Risk minimizing evacuation strategies under uncertainty

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Time dependent evacuation routes

The overall egress time is a crucial aspect in most evacuation situations. There are many models that find optimal routing strategies for evacuation scenarios. Sometimes the area that has to be evacuated is time dependent. For instance, large-scale inundations or conflagrations do not cover all the endangered area at once. One solution is to model this as a time dependent network, where an endangered area is only as long passable as long the inundation or conflagration has not reached this area. How this approach could be implemented within a microscopic multi-agent simulation has been shown in our previous work. However, this approach works only as long the advance warning time is known beforehand. When it comes to uncertain advance warning times this approach does not longer result in a routing strategy that always is risk minimizing.

Risk minimization methods

In this paper we propose a strategy that allows only risk-decreasing moves, as long as such a move exists. A move is defined as risk-decreasing if after that move the evacuee's distance to the danger is higher as before the move. Inside the endangered area the distance describes the temporal distance. For inundation scenarios this means that the location of the evacuee before that move will be flooded earlier than the location of the evacuee after that move. But even people outside the directly affected area should keep some distance to the danger. This is important because otherwise those people could block evacuees from leaving the endangered area. Therefore we propose an additional buffer around the endangered area that also has to be evacuated. Within this buffer a move is defined as risk-decreasing if after that move the evacuee's spatial distance to the danger is higher than before the move. An illustration of this risk minimizing strategy is given in fig. 1.

Simulation framework

The risk minimizing strategy has been implemented as an optimization module in a microscopic multi-agent based large-scale evacuation simulation framework. The simulation framework is based on MATSim and has been discussed in many of our previous papers. During an evacuation run each evacuee (agent) iteratively optimizes its personal evacuation plan. After each iteration, every evacuee calculates the cost of the most recently executed plan. Based on this cost, the evacuees revise the most recently executed plans. Some evacuees generate new plans using the time-dependent router. The others select an existing plan they have previously used.

Time dependent router

The outcome of a simulation of this kind highly relies on the cost function of the router. If the cost function only takes the expected travel time into account the system would converge towards a Nash equilibrium. The traffic flow simulation is implemented as a queue simulation, where each street (link) is represented as a FIFO (first-in first-out) queue. Therefore the street

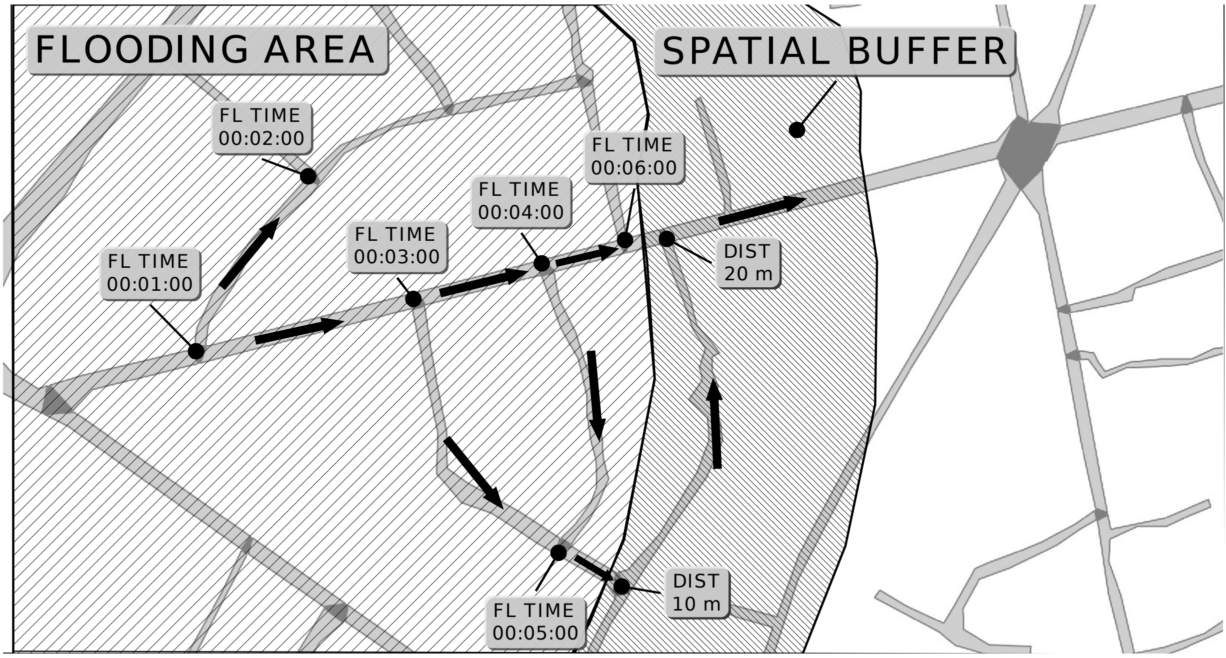

Figure 1: Illustration of the risk minimizing strategy: The boxes denoted with "FL TIME" showing the flooding time for the corresponding crossings (nodes) and the boxes denoted with "DIST" showing the distance of the corresponding crossings to the flooding area. The black arrows pointing towards lower risk.

network has to be converted into a graph based on directed links (streets) and nodes (crossings). The time-dependent router calculates a shortest path based on generalized cost function. To find a risk minimizing evacuation solution the cost function is the sum of two cost components. The first component is the expected travel time for a link. The expected travel time corresponds to the experienced travel time from the last iteration. The second component represents the risk costs. The risk cost for a link is zero if and only if the origin node is closer to the danger than the destination node. Otherwise an additional risk cost depending on the destination node's distance to the danger will be applied. Since the solution should not be a tradeoff between risk minimizing and fast evacuation routes the risk cost has to be higher than cost of the most expensive risk minimizing evacuation path.

Case study

The performance of the risk minimizing strategy will be demonstrated through a case study which is about the evacuation of the Indonesian city of Padang. Padang is located on the West coast of Sumatra Island and faces a high risk of being inundated by a tsunami wave. The city has approximately 1,000,000 inhabitants and large parts of the city have an elevation of only a few meters above sea level. The advance warning time for a tsunami wave is expected to be between 15 and 30 minutes. The risk minimizing strategy will help to give appropriate evacuation recommendations even under uncertainty. However, the simulation results have shown that in particular areas an evacuation to higher grounds seems to be not achievable in such a short time period. Therefore we would recommend to establish tsunami proof shelters in such regions. For the local evacuation planer the simulation framework could be used to find appropriate locations and sizes for the shelters. Currently we are working on the integration of the tsunami proof shelters into the simulation framework. With this feature it will be possible to estimate the effect of a tsunami proof shelter beforehand and so it will help the local decision maker not only to find appropriate locations for the shelters but will also help by the dimensioning of the planned shelters.