approach, every person in the system is modeled as an individual agent in the simulated scenario. Each agent has personalized parameters such as age, sex, available transport modes and scheduled activities.

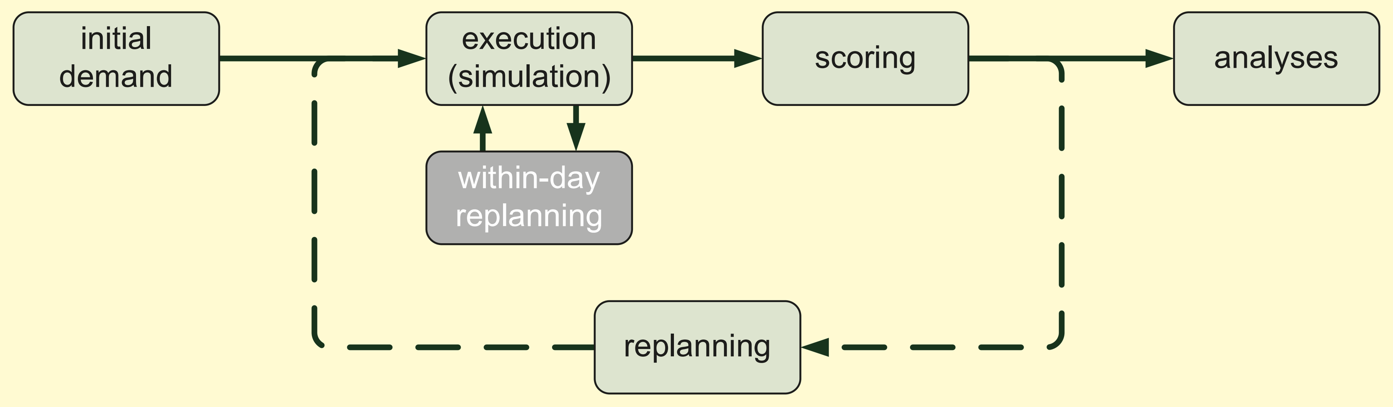
Structure of the MATSim Loop

After creation of initial demand, plans of the agents are modified and optimized in an iterative process until a relaxed system state (typically a user equilibrium) is found. The results can be analyzed later. The loop contains execution (simulation), scoring and replanning elements. Within the simulation module, agents' plans are executed. Afterward, the scoring module uses a utility function to calculate the executed plans' quality. Based on scoring module results, the replanning module creates new plans by varying start times and durations of activities, as well as routes and modes used to travel from one activity to another.



Iterative MATSim loop

When adding within-day replanning to MATSim, the iterative loop has to be adapted. The within-day replanning module is added, which interacts with the mobility simulation. The framework still can perform multiple iterations, but this is not necessary for scenarios with exceptional events.

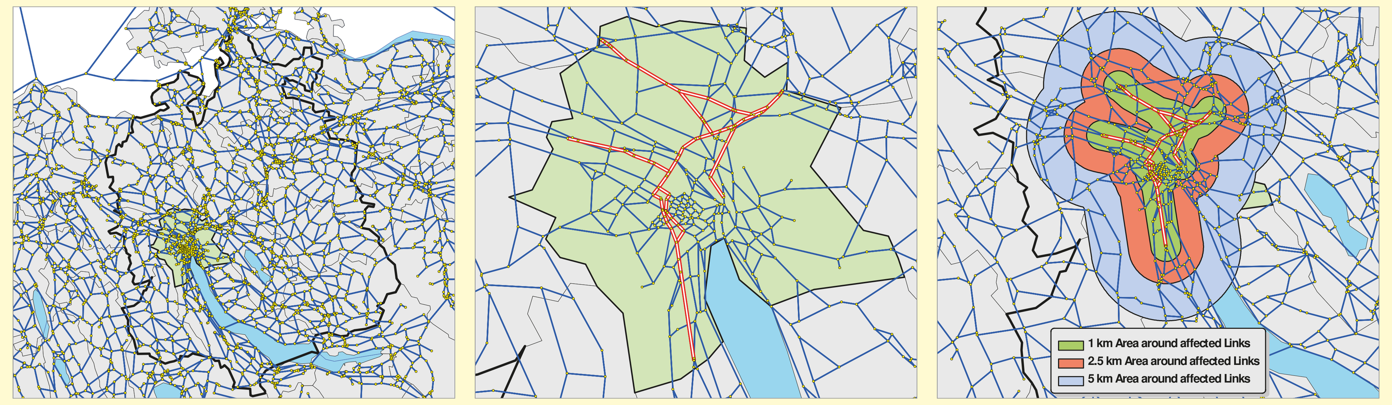


(Iterative) within-day replanning MATSim loop

Application

Scenario

To validate the proposed within-day replanning framework capabilities, it is applied to a model of the Canton Zurich. The scenario contains 67,000 agents, which is a 10% sample of the relevant population, and uses a planning network with 24,000 nodes and 60,000 links.



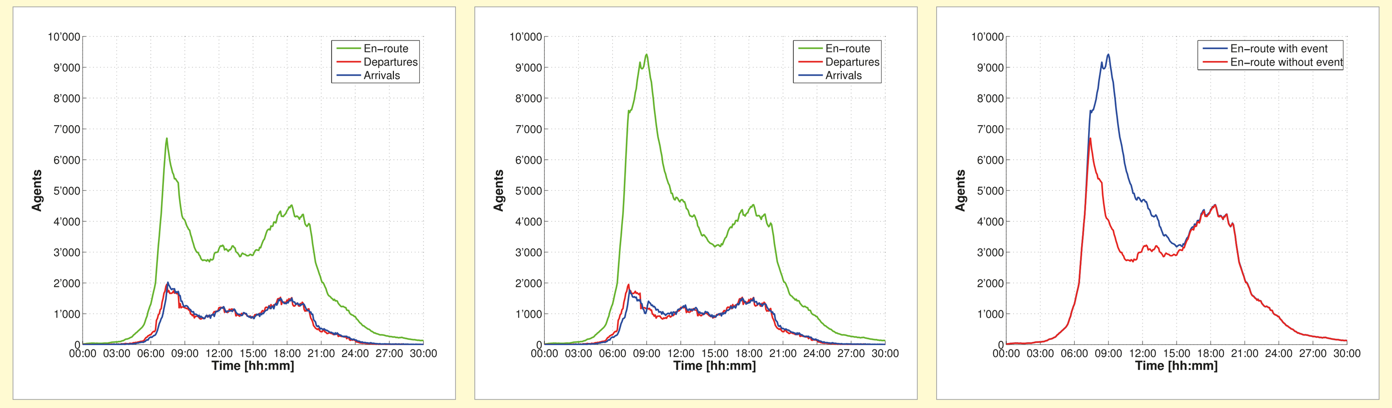
Simulation area. The thick black line marks the Canton Zurich.

Links with reduced capacities (red-white-red links).

Distance to affected links

It is assumed, that the capacity of several arterial roads in Zurich city center is reduced to 20% of the initial capacity. At 07:00 a.m., capacities are reduced; at 09:00 a.m., they are reset to their original values.

Within-day replanning is enabled when the incidents occur and disabled three hours after the capacities have been set back to their original values. These additional hours give agents the opportunity to realize that capacities have been reset. It is further assumed that only agents that would travel over the affected links in the time window where the link capacities are reduced will use within-day replanning. Moreover, those agents will only react by adapting their routes if they are within a certain distance of the affected links (0.0km, 1.0km, 2.5km and 5.0km). Additionally, the share of agents that use within-day replanning is varied (0%, 25%, 50%, 75% and 100%).



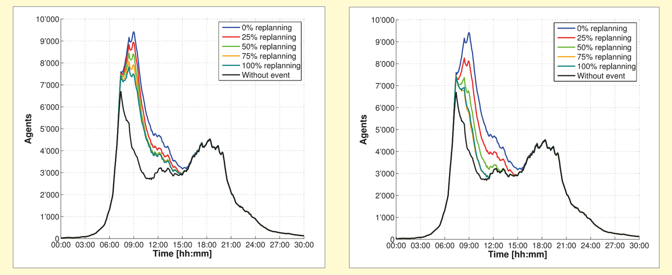
Trip distribution over the simulated period without event.

Trip distribution over the simulated period with event but without replanning.

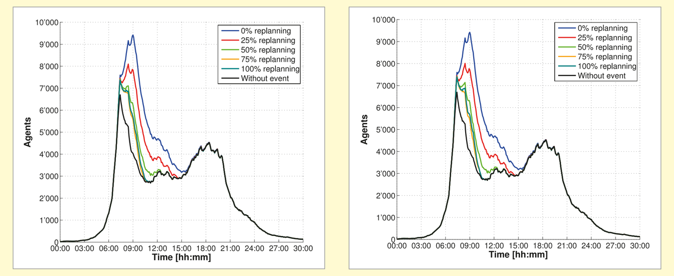
Agents en-route with and without event.

Results

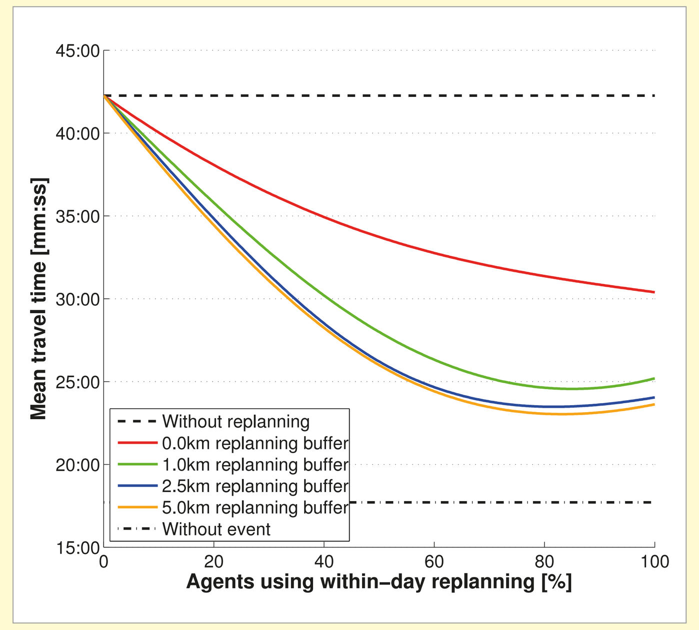
Figures (a) to (d) show the effect of different replanning shares. Each figures depicts a different replanning buffer, defining the area where agents can adapt their plans. The results show, that the higher the replanning buffer, the lower the mean travel times. As might be expected, the more agents use within-day replanning, the faster traffic flows normalize, but improvement between 75% and 100% replanning share is negligible.



(a) 0.0km replanning buffer (b) 1.0km replanning buffer

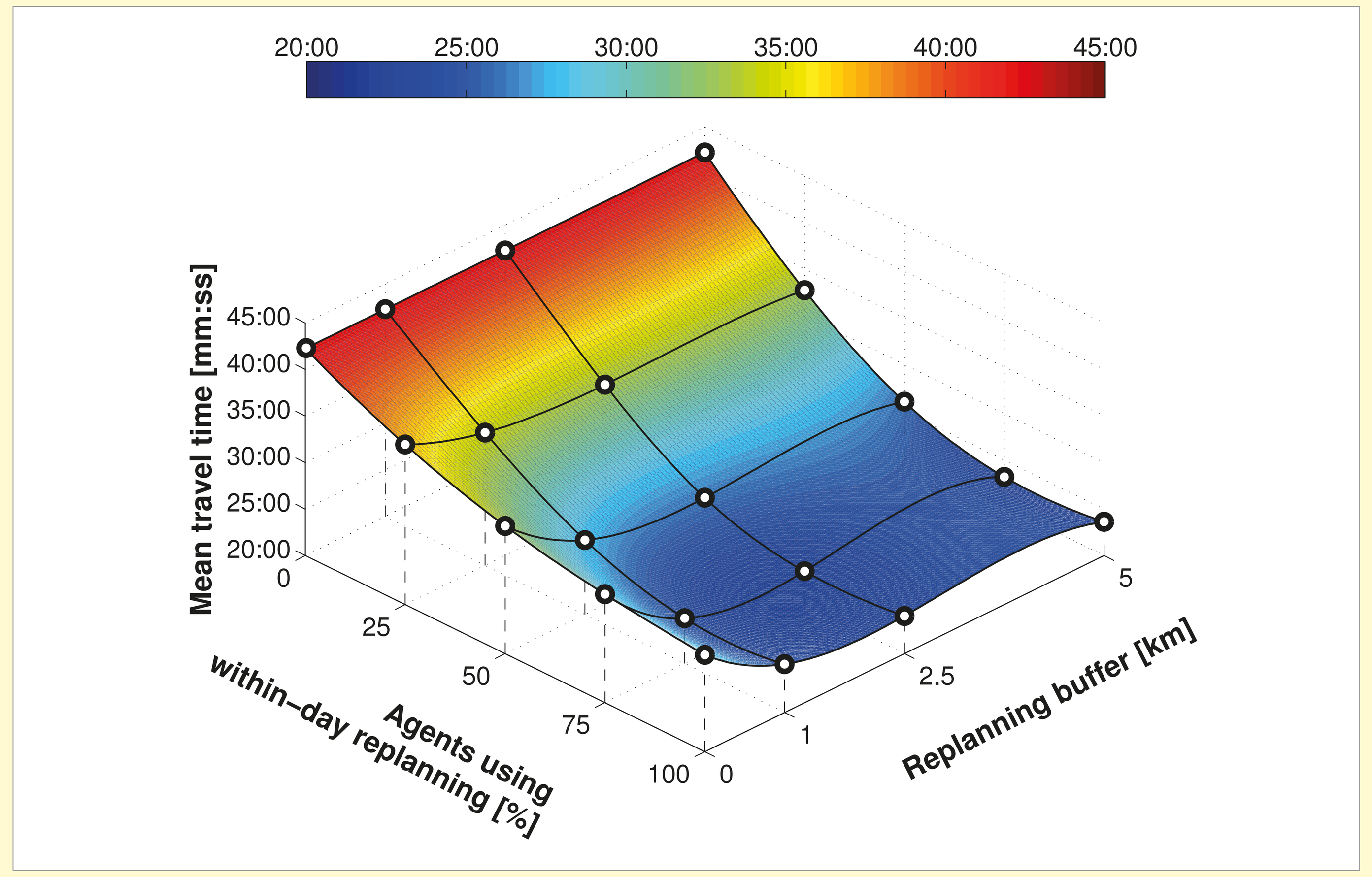


(c) 2.5km replanning buffer (d) 5.0km replanning buffer



Mean travel times

Agents are able to find better routes if they start replanning before they have entered one of the affected links and that increasing the replanning buffer over a certain value will not further reduce the mean travel times. While there is a large improvement from 0.0km to 1.0km, the difference between the 1.0km buffer and the 2.5km buffer is already much smaller. Comparing the 2.5km and the 5.0km buffer shows virtually identical mean travel times. As a result of the limited amount of available information, the mean travel times can increase again, if too many agents use within-day replanning.



Mean travel times (3D)

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Conclusion and Outlook

We explained why traditional simulation approaches fail in scenarios with unexpected exceptional events, while within-day replanning does not. The within-day replanning approach, as well as its fields of application, has been introduced and applied to a sample scenario. Evaluation of the experiments shows that implementation of within-day replanning technique produces credible and applicable results.

Future steps will include a behavioral model based on the full integration of the BDI approach into the framework. Based on this and the findings from a literature review in the field of behavior under evacuation conditions, a flexible behavioral model for extreme situations like natural hazards will be implemented and applied to sample scenarios.