A microscopic model for simulating mustering and evacuation processes onboard passenger ships

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Abstract

The analysis of evacuation processes onboard passenger ships has attracted increasing interest over the last years. Some of the approaches utilize so called flow models. Cellular Automata (CA) models, widely used for traffic simulations, on the other hand provide a more natural approach towards pedestrian dynamics. Two major difficulties are intrinsic to the problem: two-dimensional movement of pedestrians and the complexity of psychological and social influences. In this paper a simple CA-model for the description of crowd motion is presented and its implementation in a simulation software outlined. The application to mustering and evacuation processes gives hint on how they might be optimized. However, the validity of the assumptions and the scope of the applications will have to be scrutinized by comparison with detailed empirical data from actual drills or evacuations, as far as available.

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 and to get out? Where do the bottlenecks occur? With which effective solutions can congestions be prevented? 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 essay, an overview of the work that is done within the *BYPASS*-project is given. It started in October 1999 at the research group *Physics of Transport and Traffic* headed by Prof. Dr. 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-König's student research project and to support the IMO (International Maritime Organization) in establishing guidelines for the use of simulations for the safety-assessment of passenger ships [1]. The longterm goal is to develop a simulation model which allows quick and effective usage in the design-process of passenger ships. Partners are the *German ministry of transport building and housing* (*BMVBW*), the *Germanischer Lloyd* and the shipyards *Meyer-Werft* and *Flensburger Schiffbau Gesellschaft*.

2. Different ships require different evacuation procedures

The variety of passenger vessels seems 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: author, 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 RoPax- 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 points, 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 while 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 Automaton (CA) model was chosen with a minimum set of parameters per person to characterise her behaviour:

- the maximum walking speed,
- the patience before she chooses an alternative goal, if her way is blocked by congestions,

- a factor that characterizes the visual perception of her 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 persons movement.

The reduction of the parameters to this list is possible, because these are the factors that finally 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 (about 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 for big crowds 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].

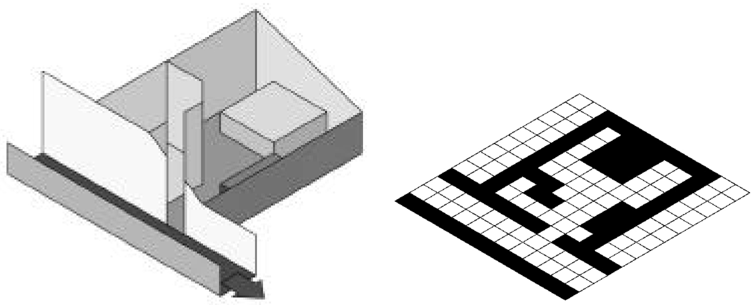

Figure 2: Example for the discretization of the floorplan.

Each cell contains different pieces of information, 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.

The discretization and the cellsize often lead to discussions. The main argument against the usage of cells is the exclusion to take small variations in the width of e.g., corridors (or doors) into account. On the other hand, a person has a discrete size, so it seems very unlikely, that the functional relation between corridor-width and flow is linear. When this article was written, members of the *BYPASS*-Project started doing research on this fundamental topic. In a doorway, the flow is measured, while the door-width will be varied in steps of ten centimetres. Tests are also planned for corridors and stairs.

Depending on her maximum walking speed and the surrounding obstacles, a person will move 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. Hereby, the simplicity of a sequential-update was maintained, while the dynamics of the pedestrians is similar to a parallel update for speeds of more than one cell per timestep. Jamwaves can therefore clearly bee seen in corridors with periodic boundary conditions. The basic procedure is shown in Figure 3:

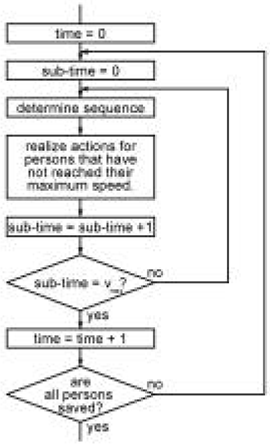

Figure 3: The basic update-algorithm.

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). Next to these route-potentials, wall-potentials can be added, which influence the way, people react on walls. They can either "push" people away or "pull" them towards obstacles. The last would be the case in e.g. bad visibility, when people tend to walk along walls and do not step into wide spaces.

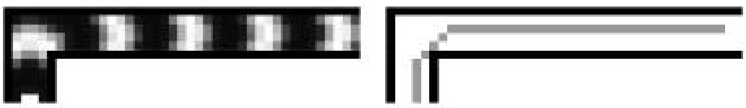

Figure 4: Iso-potential-lines in a hooked corridor, spreading from the bottom-left (left) and a resulting possible path (right).

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 cabins 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 on the assemblystation. However to allow the following people to step onto the musterstation, she does not just stop walking, but randomly moves 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 be directed towards the other exits.

By dividing passengers into groups (e.g., having cabins on the same corridor) and using various of the mentioned potentials to mark their possible goals, various route choices become possible, and thereby the situation of a big RoPax- or cruiseship getting evacuated can be matched (Figure 5).

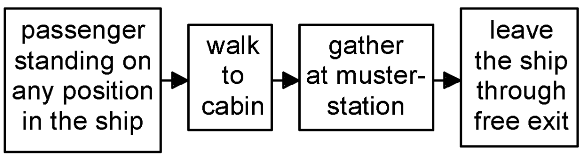

Figure 5: The possible actions of one arbitrary passenger.

5. Characteristics of the model

Decisive for the character and closeness to reality of a model for simulating pedestrians are the flow-density-relations it provides. Once again, a simple method was intended, for simulating the growth of needed space of a person moving at higher speeds. The simulations where performed 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).

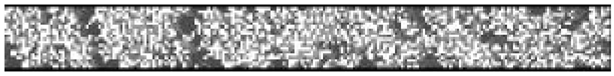

Figure 6: Corridor with periodic boundary conditions and a density of 4,4 P/m². People are moving from the left to the right and occupying only one cell. Jam-waves are clearly visible (dark areas).

The resulting flow-density-relations were compared with empirical data (taken from [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).

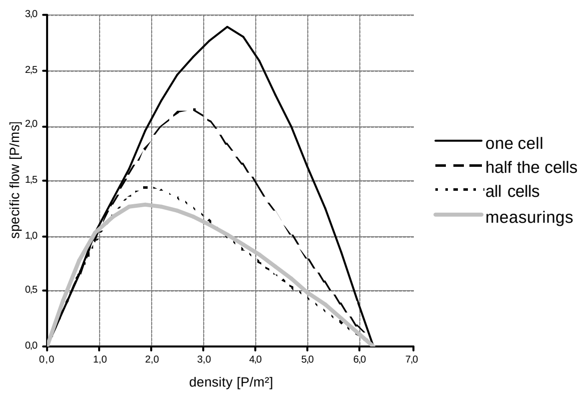

Figure 7: Flow-density-relations of the model.

In a next step, the effect of counterflow was investigated to see the effect of small numbers of people (one to ten) moving against the main stream. This will happen, when crewmembers have to move against the evacuating passengers. Because the influence of this effect is bigger in narrow spaces, the width of the corridor was set to five cells. In small densities, the disturbance by the person moving against the stream became clearly visible (Figure 8).

Figure 8: The effect of counterflow in a narrow corridor.

The effect on the flow-density-relation was also very obvious (Figure 9). At low or very high densities, the counterflow had no remarkable influence on the flow. In the middle section however, this changed dramatically. The occurring fluctuations thereby emerged from deadlock-like situations. Although all persons where distributed randomly at the start of each run, the counterflowing individuals sometimes gathered and thereby jammed the corridor. By implementing a method for lane formation, this problem could be solved.

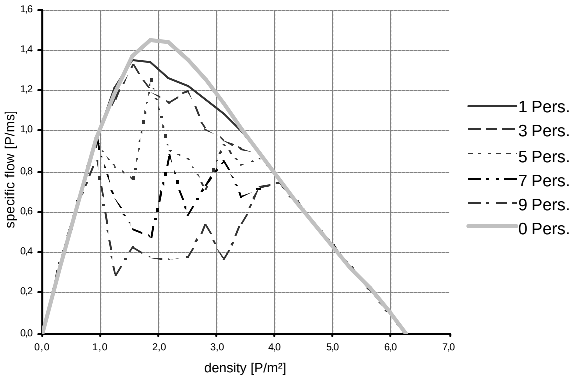

Figure 9: The effect of counterflow on the flow-density-relation.

6. Comparison with exercises

In order to verify the simulation-model, the results are compared with practical tests. There have been many evacuation trials with high speed passenger craft which are met very well by the simulation results. Because the period that the exits are blocked while the liferafts are launched has the major impact on the evacuation time (Figure 10), these results give only little information about the motion properties. It was therefore necessary, to perform a well documented evacuation trial with the main focus on the flow-density-relations.

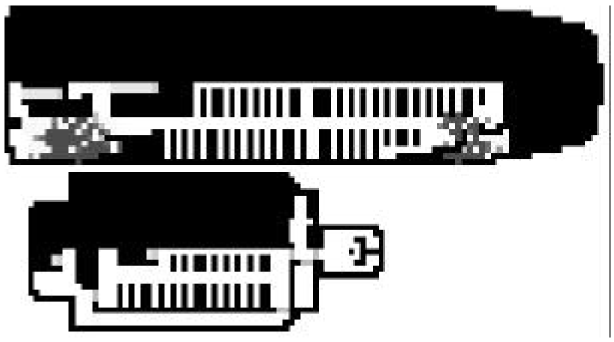

Figure 10: Queues in front of the exits during a high speed craft evacuation.

In cooperation with *UCI*-cinemas, an evacuation trial in a movie theatre was done. One hundred students participated, wearing hats with numbers for individual identification. The fact that only students participated, could easily be taken into account in the simulation by adjusting the parameters.

At the beginning, the starting position of each student was registered. At the exits, digital cameras were placed. Through these the exact evacuation time and route of each student could be evaluated. During the show, the evacuation was announced in the standard way by the theatre personnel. The students were free to choose their route and evacuated in a settled, but speedy way. Because of a closed fire door in the entrance hallway, only the evacuation exits were used.

The measured evacuation time was 66 seconds. In the simulation, one hundred evacuations were done to retrieve a fair statistic result. A mean evacuation time of

68 seconds was determined with a standard deviation of 2.5 seconds. Detailed results and evaluation will be made available [5].

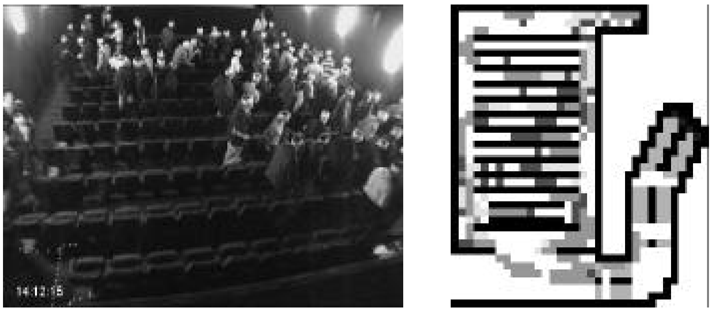

Figure 11: Comparison of reality and simulation in an evacuation exercise.

7. 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. For the use of such models in the design-process the conversion of technical drawings into the simulation software is crucial. The orientation by automatic spreading potentials already improves conversion-speeds. Next to this, a CAD-import is developed, which allows quick transformation of *dxf*-files into the internal file format.

Further verifications have to be done with the model, by comparing it with practical trials. An evacuation of a cruiseship together with the strategic partners is planned as part of the BYPASS-Project in near future. Next to this, fundamental research will be done to gather more detailed information about crowd-movement and behaviour.

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9. Authors Biography

Tim Meyer-König was born 1974 in Ris Orangis/France. He grew up in the Netherlands in the region of The Hague and after finishing school moved to Duisburg/Germany to study naval architecture at the *Institute of Ship Technology* of the *Gerhard-Mercator-University.* In his first student research-project, he developed a simulation model and implemented it into a software. His diploma-thesis dealt with the topic of orientation and routechoice, during which he implemented the potentials. In the meantime, he is a member of the working group *Physics of Transport and Traffic* and belongs to the German delegation of the *Fire Protection Committee* of the *IMO*. In July he will be one of the main-founders of the *TraffGo* company, which will realize the results of the working-group into commercial services.

Hubert Klüpfel studied physics at the Universität Würzburg and *SUNY* Stony Brook. He received his Master's Degree in the field of statistical mechanics in 1999. Since then he is a member of the group of *Physics of Transport and Traffic* at the *Gerhard-Mercator-University* of Duisburg. He works in the field of pedestrian dynamics and in cooperation with various administrative and industrial partners on evacuation simulation and safety assessment for passenger ships. Currently, he is involved in the *BY-PASS* project as a project coordinator and is providing scientific advice for the German delegation at IMO with respect to evacuation analysis for passenger vessels.

Michael Schreckenberg studied theoretical physics at the University of Cologne, where he got his PhD in statistical physics. In 1994 he moved to the *Gerhard-Mercator-University,* where he became the first German professor for *Physics of Transport and Traffic* in 1997. Since ten years he is working mainly on modelling, simulation and optimisation of large-scale transportation systems, especially road traffic. Since 1998 he is director of the Institute of Traffic and Logistics at the University of Duisburg. He is a member of the German research group for road traffic. Currently he is involved in several (research and application) projects, e.g., traffic forecast on the freeway network of North Rhine-Westphalia, SURVIVE (simulation-based analysis of individual reaction on traffic messages). In the community he is well known for many scientific contributions and conference organisations.