Assessment and Analysis of Evacuation Processes on Passenger Ships by Microscopic Simulation

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The analysis of evacuation processes onboard passenger ships has attracted increasing interest over the last years. Cellular automaton models, widely used for traffic simulations, provide a natural approach towards pedestrian dynamics. Two major difficulties are intrinsical to the problem: two-dimensional movement of pedestrians and the complexity of psychological and social influences. An improved CA-model which allows complex routechoice-behaviour for the description of crowd motion is presented and its implementation in a simulation software outlined.

1 Introduction

Tragic ferry disasters in the past have shown the need for improved safety-standards in the shipping industry. Because of the huge numbers of passengers carried on ships at the same time and the unforgivable environment they mostly sail in, small accidents can quickly result in big casualty numbers. An effective evacuation-procedure should therefore be mandatory. But what will happen, if two thousand or even more people move through a ship, try to gather their belongings or related persons? Where do the bottlenecks occur? How can congestions be prevented effectively? There are many questions that arise, when the evacuation-concept of a ship has to be evaluated and descriptive calculation methods are not able to handle the complexity of the problem in a holistic approach.

In this article, an overview of the work that is done within the *BYPASS*-project is given. It was founded in October 1999 and is executed by the research group *Physics of Transport and Traffic* of Prof. Michael Schreckenberg at the Gerhard Mercator University in Duisburg/Germany. The aim of *BYPASS* is to further develop the Cellular Automaton model formerly developed in Tim Meyer-Koenig's student research project and to support the IMO (International Maritime Organization) in establishing guidelines for the use of microscopic simulations for the safety-assessment of passenger ships [1]. Partners are the German ministry of transport (*BMVBW*), the *Germanischer Lloyd* and the shipyards *Meyer-Werft* and *Flensburger Schiffbau Gesellschaft*.

2 Different Ships Require Different Evacuation Procedures

The variety of vessels seems to be nearly endless. For classification they are therefore divided into the following three groups: High Speed Passenger Craft (HSC), RoPax- and Cruiseships. The exact definition for each type can be found in the appropriate IMO regulations [2].

Figure 1: Pictures of a typical HSC, a RoPax-Ferry and a cruiseliner (pictures: Tim Meyer-Koenig, Jos. L. Meyer shipyard).

Depending on the group that a ship belongs to, the type of the evacuation procedure varies. Because the general layout of a HSC is fairly simple and the passengers are seated in rows (just like in an airplane), it is unlikely that they will be spread all over the vessel in an emergency situation. The evacuation strategy is therefore very straightforward: After the liferafts have been deployed, the passengers will take their lifevests from beneath their seats and leave the ship via the slides.

The procedure is totally different with big RoRo- and cruiseships, because people can have cabins and are able to linger on many public places all over the ship. In case of an evacuation, they have to retrieve their vests in the cabins or at central distribution areas, gather at muster stations and walk on to the embarkation stations were they finally leave the ship. Everybody can imagine what will happen on a cruiseliner where one half of the passengers is seated in the restaurant and the other half sits in the theatre and the evacuation signal is given. Unfortunately imagination is not sufficient for prediction of the possible result.

3 Model Assumptions

The goal was to develop a model that is capable of simulating the various evacuation procedures that can occur in buildings and onboard ships, aircraft, or other kinds of public transportation systems. The basic idea was to simulate the behaviour and movement of every single person involved, which is called a microscopic approach. To increase simulation speeds, a Cellular Automata model was chosen with a minimum set of parameters per person to characterise the behaviour:

- the maximum walking speed,
- the patience before she chooses an alternative goal, if the way is blocked by congestions,
- a factor that characterizes the visual perception of the environment,

- the delay time, during which she will wait before starting to evacuate,
- a dawdle probability with which she will stop for one timestep, to simulate breaks for regeneration or orientation, and
- a factor that characterises the inertia of the person’s movement.

The reduction of the parameters to this list is possible, because these are the factors that generally characterize the movement from a physical point of view. Attributes like age, gender and stamina eventually take effect on e.g. the walking speed. As a result of these simplifications, the simulations can be done on standard computers with very high calculation speeds (10.000 persons in real-time on a 500 MHz PC with 128 MB RAM). It is therefore possible to predict evacuations in a very short time which will allow online-simulations in near future. By varying the parameters, the simulation can be adapted to any demographic values.

The floorplan of the structure to be assessed is transformed into a grid of quadratic cells with an edge-length of 0.4 meters. One person thereby occupies one cell. This derives from the maximum density in crowds, when the movement reaches a stop [3].

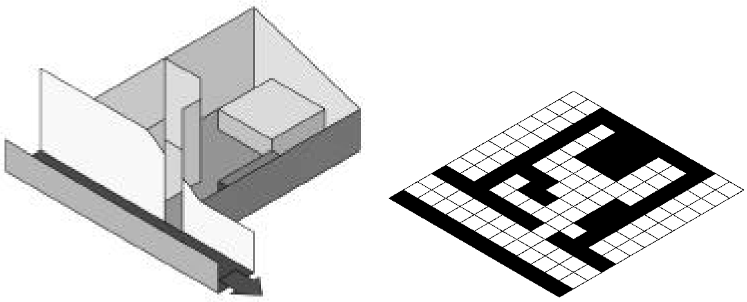

Figure 2: Example for the discretization of the floorplan.

Each cell contains different informations, depending on the way it influences the person standing on it. If it is not accessible, it represents an obstacle like a wall or furniture. Others influence the speed of the persons walking over them, so stairs and doors can be considered. To change the decks (e.g. at stairs), cells are implemented, that cause the person standing on them, to jump to the next upper or lower level. In this manner, the floorplan of complex structures can be modelled in a very simple way.

Depending on her maximum walking speed and the surrounding obstacles, a person moves from one cell to the next adjacent (via the corners or the edges). She thereby tries to avoid others and to maintain her maximum walking speed. Because the persons can move through more than one cell per time-step (one second), a parallel update was rejected, and an improved random-sequential-update was chosen. However for higher speeds the dynamics of the pedestrians converge towards a parallel update. Jamwaves can clearly bee seen in corridors with periodic boundary conditions. The basic procedure is shown in Figure 3:

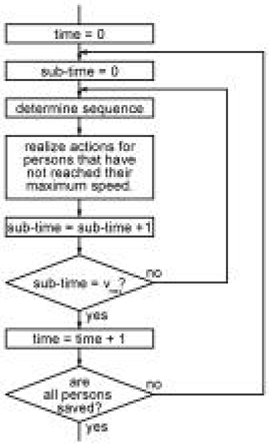

Figure 3: The basic update-algorithm.

4 Orientation

The problem concerning the orientation of a person is the global route-choice. It is easily taken into account that a person evades obstacles and other pedestrians, but the way she chooses where to go and how to get there is the decisive problem. In a first step, the information of which way a person had to walk to reach the exit was implemented by so to speak arrows in the cells that pointed into the direction a person had to walk. In the currently developed new approach, the route-information is given by a potential. This means, that only the goal-cells have to be marked. The potential then automatically spreads from one accessible cell to the following and by this throughout the whole structure. By a smoothening algorithm it adapts to the architectural circumstances, so persons following it will not stick to one side of a corridor, just because they want to bend off at the end of it (Figure 4).

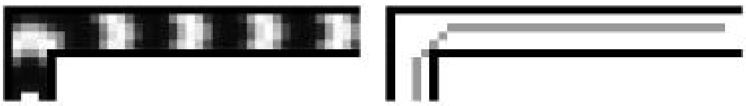

Figure 4: Iso-potential-lines in a hooked corridor, spreading from the bottom-left (left) and a resulting possible path (right).

Because the evacuation-route of a person in a RoPax- or cruiseship can contain many different waypoints (e.g. cabins, musterstations, lifeboats), three different kinds of potentials where developed. The only difference between them lies in the behaviour of the person who reaches the source-cells. Every potential has its own list of possible following goals, out of which a person reaching it can choose.

Cabin-potentials are used for marking corridors. A person reaching these kind of cells will stay on them for a given individual time, before choosing a new goal out of the list. This resembles the behaviour of passengers reaching their cabin and getting their lifevest. On the other hand, cabin-potentials can be used as simple waypoints, when the duration of stay is set to zero, so evacuation-routes can be marked by them.

Reaching a mustering potential, the behaviour of a person will change into a random-walker. This resembles passengers, who are gathering at the assemblystation. However to allow the following people to step onto the musterstation, they do not just stop walking, but randomly move on, staying on the appropriate cells. After a given blocking-time has passed, the people on the musterstation-cells are forwarded to the following goals (mostly the exits), while the new arrivals have to start waiting. This process is repeated in given interval-times, after the first blocking-time has passed. The result of this behaviour is equal to the mustering process: As long as the lifeboats are being prepared, the passengers will be assembled and afterwards led on towards the embarkation stations.

The procedure of embarking into the lifeboats is simulated by the rescue-potentials. They are blocked for a given time (preparing the lifeboats) and after that, the people reaching them have to wait for a certain egress-time before they get rescued. In this egress-time, the delay for entering a lifeboat or sliding on a marine evacuation system (MES) are taken into account. Throughout the simulation, the people which have been rescued per exit are counted and if the maximum capacity is reached, the belonging potential is switched of. Through this, the remaining passengers have to divided towards the other exits.

By dividing passengers into groups (e.g. having cabins onto one corridor) and using various of the mentioned potentials to mark their possible goals, various routechoices become possible, and thus the situation of a big ropax- or cruiseship getting evacuated can be matched (Figure 5).

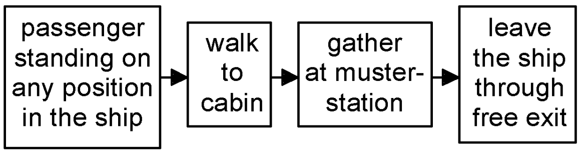

Figure 5: The possible actions of one arbitrary passenger.

5 Characteristics of the Model

Decisive for the closeness to reality of a model for simulating pedestrians are the flow-density-relations it provides. Once again, a simple method was wanted, for simulating the growth of needed space of a person moving at higher speeds. The simulations where done in a corridor (200x20 cells) with different densities of people walking in the same direction and periodic boundary conditions. Three cases where investigated: a person occupies all the cells she passes in one timestep, half the cells and finally only the cell she currently stands on. In the last case, the occurring jam-waves where most remarkable, moving against the flow and growing more and more stable with the density growing (Figure 6).

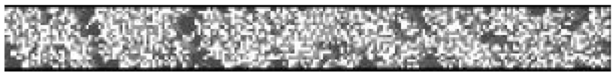

Figure 6: Corridor with periodic boundary conditions and a density of 4,4 P/m². People are moving from the left to the right and occupying only one cell. Jam-waves are clearly visible (dark areas).

The resulting flow-density-relations were compared with empirical data (4) and it showed, that the results met reality very well, if one person occupied all the cells she passed in one timestep (Figure 7).

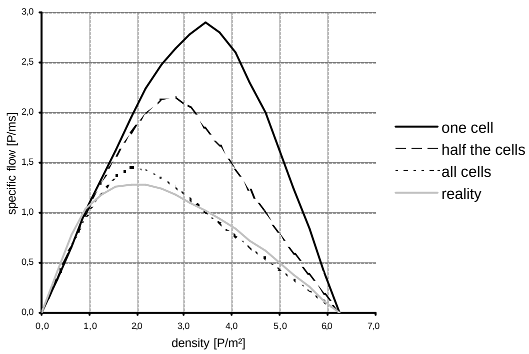

Figure 7: Flow-density-relations of the model.

6 Conclusion

It has shown that it is possible, to simulate complex scenarios and behaviour with elementary models. As a result of these simplifications, calculation-speeds are very high and allow the investigation of very big moving crowds in a short time. A verification of the model will be done, by comparing it with a practical evacuation trial on a cruiseship that is planned as part of the BYPASS-Project in the near future.

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