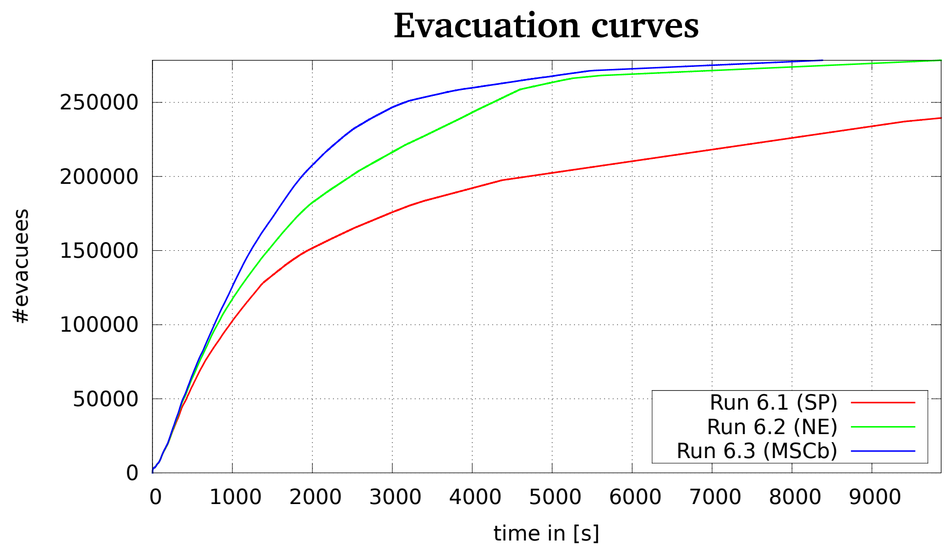

Figure 6.3: Evacuation curves of *Run 6.1* (SP solution), *Run 6.2* (NE approach), and *Run 6.3* (MSCb approach). The risk reducing evacuation strategy leads to longer evacuation times compared to an evacuation without additional risk penalty (c.f. Figure 5.3).

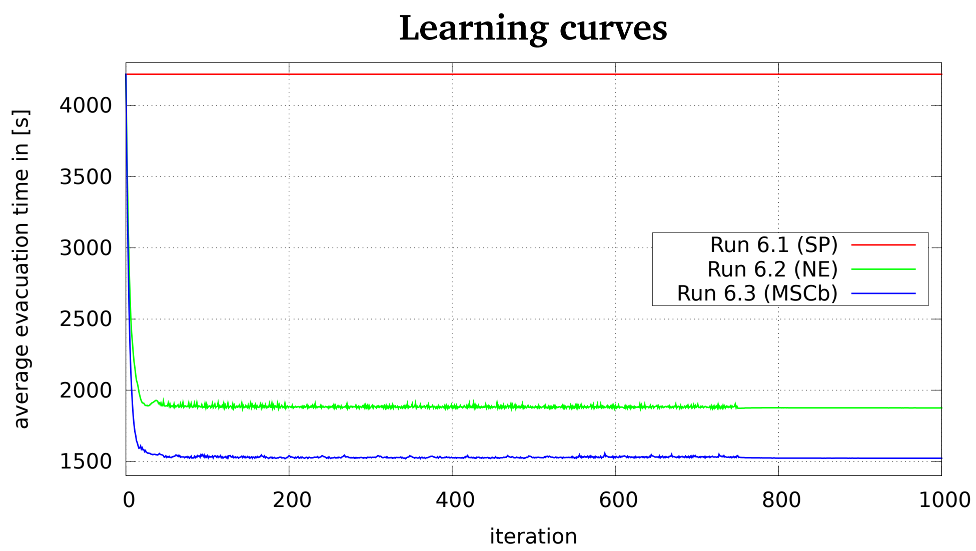

Figure 6.4: Average evacuation time over iteration number for *Run 6.1* (SP solution), *Run 6.2* (NE approach), and *Run 6.3* (MSCb approach). Note, that no learning iterations have been performed for *Run 6.1*, therefore, its average evacuation time remains constant over the iterations. For the SP solution the average evacuation time is 4 219 seconds, for the NE approach it goes down to 1 875 seconds and for the MSCb approach ends up with an average evacuation time of 1 522 seconds.

approach. The times are also worse compared to an evacuation simulation without risk costs (cf. Figure 5.2). The average evacuation times are shown as learning curves in Figure 6.4.

One learns from these results that the introduced approach leaves enough time to evacuate all agents for both the NE approach and the MSCB approach. However, in certain areas, in particular in the northern part of the city, many agents need rather long time to evacuate. Those areas have to be seen as to be highly endangered and consequentially it is strongly recommended to find solutions for a faster evacuation.

As a first step to improve the situation a detailed spatial analysis of the evacuation time is needed. Such an analysis helps to identify areas where the evacuation takes too long. Results of a grid based GIS analysis for the average evacuation times are given in Figure 6.5. The figure shows the GIS analysis for *Run 6.2* (NE approach) and *Run 6.3* (MSCB approach). The GIS analysis is performed on a 500 meter grid. For each cell in the grid the number of departing agents is recorded. The cell colors describe the average evacuation time over all agents that depart from within the corresponding cell. The numbers in the cells describe the total number of departing agents. There are no big difference regarding the average evacuation times between the NE approach and the MSCB approach. This is an indicator that the additional static risk costs push both approach closer to the same solution, which is not unexpected since the risk costs reduce the number of feasible evacuation paths. In general, it can be stated that there are a lot of agents that need long evacuation times especially in the costal area (red cells in Figure 6.5).

6.3 Discussion

The risk cost approach increases the evacuation time independent of the routing strategy considerably. However, this behavior is not unexpected since the risk cost approach "forbids" several routes that would lead to shorter evacuation times. A good example documenting this fact is the Siti Nurbaya Bridge in the southern part of the city. The visualizer screen shots in Figure. 6.6 are taken after 5, 20 and 35 minutes of evacuation. The screen shots on the top show the evacuation behavior for run *Run 5.2* (i.e. evacuation without risk costs). As there is no risk cost penalty for agents moving towards the danger many of them take the Siti Nurbaya Bridge to get to safety (green agents). However, there are a lot of agents that "think" they would make it over the bridge but get caught by the inundation (red agents). The screen shots at the bottom demonstrate the risk reducing strategy for *Run 6.2*. It is clearly shown

NE approach MSCB approach

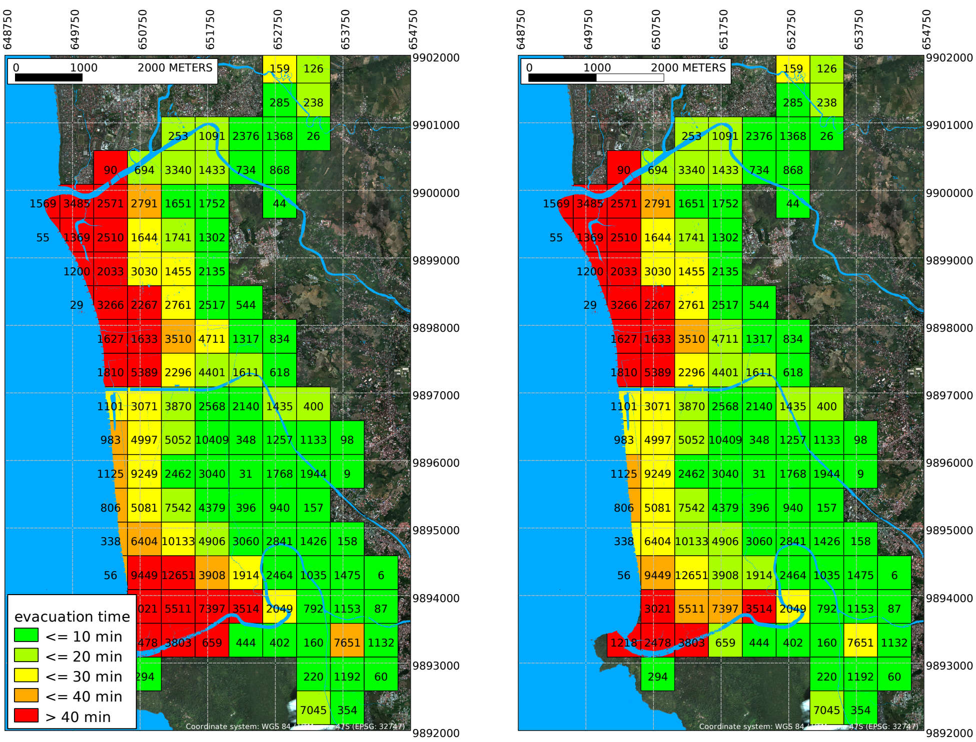

Figure 6.5: GIS analysis of the average evacuation times on a 500 meter grid. The figure on the left corresponds to *Run 6.2* (NE approach) and the figure on the right to *Run 6.3* (MSCB approach). The cell colors describe the average evacuation time over all agents per cell. Details can be found in the legend. The numbers in the cells describe the total number of departing agents per cell.

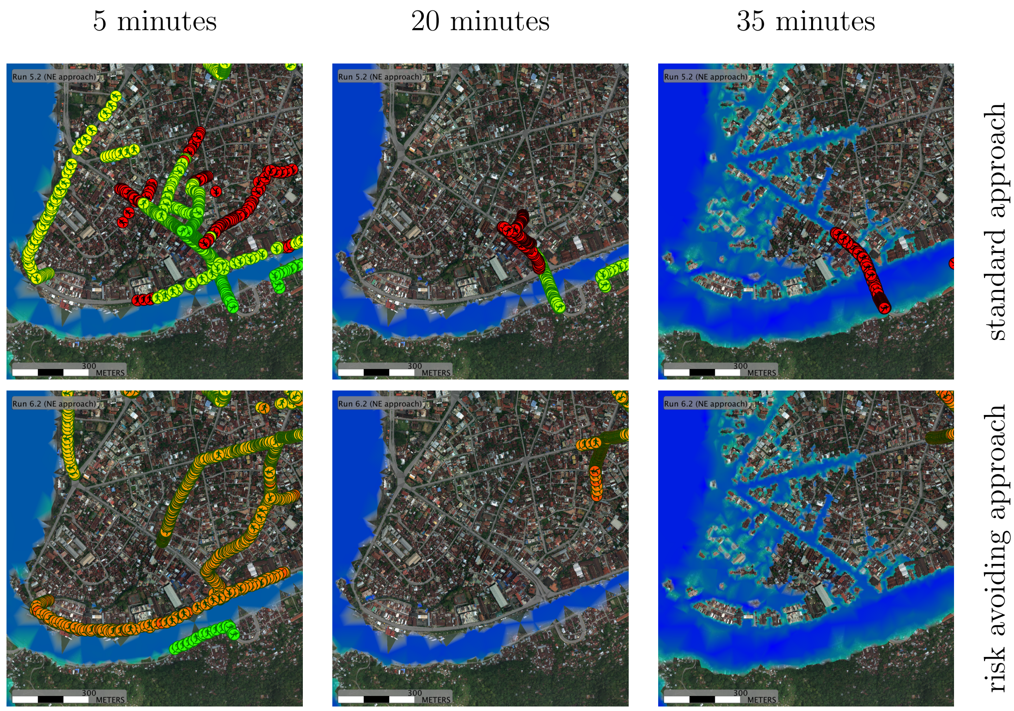

Figure 6.6: Screen shots for *Run 5.2* (top) and *Run6.2* (bottom) after 5, 20, and 35 minutes (from left to right) of evacuation. It is clearly shown that for *Run 5.2* the agents do not avoid the bridge and thus moving towards the danger first before getting to safety. In *Run 6.2* the agents avoiding this bridge because of the risk cost penalty.

that in this run agents avoid that bridge at the cost of a longer evacuation time (indicated by a more orange agents).

6.4 Conclusion

When it comes to uncertain aspects in evacuation situations one has no longer to be prepared for a single known scenario but for a range different situations. In the case of a tsunami related evacuation one uncertain aspect is the advance warning time. There may be evacuation routes that are fast if the advance warning time is long enough but would not work otherwise. If the advance warning time is not exactly known beforehand it is risky to take such evacuation routes. Therefore, a risk reducing evacuation strategy is proposed. The risk reducing evacuation strategy allows risk reducing moves only as long as such moves exist. This leads to a risk reducing behavior, where the evacuees are moving away from the danger. The risk reducing behavior is reached